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Editorial

This Volume 38 Number 1 includes twelve (12) research articles. The relevance and usefulness of respective articles are summarised below.

J.K. Ssegawa, "A Domain-Based and Integrated Conceptual Framework for Effective Project Leadership", proposes an integrated framework made of four project leadership domains. Theories and studies conducted in leadership or project leadership coupled with a reflection of experiences of the author having been a project leader or a project team member, For an effective project leadership process to take place, the project leader requires self-leadership in order to exercise leadership of project stakeholders, leadership of project tasks and leadership of the project situation. The framework deviates from the normal premise of viewing project leadership as a process directed only influencing at project team or stakeholders.

K.S. Banerjee and R.S. Melville, "Preliminary Investigation of Geotechnical Properties of the Rock Aggregates Commonly Used for Civil Engineering Construction in Trinidad and Tobago", confirm the importance of a good control of geological parameters on the strength of the rock aggregates. Blue Limestone is heavily used in the Trinidad and Tobago construction industry as aggregates for ready mix concrete, asphalt design mixes and for the production of steel among other uses. The paper suggests quartzite to be more compatible than limestone for these types of construction purposes. If limestone is the only choice for these purposes, then layered variety of limestone may be avoided because of its anomalous mechanical properties, which is resulted by alternate layers of different mineral assemblages.

E.J. Peters and V. Joseph, "An Evaluation of the Compliance of the Water Pollution Control Rules in Port of Spain, Trinidad", reports a recent study on compliance to the Water Pollution Rules (WPR) at selected facilities in the Port of Spain watershed in Trinidad. It was found that the management of facilities would not have volunteered pollution remedial actions in the absence of WPR and WPP. Moreover, the results of policy implementation appear to be quite encouraging. Overall, the compliance for the monitored stations ranged from 20% to 75% which is considered acceptable in the early stage of implementing the WPR. It is recognised that the WPR as currently implemented cannot guarantee the desirable water quality.

I.A. Samotua et al., "A Preliminary Study on the Effect of Reinforcing Polyesters with Kenaf and Sisal Fibres on Their Mechanical Properties", evaluate the potentials of using weaved and un-weaved indigenous sisal and kenaf fibre to reinforce polyester resin based on the physical and mechanical properties obtainable from the resulted composites. The composites materials and sampling were prepared in the laboratory by introducing 10g of the fibre which is about 20% fibre content into the matrix using the hand lay-up method for un-weaved and coating method for weaved samples with the aid of a mechanical roller. The results showed that density of the material reduced on introduction of fibres while the rate at which the material absorbs water increased though sisal fibre reinforced materials would absorb more.

O.S. Ismail and C.I. Chukwuemeka, "Flame Detection and Suppression System for Petroleum Facilities", present an adaptive model for fire detection and subsequent suppression is presented. The model applies a Pyro-electric Infrared sensor (PIR)/Passive Infrared Detector (PID) for infrared fire detection. Sample analog signals were generated and simulated within the framework of the modeled PIR sensor/PID. The signals were modeled around the flame flicker region (1-13Hz) and outside the region. A Joint Time Frequency Analysis (JTFA) function was applied to model the Digital Signal Processing (DSP). This involved extraction of fire and non-fire features from the sample signals. A Piecewise Modified Artificial Neural Network (PMANN) and the Intraclass Correlation Coefficient (ICC) were employed in the decision framework.

S. Bahadoorsingh et al., "A Re-engineered Transmission Line Parameter Calculator", document the development and testing of a Transmission Line Parameter Calculator (TLPC), which computes the impedance parameters for short and medium transmission lines. LPARA, an existing software at The Trinidad and Tobago Electricity Commission (T&TEC), has been taken as the standard for comparison, since it has been tested and proved consistent with Power World Software, as well as it has been satisfactorily employed for decades at T&TEC. Comparative testing of the newly developed TLPC with LPARA revealed a maximum percentage difference of 0.05%, 0.02% and 0.80% in Series Resistance, Series Reactance and Shunt Admittance Matrices, respectively. It is claimed that the TLPC has interactive program help, error checking, and validation of all user inputs.

E.I. Ekwue et al., "Thermal Conductivities of Some Agricultural Soils in Trinidad as Affected by Density, Water and Peat Content", measure the thermal conductivities of twenty-six (26) agricultural soils in Trinidad in the field and the laboratory with a KD2 sensor and probe. Results show that there are agreement between the laboratory and field measurements of thermal conductivity and the corresponding predicted values using the Campbell model of thermal conductivity. The results obtained are discussed in relation to pipe laying and agricultural operations in Trinidad and Tobago. Apart from soils with appreciable sand contents, most soils would require standard backfills during cable laying.

The need for professional staff capable of functioning with accepted survey standards is fundamental to maritime safety. In his article, "Needs for Professional

Hydrography in the Caribbean towards Risk Reduction in Maritime Navigation", **K. Miller** explores whether the requirements for provision of hydrographic data to the international community are being maintained. It is anticipated that shipping activities will increase in both density and size of vessels, the need for professional staff capable of functioning with accepted survey standards is then fundamental to maritime safety. This article identifies the need for professionally qualified staff to maintain state services.

S. Patterson and K.F. Pun, "A Value Management Approach for Managing Social Project Risks of International Funding Discontinuity in Guyana", explore the efficacy of using Value Management (VM) as an approach to minimise the risks of the projects going into cessation after funding from International Development Partners (IDPs) is no longer forthcoming. A simulated "Value Statement" workshop was facilitated by VM experts to identify obstacles and examine factors affecting project sustainability. A VM-based strategic framework was then developed. It was found that adopting VM at the initial stage of social development projects could bring impact on reducing the risks of projects being unsustainable when external funding ends. Risk management (RM) and Gateway (GW) methods could be synchronised with VM as parallel processes for successful project implementation.

In their article, "An Evaporative Cooler for the Storage of Fresh Fruits and Vegetables", **S. Deoraj et al.** present the design, development and testing of an evaporative cooler for the storage of fruits and vegetables. The cooler comprised of two extraction fans, a cooling pad media, a plate-fin heat exchanger, a water tank, a storage and a cooling chamber. It is claimed that the system is an economical and efficient method used for the reduction of temperature and increase in the relative humidity for the storage of produce by applying the principles of the evaporative of water. The cooler would be one best storage method in terms of preserving the acidity of the tomatoes as well as their total solubility solids

O.O. Daramola et al., "Influence of Submicron Agro Waste Silica Particles and Vinyl Acetate on Mechanical Properties of High Density Polyethylene Matrix Composites", investigate mechanical behaviour and microstructure of the developed composites. The study developed two groups of High Density Polyethylene (HDPE) matrix composites reinforced with silica particles extracted from rice husk ash (RHA) and Vinyl Acetate. It was observed that the mechanical properties increased with an optimum value of 4wt. % of silica particles in HDPE. There was improvement in the mechanical properties of the siliceous HDPE composites when compared with Ethylene Vinyl Acetate (EVA) composites

J.B. Saitoo and A. Pooransingh, "Automated Money Detection Application for Trinidad and Tobago Currency Notes", investigate the Local Binary Patterns (LBP) as a method to recognise Trinidad and Tobago currency notes. A mobile application was developed and the effectiveness of the LBP algorithm was tested in terms of speed, robustness to illumination, scale and rotation. The LBP algorithm realised a recognition rate of at least 95 percent for Trinidad and Tobago currency. The recognition rates on mobile devices were compared for the LBP and the ORB (Oriented FAST and Rotated BRIEF) methods.

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.

The views expressed in articles are those of the authors to whom they are credited. This does not necessarily reflect the opinions or policy of the Journal.

KIT FAI PUN, *Editor-in-Chief*

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A Domain-Based and Integrated Conceptual Framework for Effective Project Leadership

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Abstract: *This paper argues that the project environment is unique and therefore the understanding of project leadership should be approached from that point of view. It also argues that the project leadership theories that have been developed have not explained project leadership in an integrative manner. By analysing definitions, theories and studies conducted in leadership or project leadership coupled with a reflection of experiences of the author having been a project leader or a project team member, the paper proposes an integrated framework made of four project leadership domains. For an effective project leadership process to take place, the project leader requires self-leadership in order to exercise leadership of project stakeholders, leadership of project tasks and leadership of the project situation. The framework deviates from the normal premise of viewing project leadership as a process directed only influencing at project team or stakeholders. Moreover, certain capabilities are needed to 'master' each domain in order to achieve effective project leadership. The paper proposes testing the model as a recommendation for further research.*

Keywords: *Project leadership, leadership, project manager, project leader, project management*

1. Introduction

In modern times, projects are used as focused organisational work structures for achieving corporate goals (Pinto, 2013). However, this happens only if projects are delivered successfully. Project leadership has been identified as one of the critical factors for achieving project management success (Gray and Larson, 2011). This premise has made project leadership the subject of intensive research for over a decade (Clarke, 2012). A number of theories have been developed (or adapted from general management) by project management scholars to determine what capabilities are required for an effective project leader (see reviews by e.g. Turner and Muller, 2005; Toor- and Ofori, 2008a; Clarke, 2012; Walker and Walker, 2011; Hiller et al., 2011). The research has enriched our understanding especially in two areas. First, the increased likelihood that an effective project leader will achieve project management success (Nixon, Harrington, and Parker, 2012; Anantaltmula, 2010), as measured by the 'iron triangle' (Cooke-Davies, 2002). Second, that project leaders are not born but can be trained and developed to be effective (Toor and Ofori, 2008a; Muller and Turner, 2010a, b).

Despite the development of a myriad of project leadership frameworks, a holistic understanding of project leadership is still illusive. Project leadership is often depicted in a disjointed manner without providing linkages among its constituent constructs. Cleveland, Stockdale and Murphy (2000) noted that theories discuss leadership from different angles, for example, the nature of who leads (i.e. characteristics or personality of leaders), how they lead (i.e. leadership behaviour or style), and under what circumstances they lead (i.e. situation or context). Clarke (2012)'s specific review of project leadership literature noted three major streams of research namely leadership style; leadership behaviours and roles; and leadership traits (competencies, characteristics and personality). This trend may be referred to as the '*single spanner syndrome*' where a person on the ground, passes on one spanner at a time, instead of the entire tool box, to another fixing a roof of a house. Sydänmaanlakka (2003) added that today there are a lot of theories which try to describe leadership from different points of view only to make the [project] leader's life more confusing rather than being helpful.

This article joins others (e.g. Fernandez, 2005; Ismail et al., 2011) in arguing that literature lacks an integrative framework which practioners can apply to increase their project leadership effectiveness. Its purpose therefore, is to discuss a proposed integrated project leadership framework. The next section describes the approach used to develop the framework while the third section discusses the justification for having the specific project leadership domains in the model. The discussion goes further by describing strategies and capabilities required to master the identified domains. The last section provides the implication of the framework particularly for effective project leadership and how it can be improved through further research.

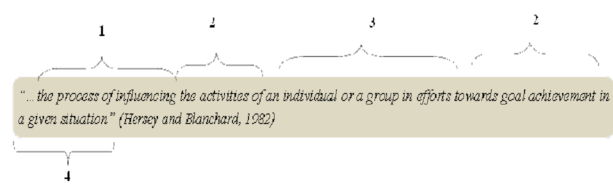
2. Methodology

Being a conceptual study the approach was based on an extensive search and critical review of literature. However, the framework of Bennett, Dunne and Carre (2000) provided useful insights to the study. The framework addresses the question of graduate employability and has been cited widely in various scholarly articles (e.g. Google Scholar recorded 420 citations). The framework consists of four domains of graduate employability viewed as necessary for obtaining meaningful and sustained employment. They include managing oneself, managing others, managing information, and managing tasks. Bennett et al. (2000) noted that employable graduates must possess all four domains. Employable graduates must manage tasks based on the information which is directly or indirectly related to the tasks. Simultaneously, they must manage themselves, as well as others in the organisation. Conceptually, the framework defined a domain as a group of graduate attributes with related outcomes, for example, managing task domain will include attributes such as meeting deadlines; and creating viable solutions for solving problems (Katz, 1993).

With Bennett et al. (2000)'s framework in mind two research questions were posed to guide the study with the first being: Could project leadership be organized based on some form of domains (RQ_1)? A systems theory approach (Ashy, 1956) was also applied in defining 'domain' in the sense that project leadership was viewed as made up of interrelated and interacting parts (domains) linked together to produce an outcome (effective project leadership) amidst a dynamic project environment. This would mean that domains are broad 'elements' that make up the scope of effective project leadership. The second question was: How can these domains be mastered by project leaders in order to be effective project leaders (RQ_2)? As explained later project leaders need to identify appropriate strategies and deploy their capabilities to master identified domains. Strategies are defined as broad capabilities designed to collectively master a project leadership domain.

The two research questions guided the search through definitions, theories/models/frameworks and results from leadership/project leadership studies. This was further guided by a search for the terms "leadership', 'management', 'project leadership' and 'project management'. Scholarly work included books (e.g. Yukl, 1989; Bass and Stogdill, 1990; Northouse, 2012); articles in peer reviewed journals found in on-line databases such as Emerald, Science Direct and Ebscohost; and references of articles found in reviews such as those by Bolden et al. (2003), Turner and Muller (2005), Toor and Ofori (2008a,b), Avolio, Walumbwa and Weber, 2009; Walker and Walker (2011), Hiller et al. (2011) and Clarke (2012). The terms 'management' and 'project management' were included in the search because they are often closely linked with leadership and project leadership, respectively. Where appropriate, effort was made to change the wording used in general leadership discourse to fit the project management nomenclature, for example, 'followers' was interpreted to mean either 'project stakeholders' or 'project team'. The content analysis technique which allows the identification and organisation of emerging themes in text (Bryman and Bell, 2003) was used in identifying project leadership domains, strategies and capabilities.

The search for articles and compilations of definitions by various authors (e.g. Rost, 1993; Barker, 2002; University of Warwick, n.d; Sydänmaanlakka, 2003; Northhouse, 2012; Adeoye, 2009; Winston and Patterson, 2006) yielded a total of 55 definitions. In addition, a total of 65 leadership/project leadership models/frameworks were identified from articles and scholarly reviews (e.g. Avolio, Walumbwa and Weber, 2009; Clarke, 2012). Figure 1 shows an example of how the analysis of a definition to identify project leadership domains was conducted.



1: Nature of project leadership is a process of influencing;
2: Activities and goal achievement –- project tasks and success;
3: Individual and group- project team/stakeholders;
4: Given situation – project situation

Figure 2. Definition of project leadership

The analysis indicated that in most definitions (83%) and models (70%) [project] leadership was referred to as a process of influencing (though in some definitions and models, for example, it was referred to as a process of exchange). Table 1 shows results of an analysis to identify project leadership domains. Four domains emerged namely leadership of project stakeholders and leadership of project tasks which were mentioned in all (100%) definitions and models; leadership of project situation was mentioned in 64% and 71% of the definitions and models, respectively; and self-leadership was least mentioned i.e. in 53% and 63% of the definitions and models, respectively.

A comparison with Bennett et al. (2000) model indicated that three of the domains were similar namely self-leadership ('management of self'), leadership of project stakeholders ('management of others') and leadership of project tasks ('management of tasks'). However, leadership of project situation was introduced in the proposed project leadership framework as a number of models supported its inclusion (e.g. the situational and contingent theory cluster) and also happens to reflect the unique, dynamic and situational nature of the project environment.

Table 1. Result of an analysis of literature to identify project leadership domains

Project leadership Domains	Definitions (N =55)		Models (N=65)	
	(No.)	(%)	(No.)	(%)
1: Self-leadership domain	27	53%	33	63%
2: Leadership of project stakeholders (influencing followers)	55	100%	65	100%
3: Leadership of project tasks (achievement of goal/task)	55	100%	65	100%
4: Leadership of project situation (in a given situation)	35	64%	46	71%

'Management of information' was dropped because it was believed that it is subsumed in the leadership of project tasks domain since tasks are driven by project information. Also, 'task' was preferred to 'goal' because from a project management's point of view, tasks lead to the achievement of a project goal and it is within the execution of project tasks that project leadership manifests. However, it is fully acknowledged that the ultimate outcome of effective leadership should be the achievement of a project goal.

As a last point regarding the analysis and the subsequent discussion of the domains, the author could not withhold reflecting on past personal experiences of project leadership as a project team member, a project leader and a trainer of project leaders. Such experiences became useful in corroborating the theoretical propositions from literature in constructing the proposed model and in providing practical examples.

3. Project Leadership Domains and Strategies

This section discusses the four identified project leadership domains (self-leadership, leadership of project tasks, leadership of others and leadership of situation), strategies and the associated capabilities identified in literature. The order in which they are discussed has no consequence to effective project leadership because in practice the strategies are deployed concurrently.

3.1 Self-leadership Domain

The self-leadership domain was identified in a number of leadership models including ancient leadership approaches (e.g. see Sydänmaanlakka, 2003; Muller and Turner, 2005b); trait approaches (see e.g. Parry and Bryman, 2006; Northhouse, 2012), emotional intelligence (Goleman, 1998); the exemplary leadership model (Kouzes and Posner, 2003), leadership pipeline model (Drotter and Charan, 2001), servant leadership (Greenleaf, 1996), superleadership (Manz and Sims, 1991; Manz and Neck, 2004), authentic leadership model (George, 2003) and the 6-L model (Tirmizi, 2002).

The inclusion of the domain of self-leadership in the proposed project leadership framework emphasises that 'what project leaders are (e.g. think, act and behave)' affects 'how they are perceived' by project stakeholders. In turn this affects 'extent to which they influence project stakeholders' and hence 'what they are able to achieve'. The nature or persona of the project leaders impacts on their behavioural profile, an important aspect for effective project leadership (Toor and Ofori, 2008b). It is argued therefore, that to focus on 'what project leaders do [influence] with project stakeholders' without looking at their nature is to tell a half-story of project leadership. It gives the impression that the nature of a project leader is inconsequential in understanding project leadership, which is a fallacy.

This idea is supported by Kippenberger (2002) who noted that leadership is a reflection of the character, personality and experience of the leader. The perception of project stakeholders towards the project leader affects their relationship and hence the project leadership process. Manz and Sims (1991:23) succinctly noted that 'it is important for leaders to first learn how to lead themselves before they lead others'. Drotter and Charan (2001) also noted that potential leaders must learn to 'manage' themselves as this prepares them to effectively deal with [project] work and human relationships.

Self-leadership can be achieved through the development of appropriate strategies and deployment of capabilities based on the individual's persona as characterised by their cognitive, emotional, physical, spiritual and social (CEPSS) elements (Goleman, 1998, Sydänmaanlakka, 2003; Kouzes and Posner, 2003; Muller and Turner, 2005b; D'intino, Goldsby, and Houghton, 2007). The cognitive element refers to the individual's thinking, reflective and learning pattern which drives and affects (positively or negatively) personal actions and decisions. The emotional element relates to the ability to identify, understand, use, and manage emotions in such a way as to relieve stress, overcome challenges, and defuse conflict (Segal and Melinda, 2012). The spiritual element relates to the values, meanings, beliefs and personal objectives of an individual while the physical element relates to the physiological aspects of an individual (e.g. health and eating, sleeping, exercising and resting habits). The social element refers to a catalogue of environmental factors which affect the well-being of an individual (e.g. housing, financial and human relationships).

Sydänmaanlakka (2003) noted that a leader will be impacted positively when there is balance in the total well-being as judged by these elements (CEPSS) because they provide the individual with the mental and emotional stability to act and behave in an appropriate manner. For example, illness, distress in marriage or financial problems, can be some of the destabilising factors in an individual's life which may have a huge knock on effect on project leadership.

Some scholars have included spirituality in the self-leadership domain, for example, Fry (2003) noted that the ultimate effect of leadership is to bring together four fundamental forces of human existence namely body, mind, heart, and spirit. This provides the motivation for high performance and personal experience of joy and tranquillity which will flow to project leadership.

From the work of various scholars (e.g. Krathwohl, Bloom and Masia, 1973; Manz and Sims, 1991; Goleman, 1998; Drotter and Charan, 2001) three interrelated strategies were identified as being critical to achieving self-leadership. They include self-awareness, self-management and self-concept.

3.1.1 Self-awareness strategy

Through self-awareness individuals are able to recognise a deviation in any , or combination of all of the CEPSS elements and their impact on the total well-being. The deviation may affect, for example, the individual's thinking pattern, decisions, actions and behaviour which in turn has an impact on the self-leadership domain. To deal with the deviation especially if it is adverse, individuals must have the ability to read or seek information on CEPSS elements through what Manz and Sims (1991) called self-observation. Feedback from the project team, directly or indirectly is part of self-observation.

3.1.2 Self-management strategy

Self-management, regulation or control is a natural follow up of the self-awareness. Goleman (1998) noted that self-management deals with managing the thinking and emotions such that they do not adversely affect judgement, actions and relationships with others. However, self-management goes beyond thinking and emotions and includes the ability of an individual to control of CEPSS elements in order to adapt to the changing circumstances. One of the self-management capabilities is self-assessment which is the determination of own propensity to change observed deviation in personal elements (Manz and Sims, 1991). Self-assessment must be optimal, i.e. neither too pessimistic nor too optimistic, but a reflection on the personal strength and weakness. Other self-management capabilities geared at managing observed deviations in the CEPSS elements include being able to:

i) motivate oneself to achieve set targets in terms of time and extent;

ii) identify and seize opportunities that initiate personal changes;

iii) develop confidence in oneself to sustain a sense of self-worth;

iv) adapt to changing situations to cope with stressful and uncertain project situations (i.e. being patience and resilience);

v) organise and prioritise personal affairs to create time to meet project milestones; and

vi) constantly reflect and learn from past experiences to improve the self-image.

3.1.3 Self-concept strategy

By developing a self-concept capability project leaders should strive to preserve and sustain their true image. The premise of the self-concept is that no individual is born with an undesirable behaviour, it is shaped by the environment and hence it can be changed. Literature review (e.g. Brown and Trevino, 2006; George at al., 2007; Brown and Trevino, 2006; Walker and Walker, 2011) identified several capabilities for achieving the self-concept strategy, including self-respect, integrity, accountability and servitude. Self-respect requires being true to themselves by not faking their image and hence upholding their values and principles; and practicing what they preach by setting a good example both in action and behaviour (Kouzes and Posner, 2003). Closely related, is the ability to uphold integrity by sustaining an ethical, honest, fair and transparent personal profile (Walker and Walker, 2011). In addition, individuals must be accountable for their decisions and actions. Lastly, servitude requires being able to avail oneself to the service of project stakeholders and sharing with them decision making processes (Greenleaf, 1996).

The theory of authentic leadership reinforces the self-concept strategy. According to the theory (see e.g. Avolio et al., 2004; Avolio and Gardner, 2005) authentic leaders as those who are deeply aware; of how they think and behave; of their own values, knowledge, and strengths; aware of the context in which they operate. In addition they are confident, hopeful, optimistic, resilient, and are of high moral character. Two real life project scenarios can put some aspects of the self-leadership domain in context. In one project scenario 'a project manager often came late to meetings and each time gave all sorts of excuses for being late. It became unbearable for the project team members who and started being agitated about time they spend waiting for the meeting to start'. The reaction of the project team provided a cue about the undesired behaviour (self-observation). The project leader targeted to change (through self-assessment) the behaviour of late-coming which was most likely emanating from lack of organising and prioritising activities to create time to meet project meetings. In another incident 'a project team member uttered something which the project leader interpreted ('thought') as a statement meant to undermine his authority. The project leader lost his temper ('emotion') and this resulted in a nasty incident'. Loss of temper was a result of loss of control of emotions which in turn blurred the thinking of the project manager leading to the adverse behaviour. The scenario indicates that a habitual loss of temper must be targeted by project leader for change to avert its disruptive potential.

3.2 Leadership of Project Tasks

The inclusion of the leadership of project tasks domain deviates from the commonly held view of project leadership which is about 'influencing stakeholders'. Literature (e.g. Kerzner, 2013; Meridith and Mantel, 2011) indicates that project leadership actually manifests through the execution of project tasks. Project leaders are held accountable for the smooth and efficient execution of tasks by project stakeholders, even if they delegate the responsibility (Meridith and Mantel, 2011). The project team members, for example, look up to the project leader to guide them in identifying, resourcing, assigning, coordinating and controlling project tasks. Comments such as *'... he is a weak leader who cannot even marshal adequate resources for the projec*t' have been heard from frustrated project teams starved of resources. It would then appear that the legitimacy and credibility of project leaders is sustained only if the project stakeholders perceive project leaders as having the capability to execute the project tasks, including marshalling adequate project resources. The project sponsors too, often judge the effectiveness of a project leader based on the progress of project tasks and the meeting of project milestones and reporting deadlines. Other project stakeholders (e.g. suppliers) expect project leaders to use their leadership prowess to maintain a smooth relationship, particularly by solving project related challenges including negotiating with the finance departments to expedite payments.

One might say that the examples above are functions of the project management processes. However, this paper argues that there is a close relationship between project management and project leadership. Despite the fact that the two are distinct constructs, in project practice their separation leads to an inadequate understanding of the latter. Parry (2004) observed that an effective project leader is one who sustains the efficient and effective execution of tasks throughout the project's life cycle. Project leaders with poor leadership of project tasks eventually turn out to be ineffective leaders. Muller and Turner (2010a) quoting Henry Mintzberg noted that the 'separation of management and leadership is dysfunctional: leaders who do not manage will not know what is going on (perhaps practising a lassie-faire style of leadership); management without leadership [of project stakeholders] is demoralising'. The reason for this is simple. As already noted project leadership manifests through the execution of project tasks or processes.

Project leadership and project management are Siamese twins whose separation can lead to a 'very complicated surgical project leadership process.' Project management processes include planning by identifying the broad project work to be done i.e. project objectives and deliverables; organising by arranging work in a systematic structure; identifying responsibilities and roles for project stakeholders; resourcing project tasks; budgeting, accounting and controlling project resources; coordinating the project tasks to ensure their integrated and efficient execution to achieve the project goal; and reporting and providing feedback on project progress and issues to project stakeholders. These are generalist and not technical functions (Meredith and Mantel, 2011) which require a project leader to have project management knowledge and be able to use the associated tools and techniques to successfully complete project processes (PMI, 2013).

What strategies and capabilities does a project leader require for the domain of leadership of project tasks? A review of literature indicated that the transactional leadership theory (e.g. Bass, 1985) provides a significant explanation to this effect. According to the theory a project leader needs to identify the needs, wants and expectations of project stakeholders in order to satisfy them (reward) in exchange for their effort to complete the project tasks (Rollinson, 2005). In reviewing literature, the transactional leadership was found to be offering the most appropriate strategies for mastering the domain of leadership of project tasks. The theory views a task as a transaction between the project manager and the project team or stakeholders. In this regard the theory offers three critical strategies a project leader may use in the leadership of project tasks namely management by exception, contingent reward, and laissez-faire.

3.2.1 Management by exception strategy

Managing by exception requires a project leader to have the competence for setting the standards or defining objectives required for executing project tasks (OGC, 2009; Kotter, 1990). This can be achieved by active or passive management by exception. Tyseen, Wald and Speith (2013) noted that active management by exception requires a project leader to attend to the work of project stakeholders by correcting deviations where they occur in order to meet project task requirements (or complimenting where there is achievement). This is useful where work is unstructured and where the project leader has to couch and mentor the project team to complete the tasks. Passive management by exception on the other hand is where the project leader waits until project tasks become almost severely impaired by challenges before intervening. Passive management by exception is a natural strategy in project management that requires a project leader to act simply as a coordinator of tasks that require delivery of project outputs.

3.2.2 Contingent reward strategy

Contingent reward is a follow up strategy of management by exception which may produce two extreme scenarios: either project stakeholders have performed their tasks and achieved the set standard or objective; or they have not attained what is required (Kotter, 1990). The former requires a contingent reward while the latter requires a contingent sanction. However, literature (e.g. Alimo-Metacafe and Alban-Metacafe, 2005) seems sceptical about the project leader's ability to reward or sanction since they are often endowed with inadequate formal authority. The strategy nonetheless adds to the project leader's strategic arsenals. Northouse (2007), for example, suggests that if the contingent reward strategy is used appropriately it can improve performance.

3.2.3 Laissez-faire strategy

Though in practice, the laissez-faire is sometimes employed by some [non-]project leaders, it is not really leadership strategy because it is an abdication of responsibility by avoiding taking decisions. Since the purpose of the proposed framework is to identify strategies for effective project leadership, prescribing the laissez-faire strategy would be misnomer. Furthermore, a project leader is often referred to as 'single point of responsibility' (PMI, 2013) and abdicating responsibility therefore contradicts this key principle.

3.3 Leadership of Project Stakeholders

Leadership of project stakeholders was the most discussed domain in literature (see reviews e.g. Northouse, 1997; Bass and Stogdill, 1990). Frameworks which discuss this domain include, for example, transformational leadership theory (Burns, 1978; and Bass, 1985), exemplary leadership model (Kouzes and Posner, 2003), leader member exchange (Graen and Uhl-Bien, 1995) and emotional intelligence (Goleman, 1985). The central theme of the theories is that leadership is a process of influencing others to achieve a project goal. The view of this article is that this is true but a partial view of project leadership. The proposed model is based on the premise that project leadership begins with the project leaders i.e. the ability to lead themselves. This gives them credibility (Kouzes and Posner, 2003) for obtaining favourable perception, attitude and cooperation from the project stakeholders (this is the cradle of the influencing process). In addition, they must be seen to be competent in managing project tasks and being able to handle project situations as they evolve. Once these are in place the process of influencing project stakeholder can start taking place.

Literature (e.g. Tyseen, Wald and Speith, 2013; Prabhakar, 2005) seems to indicate that transformational theory provides a significant baseline of strategies for influencing project stakeholders. The strategies are idealised influence, inspirational motivation, intellectual simulation and individualised consideration. Before discussing these strategies it is noted that there is criticism levelled against the theory. Yukl (1999), for example, noted that it is ambiguities regarding the influencing processes. The view of this paper is that the inadequacy stems from viewing leadership as a single domain construct– leadership of followers – instead of being multi-domain as suggested by the proposed framework. Therefore, if transformational leadership theory is viewed not as the sole contributor to leadership understanding, greater appreciation can be made of its strategies. It is noted, for example, that to execute the idealised influence strategy a project leader must master the self-leadership domain while intellectual stimulation strategy manifests during the leadership of the project tasks. As discussed later, other models, for example, the exemplary leadership model augments and reinforces several constructs in the transformational theory. The next sections briefly discuss the four strategies of transformation leadership and how they apply to the domain of leadership of project stakeholders.

3.3.1 Idealised influence strategy

Idealised influence strategy depicts the nature of project leadership and how it manifests during project leader's interaction with project stakeholders. It is linked to the cognitive and emotional elements discussed under the self-leadership domain. For project leaders to deploy the strategy they must have a clear set of values and principles to act as role models for project stakeholders. Bass and Avolio (1994) noted that idealised influence strategy requires positive charisma. This capability gives a project leader the vision and a sense of mission to reassure project stakeholders that project challenges are surmountable. This disposition promotes confidence among project stakeholders in the execution of tasks and hence the achievement of a project goal (Conger and Kanungo, 1998; Howell and Frost, 1989). Incidentally, this is a kind of charisma that is not self-centred and deviant but which facilitates a project leader to behave in an admirable manner based on a display cognitive prowess and behavioural appropriateness. Another capability required to implement idealised influence is networking - the ability to acquire and maintain contacts with individuals who can be relied on to facilitate in solving project challenges when they arise. The 'network only hangs around and maintains contact' where there is idealised influence from a project leader. The end game of idealised influence is for the project leader to gain the trust and confidence of the project team.

3.3.2 Inspirational motivation strategy

Implementing the inspirational motivation strategy requires project leaders who articulate their vision that appeals and inspires project stakeholders with optimism about the possible successful completion of a project (Bass and Avolio, 1994). Once this is communicated it provides, especially for the project team, the binding glue to efficiently and effectively execute project tasks.

Therefore, this is closely linked to the idealised influence strategy.

Inspiration motivation requires two related capabilities; the ability to craft a compelling vision and the means to articulate it to project stakeholders. Crafting a vision is the ability to develop a compelling project vision and aligning it to both the goals of the project team and organisation. This requires, first, a mental imagery (an outcome of the self-leadership domain); and second, the eloquent use of oral and written communication to articulate the vision and inspire project stakeholders to 'buy' into the project vision. In trying to inspire the project team, a project leader at a kick-off meeting made the following remarks: *'... The company has selected a few of us to deliver this strategic project not because of our existence in the organisation but because of what they see in us, a team of cable people. The journey we are embarking on will be treacherous but it is worth travelling because it is achievable. There will be trying moments but unity, cooperation, hard and smart work will together make us triumph. The achievement will be yours, mine and above all for the organisation we serve'*.

In addition, researchers (e.g. Bass and Avolio, 1994) have noted that the use of symbols and artefacts (e.g. in the speech - the likening of project delivery to a journey) can enhance the conveyance of the vision to project stakeholders.

3.3.3 Intellectual stimulation strategy

The intellectual stimulation strategy aims at provoking project stakeholders to 'think out of the box' in order to solve project challenges in a different way. A project leader needs to empower project stakeholders through the creation of a conducive environment (democratic and with no-blame seeking tendencies) that allows participation in the creation of solutions, ideas, reflection and learning (Bass and Avolio, 1994).

3.3.4 Individualised consideration strategy

Individualised consideration strategy requires a project leader to treat each project stakeholder in a 'customised' manner by attending to their personal and project related needs. In general terms, when using this strategy the project leader gives due respect to project stakeholders by recognising and appreciating their individual contribution to project work. Two capabilities have been identified to execute the individualised consideration strategy namely empathy and mentoring. By empathy a project leader seeks to understand the emotional structure of a project stakeholder and respond to his or her emotional reactions (Goleman, 1998). Mentoring aims at couching and developing project team members where there is a skills gap. This enhances their self-worth and self-fulfilment resulting in further performance and growth (Bass and Avolio, 1994). Some scholars (e.g. Kouzes and Posner, 2003; Greenleaf, 1996) have suggested that the strategy 'makes leaders out of followers'.

3.4 Leadership of the Project Situation

Project leadership does not take place in a vacuum; it takes place in an environment where a project leader interacts with so many facets, both human and non-human. In other words, projects are planned and implemented within a particular situation. The situation may remain stable over time but often changes over the project's life cycle, for example, organisational procurement policies may be changed during the implementation of the project; or when a project assumption fails to hold. The project situation affects the project leadership process to the extent that a project leader may fail to deliver a similar project that he/she successfully implemented before. Therefore, the inclusion of leadership of project situation in the framework is to acknowledge this domain. Likewise some leadership theories, for example, the contingent and situational schools (see e.g. Fiedler, 1967; House, 1971; Vroom and Jago, 1988; Hersey and Blanchard, 1988) have acknowledged situational variables as factors in achieving effective leadership. Unfortunately, none provides an exhaustive list of all possible situational variables.

However, literature (e.g. Hammuda and Dulaimi, 1997; Slevin and Pinto, 1986; Chan et al., 2004) indicates that situational variables emanate from various sources of the project's profile and its environment. They include nature of project (e.g. tasks complexity, tightness of schedule, duration, resource endowments and size); nature of stakeholders (e.g. diversity, culture, support of the project team, and competence of the project team); spread of participants (e.g. virtual vs. face-to-face teams); organisation factors (e.g. management support, union/employee support, organisational culture and structure, policies and procedures and project maturity); industry factors (e.g. industry standards and norms, competition levels, strength of trade associations, green issues and state of industry - boom, down turn or stable); national (e.g. state of economy, political stability and state of the infrastructure); and global (e.g. threats of terrorists, epidemics and recession).

Review of literature indicated that it is not possible to use one strategy for all situations. The contingent and situational schools of leadership provide two broad strategies for dealing with project situations namely changing the project situation and changing the leadership style (Rollinson, 2005).

3.4.1 Change the project situation strategy

The reason for changing the situation could be because the current setup does not allow a smooth execution of project tasks. In their exemplary leadership framework, Kouzes and Posner (2003) support this view by asserting that challenging the process is a good leadership strategy. Capabilities for changing the project situation were identified as conceptual, negotiation and persuasion. Katz (1955) noted that the conceptual capability provides a 'bird's eye view' of how various parts of a project fit together. This is why a project leader is required to assume a stance of a generalist as opposed to being a specialist (Meredith and Mantel, 2011) so that he/she is not subsumed in details. This ability is useful in reconfiguring the project situation to achieve the same objectives and avoid being bogged down in technical, professional or functional silos. However, changing the situation will often attract disagreements and misunderstandings with some project stakeholders. Therefore, negotiation and persuasion capabilities are needed to sell the change and persuade project stakeholders that a 'win-win' situation will emerge.

3.4.2 Change the leadership style strategy

In some cases it is not possible to change the situation but to change the leadership approach. In reviewing literature, a range of capabilities were identified ranging from the extreme case of the need to attend to project tasks or relationship with project stakeholders. This provides four capabilities namely directive, supportive, participative and achievement oriented (House, 1971; House and Mitchell, 1974, Vroom and Jago, 1988; Hersey and Blanchard, 1988; Houghton, 2005). Directive capability is where a project leader gives subordinates firm guidance and clear instructions wherever possible. Supportive capability is where a project leader tries to be as approachable as possible to project team. Using the participative capability the project leader solicits project team's suggestions and incorporates their input into the decision process. Lastly, achievement-oriented capability is where the project leader tries to get the project team to assume full responsibility for their work, to set challenging targets and expects them to achieve them. Rollinson (2005) noted that in practice, it is possible that project leaders may use all capabilities during the life cycle of the project.

4. Discussion

Based on the preceding discussion a working definition and an integrative framework for effective project leadership are proposed. The proposed framework is specifically directed at project leadership and hence project work which is often described as temporary and unique both in context and outcome (PMI, 2013). It is strongly argued that to construct a realistic understanding of project leadership, the nature of project work and the situation in which the project tasks are executed must be recognised and understood (Tyseen, Wald and Speith, 2013). This sets project leadership apart from political and corporate leadership. Effective project leadership is therefore, defined as: ... an interactive process in which a project leader's persona influences project stakeholders towards the achievement of project tasks within a given project situation to achieve a project goal. The definition includes the nature (a process), expected outcome (project goal) and all the four project leadership domains identified.

Figure 2 summarises the proposed model and indicates that for an effective project leadership process to successfully occur a project leader requires self-leadership in order to exercise leadership of project stakeholders, leadership of project tasks and leadership of the project situation.

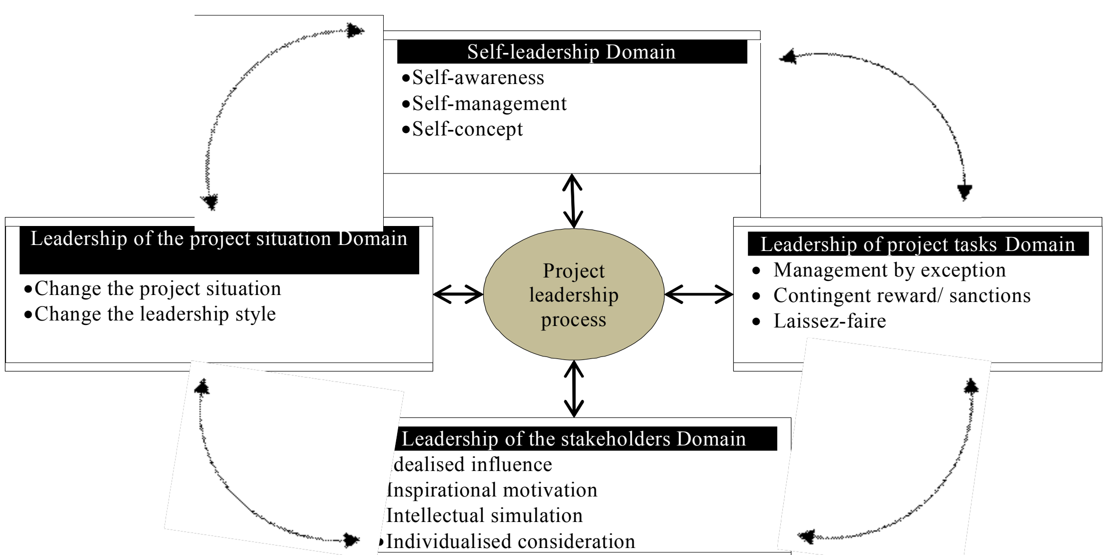


Figure 2. The Perspectives of Project Leadership

The self-leadership domain emphasises that the project leader needs to manage his persona – thinking, behaviour, actions and all aspects surrounding him – to gain credibility in the eyes of project stakeholders. In line with other leadership discourse (e.g. transactional theory) the framework views project leadership as an interactive process. However, the point of departure is that a number of theories concentrate on the domain of leadership of stakeholders (e.g. transformational theory) and ignore the other three domains. In addition, some theories (e.g. transformational theory) view leadership as a one-directional process where a leader influences a group of passive followers.

In contrast, it is argued that project leadership is an interactive process which is multidirectional (hence the arrows pointing to and from the centre in Figure 1). The project leader influences and is influenced by project stakeholders task and situation (Gofee and Jones, 2007). Viewing leadership as an interactive process also means it can be learnt and developed through interaction. This is in line with the view that people are not born with project leadership traits (Gofee and Jones, 2007).

Furthermore, viewing leadership as an interactive process also indicates the transactional nature of the construct. Some form of social exchange occurs between a project leader and project stakeholders (particularly the project team) during the execution of project tasks. Therefore, without project tasks, it is unimaginable how project leadership can manifest. In fact the life span of project leadership is the duration of the project. In addition, the word ‘tasks’ has been construed as leading to a project ‘goal’. From a project management point of view, the successful completion of project tasks leads to achievement of a project goal (APM, 2012). The execution of project tasks provides the interaction in which project leadership is exercised by a project leader. Project tasks are often performed in an ever-changing situation caused by the project’s specific and dynamic variables (e.g. organisational policies). These situational dynamics combine to affect the effectiveness of the project leadership process. While most leadership models use the word ‘followers’, the framework adopts the project management terminology of ‘project stakeholders’. The latter emphasises that a project leader does not only show leadership capabilities among the project team members but with diverse parties with various stakes on a project e.g. management, sponsors, regulators and suppliers (Cleland, 1986).

The proposed framework also emphasises that project leadership is a continuous process right from when a project leader is identified. It is neither a once-off activity nor one which comes in quanta. Furthermore, even though the project leadership domains have been ordered in a linear sequence in practice they are not engaged in any particular order. In fact the project leadership perspectives are ‘operated as if they were blades of a windmill rotating about a centre’ (hence the circular arrows in Figure 1). The speed of the blades may also depict the changing project situation. The framework therefore, emphasises that when the project leader learns to ‘tame’ or master the four project leadership domains, there is a high chance for effective project leadership to occur. Lack of attention to any of the four domains is likely to lead to a dysfunctional project leadership process.

5. Conclusion

Project leadership is a very important aspect in project delivery. However, despite the numerous research studies, understanding how it works has often proved elusive. A number of project leadership theories have been developed or adapted to provide an understanding of its nature. What is noticeable is that most theories have not provided an integrative approach for project leadership. This paper has proposed a framework which views project leadership as a four-domain integrated construct consisting of self-leadership, leadership of project stakeholders, leadership of project tasks and leadership of the project situation. This has been noted as deviation from the normal view that project leadership should only be about influencing project stakeholders. The framework emphasises that for project leaders to be affective, they must acquire and develop capabilities to enable them to execute the various strategies identified for each the of four project leadership domains.

It suffices to note that the framework is expansive enough to include recent topics such as gender and cultural differences in leadership (e.g. Tirmiza, 2002). For example, if there are cultural issues, a project leader must deal with them by identifying them as belonging to the domain of project stakeholders and/or project situation and deploy the most appropriate strategies and capabilities. Further research is being carried out to test the propositions in the framework and will appear in a forthcoming article.

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Preliminary Investigation of Geotechnical Properties of the Rock Aggregates Commonly Used for Civil Engineering Construction in Trinidad and Tobago

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Abstract: *To assess the geotechnical quality of rock aggregates used for construction purposes, two (2) rock types namely Blue Limestone (both massive and layered) and quartzite have been collected from the Northern Range of Trinidad. Blue Limestone is heavily used in the Trinidad and Tobago construction industry as aggregates for ready mix concrete, asphalt design mixes and for the production of steel among other uses. Rocks such as quartzite rather play a smaller role (if any) within the same industry. These rock samples were tested to evaluate the correlations between some important petrographic properties (e.g. rock foliation plane, mineral cleavage plane, rock texture and micro-structure) and the measured geotechnical findings (e.g. uniaxial compressive strength and Schmidt Hammer test values). Then these comparative studies have been examined by rock porosity and density parameters. This study confirms a good control of these geological parameters on the strength of the rock aggregates. This study also suggests quartzite to be more compatible than limestone for these types of construction purposes. Limestone may be disadvantage as it may easily react with acidic water. If limestone is the only choice for these purposes, then layered variety of limestone may be avoided because of its anomalous mechanical properties, which is resulted by alternate layers of different mineral assemblages.*

Keywords: *Rock aggregates, geotechnical properties, geological significances*

1. Introduction

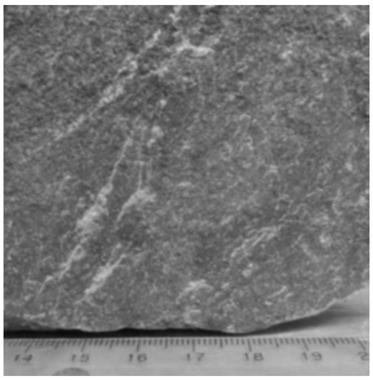
Rocks and rock aggregates are one of the major sources of construction materials in the world. Geotechnical behaviours of these materials, which control the life of any civil engineering construction, are mainly governed by some important geological parameters whenever these materials are being exposed to the environment or external load is applied on them. Therefore, correlation of their geological and expected geotechnical parameters is very important before starting any construction project. Numerous studies have been conducted in this topic by many researchers all over the world (Bieniawski, 1974; Behrestaghi et al., 1996; Tuğrul and Zarif, 1998; Agustawijaya, 2007). These geological properties are said to be influenced mainly by the mineral constituents and also by the textural characteristic (e.g., grain size, grain shape, grain orientation, and arrangement of grains) of the material (Sharma et al., 2011). Other physical and mechanical factors that may be considered include but are not limited to porosity, density and compressive strength, which are consequently influenced by mineral and textural properties of the material (Behrestaghi, et al., 1996; Tuğrul and Zarif, 1998; Dimantis et al., 2009; Tandon and Gupta, 2013). This type of study can accomplish the high demand of information required in the construction industry before designing the project.

Because of negligible amount of available data in Trinidad and Tobago (T&T), this study was designed for the benefit of Trinidad and Tobago construction industry. With the aim to provide preliminary information by correlating geotechnical properties and petrographic properties of rocks and rock aggregates in T&T, simple, inexpensive and easy-to-use methods were considered in the present study, which could eventually lead to deeper studies using improved methods. For this purpose, two major rock types namely blue limestone and quartzite, which are profusely used in Trinidad and Tobago construction industry, were considered. The research approaches adopted were (a) petrographic study of these selected rocks and (b) their geo-mechanical properties (which include uniaxial compressive strength, point load strength index, porosity, dry density, and Schmidt hammer rebound values). Therefore, the objectives of the present study are (i) to examine these rocks by their petrographic properties and geotechnical properties, (ii) to correlate and describe the relationship between their geological and geotechnical properties and (iii) to provide information that can help the local construction industry to select the best available materials.

2. Methodology

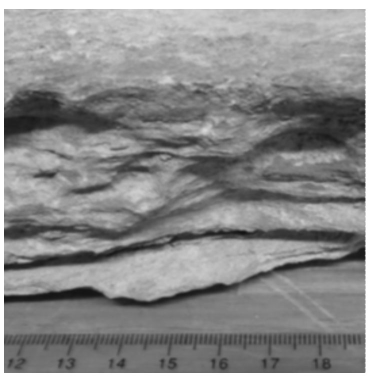
2.1. Sample collection

This study was undertaken in two major rock types namely quartzite and metamorphosed limestone, which were collected from the Northern Range of Trinidad. These limestone samples are of two varieties – massive limestone and layered limestone (see Figure 1). A total of eight (8) massive limestone, nine (9) layered limestone samples were collected from a quarry (currently in operation) in La Pastora district along Cutucupano road (i.e., 10°43'15.15"N and 61°28'41.40"W) and ten (10) quartzite samples were collected from a fresh rock exposure along the Long Coast Road in Arima-Blanchisseuse area (i.e., 10°47'47.55"N and 61°19'05.60"W).

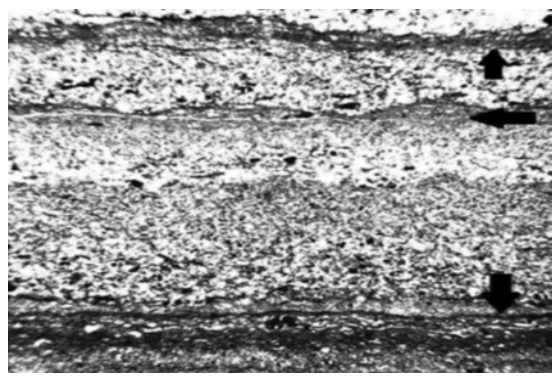


Massive limestone (scale in cm)

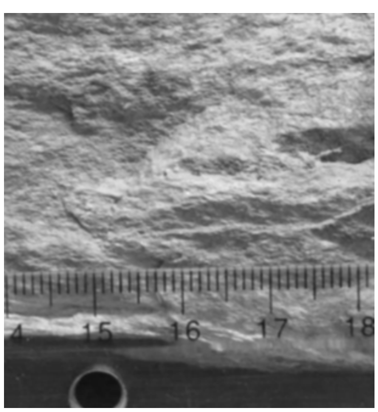
Photomicrograph of massive limestone (50x magnification)



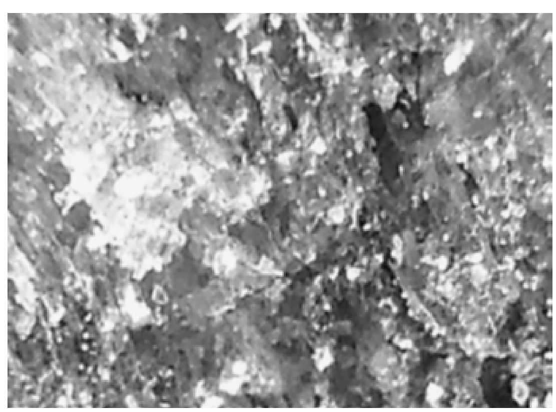
Layered limestone (scale in cm)



Photomicrograph of massive limestone (20x magnification)



Quartzite (scale in cm)



Photomicrograph of massive limestone (50x magnification)

Note: Black arrows in layered limestone photomicrograph show foliation plane.

Figure 1. Petrographic Views of Selected Rocks

Fresh rock samples were taken back to the laboratory for further examination and detailed petrographic study after in situ measurements were carried out in the field. All rock samples were physically examined by their grain size, foliation planes, micro-features (such as fractures and mineral cleavage planes) and hardness. A fabricated magnifier was used to closely examine these petrographic properties.

2.2 Measurement of Porosity and Mass Dry Density

In this study, effective porosity (i.e., a measure of inter-connectedness of pores with reference to water permeability (Gibb et al., 1984)) and mass density (kg/m^3) were measured for all the rock samples under investigation. Effective porosity was determined by immersing rock pieces (~ 450g) into water for 24 hours and drying to a constant mass. This water displacement method was adopted to measure the bulk volume of saturated rock pieces. Porosities for the samples are shown in Table 1. The values were obtained by averaging three vigilant test results from individual sample in order to minimise probable experimental errors particularly in volume measurement (ISRM, 1981).

Effective porosity is taken into consideration as opposed to the total porosity which is simply the ratio of the total void volume to the total bulk volume. In each case of effective porosity measurement, water absorbed by the rock was deducted.

2.3 Measurement of Geotechnical Properties

2.3.1 Schmidt Hammer Rebound Test

The Schmidt hammer is an apparatus to measure the hardness of concrete by measuring the correlation of hammer-rebound principle and strength of the material. All tests performed with the hammer were done on both parallel and perpendicular direction to the foliation plane (Malhotra and Carino, 2004; Sharma et al., 2011). At least 3 readings were taken from each rock specimen, and up to 12 readings, depending on the similarity of numbers recorded. The means of the five values were used for the analysis and a correction factor of 1.4 was also applied.

2.3.2 Point Load Strength Test

Point load test is a well-accepted rock mechanics testing procedure to calculate the rock strength index, which can be used to estimate other rock strength parameters. The

Table 1. Porosities for the Samples

Sample	Rock Type	Average Schmidt Hardness	Uniaxial Compressive Strength(UCS) MN/m^2		Dry Density (Kg/m^3)	Porosity (%)
KL-1	Massive Limestone	31.7 ± 8.7	97.9 ± 2.4		2244.2 ± 120.5	BDL
KL-2			102.6 ± 2.8		2286.0 ± 135.6	0.27
KL-3			95.7 ± 4.5		2304.5 ± 140.2	0.39
KL-4			102.77 ± 5.2		2549.3 ± 142.3	BDL
KL-5			100.8 ± 6.7		2524.7 ± 122.5	0.16
KL-6			95.2 ± 2.8		2364.4 ± 152.3	0.32
KL-7			93.4 ± 9.5		2482.1 ± 146.3	BDL
KL-8			119.8 ± 8.4		2366.7 ± 125.8	0.18
Average			**101.0 ± 8.4**		**2390.2 ± 115.0**	**0.16**
			Parallel to foliation plane	**Perpendicular to foliation plane**		
KL-9	Layered Limestone	32.8 ± 6.5	89.7 ± 3.2	136.4± 10.6	2413.0 ± 150.6	1.94
KL-10			96.9 ± 3.8	155.4 ± 10.8	2132.0 ± 148.2	2.11
KL-11			95.0± 4.2	129.3 ± 9.4	2305.4 ± 174.2	1.71
KL-12			76.5 ± 5.8	155.5 ± 12.3	2536.2 ± 165.3	3.27
KL-13			92.7± 6.2	122.3 ± 6.5	1948.1 ± 156.3	1.59
KL-14			79.3 ± 4.9	175.5 ± 18.5	1883.1 ± 125.3	3.31
KL-15			97.7 ± 3.8	107.3± 11.2	2736.8 ± 142.8	2.21
KL-16			96.6 ± 4.4	109.8± 6.8	2701.1 ± 155.2	1.83
KL-17			115.3 ± 5.7	124.8 ± 9.4	2539.5 ± 147.2	2.15
Average			**93.3 ± 11.3**	**135.1 ± 22.9**	**2355.0 ± 311.5**	**2.23**
KL-18	Quartzite	66.1±11.2	195.0 ± 35.3		2692.3 ± 221.3	0.98
KL-19			202.0 ± 28.9		3080.5 ± 185.3	3.62
KL-20			237.6 ±31.5		3031.0 ± 153.8	2.75
KL-21			245.5 ± 41.5		2889.3 ± 115.9	1.81
KL-22			233.0 ± 39.6		2314.3 ± 214.3	3.45
KL-23			213.5 ± 43.0		2971.4 ± 152.3	1.76
KL-24			222.5 ± 56.3		2539.5 ± 185.4	2.60
KL-25			197.9 ± 25.3		2413.7 ± 124.3	1.96
KL-26			233.7 ± 29.4		2637.8 ± 214.2	2.66
KL-27			184.4 ± 35.2		2641.0 ± 184.7	1.94
Average			**216.5 ± 20.9**		**2721.1 ± 263.2**	**2.35**

*BDL – As per normal water displacement procedure.

apparatus for this test consists of a rigid frame, two point load platens, a hydraulically activated ram with pressure gauge and a device for measuring the distance between the loading points (Rusnak and Mark, 1999). This cost-effective test is highly favoured not only for its efficiency to analyse fragile materials but also the result from this test shows less scatter than other uniaxial compressive strength, which makes the measurement of strength anisotropy simple.

The point load test involves compressing of a rock sample between conical steel platens until failure occurs. The procedure used was adopted from the ASTM D5731-08 standard Uniaxial compressive strengths were then determined from the compressive strength of rock specimens measured using point load test.

3. Results and Discussion

3.1 Porosity and Dry Density Test

It is observed from Table 1 that both types of limestone specimens had similar dry densities which fall within the range of densities expected in these types of rocks (edumine.com). Quartzite specimen recorded the highest dry density value, while the mica schist specimen had the lowest dry density value. These values may be influenced by the porosity values that were observed during this study. Massive limestone recorded very low level porosity (~ 0.16%) while its layered counterpart recorded a 3.66% porosity value. The quartzite recorded a small porosity value of 1.47%.

3.2. Geotechnical Investigation

Table 1 shows the results of Schmidt hammer test on porosities for the samples. It was found that massive limestone had slightly higher rebound values than layered one, while quartzite produced the highest rebound value which coincides with its high hardness rating of more than 6.5 in Mohs Hardness scale.

The uniaxial compressive strength (UCS) of the selected rock samples is also given (see Table 1). Here quartzite again showed the highest strength with an average value of 101.83±8.36NM/m^2. Layered limestone exhibited good anisotropy in UCS values, as the results were low (i.e., average value of 93.30± 11.32 NM/m^2) when test was conducted parallel to the foliation plane, but the results were high in perpendicular direction (i.e., average value of 135.14± 22.86 NM/m^2). Massive variety of limestone produced strength values higher than the strength values in layered limestone along foliation parallel direction but these values were less than the foliation perpendicular strength values in layered limestone (i.e., average value in massive limestone 216.50± 20.93 NM/m^2).

3.3. Geological Contribution to Geotechnical Variations

Study of the petrography and physical properties of the material are subsidiary part of any geotechnical investigation (İrfan, 1996; Tuğrul and Zarif 1998; Sharma et al., 2011)

Rock groups selected in this study indicated significant difference in their geotechnical properties whether these are compared in the same group or in separate groups. Both massive and layered limestone samples produced half of the Schmidt hardness showed by quartzite samples. UCS results were also 1.5 to 2 times higher in quartzite than both types of limestones. These contrasting features can be explained with the help of their pretographical signatures, which are identified in this study. Quartzite is mainly composed of quartz minerals and it has granoblastic texture (see Figure 1), which makes in one of the most compact rock in the world. In quartzite, early formed quartz grains are generally recrystallised to very fine and equant sizes due to metamorphic process, and during this process partial melting of the mineral also plays an important role by arranging these crystals in an inter-locking framework (Török and Vásárhelyi, 2010; Zhang et al., 2011; Tandon and Gupta, 2013).

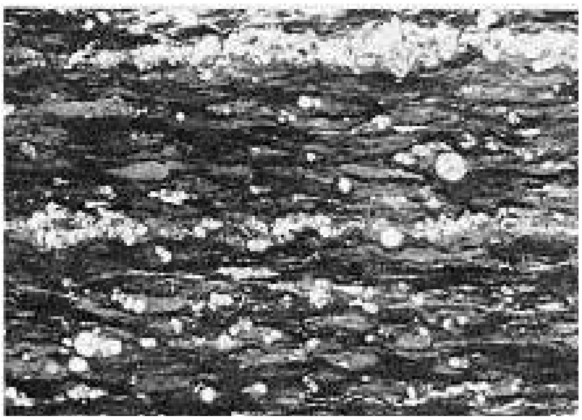
All these rearrangement processes help quartzite to reduce its void spaces and can be reconciled with its compactness to resist high amount of external load. The only possible way that can develop porosity in quartzites is impurities created by small portion of mica and internal fractures.

On the other hand, porosity of limestone was also low especially in massive one and it was nearly similar to quartzite. Low porosity can be attributed to the same granoblastic texture in limestone, which mainly composed of partially recrystallised and equant calcite minerals. Moreover, difference in melting point of calcite (i.e., below 850°C) and quartz (i.e., above 1600°C) also has a good control on the crystal rearrangement processes during metamorphism of the pre-existing rocks (MLPt, Digitalfire Reference Database).

In similar type of deformation and metamorphism, calcite mineral behaves ductile while quartz shows brittle nature (Brodie and Rutter, 2000). This ductility or plasticity of calcite helps to reduce more porosity in limestone. Layered limestone acquires marginally higher porosity due to the presence of foliation plane, which is produced by impurities in the form of mica and in some cases elongated calcite grains. Figure 2 shows the foliation plane resulted by arrangement of mica rich layers of limestone.

Two main parameters that may decrease UCS values in limestone are hardness and internal structure (rather crystal habit) of calcite crystal. In Mohs' Hardness scale calcite shows the hardness of 3 while quartz has the hardness of 7. Limestone is mainly composed of calcite, therefore hardness of calcite crystals help significantly to reduce the UCS values in limestone. Calcite has one more important property due to its crystallographic feature called mineral cleavage plane.

It is defined by the tendency of a mineral to break along flat planar surfaces as determined by the structure of its crystal lattice, which are caused by the alignment of weaker bonds between atoms in the crystal lattice. Calcite has three (3) sets of cleavage planes that again help it to break at comparatively low external pressure.



Note: White layers are the calcite rich layers while the elongated grains (mainly mica) form foliation plane. Some calcite grains (white in colour) found to be elongated in their shape (magnification 50x).

Figure 2. Photomicrograph of Layered Limestone

More interestingly, in layered limestone, UCS values were nearly two-times higher along the foliation perpendicular direction than the UCS values along foliation parallel direction. This variation may be acceptable due to the presence of then mica rich calcite layers, which are sandwiched between calcite rich layers (see Figure 2). These layers produce impurities in the compactness of the limestone by arranging mica-flakes in a same direction developing foliation planes in these rocks. Mica is one of the soft mineral (i.e., hardness is ~2.5 in Mohs' Scale of hardness and has 1 set cleavage plane), hence, these thin layers with different mechanical properties produce anomaly in the overall rock strength.

4. Conclusion and Recommendations

Determination and correlation of important geological and geotechnical properties of rock and rock aggregates are very crucial part of rock mechanics. Though present study was very primitive, but it can be very important and informative in the context of Trinidad and Tobago construction industry.

This study affirms certain important geological parameters (such as rock foliation plane, mineral cleavage plane, rock texture and micro-structure) have good impact on the strength of the rock or rock aggregates. Among the two analysed rocks, quartzite was found to be more efficient for civil construction. Apart from the geotechnical imperfections, limestone may be avoided for its readiness to react with acidic water.

Moreover, this study observed heterogeneity in the geo-mechanical behaviour of layered limestone. It is therefore recommended to avoid layered limestone particularly in the field of compression. Detailed petrographic and micro-structural (fabric) analysis is required to assess more geo-mechanical properties (such as tension and abrasion along with compression) of the rock aggregates used in T&T.

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An Evaluation of the Compliance of the Water Pollution Control Rules in Port of Spain, Trinidad

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Abstract: *Water quality is a growing concern throughout the developing world and the effects of water pollution can be very costly. Preventing and cleaning up pollution in developing countries are met with many structural obstacles, particularly economic ones. To address the problems of environmental degradation due to land based water pollution, Trinidad and Tobago introduced, in 2001, the Water Pollution Rules (WPR) to regulate the quality of effluent discharged to the environment. In 2009, the EMA began issuing Water Pollution Permits (WPPs) to facilities whose effluent contained pollutants outside the permitted levels. This paper reports on compliance to the WPR at selected facilities in the Port of Spain watershed in Trinidad. The study found that the management of facilities would not have volunteered pollution remedial actions in the absence of WPR and WPP. Moreover, the results of policy implementation appear to be quite encouraging. Overall, the compliance for the monitored stations ranged from 20% to 75% which is considered acceptable in the early stage of implementing the WPR. To improve the success of WPR, consideration should be given to the implementation of the WPR according to the polluter-pay-principle and/or increasing the fines and penalties of enforcement. It is recognised that the WPR as currently implemented cannot guarantee the desirable water quality.*

Keywords: *Pollution control, rules, compliance*

1. Introduction

In developing countries, population growth and rapid urbanisation, together with changes in lifestyle and economic development, have heightened the demand pressure on the limited water resources thereby reducing the quality of these resources. The costs associated with water pollution can be high in developing countries in terms of addressing health related issues, environmental degradation, reduced quality of life and the clean-up requirements in the future. Preventing and cleaning up pollution in developing countries are met with many structural obstacles, particularly economic ones. In practice, capital is rarely available to invest in equipment to control pollution unless there is pressure from government through the enforcement of regulations. Generally, governments are rarely motivated to regulate industries unless there are compelling reasons to do so, and there is pressure from their citizens (Guidotti, 1998). Notwithstanding, some developing countries are taking action to address the problems of pollution by relying heavily on the implementation of conventional regulatory approaches such as mandatory emission limits and technology standards (Blackman, 2006).

In Trinidad and Tobago (T&T), land based sources of water pollution pose a major threat to water resources. In the absence of appropriate legislations in Trinidad and Tobago, wastewater has been discharged from industrial, mining, commercial and manufacturing facilities to watercourses for many decades, compromising the quality of surface and coastal waters. Similarly, other diffused sources of water pollution, such as, urban and agricultural runoff, also played a part in the degradation of water quality. The effects of pollution on the water resources have prompted some research interest. For example, a number of studies documented incidents of pollution on key water resources (Sampath, 1982; Siung-Chang *et al*., 1987; Regulated Industries Commission, 2004; Lucas and Alkins-Koo, 2004). Other studies have considered the impacts of heavy metals and agricultural chemicals in water resources (Ramsingh, 2009; Sharda, 2010). Nonetheless, not much relevant scientific information has been available in the past to provide a quantitative assessment of water quality in Trinidad and Tobago, and where data are available, they have not been reliable compilations from which to determine the state of water quality or to estimate trends (EMA, 2005).

This is because the monitoring of water quality parameters has generally been given low priority; the technical base for monitoring water quality is weak; there is lack of coordination between agencies; and key indicators for assessing water quality, particularly biological indicators are limited. The earlier legislations enacted to treat with environmental management of water pollution were ad hoc and non-specific, and they fell under the remit of various ministries and departments of government. As a result, effective enforcement of these legislations was stymied and lacked institutional and legal focus. In order to address the problems of water pollution, the Water Pollution Rules (WPR) were introduced (EMA, 1999).

Safeguarding the quality of water is important to peoples' health. It is therefore, necessary to ensure that adequate systems to monitor water quality are in place and that such systems are effective. The EMA recognizes the limitation of the WPR in that the primarily focus is on end-of-pipe or point source. The WPR do not address the problem of non-point source pollution, that is, pollutants derived from diverse and diffuse sources moving over land and through the ground such as fertilizers, pesticides, and oil and grease from urban runoff (EMA, 2014). Groundwater aquifers are particularly vulnerable to this source of pollution. Non-point pollution is harder to locate and control than point sources and can explain why authorities generally tackle end-of-pipe pollution as a first step.

The WPR require water quality monitoring which is important to detecting incidents of water pollution and in measuring the level of compliance and is critical to understanding the impact of water pollution on the environment. However, it has been observed that one of the most important issues contributing to water pollution has been the lack of enforcement of environmental Legislation (The Water Resources Agency, 2001). Ultimately, two questions that need to be answered in the context of the WPR are (1) what is the level of compliance? and (2) are the rules leading to improved water quality? While the second question is critical to judging the efficacy of the WPR, it requires a more broad-based research effort.

In 2009, the EMA began issuing Water Pollution Permits (WPPs) to end-of-pipe pollution facilities whose effluent contains pollutants outside the levels permitted (EMA, 2009). The paper investigates the performance of some of these facilities and is therefore limited to the first question above. Consequently, it reports on the assessment of compliance to pollution parameters which are set for seven facilities operating in the Port of Spain watershed. It also gleans from interviews and surveys, the lessons learnt from implementation of the WPR.

2. Background

Water pollution prevention and control measures are critical to improving water quality and reducing the need for costly water and wastewater treatment. Since water pollution can come from many different sources, a variety of pollution prevention and control measures are needed (EPA, 2013). Since governments have a primary duty to protect people and their properties, pollution control is a legitimate function of government. As such, governments have a role to ensure that polluters pay for the damage they cause and are restrained from causing harm in the future by establishing a polluter-pay-principle (PPP). The PPP is one of the fundamental principles of modern environmental policies. The charge is usually added by the polluter to the production cost of the goods and is passed to the consumer (Munir, 2004). This approach is rarely embodied in environmental laws (Alder, 1995).

One of the earliest interventions to address water pollution was the Federal Water Pollution Control Act of 1948 in the United States. This Act was radically amended in 1972 in response to increasing public awareness and concern for controlling water pollution, giving rise to the Clean Water Act (CWA) (EPA, 2014).

Until the 1990s, there was a scarcity of rigorous studies on pollution control in developing countries. However, there was convincing casual evidence that regulations to protect the environment were ineffective or unnecessarily costly (Eskeland and Jimenez, 1992). Since then, the growing interests in tackling the worsening problem of air and water pollution in developing countries have resulted in a robust debate among policymakers and academics about the pros and cons of using economic incentive policies instead of, or alongside, command-and-control (CAC) policies to reduce pollution (Blackman, 2006).

The CAC policies, which proliferated during the 1970s as the preferred approach to environmental control, were enacted to bring about a change in behaviour. It was used as an enforcement machinery to get people to obey the law and typically required polluting facilities to use specified abatement devices or to cap emissions at prescribed levels. It dominated policy in developed countries because there was greater focus on remediation rather than comprehensive prevention techniques (Bocher, 2012). The use of CAC policies may be a useful initial approach, particularly, when there is limited information and the environmental damage is a serious concern (Di Falco, 2012). The observed results of the implementation of command-and-control policies, however, are in general not always very encouraging (Eskeland and Jimenez, 1992; Russell and Vaughan, 2003; Blackman, 2009). Consequently, it is not surprising that the implementation of market-based instruments or economic incentives for regulation has been on the increase due, in part, to the disenchantment with CAC approach (Harrington and Morgenstern, 2004).

Market based instruments or economic incentive policies provide financial rewards, including the use of taxes and subsidies, as incentives for compliance with water quality standards (Baldwin and Lodge, 2011). Economic incentive policies have the dual benefits of motivating polluters to cut emissions in a cost-effective manner while, at the same time, encouraging regulatory authorities to improve permitting, monitoring, and enforcement of water quality standards (Blackman, 2009). The general success of marked-based instruments in pollution control has been reported in the literature

(Seroa da Motta, 2006; Blackman, 2010). Market based instruments are often considered as an alternative to CAC however, in reality they co-exist. The success of market based instruments depends upon a well-functioning monitoring and CAC system, including properly functioning institutions (Di Falco, 2012).

The success of environmental policies in reducing water pollution is varied. In India, where environmental regulations are patterned on those from the United States and Europe, Greenstone and Hanna (2011) found that they were ineffective. Nonetheless, based on the Indian experiences, they concluded that environment regulations can be enforced successfully in countries with relatively low levels of income and weak institutions. In Columbia, notable progress has been reported in pollution control of water bodies (Kathuria, 2006). In this case, a strategy of collaboration between government, local business and communities encouraged the development and implementation of plans for cleaner technologies by many companies.

Some environmental regulations have been unsuccessful because they do not match the technical requirements and economic reality of the country or region, or because they do not take into consideration the institutional capabilities of the society that has to implement these regulations (Singh and Rajamani, 2003). To improve the level of success, some countries include, under the terms of a permit, compliance promotion programmes and activities. Although these programmes are very often comprehensive, the compliance rates remain unsatisfactory as detecting and prosecuting non-compliance are complex, as well as time and resource consuming (GFSD, 2004).

The starting point for structured water pollution management is the establishment of adequate legislation. However, critical to the effectiveness of the legislation is the ability to obtain compliance. In developed countries, full compliance with environmental regulations was rarely observed in the past. In the USA, sources in violation for air pollution was 65% (Russel, 1990), in the United Kingdom, compliance were sometimes as low as 50% (Heyes, 2000), while in the Netherlands, 67% of industries complied with the Surface Water Pollution Act (Prinsen and Vossen, 2002). In less developed countries such as China, Tanzania, Nigeria, Rwanda and Kenya, the levels of compliance with the environmental laws are below 59% (Ostrovskaya and Leentvaara, 2011).

In developing countries, compliance is highly dependent on the governmental willingness to enforce regulations. Enforcing agencies are often not mature enough and lack the ability and capacity to perform their activities properly. Further, there is a lack of formalised procedures to plan and set priorities that can help enforcers to use their limited resources more productively (Ostrovskaya and Leentvaara, 2011).

3. Trinidad and Tobago Water Pollution Rules

The WPR of T&T impact on and apply to a very wide cross section of the community, ranging from small scale beauty salons to heavy industries. Compliance with the WPR and cooperation with the EMA are necessary steps in facilitating the implementation of an effective water resource management strategy (Rambarath-Parasram, 2007).

Following the 1992 Earth Summit, the Trinidad and Tobago Government committed itself to addressing national environmental issues and to improving environmental performance (GOTT, 2012). In March 1995, the Environmental Management Act (EM Act) which established the EMA was passed. The EMA is mandated to write and enforce laws and regulations for environmental management, educate the populace about national environmental issues, control and prevent pollution and conserve the country's natural resources (GOTT 2011). As a result, a National Environmental Policy (NEP), which was designed to promote conservation and encourage the wise use of the environment, was adopted in 1998. A key principle of the policy is that the cost of preventing pollution or minimizing environmental damage due to pollution is to be borne by those responsible for the pollution (EMA, 1999). In keeping with this principle, the EM Act (GOTT, 2000a) mandated that the EMA determine the sources, distribution and types of water pollution, and develop a Water Pollution Management Programme to control and reduce the water pollution. The primary policy instrument used for achieving these objectives is the permit system of the WPR (GOTT, 2000b).

"The Water Pollution Rules 2001 (as amended) became operational in May, 2007 with the aim of ensuring that industries in Trinidad and Tobago control and reduce the volumes and concentrations of pollutants discharged in their waste water. Over time it is expected that the quality of our Inland Surface Waters, Coastal Nearshore, Marine Offshore, and Environmentally Sensitive Areas and Groundwater would improve" (EMA, 2014).

There are two major processes for the implementation of the WPR. First, there is a Source Registration (SR) where a comprehensive register of water polluters is generated from identified sources based on vulnerable watersheds. Facilities that regularly discharge water pollutants into the environment at or above the specified levels are required to complete and submit an application to the EMA for SR (GOTT, 2001b). During the SR process, pollution levels of discharges are checked against acceptable benchmark levels. A facility not meeting the benchmark is identified as a water pollution source and is issued a Source Registration Certificate (SRC) and is monitored over a period of three years. A SRC does not by itself represent any endorsement, licence or permit to operate by the EMA.

The second phase of the implementation of the WPR, hereafter referred to as the permitting phase, is the process to control and reduce the volume and concentration of effluent to meet the permissible levels. The permitting phase is initiated when monitored parameters exceed the permissible levels during the SR phase. The EM Act mandates the EMA to establish procedures for the issuance of a Water Pollution Permit (WPP) to authorise any facility to discharge wastewater under specific conditions. This controls water pollution by regulating point sources pollutant discharges. A WPP supersedes the SRC and is issued for a maximum period of five (5) years in the first instance. The terms and conditions of WWP include:

- Approved effluent discharges into receiving waters;
- Location of sampling point for compliance monitoring;
- Parameters/substances to be monitored at each sampling point;
- Monitoring schedule which outlines the frequency of sampling;
- Interim and final discharge limits for each pollutant; and
- Appropriate monitoring and reporting regime for effluent discharges, influent and ambient water quality.

The WPP is based on the acceptable benchmarks for 29 parameters. These are set according to four (4) specific receiving environments which are inland surface water, coastal near-shore, marine offshore, environmentally sensitive areas and/or groundwater. When identifying facilities requiring permits, the Authority considers the following criteria:

- Facilities located in watersheds vulnerable to surface water pollution;
- Proximity to sensitive receptors;
- Discharges into sensitive environments; and
- Complaints and compliance history.

During the permitting phase, permit holders must take measures to improve the operations so that compliance could be achieved. They are also required to submit a Pollution Control Plan (PCP), a Quality Assurance Project Plan (QAPP) and a Best Management Practices Plan (BMPP) to the EMA.

The EMA has already accepted that the impact caused by non-point source pollution is important and requires serious attention and action in order for it to achieve its mandate of clean water for all. A non-point pollution management programme has been proposed to complement the WPR. This proposed non-point source pollution management programme is expected to satisfy the long term goal of protecting Trinidad and Tobago's waters from further degradation (EMA, 2014).

The starting point for the review of the implementation process of the WPR in Trinidad and Tobago was a comparison between the legislative structure for the implementation of the WPR in T&T and three other developing countries namely Indonesia, Columbia and Poland. The following similarities were observed:

- The main environmental legislation had to be complemented by subsequent subsidiary legislation;
- The establishment of an Environmental Management Authority; and
- The self-reporting requirement of the permittee.

The following features, found in the countries, considered were absent in T&T:

- Revenue generation from the licensing system;
- Incrementally increasing stringency in the standards; and
- Decentralisation of the policing responsibility.

4. Methodology

4.1 Study Site

The study site, Port of Spain watershed, has been identified as having a high risk of vulnerability to water pollution from land based activities. In total, forty-seven (47) facilities have been registered as sources of water pollution under the SR process. Among them, seven (7) of the eight facilities that have been issued WPPs between 2010 and 2011 were the focus of this study. These facilities include chemical manufacturing, food and beverage processing, vehicle repair and maintenance, energy related processes, and waste collection and disposal.

4.2 Data Collection

Self-monitored pollution parameters data, which were collated in Discharge Monitoring Data Reports (DMDR) and submitted monthly to the EMA, were analysed. As a requirement of the WPP, permittees are required to collect and analyse samples according to the EMA's approved QAPP. The QAPP identifies the quality assurances and quality control measures to be undertaken in the collection and analysis of samples of wastewater and the reporting of the acquired results. Each permit includes a monitoring schedule which specifies the parameters to be monitored at specific discharge points and the frequency of monitoring. A daily value for each parameter is determined by taking a minimum of four (4) grab samples over the operational cycle of a day.

Data for periods of up to two and a half years prior to 2013 were available. The pollution parameter values were compared to benchmark permissible levels. Table 1 shows the parameters and the companies that were analysed. The data were checked for consistency and accuracy by comparing them with the supporting data records (such as calibrations, chain of custody documents, preservation of sample methods, sample dates, holding times and analysis dates). The PCP, QAPP and BMPP (EMA, 2005) that were submitted to the EMA, as a requirement under the WPR for each

Table 1. Parameters Monitored at Facilities with Water Pollution Permits

Type of company	**Chemical Manufacturing**	**Energy related Processes**	**Food and Beverage Manufacturing**			**Maintenance and Repairs**	**Waste Collection and Disposal**
	BPTL	**PowerGen POS**	**TDL**	**TJCL**	**CGA Limited**	**VMCOTT**	**WDL**
Parameter/Substance							
Temperature	✓	✓*	✓	✓	✓	✓	
Hydrogen ion (pH)	✓	✓	✓*	✓	✓	✓	
Total Suspended Solids (TSS)	✓*		✓*	✓	✓	✓*	✓*
Five day Biological Oxygen Demand (BOD_5 at 20°C)			✓*	✓*	✓		✓
Chemical Oxygen Demand (COD)	✓*	✓				✓*	✓
Total Oil & Grease (TO&G)				✓	✓		✓
Total Petroleum Hydrocarbons (TPH)	✓	✓	✓		✓	✓*	✓
Ammoniacal Nitrogen (NH_3-N)			✓				
Total Phosphorus (as P)			✓		✓		✓
Faecal Coliforms				✓*	✓*		✓*
Dissolved Hexavalent Chromium (Cr^{6+})	✓					✓	
Dissolved Iron (Fe)	✓						
Total Lead (Pb)						✓	
Total Nickel (Ni)		✓					
Total Zinc (Zn)	✓						
Total Cadmium		✓					
Flow rate	✓	✓	✓	✓	✓	✓	✓

Remarks: *- critical parameter

WPP, were reviewed to assess consistency in evaluation by the EMA personnel in approving permits. Furthermore, this review compared the proposed mitigation methods to prove industry specific best management practices.

4.3 Interviews

Unstructured interviews and online surveys were conducted among government agents, permittees and the general public to determine their levels of awareness of the WPR. Employees of the EMA were interviewed, in person, to identify how implementation success was measured. Permittees were interviewed using open-ended questions which were supplemented with telephone interviews for further clarifications. The questions were used to obtain information on:

- The effect of the WPR on the awareness of water pollution issues and behaviour towards water pollution;
- The perceptions and opinions on the effectiveness of the permitting processes, the effectiveness of the EMA in administering the WPR and ways of improving the processes; and
- The views on alternative approaches for administering WPR, for example, use of the PPP.

The interviews facilitated dialogue and allowed participants to express their experiences more freely on the application process, support systems from EMA and parity with respect to affixed fines and penalties. Structured interviews were carried out, in person, with members of the general public to assess their awareness and perception of efficacy in the implementation of the WPR. The general public were surveyed through a six question interview to obtain their perception and awareness of the nature of the water pollution problems and relevant legislation, and to assess the efficacy of the regulator.

4.4 Measuring Compliance

Ideally, non-compliance should be based on some deviation from the background concentration for particular pollutant in the environment in which it is discharged and/or inadequate implementation of the procedures, and maintenance of the control measures, required by the permit. The way in which non-compliance is to be interpreted and evaluated is not very clear for the implementation of the WPR. This leads to some level of uncertainty in determining an appropriate definition. For example, should non-compliance be taken on the basis of one parameter or a group of parameters? Failure to meet any of the set requirements could be judged a legal violation.

However, for practical purposes, selected requirements may be applied without exception. In the case in Indonesia in the 1990s, non-compliance was defined as violation of the standard for one month or more during the six-month period (Afsah et al., 1995). This approach is not considered here since samples were taken on a monthly basis and not as regular as was done in the Indonesian case. In this study, compliance is determined on a parameter basis. Thus, the level of compliance is computed as the portion of time that the effluent sample results were within the prescribed levels for a particular parameter.

5. Results and Discussions

5.1 Result-Based Monitoring

The results of the pollution parameters monitored at the different facilities are given in Tables 2 to 7. These include the mean and standard deviations of the pollution parameters for each facility from a minimum of 30 data samples taken over the review period. The percent of compliance of each of the pollution parameter is based on the data provided by each facility. At the EMA, compliance and non-compliance statuses are not clearly defined. In other jurisdictions, a facility is considered to be probable in an out-of-compliance status when the value of any compliance parameter in any compliance monitoring sample exceeds the permissible level or other applicable permit limit (UGWQP, 2014).

The level of compliance is computed as the percentage of the time that the effluent sample results were within the prescribed levels. For example, in Table 2, for food and beverage processing, Plant 1 has been fully compliant for temperature at both discharge points (A and B) and pH at discharge point B. In all other cases, the plant was not meeting the established effluent standards. Non-compliance in the parameters TSS and BOD_5 was high, exceeding the permissible level by a factor of 4 or more. At both plants, the compliance for faecal coliform was very poor; always non-compliant in Plant 1 and occasionally slightly compliant in Plant 2. The low compliance rate observed at the food and beverage plants is expected as wastewater from the fruit juice industry that will contain contaminants from the facilities cleaning and process wastewater. When this wastewater enters the natural environment it can have toxic effect on aquatic life. This suggests a case for more rigorous monitoring of the discharge points at these facilities.

As shown in Table 3, there was full compliance for temperature, iron and zinc for the paint plant. The levels of pollution from the two discharge points were different. At Location A, where the discharge flow rate was higher, there was a greater concentration and volume of pollutants.

Table 4 shows pollutant monitoring for the power generating plant. In this case, as the intake water is used mainly for cooling, the major impact is expected to be from temperature increases and from the contamination of the intake water from hydrocarbons, cleaning material and other substances that are used in daily operations of the plant. Further analysis for location A (not shown in the table) indicated that there is an increase of about 6.5°C in the temperature of the influent water. For the four discharge points and the six parameters monitored, the plant is meeting full compliance for 75% of the time. At discharge point D (where only cooling water was

Table 2. Pollutant Monitoring for Food and Beverage Plants

Parameter	Temp (°C)	pH	BOD_5 (mg/L)	TSS (mg/L)	TO&G (mg/L)	FC (counts per 100mL)	Flow Rate (m^3/day)
Permissible Level	**35**	**6-9**	**30**	**50**	**10**	**400**	**NA**
Plant 1							
Mean	29.4	6.77	447	44.835	4.52	247597	717.46
STD	1.45	0.55	360	41.86	4.27	359644	535.27
% Compliance **(A)**	100	52	0	52	91	0	
% Compliance **(B)**	100	100	48	100	91	0	
Plant 2							
Mean	31.88	7.49	26.79	42.81	43.51	646857.81	82.89
STD	3.18	0.71	12.68	103.74	97.40	720392.85	111.66
% Compliance	88	100	67	96	38	13	

Table 3. Pollutant Monitoring for the Paint Plant

Parameter	Temp (°C)	pH units)	TSS (mg/L)	COD (mg/L)	TPH (mg/L)	Cr^{6+} (mg/L)	Fe (mg/L)	Zn (mg/L)	Flow rate (m^3/day)
Permissible Level	**35**	**6-9**	**50**	**250**	**25**	**0.1**	**3.5**	**2**	**NA**
Location A									
Mean	28.59	7.75	379.08	1205.36	10.87	0.15	0.22	0.34	2607.38
STD	1.72	1.07	693.25	1324.58	35.02	0.16	0.21	0.48	5231.94
% Compliance	100	88	25	25	96	60	100	100	NA
Location B									
Mean	29.04	7.34	260.11	816.74	8.13	0.01	0.21	0.18	209.67
STD	1.46	0.70	683.98	1334.52	19.02	0.005	0.130	0.238	309.49
% Compliance	100	96	54	38	92	100	100	100	NA

discharged), there was full compliance for all pollutant parameters monitored. Hence at discharge point B, there was high non-compliance with temperature during a five-month period when the company experienced operational challenges.

At the vehicle repairs and maintenance facility, characterised by small flows, the compliance was above 60% for all the parameters (see Table 5). The large standard deviations suggest high fluctuations in the main pollutant discharges over the reporting period. However, further analysis shows small declining levels of TSS and TPH but increasing levels of COD and Dissolved Hexavalent Chromium (Cr6+). As this facility handles significant quantities of hydrocarbon in its operation, the declining trend over the reporting period may suggest that there was improvement due in part to the implementation of the WPR.

Table 6 shows the results from the parameters monitored at a distillery plant. Typical wastewater from distilleries carries appreciable organic load and the spent wash is coloured and highly acidic with an offensive odour, which poses serious environmental problems. The level of compliance for temperature, total petroleum hydrocarbons (TPH) and nitrates (NH3-N) are better than for TSS, BOD and P. It is expected that the TSS and BOD levels for such plants can be problematic due to the characteristic of the products used in the production process. However, further analysis shows that there was a moderately increasing trend of the level of BOD and TSS over the reporting period. Since there are many available cost effective methods of treating distillery wastewater, it may be necessary to introduce more stringent requirements for reducing pollution loads from the distillery plant.

For the pollution monitoring at the waste disposal facility, compliance has been achieved only for P and BOD (see Table 7). The pollutants FC and TSS are of concern since they have negative impact on public health. Nonetheless, a trend of improvement over the monitoring period has been observed for total oils and grease (TO&G), TSS and TPH.

The simple measure of compliance shows that none of the facilities were meeting all the set standards. When considering the physico-chemical and biological parameters, all the facilities were discharging within the temperature condition set, except for the power generating plant where the discharge at one location was outside the set conditions for a specific period. Thirty-seven percent of the discharge points were fully meeting the requirement for pH, while the others average about 78% with the lowest compliance being 20%. It is of note that only the waste disposal plant was meeting the BOD benchmark. The average compliance for BOD at the other discharge points monitored was 31%.The unexpected good compliance for BOD at the waste disposal plant suggests the need for an audit of monitoring process in the future.

Table 4. Pollutant Monitoring for Power Generating Plant

Parameter	Temp (°C)	pH	COD (mg/L)	TPH (mg/L)	Ni (mg/L)	Cd (mg/L)	Flow rate (m^3/day)
Permissible Level	**35**	**6-9**	**250**	**25**	**0.5**	**0.1**	
Mean	32.9	7.7	65.6	2.3	0.01	0.01	126324
STD	2.42	0.5	45.0	3.7	0.0025	0.0025	85674.
% Compliance **(A)**	100	89	85.7	100	100	100	NA
% Compliance **(B)**	45	100	91	91	100	100	NA
% Compliance **(C)**	100	100	100	96	100	100	NA
% Compliance **(D)**	100	100	100	100	100	100	NA

Table 5. The Results for the Vehicle Repairs and Maintenance Facility

Parameter	Temp (°C)	pH	TSS (mg/L)	COD (mg/L)	TPH (mg/L)	Cr^{6+} (mg/L)	Pb (mg/L)	Flow Rate (m^3/day)
Permissible Level	**35**	**6-9**	**50**	**250**	**25**	**0.1**	**0.1**	
Mean	28.9	7.8	60.4	176	26.58	0.1	0	0.09
STD	1.62	0.82	90.0	284	66.11	0.09	0	0.18
% Compliance **(A)**	100	90	64	68	89	71	100	NA
% Compliance **(B)**	100	96	85	100	85	73	100	NA

Table 6. The Results for a Distillery Plant

Parameter	Temp (°C)	pH	TSS (mg/L)	BOD (mg/L)	TPH (mg/L)	NH_3-N (mg/L)	P (mg/L)	Flow Rate (m^3/day)
Permissible Level	**35**	**6-9**	**50**	**30**	**25**	**10**	**5**	
Mean	27.9	5.89	43	271	4.36	1.08	1.55	40.4
STD	2.16	0.68	76.6	518.3	5	1.57	2.2	60.2
% Compliance **(A)**	95	20	95	20	100	100	85	NA
% Compliance **(B)**	100	94	67	6	89	95	67	NA
% Compliance **(C)**	100	80	57	48	100	100	100	NA

Table 7. Pollutant Monitoring for Waste Disposal Plant

Parameter	TSS (mg/L)	BOD (mg/L)	COD (mg/L)	TO&G (mg/L)	P (mg/L)	TPH (mg/L)	FC (counts per 100mL)	Flow Rate (m^3/day)
Permissible Level	**50**	**30**	**250**	**10**	**5**	**25**	**400**	**NA**
Discharge point A								
Mean	59.87	17.06	NA	14.17	0.61	NA	139941	206.52
STD	49.83	9.31	NA	30.41	0.37	NA	237645	206.02
% Compliance **A**	72	100	NA	86	100	NA	53	NA
Discharge point B								
Mean	80.61	NA	116.11	NA	NA	37.4	NA	365.77
STD	96.74	NA	128.02	NA	NA	143.8	NA	363.56
% Compliance **B**	67	NA	71	NA	NA	91	NA	NA
Discharge point C								
Mean	99.93	NA	217.83	NA	NA	5.43	700844	175.7
STD	66.05	NA	360.7	NA	NA	5.61	611385	110.78
% Compliance **C**	34	NA	83	NA	NA	100	17	NA

The monitoring of COD shows that except for the power generating plant, compliance was about 63%. The non-compliance of BOD and COD has the potential to affect aquatic life in the waterways. The analysis for TSS shows that there was full compliance in less than 10% of the monitored points while the remainder averaged 70% non-compliance. An analysis for P shows that 50% of the monitored points fully complied with the benchmarks in the given permits. For TPH, 45% of the monitored points met full compliance while the average compliance of the others was 90%. On the other hand, no monitored point met full compliance for TO&G and the average compliance was 76%. In the case of heavy metals, there was full compliance for iron, lead, nickel, zinc and cadmium. At the sites monitored for chromium, compliance ranged between 80% and 70%.

As the requirements for the WPR was based on the concentration of the pollutant, no in-depth attempt was made at using flow rates to analyse the quantity of the pollutant being discharged. For example, based on the results in the study and estimates of operational durations, the distillery plant could discharge as much as 500kg, 60kg and 20kg of solids, petroleum hydrocarbons and phosphates respectively on a daily basis. However, undertaking meaningful analysis of the quantities, the information on total discharge volumes which are not now available would be required.

5.2 Observations from Survey and Interviews

Although the EMA is mandated to undertake activities for improving public awareness of the environmental legislation and wastewater management including the WPR, it was found that less than 20% of the public interviewed was aware of the activities of the EMA. It was also found that the public was not very interested in the WPR.

The EMA has acknowledged that there are sources of water pollution, which should be within the permitting process, that have not been registered. Site visits to facilities during this study found that in some cases there were more discharge points than what were approved. Furthermore, some facilities submitted renewal applications without including the additional discharge points and were issued SRC. This suggests a deficiency in the stringency of the renewal process.

Inconsistencies were found amongst the approval criteria for permit documents such as the QAPP, BMPP and PCP and the use of Best Professional Judgment in determining monitoring schedules. Although internal checklists are used for reviewing the documents, the approval process can be discretionary due to limited technical capacity and resource deficiencies.

The study found that the facilities, with WPR permits, would not have complied voluntarily with the WPR if they were not legislated. Further, there was little support for the implementation of the WPR in keeping with the PPP. Nonetheless, it was also found that there was an increased awareness of water pollution issues amongst the staff of the EMA and the facilities that were monitored and that there was an improvement in the culture with respect to water pollution. The improved culture is the result of changed/improved behaviours of staff of the EMA and the monitored facilities and their awareness of the implications of negative behaviours on the wider populace.

Facility operators agreed that the fees to the EMA were small; however, there was a general concern about the high cost of complying with the WPR. For example, in the case of Powergen, the cost of implementing the rules for the years 2001 to 2009 has been estimated at US$ 438,922 (Roberts and Little, 2011). The validity of these costs concerns needs to be examined as it was found that treatment costs in implementing water pollution rules are small and can be as low as 0.2% of the industry's total production costs (Chooi, 1984). Further, there are indications that in some cases, the quality of effluent discharged was higher than that of the receiving environment and this is prompting the call for the simultaneous monitoring of the receiving water.

The EMA management considered the WPR to be successful as measured through its observations from site visits, areal fly-overs and preliminary analyses of data. An example of the success is cited in the case of a juice making plant where discharges, once refused by the central wastewater treatment plant, are now accepted for discharge to the sewer system that conveys wastewater to the treatment plant. While concrete evidence was provided, this claim of success may be partly corroborated by an example of the reduction in the case of TO&G for the waste disposal facility as shown by the exponential trend-line in Figure 1, and the linear trend-line shown for distillery plant in Figure 2 as found in this study, respectively.

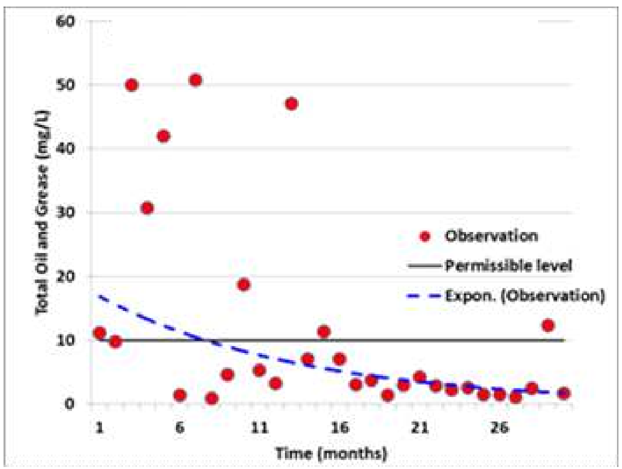

Figure 1. Total Oil and Grease in Wastewater from a Wastewater Disposal Facility

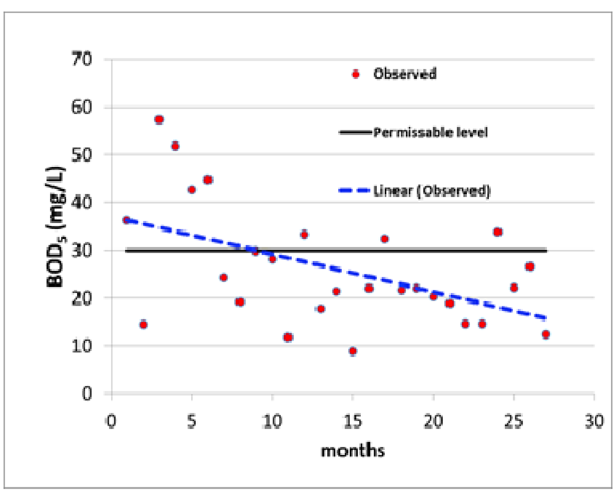

Figure 2. BOD_5 during Monitoring Period

Despite the relative successful application of the WPR, the instrument suffers from some design and implementation problems. After a facility is issued a SCR, there is no follow up from the EMA until the time for a renewal certificate. Further, the discretionary nature of the self-monitoring provides opportunities for misapplication of sampling methods and protocols which ultimately can lead to doubts about the veracity and accuracy of the data provided to the EMA and misrepresentations of the level of compliance. The challenges associated with self-reporting are exacerbated under the current implementation practices, which require that prior permission be given to the EMA for site visits. Ideally, the regulator should be able to verify information by having the ability to make random and undeclared visits. This will prevent a facility from concealing any shortcomings.

Permittees were generally unprepared for the level of involvement required by them for the implementation of the WPR. It was perceived that there could be cost reduction if the EMA played a more facilitative role in the preparation of the respective plans (QAPP, BMPP and PCP) and operated a laboratory for the required tests. Further, many small- and medium-sized firms can have difficulty to internalise environmental costs in their products or finance cleaner technologies. As a result, the EMA can encounter difficulties in enforcing the implementation of the WPR by these firms.

6. Conclusions

Although the approach used in implementing the WPR in T&T shares some similarities to those of other developing countries, the high level of success experienced in these countries has not been observed in T&T. The results from the implementation of the WPR for addressing water pollution are encouraging as they relate to the entities investigated. Overall, the compliance with the WPR for the monitored stations ranged from 20% to 75%. This can be considered satisfactory in the early stage of implementation as there is usually a lag in the impact of the application of policy instruments and it was not expected, a priori, that the EMA would ‘get it right’ immediately.

Nonetheless, in the future, full compliance would be the only acceptable condition to ensure that the desirable quality of the water resources is achieved. Water pollution permits, which were issued as part of the WPR, have not been audited to verify that facilities have implemented mitigation measures or that the best management practices were adopted to achieve prescribed standards. In the study, there was no direct attempt to capture reasons for non-compliance. However, interviewed participants indicated that there is the need to establish an "enforcement presence" and provide consistency and uniformity to sanctions imposed for non-compliance.

There is evidence to suggest that the implementation of the WPR has increased the level of awareness of water related environmental issues among the staff of the

EMA and the facilities that are monitored by the general public. At the same time, there are calls for reviewing the monitoring processes to facilitate better outcomes. In this regard, in the future, public pressure may play an important role in improving compliance.

Moreover, there are two issues that should be considered in determining the overall success of the WPR. Firstly, the issue about the number of end-of-pipe pollution entities that are currently captured and secondly, the relative impact of non-point source pollution. Given that many entities that should be captured by the WPR are not yet fully monitored, the success of the overall impact of the rules is questionable. While the paper reported only on the WPR, which focused on end-of-pipe pollution, it is recognised that the effects of non-point pollution on water quality could be such that it can be greater than that from end-of-pipe pollution (EMA, 2014). The EMA's proposed non-point source pollution management programme would require scientific assessment of water quality through in-house and or voluntary efforts.

The EMA as a regulatory institution is understaffed and may be lacking of financial resources. This can impair both monitoring of the pollution parameters and enforcement of the WPR. Hence, some reforms of the WPR are needed. As the current fines and penalties are not acting as a deterrent, it is recommended that as a first step, consideration should be given to increasing the fines and penalties of enforcement under the WPR. The potential of significant charges and fines is to increase voluntary compliance. Therefore, continuous monitoring of discharges may not be required. In the long term, consideration should be given to the implementation of the WPR according to the PPP with adequate fines and penalties of enforcement. The absence of discharge fees potentially creates disincentives for the regulatory authority to improve permitting, monitoring, and enforcement.

The legislation should be amended to allow the EMA to carry out unannounced visits. This would facilitate the establishment of an auditing mechanism for the current self-monitoring and self-reporting required by the permittees. In addition, the EMA should consider providing appropriate general and limited site-specific, compliance assistance, consistent with the primary purpose of the WPR, as this can motivate more cooperation from polluting enterprises.

One of the requests from permittees was for the EMA to set up its own laboratory. The request has some merit and is therefore recommended. This would facilitate the regularisation of the monitoring of the pollution parameters by the EMA. As T&T is well endowed with a system of freedom of information, The EMA is encouraged to have public disclosure policies that would provide information to communities, consumers and other stakeholders on environmental performance of individual polluting entities. This can raise the awareness of the general public and bring public pressure on defaulters as it creates a political dynamic that increases formal regulatory pressure on the defaulters. As a complement of the study, further studies are recommended. Such studies should aim to establish the level of non-point pollution visa-vis end-of-pipe pollution and the relationship between production levels at manufacturing facilities, effluent flow rate and effluent quality.

To implement these recommendations, the EMA would need to improve the institutional capacity for monitoring and consider greater networking amongst agencies or regional corporations involved in water resource management in order to facilitate more diligent enforcement of the WPR.

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A Preliminary Study on the Effect of Reinforcing Polyesters with Kenaf and Sisal Fibres on Their Mechanical Properties

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Abstract: *Kenaf and Sisal fibres generally have some advantages such as their eco-friendly nature, biodegradability, renewable nature are lighter than synthetic fibres. The aim of this study is to evaluate the potentials of using weaved and un-weaved indigenous sisal and kenaf fibre to reinforce polyester resin based on the physical and mechanical properties obtainable from the resulted composites. The composites materials and sampling were prepared in the laboratory by introducing 10g of the fibre which is about 20% fibre content into the matrix using 1) the hand lay-up method for un-weaved samples, and 2) coating method for weaved samples, with the aid of a mechanical roller. Samples were prepared based on ASTM: D3039-08 for tensile test. Properties such as tensile strength and modulus, hardness, impact strength, flexural strength, density and water absorption were analysed. The results of the characterization showed that density of the material reduced on introduction of fibres while the rate at which the material absorbs water increased though sisal fibre reinforced materials absorbed more. This was due to the void content of composite which increased due to the fibre inclusion within the composite. The results also show that the flexural strength of the composite material developed increased with fibre introduction, though weaved fibre possesses more strength than un-weaved ones. Finally, no particular composition possesses optimum value for all the properties measured.*

Keywords: *Kenaf; Sisal; Polyester; Fibre; Composite, Physical Properties; Mechanical Properties*

1. Introduction

The need for the world to fully become environmentally friendly and to fight the sometimes painful instability and non-availability of petroleum based thermoplastics, coupled with the need to make manufactured products more accessible and affordable to consumers have necessitated incessant efforts into processing and production of natural fibre composites, which can result in reduction of production cost to companies and impart greater mechanical properties to polymeric materials (Wambua et al., 2003). The use of natural fibre as reinforcement for polymeric matrix has recently attracted attention of researchers because of their advantages over other established materials (like ceramics, metals etc.). They are environmental friendly, fully biodegradable, abundantly available, renewable, have low density and are relatively cheap (Shibata et al., 2006). The need to start reinforcing resin has arisen due to the high need for the exhibition of improved mechanical characteristics of composite materials (Larbig et al, 1998).

Kenaf (*Hibiscus cannabinus*, L. family *Malvaceae*) is seen as an herbaceous annual plant that can be grown under a wide range of weather conditions; for example, it grows to more than 3 m within 3 months even in moderate ambient conditions with stem diameter of 25-51 mm. It is also a dicotyledonous plant, meaning that the stalk has three layers; an outer cortical also referred to as ('bast") tissue layer called phloem, an inner woody ("core") tissue layer xylem, and a thin central pith layer which consists of sponge-like tissue with mostly non-ferrous cells (Ishak 2007; Ishak et al., 2009).

A number of components, in particular, structural materials, interior of aircrafts, automotive components previously made with glass fibre composites are now being manufactured using environmental friendly composites consisting of natural fibres due to their thermal properties, low density, flexibility, low cost, lightweight and apparently their environmental superiority compared to glass fibre composites (Liu et al., 2007).

The use of natural plant fibres as reinforcement in polymer composites for making low cost engineering materials has generated much interest in recent years. New environmental legislation as well as consumer pressure has forced manufacturing industries (particularly automotive, construction and packaging) to search for new materials that can substitute for conventional non-renewable reinforcing materials such as glass fibre. Recently, car manufacturers (such as Bavaria Motor Works (BMW)) have started manufacturing non-structural components such as foot paddle using kenaf fibres for the 5 series model of the brand due to their higher specific strength and lower price compared to conventional reinforcements (Mattoso et al., 1997).

The results of a study of the mechanical properties such as tensile, flexural and impact properties of sisal bast and core fibre reinforced unsaturated polyester composites carried out showed that the optimum fibre content to obtain the highest tensile strength and flexural strength for both sisal bast and core fibre composites were 20%wt (Mukherjee and Satyanarayana, 1984).

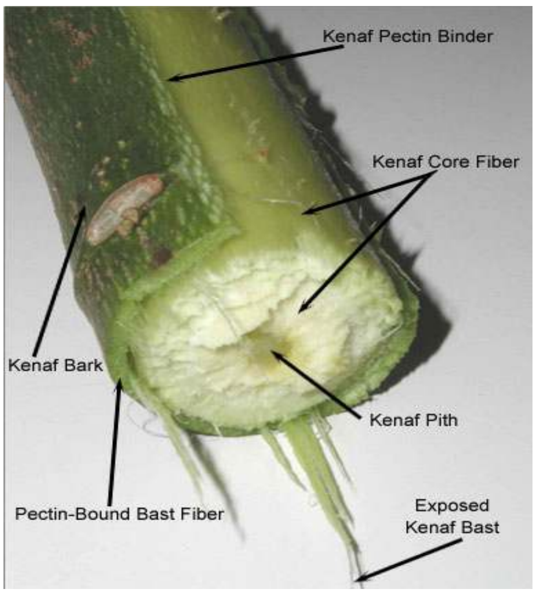

Figure 1: Exposed physical appearance of kenaf
Source: Nilsson (1975)

Sisal plants look like giant pineapples, and during harvest the leaves are cut as close to the ground as possible. The soft tissue is scraped from the fibres by hand or machine. The fibres are dried and brushed to remove the remaining dirt resulting in a clean fibre. Sisal produces sturdy and strong fibres. Sisal fibre is one of the prospective reinforcing materials whose use has been more experimental than technical until now. The use of 0.2% volume fraction of 25 mm sisal fibres leads to free plastic shrinkage reduction. Sisal fibres conditioned in a sodium hydroxide solution retained respectively 72.7% and 60.9% of their initial strength after 420 days. As for the immersion of the fibres in a calcium hydroxide solution, it was reported that original strength was completely lost after 300 days (Tara and Jagannatha, 2011). Figure 2 shows a typical sisal plant.

Hence, the essence of this research work is to carry out preliminary studies into the potentials of using indigenous sisal and kenaf fibre as reinforcement for polymeric composite material and the effect of weaving the fibres before introduction on the physical and mechanical properties of the composite. Therefore, the specific objectives of the research work are as follows:

1) To prepare and treat the reinforcing fibres.
2) To produce the composites.
3) To investigate the physical properties of the composites.
4) To investigate the mechanical properties of the composites, and
5) To compare the properties of weaved and un-weaved reinforced composite.

Figure 2: Typical Sisal Plant

2. Literature Review

Other researchers (Ochi, 2007; Madugu, et al., 2010; Nishino et al., 2011) have carried out separate work using kenaf and sisal fibres as reinforcements for composite production from which some are developed for particular application. So many researchers attempted to make bio-composites by using different natural fibres and different polymer matrix which could be thermoset and thermoplastic. They investigated bio-fibre composite in terms of water absorption, interfacial bonding, mechanical (tensile, flexural, impact, compressive and shear strength) properties in different fibre volume content and different ratio, recyclability, durability, chemical treatment effects and more (Chow, 2007; Bachtiar et al., 2008; Pasquini et al., 2008; Gu, 2009; Chen et al., 2009; Seki, 2009; Xue et al., 2009). The use of kenaf bio-composites in industry is increasing due to good properties of kenaf fibres and its contribution to environmental sustainability and eco-friendly products. The performance of materials is always presented in terms of their mechanical characteristics, such as tensile properties, flexural properties, compression properties, impact properties and tears behaviour (Akil et al., 2008).

Ochi (2008) reported that unidirectional kenaf fibre reinforced PLA (Poly-lactic acid) composites at a fibre content of 70% have high tensile and flexural strength of 223 MPa and 254 MPa, respectively. An extensive study was done by Rassmann et al. (2010) who used un-woven kenaf mat with three thermoset polymers including epoxy, unsaturated polyester and vinyl ester to make KFRP (Kenaf polymer reinforced) samples. The study utilised resin transfer molding (RTM) fabricating method in various fibre volume contents. The mechanical and water absorption properties of the composites were monitored for the study. It showed that the composite properties were influenced by the polymer type and the fibre volume content. Unsaturated polyester composites have higher modulus and impact properties as compared to other resins, while epoxy composites exhibited higher strength values and vinyl ester composites displayed higher water absorption characteristics. In 2004, this was the first time any group of researchers try to fabricate oil palm based hybrid bio-composites by hybridization of oil palm fibres with other natural fibres by the unique combination of sisal and oil palm fibres reinforced rubber composites (Jacob 2004a, 2004b). The researchers studied the effect of fibre loading, fibre ratio, and treatment of fibres on mechanical properties of sisal/oil palm fibre reinforced hybrid composites (Jacob, 2004a).

Results indicated that increasing the concentration of fibres reduced tensile and tear strength, but enhanced tensile modulus of the hybrid composites. They also reported that 21 g sisal and 9 g oil palm based hybrid composite show maximum tensile strength and concluded that tensile strength of hybrid composites depend on weight of sisal fibres rather than oil palm fibres due to high tensile strength of sisal fibres. It was also observed that the treatments of both sisal and oil palm fibres causes better fibre/matrix interfacial adhesion and resulted in enhanced mechanical properties. Similar studies carried out on the influence of fibre length on the mechanical properties of untreated sisal/oil palm fibre based hybrid composites reported that increase in fibre length decreases the mechanical properties of hybrid composites due to fibre entanglements (Jacob, 2004b).

Satyanarayana et al. (1984) studied the mechanical properties of chopped sisal fibre – polyester composites. Chopped sisal fibre-polyester composites were prepared by the compression molding technique. It was found that the specific modulus of the composite was 1.90 as compared to 2.71 obtained from glass fibre reinforced plastics, while the specific strength was of the same order as that of polyester resins (i.e., of 34-41 MPa). The impact strength was 30 $Jm\text{-}^2$, which is three times higher than that of polyester and 30% less than glass fibre reinforced plastics. Accelerated testing revealed that there was little change in initial modulus, and reductions of ultimate tensile strength by 5%, flexural strength by 16% and water absorption by 5.4% within the material.

A lot of research work have been done in the area of development and characterization of eco-friendly bio-composite materials, but more must still be done.

3. Materials and methods

3.1 Materials

Materials used for this research include:

1) Unsaturated polyester resin,
2) Kenaf fibre,
3) Sisal fibre,
4) Methyl ethyl ketone (catalyst),
5) Cobalt naphthalene (accelerator), and
6) Sodium Hydroxide (NaOH).

3.2 Methods

3.2.1 Preparation of Sisal Fibre

Sisal leaves were obtained from sisal plant at Botanical Garden, Ahmadu Bello University Zaria-Nigeria. The sisal leaves were beaten until the fibres were separated from them. A knife was then used to scrape the surface of the leaves to remove the fibres into strands. The extracted fibres were washed with water to remove the cellulose on their surfaces. The fibres were then sundried for ten (10) hours, after which they were soaked for six hours in a prepared 6% concentration solution of NaOH and then washed under a running tap. It was then dried under room temperature for 24 hours.

3.2.2 Preparation of Kenaf Fibre

Kenaf plants, on the other hand, were obtained from National Research Institute for Chemical Technology (NARICT), Zaria-Nigeria. The kenaf plants were soaked in water for a week and then beaten against the floor to separate the bast from the core. The kenaf bast fibre were then drawn into strands and treated like sisal.

3.2.3 Composite Production

Unreinforced isophthalic polyester resin was cured by adding one percent (1%) of cobalt naphthalene (accelerator) and Methyl ethyl ketone peroxide (catalyst) and then stirred until it became homogeneous. This was allowed to cure in the presence of sun light. This served as a control sample for the research. Ten grams (10 g) of weaved and un-weaved sisal and kenaf fibres which is approximately 20% volume fraction were then introduced separately into the resin using hand laying method for the un-weaved and coating method for the weaved sample. The volume fraction was chosen based on findings reported in earlier research (Mukherjee and Satyanarayana, 1984). They were then cured as the unreinforced resin.

3.2.4 Physical Properties Determination

3.2.4.1 Density

Rectangular samples were cut out neatly from the prepared samples. The mass (m) of the samples were measured with the aid of digital weighing balance while their volumes (v) were calculated using the product of their length, width and thickness. Three (3) samples of same composition were tested to obtain an average. The densities of the samples were obtained using the relation shown in Equation 1.

$$\rho = \frac{m}{v} \quad (1)$$

Where ρ = density (g/cm^3);

3.2.4.2 Water Absorption

Water absorption test is a physical test that gives detail of the level at which the material absorbs solvents when placed in such environments. Samples were weighed initially using a digital weighing balance and recorded as W_1 then they were soaked in water in an enclosed container for 24 hours. The soaked samples after being removed from water were cleaned with a damp towel then reweighed and recorded as W_2. The percentage water absorption was obtained from the relation shown in Equation 2 (Chow, 2007).

$$A = \frac{w2 - w1}{w1} \times 100 \quad (2)$$

Where A= Percentage water absorption (%)

3.2.5 Mechanical Properties Determination

Two (2) samples of same composition were subjected to each of the mechanical properties tested for in this study. This was done to find average values.

3.2.5.1 Tensile Strength Test

Tensile strength indicates the ability of a composite material to withstand forces that pull it apart, as well as the capability of the material to stretch prior to failure. Tensile tests were carried out using a Hounsfield Tenso-meter (TMER3), with maximum load of 20 KN. The standard specimens were mounted by their ends into the holding grips of the testing apparatus. The machine is designed to elongate the specimen at a constant rate, and to measure the instantaneous applied load and the resulting elongations simultaneously using an extensometer. The ASTM standard test method for tensile properties of polymer composites with the designation D3039-76, 2000 was used. The samples ultimate tensile strength (σ) and young's modulus (ε) were determined and recorded.

3.2.5.2 Hardness Test

The hardness test of composites is based on the relative resistance of its surface to indentation by an indenter of specified dimension under a specified load. In Rockwell test, the depth of the indenter penetration into the specimen surface is measured. The indenter universal hardness testing machine 8187.5 LKV model B, an electronic digital machine was used to measure the hardness of the samples at different spots and the results were displayed on the screen. The indenter used is a hardened steel ball diameter 1/16". Loading procedure starts from applying a minor load of 10 kg and then the major load of 60 kg.

3.2.5.3 Impact Test

The impact tests of the composites sample were conducted using a fully instrumented Avery Denison test machine. Charpy impact tests were conducted on notched samples. Standard square impact test samples of dimensions 70 x 10 x 10 mm with notch depth of 2 mm and a notch tip radius of 0.02 mm at angle of 45^0 were used. The value of the angle through which the pendulum has swung before the test sample was broken corresponds with the value of the energy that will be absorbed in breaking the sample. This was read from the calibrated scale on the machine. The test is widely applied in industries, since it is easy to prepare and conduct. Results can also be obtained quickly and cheaply.

3.2.5.4 Flexural Test

The flexural test method measures the behaviour of materials when subjected to simple beam loading. Flexural test is often done on relatively flexible materials such as polymers, wood and composites. A 3-point bending test was carried out on the samples. The flexural strength was determined for each sample using the relation shown in Equation 3 (Samotu et al., 2012).

$$\sigma f = \frac{3Pl}{2bt^2} \quad (3)$$

Where;
σf = Flexural stress (MPa)
P = Load (N)
l = Support span (mm)
b = Width of test beam (mm), and
t = thickness of test beam (mm)

3.2.6 Sample Labelling

The format by which the samples are labelled is summarised in Table 1.

Table 1: Sample Labelling

s/n	Sample Type	Sample Label
1.	weaved kenaf	(KW)
2.	un-weaved kenaf	(KUW)
3.	weaved sisal	(SW)
4.	un-weaved sisal	(SUW)
5.	unsaturated polyester	(UP)

4. Results

4.1 Physical Properties

4.1.1 Density

The densities of the samples determined are summarised in Table 2, while the comparison based on average is shown on Figure 3.

Table 2. The Densities of the Samples

Sample	ρ_1	ρ_2	ρ_3	$\rho_{average}$	Standard Deviation.
(KW)	1.12	1.15	1.21	1.16	0.05
(KUW)	1.15	1.18	1.18	1.17	0.02
(SW)	1.14	1.17	1.17	1.16	0.02
(SUW)	1.17	1.21	1.04	1.14	0.09
(UP)	1.20	1.19	1.21	1.20	0.01

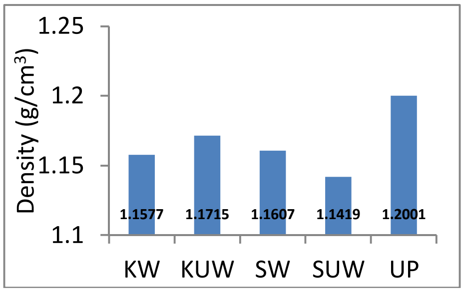

Figure 3. Composite Density

4.1.2 Water Absorption

The rate at which samples absorb water is summarised in Table 3, while the comparison based on average values is shown on Figure 4.

Table 3. The rate at which samples absorb water

Sample	A_1 (%)	A_2 (%)	A_3 (%)	$A_{average}$ (%)	Standard Deviation.
(KW)	1.09	0.68	0.92	0.90	0.21
(KUW)	0.78	1.10	0.75	0.88	0.19
(SW)	1.48	1.37	1.46	1.44	0.06
(SUW)	1.05	1.00	1.10	1.05	0.05
(UP)	0.39	0.36	0.35	0.37	0.02

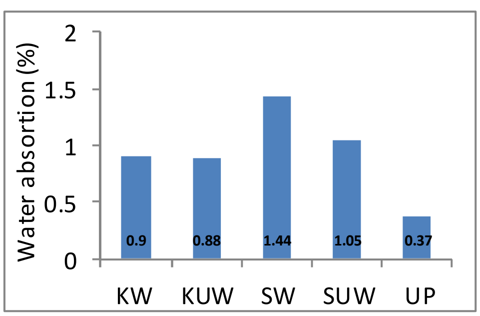

Figure 4. Composite Water Absorption

4.2 Mechanical Properties

4.2.1 Tensile Strength

The tensile strength (σ) and young's modulus (ε) for the two samples tested are summarised in Table 4, while the comparisons based on average values are shown on Figures 5 and 6.

Table 4. The tensile strength and young's modulus for the samples

Sample	σ_2 (N/mm^2)	σ_1 (N/mm^2)	$\sigma_{average}$ (N/mm^2)	$\varepsilon_{average}$ (N/mm^2)	Standard Deviation.
(KW)	16.29	15.74	16.02	73.52	0.28
(KUW)	26.16	17.24	21.70	110.40	4.46
(SW)	4.11	5.56	4.99	77.73	0.73
(SUW)	18.23	16.47	17.35	77.84	0.88
(UP)	12.32	20.60	16.46	102.88	4.14

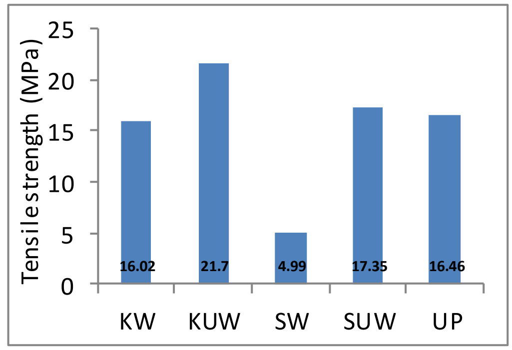

Figure 5. Composite Tensile Strength

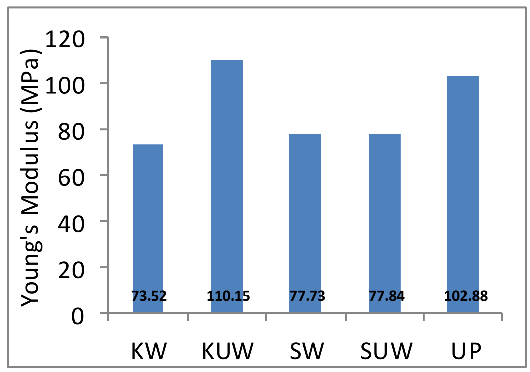

Figure 5. Composite Young's Modulus

4.2.2 Composite Hardness

The hardness numbers for the samples are summarised in Table 5, while the comparison based on average values is shown on Figure 7.

Table 5. The hardness numbers for the samples

Sample	HN_1 (HRF)	HN_2 (HRF)	$HN_{average}$ (HRF)	Standard Deviation.
(KW)	9.67	9.35	9.51	0.16
(KUW)	10.55	10.89	10.72	0.17
(SW)	25.80	25.40	25.60	0.20
(SUW)	18.82	18.98	18.90	0.08
(UP)	17.75	17.85	17.80	0.05

4.2.3 Impact Property

The Impact energies for the samples are summarised in Table 6, while the comparison based on average values is shown on Figure 8.

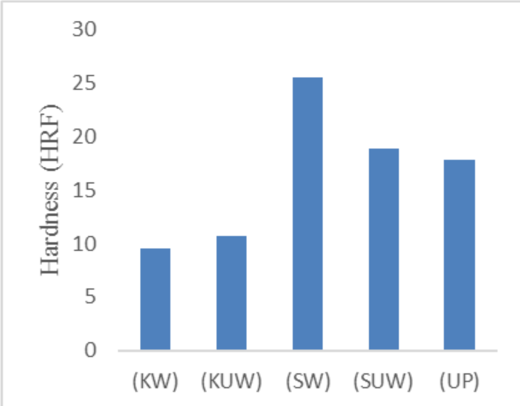

Figure 7. Composite Hardness Number

Table 6. The Impact energies for the samples

Sample	IE_1 (KJ/m^2)	IE_2 (KJ/m^2)	$IE_{average}$ (KJ/m^2)	Standard Deviation.
(KW)	14.00	13.18	13.59	0.41
(KUW)	10.00	9.20	9.60	0.40
(SW)	16.00	16.02	16.00	0.01
(SUW)	15.60	14.40	15.00	0.60
(UP)	4.00	4.40	4.20	0.20

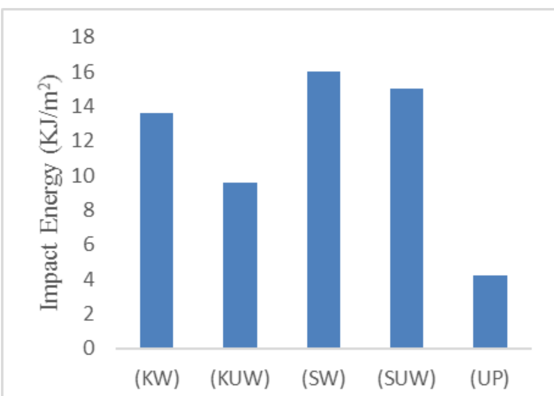

Figure 8. Composite Impact Energy

4.2.4 Flexural Property

The flexural strengths for the samples are summarised in Table 7, while the comparison based on average values is shown on Figure 9.

Table 7. The flexural strengths for the samples

Sample	σ_{f1} (N/mm^2)	σ_{f2} (N/mm^2)	σ_{f3} (N/mm^2)	$\sigma_{f\,average}$ (N/mm^2)	Standard Deviation.
(KW)	48.31	43.86	44.63	45.60	1.94
(KUW)	39.00	42.86	39.67	40.51	1.68
(SW)	41.55	41.20	41.77	41.50	0.24
(SUW)	33.33	35.42	31.25	33.33	1.70
(UP)	18.10	19.70	17.8	18.53	0.83

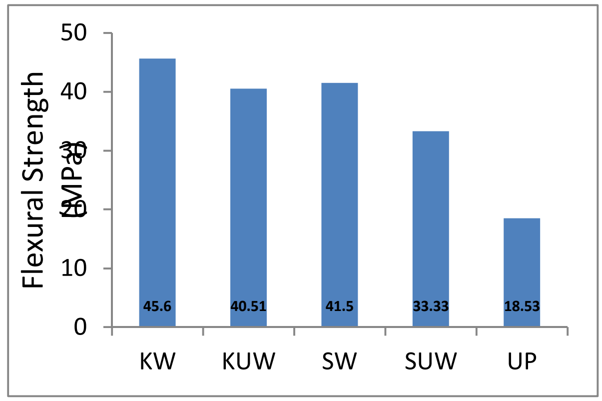

Figure 9: Composite Flexural Strength

5. Discussion of Results

From the results of the characterisation, it can be observed that introduction of reinforcement lowers the density of the composite material as unsaturated polyester has density of 1.2 g/cm^3, which reduced to 1.16 g/cm^3 and 1.17 g/cm^3 obtained from KW and KUW respectively, and 1.16 g/cm^3 and 1.14 g/cm^3 obtained from SW and SUW, respectively. This implies that both reinforcing fibres are less dense that the matrix (see Figure 3). Weaving of the fibre before introducing them into the matrix does not affect the density of the composite as the density results with weaved and un-weaved fibre are close to each other.

Moreover, from the results summarised in Table 3 and Figure 4, weaving of the reinforcement increased the percentage water absorption for both fibres used but the effect is well pronounce in the sisal fibre reinforced composite as compared to samples reinforced with kenaf fibres. This shows that weaving the fibre contributed to the creation of pores within the samples. The result also implies that the sisal fibres are more hydrophilic in nature than the kenaf fibres. Moreover, introduction of reinforcement generally increased the rate at which the composite material absorbed water.

On the mechanical properties measured, weaving the reinforcement lowers the tensile properties for both fibres used. This can be clearly seen on Figures 5 and 6 as the values of tensile strength and Young's modulus of weaved fibre reinforced samples are lesser than that of the un-weaved reinforced ones. This can be associated to poor bonding between the reinforcements and the matrix for both fibres used despite the treatment in sodium solution before using them. Introduction of kenaf fibre into the matrix lowered the hardness of the material, although weaving the fibre does not significantly affect the hardness value. On the other hand, weaving sisal fibre increased the hardness of the composite significantly even more than the hardness value of the control samples (see Figure 7). Materials with high hardness value are expected to be less tough which accounts for the lower impact energy obtained from sisal fibre reinforced composite. This implies that kenaf fibre reinforced materials are tougher than those reinforced with sisal fibre and the unreinforced samples (Control). This variation also agrees with the findings of early researchers (Ishak, 2007; Bower, 2009).

Finally, the introductions of reinforcements increase significantly the flexural strength of the composite material. This is due to the role played by the reinforcing fibre in carrying load that acts transversely to their axes. Moreover, weaved fibre reinforced composite samples possessed higher flexural strength than the un-weaved fibre reinforced ones. However, the tensile strength reduces on the introduction of the fibre, this can be associated to low inter phase bonding between the fibre and the matrix as stated earlier. But the values of the tensile strength and modulus are within the acceptable range of polymer composite materials (Samotu et al., 2012).

6. Conclusions

From the results of the tests and analyses carried out, it could be concluded that kenaf and sisal fibre, weaved or un-weaved can be used to reinforce polyester resin. Introduction of reinforcement lowers the density of the composite material developed although weaving them does not affect the density. Besides, introduction of reinforcement increases the rate at which the composite material developed absorbs water, though sisal fibre reinforced materials absorb more.

Moreover, introduction of reinforcement increases the flexural strength of the composite material though weaved fibre possesses more strength than un-weaved ones. However, no particular composition possesses optimum value for all the properties measured. With systematic and persistent research there will be a good scope and better future for sisal/kenaf fibre -polymer composites in the coming years.

Future research work should be done on proffering the best control during fabrication. The assumptions about composite materials behaviour may not perfectly match to the actual behaviour of materials. Based on the assumptions of composite materials, the material could carry load perfectly till one of the component reach its ultimate strength or strain, then the composite material fails due to the increment of load. This assumption needs the best control during fabrication in order to produce the best characteristics of composites such as perfect interfacial bonding between fibre and matrix, interfacial bonding between layers, zero void content and good impregnation of fibres.

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Flame Detection and Suppression System for Petroleum Facilities

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Abstract: *An adaptive model for fire (flickering flame in the infrared region) detection and subsequent suppression is presented. The model applies a Pyro-electric Infrared sensor (PIR)/Passive Infrared Detector (PID) for infrared fire detection. Sample analog signals were generated and simulated within the framework of the modeled PIR sensor/PID. The signals were modeled around the flame flicker region (1-13Hz) and outside the region. A Joint Time Frequency Analysis (JTFA) function was applied to model the Digital Signal Processing (DSP). This involved extraction of fire and non-fire features from the sample signals. A Piecewise Modified Artificial Neural Network (PMANN) and the Intraclass Correlation Coefficient (ICC) were employed in the decision framework. The PMANN generated polynomials which analysed and 'memorised' the signals from DSP. The ICC further categorised cases as 'fire' or 'non-fire' by comparing data from the PMANN analyses. In cases of detected fire, valves to several fire suppression systems (like water sprinklers and foam injection lines) can be opened. Hence, the Solenoid Hydraulic Valve was modelled to be controlled by a Proportional Integral Derivative Controller (PIDC). The whole model of detection and suppression can be further developed, studied and subsequently implemented.*

Keywords: *Flame detection, passive infrared detector, digital signal processing, artificial neural networks, fire suppression*

1. Introduction

Petroleum facilities, also known as oil and gas storage facilities are sites where combustible/flammable liquids are received from shipping vessels, pipelines, tankers etc. These products can be stored or blended in bulk for the purpose of distribution by tankers, pipelines and other methods of transfer and transportation. From this definition, one expects the observation of very high safety standards on such sites to prevent loss of any kind especially by fire. Despite the progress made in the design and installation of safety facilities for oil storage sites, they remain one of the most hazardous places on earth. Late detection and/or suppression of fires are among the primary reasons why little fire outbreaks leads to major oil storage site fire disasters. Two studies on petroleum facilities (Persson and Lonnermark, 2004 and James and Cheng-Chung, 2006) listed the following as the main causes of fire outbreaks in oil and gas storage sites: lightning, maintenance error, operational error, sabotage, equipment failure, crack and rupture, static electricity, leak and line rupture, open flames, natural disasters and runaway reactions. The results show that most fires in these storage sites primarily affect the tanks, with lightening being the main cause of fire outbreaks.

Even though many problems can be traced to fire outbreaks in oil storage sites, usually their spread is associated with low quality engineering. A model solution is proposed to the problem of early detection and automatic suppression. This particular problem is most rampant in oil and gas storage sites in local Nigeria as well in some other developing nations. Although several enhanced fire prevention/fighting engineering mechanisms are already being employed to mitigate this problem, research and development of new and better ones still continue. This work is just another window into that wide field of research.

2. Related Work

The use of fire detection systems incorporated with fire suppression started with Philip W. Pratt of Abington, in 1872 ("Automatic fire suppression," 2015, para 2). He patented the first automatic sprinkler system. Thus, there was a detection system in his design that automatically actuated the sprinklers. Generally, from the anatomy of fire, represented by Equation (1). There are four (4) main areas of fire detection: smoke, gas (like CO_2, CO, H_2S, etc.), heat and light. The light emitted cover both the infrared and ultraviolet regions.

$$\text{HC(hydrocarbon)} + \text{O2(g)} + \text{Energy}_{(\text{absorbed})} \rightarrow \text{CO2(g)} + \text{H2O(vap)} + \text{Heat}_{(\text{released})} + \text{light} + \text{other gases} \quad (1)$$

Conventional smoke detectors typically detect the presence of certain particles generated by smoke and (1) by ionization or photometry. An important weakness of such detectors is that the smoke has to reach the sensor. For heat detectors, the heat must be sufficient enough to activate the heat sensor. This may take a significant amount of time to issue an alarm. The time delay can cause an uncontrollable fire to develop. Therefore, it is not possible to use them in open spaces. For UV detectors, they are plagued by many false alarm signals, which reduce their reliability (Nolan, 1996). With minimal and controllable false alarms (using sophisticated detection algorithms), infrared detection remains the most reliable.

Several detection algorithms have been applied over time in the area of infrared flame detection. Some of the prominent algorithms include the statistical analysis of the apparent source of the heat of fires (Zhu et al, 2008) at a near infrared zone. After tests and experimentations, it was concluded that the detector functioned well for open flames, producing very few false alarms, while smoldering fires were hardly detected, since there was no direct radiation to the detector. They were only detected when they had direct radiation. Several Advanced Very High Resolution Radiometer (AVHRR) fire detection algorithms were reviewed in another study (Li et al 2000). The study aimed at uncovering their principles of operation and limitations, while also making possible recommendations for improvement.

Moreover, an adaptive method for hydrocarbon flame detection was developed using a Joint Time Frequency Analysis (JTFA) functions for Digital Signal Processing (DSP) and Artificial Neural Network for the decision mechanism (Javid et al., 2008). The JTFA functions used were the Short Time Fourier Transform (STFT) and The Fast Fourier Transform (FFT), with the Hamming Window function applied to narrow the coefficients to a particular range. That study gave convincing results and was eventually developed into a marketable practical application. Furthermore, using the Markov Model decision algorithm and Lagrange wavelet filter banks to extract fire features from signals recorded by pyro-electric infrared sensors, a fire detector was modeled which could easily detect fire within the flickering flame frequency (Fatih et al., 2012). Out of 220 fire test sequences, they recorded 3 false alarms and 217 correct alarms. Each detection had a response time of 77seconds.

Some of the most prominent suppression systems include fire water distribution systems, sprinkler systems, water spray and deluge systems, water flooding systems, fire water control and isolation valves (Nolan, 1996). In developing countries (e.g. Nigeria), the pipelines supplying water or other fire suppression liquids to these systems contain manually operated valves. This slows down the process of suppression during emergencies. However, by applying automatically actuated valves as proposed in this work, it will ease the fire suppression process. Proportional Integral Derivative Controllers (PIDC) has been applied in many areas to automatically actuate valves. Some of the applications include the study of The Position Control System of a hydraulic cylinder based on microcontrollers (Munaf, 2008). Using the MATLAB software, a PIDC in connection to the hydraulic valve was simulated. The purpose was to use the controlling mechanism of the PIDC to cause the cylinder to function automatically. Besides, pneumatic actuator systems were designed and controlled using PIDCs and valves (Lai et al., 2012). The pneumatic systems, being non-linear, were controlled using linear control mechanisms like PID controllers and valves.

This work used an algorithm which applied the Discrete Wavelet Transform (DWT) (a JTFA function) for DSP, a Piecewise Modified ANN (PMANN) and the Intraclass Correlation Coefficient (ICC) for the decision framework. The DWT made on-line analysis and feature extraction of signals possible with the shortest time delay. The PMANN analysed and 'memorised' data (from the DSP) that could be easily matched for "fire" and "non-fire" cases using the ICCs. It further applied the PIDC to control a solenoid hydraulic valve, which is commonly used in petroleum facilities. Figure 1 shows the flow chart for the model adapted in this work.

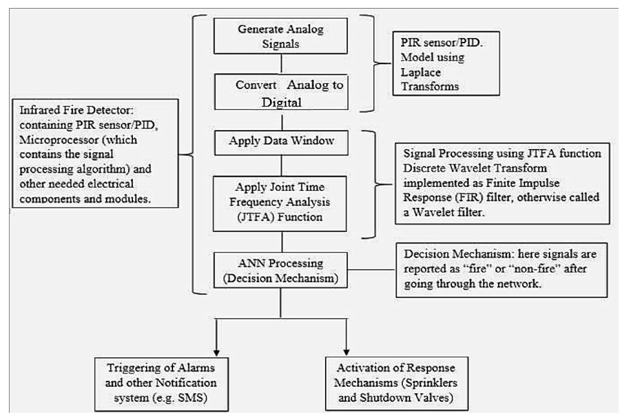

Figure 1. Flow Chart for the modeling of Fire Detection and Suppression System

3. Methodology

3.1 The Pyro-Electric Infrared Sensor (PIR)/Passive Infrared Detector (PID)

A PIR sensor/PID is comprised of three main parts, namely the Fresnel lens (which focuses the IR radiation to the sensor), the PIR sensor which senses the IR radiation and an amplifier/comparator or amplifier/ analog to digital converter (ADC) circuitry depending on the generation of the PID (Emin, 2009). The Fresnel lens offers a field of view (FOV) of 110o over a distance of 11m. This work simulated the third generation PID, where the comparator circuitry is replaced by analog to digital converter (ADC) as shown in Figure 2. Hence, after amplification, we have the ADC. The ADC gains were then fed into a microprocessor containing the detection algorithm for further signal processing and categorisation decision (if the model is to be implemented).

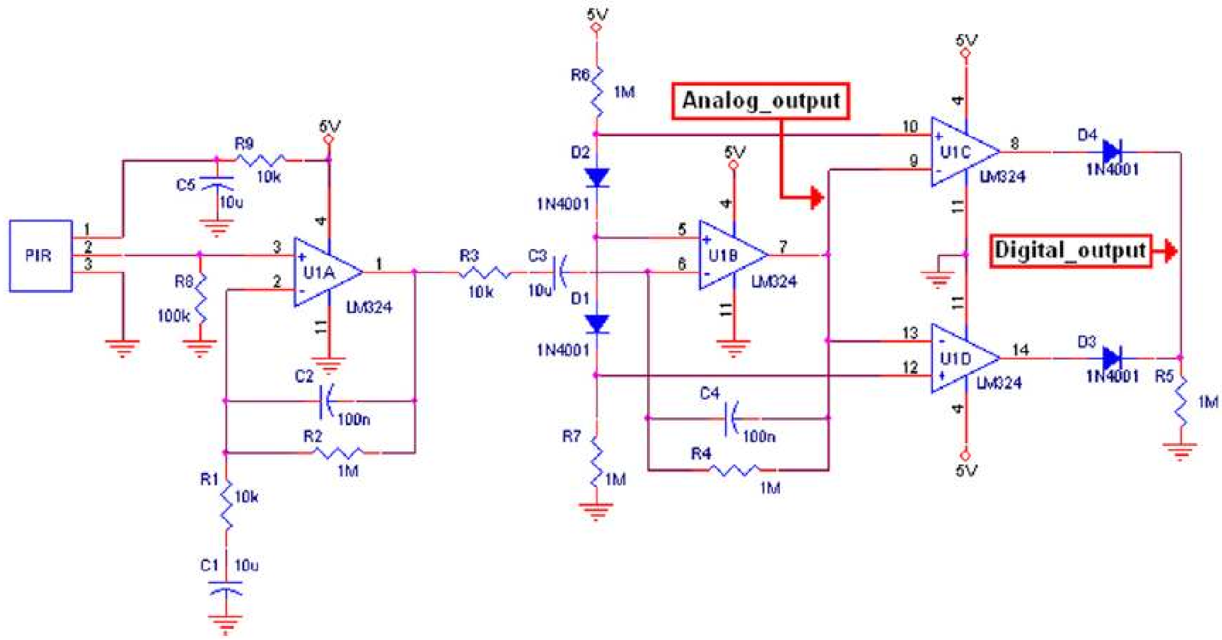

Figure 2. Third Generation PID circuitry for capturing analog signals and converting them to digital signals

Such a sensor/detector can be modeled as a capacitor with capacitance Cd with a Poly-Vinylidene Fluoride **(**PVDF) film as the dielectric with thickness d and surface area A (Odon, 2010). When IR radiation of power Φ(t), varying in time is incident on the active surface of the PIR sensor, an electric charge q(t) is generated. This is transferred as a signal with information content either as voltage V(t) on the detector electrodes or current Ip(t) flowing through the low load resistance of the detector output. Converting IR radiation into an electric signal is done in 3 stages: converting radiation power Φ(t) to thermal change on the sensor surface i.e. temperature ΔT(t), the second stage is the thermal to electric conversion i.e. ΔT(t) to Ip(t), and the last stage is the current to voltage signal conversion i.e. Ip(t) to V(t). The PID detects infrared radiations from several sources within its range or field of view.

From automatic control theory, the procedures for the creation of block diagrams for simulation involves connecting the block transfer function in series, where series connection implies multiplication. For our model, we arranged them in the order: $G_T(s)$ (radiation to thermal), $G_{TIp}(s)$ (thermal to electrical) and $G_{IpV}(s)$ (electrical to voltage), describing properties of the appropriate signal conversion stage. Hence, the equivalent transfer function is expressed as Equation (2) and a schematic of the process is shown in Figure 3:

$$G(s) = G_T(s) \times G_{Tip}(s) \times G_{IpV}(s) \tag{2}$$

A Laplace transfer function was developed for the simulation, expressed as Equation (3) (Odon, 2010):

$$G(s) = \frac{p\eta R}{c'dC} \cdot \frac{s\tau_{th}\tau_e}{s(s\tau_{th}+1)(s\tau_e+1)} \tag{3}$$

where p is the pyro-electric coefficient, η-absorption coefficient of radiation, R-equivalent resistance, C-equivalent capacitance, d-thickness of PVDF film, c prime-volume specific heat, τ_{th} -thermal time constant and τ_e -electric time constant. Using values for a standard detector with small PVDF thickness, sample IR radiations around the flickering flame frequency (1-13Hz), and also far from it, were generated and simulated on the MATLAB/SIMULINK software as shown in Figure 4. The values for the various parameters were obtained from standard values for PVDF IR sensor (Piezo Film Sensors Technical Manual by Measurements Specialties Inc.) and from other test results (Odon, 2010). The values of parameters for the PVDF PIR sensor/PID are outlined in Table 1.

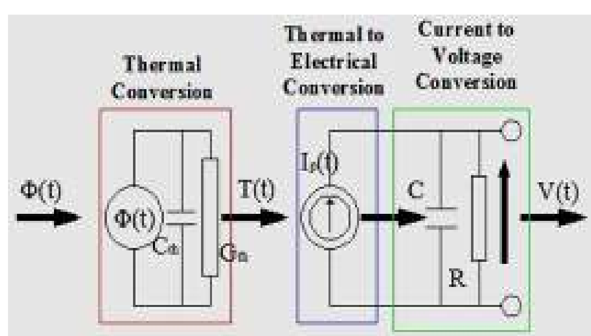

Figure 3. Schematic Diagram for Conversion of IR radiation to Voltage Signal

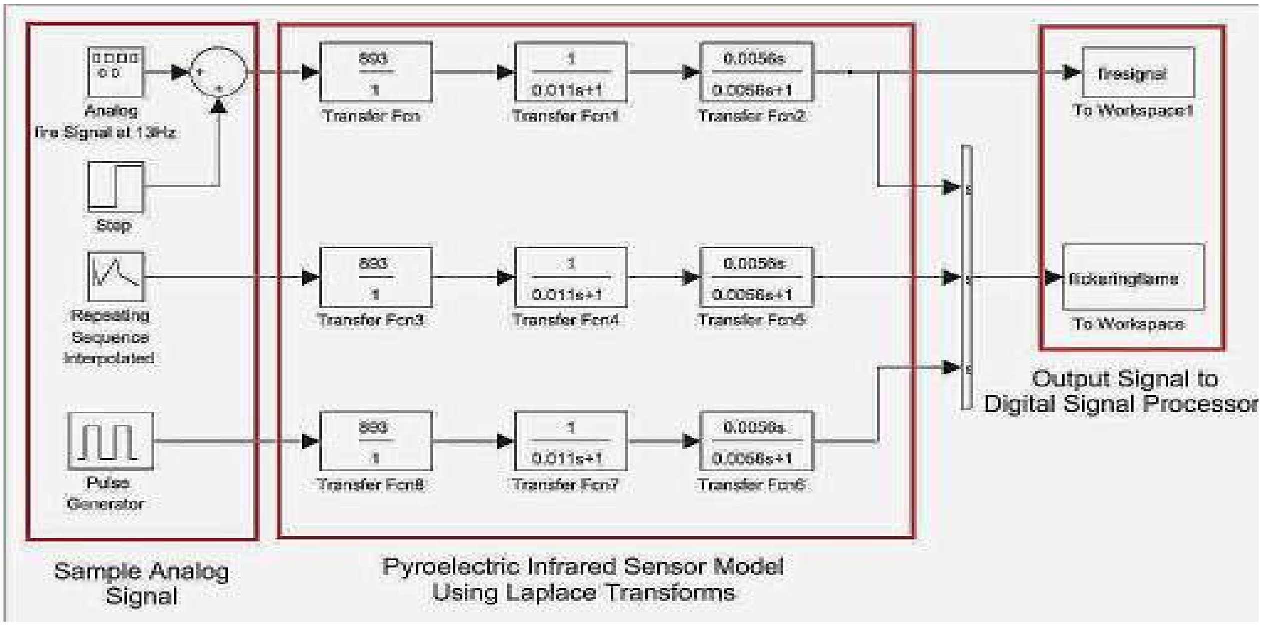

Figure 4. MATLAB/SIMULINK block for sample flickering flame signal (13Hz)

Table 1. Parameters for the PVDF PIR sensor/PID

Name	Value	Unit
Pyro-electric coefficient p	3×10^{-6}	$C/cm^2.K$
Volume specific heat c'	2.4	J/cm3.K
Permittivity ε	106×10^{-14}	F/cm
PIR film thickness d	25	Mm
Thermal conductivity gth	0.00135	W/cmK
Detector active surface A	132×10^{-2}	Cm^2
PIR detector Capacitance Cd	560	pF
Amplifier input capacitance CL	Negligible	pF
Amplifier input resistance RL	10	MΩ
Absorption coefficient of radiation η	1	-
Electrical time constant of detector-amplifier circuit τe	0.0056	S
Thermal time constant τth	0.0110	S

3.2 The Detection Algorithm

3.2.1 Digital Signal Processing

The digital signal processing algorithm was developed using the Discrete Wavelet Transform (DWT) JTFA function implemented in real-time as wavelet filters (Schneiders, 2001). The signals were first passed through a window function (the Hamming window) to attenuate the input signal, thereby reducing spectral leakage and causing the signal to be more periodic. A window length of 256 was chosen. This is advantageous since it reduces the response time of the detection mechanism by two (Javid et al., 2008). The window function is expressed as in Equation (4) (Robert, 2012),

$$w(n) = \frac{1}{2}\left\{1.08 - 0.92\cos\left(\frac{2\pi n}{N-1}\right)\right\} \quad (4)$$

With a 256 window length, a Nyquist sampling frequency of 50Hz was chosen. The flickering flame frequency of 13Hz (Fatih et al., 2012) was used as the cutoff frequency. The Nyquist sampling frequency is determined from $f_s \geq 2$ (cutoff frequency). Applying the formula, we get 26Hz as our sampling frequency. But a 50Hz sampling frequency was chosen to widen the frequency range in order to obtain a better sampled signal.

For real signals, only half of the number of samples (the same as the window length) contains essential information without redundancy. Hence, using Rayleigh's Limit (Robert, 2012), the frequency resolution is expressed as Equation (5), which becomes Equation (6) for the signals:

$$\Delta f = \frac{f_s}{N} \quad (5)$$

$$\Delta f = \frac{f_s}{0.5N} \Rightarrow \Delta f = \frac{50Hz}{(0.5)256} = 0.4Hz \quad (6)$$

Real-time wavelet filters are defined by their Quadrature Mirror Filters (QMF) used for DWT. QMFs are perfect reconstruction filter banks where the calculation of coefficients for the filters at all levels is seen as making an orthonormal (orthogonal and normalised) projection onto a new base. These filters banks contain highpass (H) and lowpass (L) filters of length N+1 (Schneiders, 2001), where N is the number of points or filter order which is the same as window length.

Depending on the number of levels, denoted as P, the analysis filter was applied to the input signal to calculate coefficients for the first level. Using N old input points, the coefficient was then calculated for the next level. Hence, the total number of old input samples needed for computation of a new coefficient at a certain decomposition level is defined by Equation (7) (Schneiders, 2001):

$$l_u = \sum_{i=1}^{P} N2^{i-1} \quad (7)$$

where i is the decomposition level varying between 1 and the maximum, P, and N the order of the original filters. From this point, coefficients were obtained as the output at each level. This way made on-line analysis and feature extraction possible with the shortest time delay for each decomposition level. This is good for real time situations like flickering flames and other radiation emitting objects. Such structure was built on the MATLAB software. The code produced a filter matrix A, which was implemented as discrete (Finite Impulse Response) FIR filter block on MATLAB/SIMULINK. Since all coefficients are updated at every sample hit, the time resolution increased. Hence, for filter structure as a wavelet analyser the time resolution is expressed as Equation (8) (Schneiders, 2001):

$$\Delta t = \frac{1}{f_s} \quad (8)$$

The time-resolution is equal to the sample time of the system. For the DWT perfect reconstruction multi-resolution tree the frequency resolution is a function of the decomposition level P expressed as Equation (9) (Schneiders, 2001):

$$\Delta f = \frac{f_s}{2^{P+1}} \quad (9)$$

Using the values for sampling frequency and frequency resolution, the time resolution was determined and decomposition level was set to be Δt = 0.02s and P = 6 as shown below.

$$\Delta t = \frac{1}{f_s} = \frac{1}{50Hz} = 0.02s \quad (10)$$

And from Equation (6), we had

$$0.4Hz = \frac{50Hz}{2^{P+1}}, \text{where } P \approx 6.0 . \quad (11)$$

Using N=256 points, the filter lengths were calculated as: L = H = N + 1 = 256 + 1 = 257

Substituting the values for the number of points N, filter lengths for the highpass (H) and lowpass (L) filters and the decomposition level P into our MATLAB code generated the needed coefficients. These coefficients were substituted into the Finite Impulse Response (FIR) filter block on MATLAB/SIMULINK software, as shown in Figure 5. Hence, the block was renamed 'Wavelet Filter'. The coefficients obtained are given in the matrix A.

A = {0.00, 2.82, 0.00, 0.00, 0.00, 0.00}

The digital signal processing as described here ensures that specific features of the signal are extracted, so that false alarms can be reduced to the barest minimum.

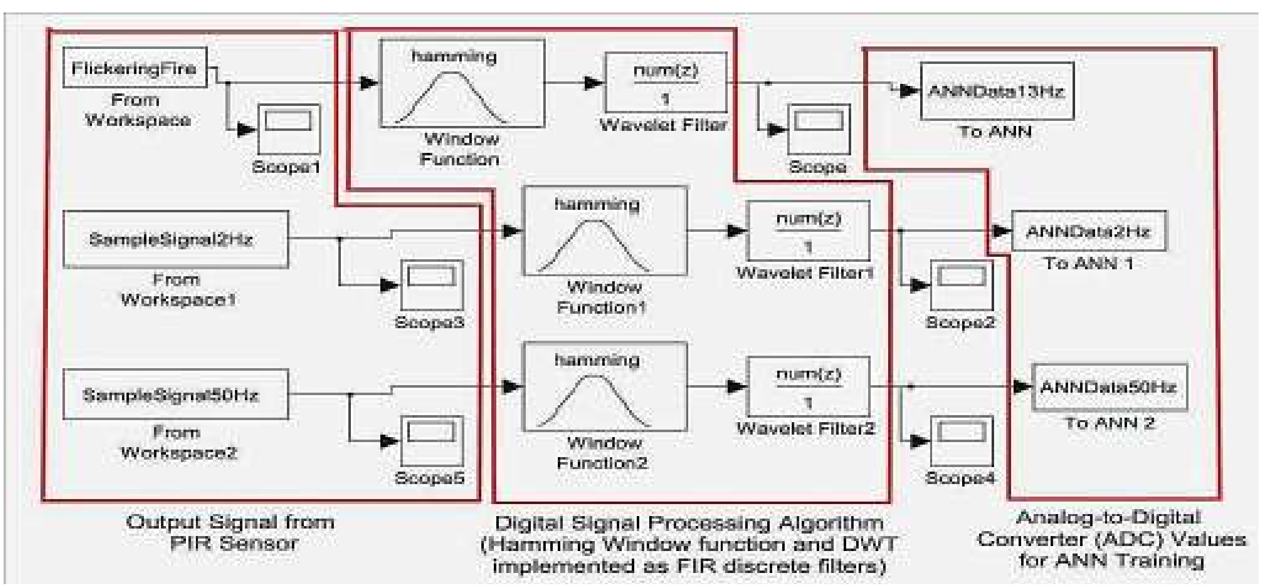

Figure. 5 MATLAB/SIMULINK block for sample flickering flame signal (13Hz)

3.2.2 The Decision Mechanism

An Artificial Neural Network (ANN) algorithm and the Intraclass Correlation Coefficient (ICC) constituted the decision rule. Previous research employed neurons and several complex scaling parameters to classify the network and get the desired output (Javid et al., 2008). The use of neurons for ANN is very difficult and complex. Hence, in this model neurons were not used. Instead the algorithm made use of polynomial approximations or the Least Squares approximation method, whereby polynomial equations were generated to establish a link between the input and the output (Chukwuka, 2014).

For this algorithm, the input parameters were distributed into the network, rather than lumping them into the network. Lumping the inputs into the network creates several errors while distributing them reduces these errors (Chukwuka, 2014). Four (4) distributions were made, which generated four equations resulting in a Piecewise Modified ANN (PMANN). Figures 6 and 7 are the algorithm flow charts.

The polynomial generated for our own case is expressed as Equation 12 (Chukwuka, 2014):

$$\text{"Fire" or "Non}-\text{fire"} = \sum_i^k (a_i + b_i x_i + c_i x_i^2 + d_i x_i^3) \quad (12)$$

where k is the number of inputs being considered. For the purpose of simulation k=3. But the network was trained with the model flame flicker frequency (13Hz) signal, so that it would be able to differentiate fire cases from non-fire during simulation.

Let Wi be the input weights and Sfi their scaling factor, and ai, bi, ci and di be the coefficients of each input considered. The coefficients are expressed as in Equation (13):

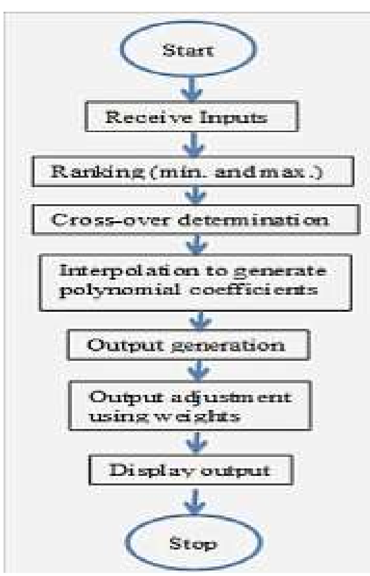

Figure 6. Flow Chart for proposed PMANN

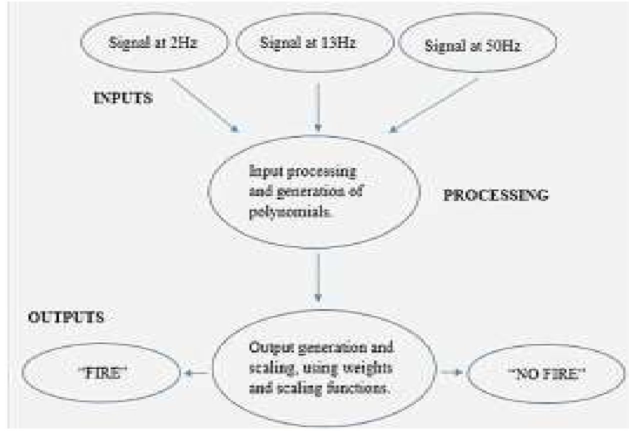

Figure 7. Inputs and Outputs of the Neural Network

$$a_i = a \times Sf_i \times W_i$$
$$b_i = b \times Sf_i \times W_i$$
$$c_i = c \times Sf_i \times W_i$$
$$d_i = d \times Sf_i \times W_i \quad (13)$$

For this model and simulation, the weight was set to be Wi = 1.0 and scaling factor to be Sfi = 0.01. This simplified the scaling process, making the equations easily evaluated within the framework of the network. The coefficients obtained could be matched for 'fire' and 'non-fire' cases using simple statistical correlations like the ICC. The algorithm was designed to receive inputs, sort them out, adjust their parameters and compute the expected result. The polynomial equations obtained from the above analysis were logged into a MATLAB m-file. The ensuing programme ran for different data sheets containing signal coefficients from the DSP.

Using the Intraclass Correlation Coefficient (ICC), data from the PMANN analysis are differentiated into "fire" and "non-fire" cases. The ICC is used to quantify the degree to which measurements with a fixed degree of relatedness match each other in terms of quantitative trait. Besides, this statistical analysis can be applied to assess the consistency (or agreement) of quantitative measurements made by different observers measuring the same quantity. All these are classified as reliability analysis. Hence, this method was applied to analyse the data gotten from PMANN. The coefficients obtained from the data of sample signals of frequency 2Hz, 50Hz and 13Hz (fire signal) were matched against those of the 13Hz (fire signal) used for training.

For a perfect match, the scenario was recorded as "fire" otherwise it was recorded as "non-fire". This analysis was carried out on the SPSS 16.0 software. The results obtained were for the "class 2" or "two-way" random single and average measures (consistency/ absolute agreement) ICC with a 95% confidence interval. Here, the measurement raters are chosen at random. The reliability of the analysis is interpreted between the lower and upper bound of the confidence interval (see Figure 8).

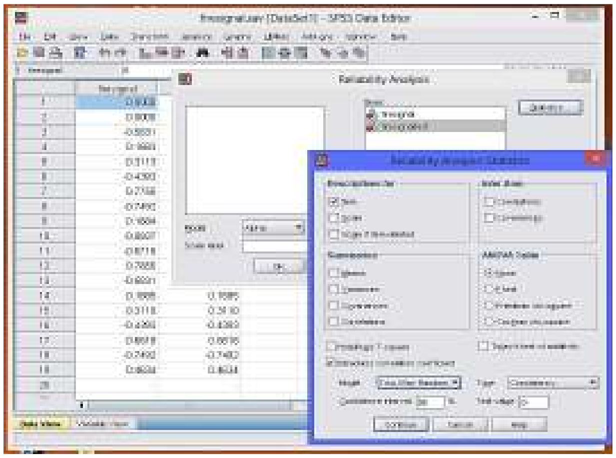

Figure 8. SPSS ICC Reliability Analysis

3.2.3 Suppression Mechanism

The fire suppression response mechanism involved the modeling of control valves. The aim was to come up with a model that could be able to control (open/close) fire suppression systems (foam injection lines, water deluge lines, and water sprinkler lines, etc.), pipelines and also active pumps. By using Proportional, Integral and Derivative Controllers (PIDCs), we simulated the control of an Active Hydraulic Device (ADH) such as hydraulic proportional valves (Yong, 2009).

Under normal system operations in these sites, pumps used for loading and unloading of petroleum products are always running to keep business moving. Also, fire pipelines for suppression systems are always pressurised for emergency cases. These valves can be connected at key places along these pipelines, such that immediately this model detector senses fire, signals are sent to these valves for prompt control as the case may demand.

Developed out of the ineffectiveness of the Proportional (P) and Proportional Derivative (PD) controllers, the PIDCs are better in function and response since they integrate the Proportional (P) and Proportional Derivative (PD) controllers. They have several applications, including use at oil and gas storage sites.The conve ntional PID equation is expressed as Equation (14) (Yong, 2009)

$$U(t) = K_c(e + \frac{1}{T_i}\int_0^t edt + T_d\frac{de}{dt}) \quad (14)$$

where e is the controller error, that is the deviation of the process variable u(t) from its set point uo. Constants KC, Ti and Td are, respectively, the proportional gain, integral time and derivative time constants of the PIDC. They represent the characteristics of the controller. The Laplace transfer function is expressed as in Equation (15) (Katsuhiko, 2010).

$$\frac{U(s)}{E(S)} = K_c\left(1 + \frac{1}{T_i s} + T_d s\right) \quad (15)$$

In determining the values for Kc, Ti and Td for simulation, the Zeigler-Nichols method of tuning PIDCs was used (Katsuhiko, 2010). The method has two (2) approaches, the process reaction method and continuous cycling method. For the model, the process reaction method was applied.

This is based on the assumption that the open-loop step response of most process control systems has an S-shape, called the process reaction curve. It is characterised by two (2) constants, the delay time L and time constant T. For the PIDC K_c = 1.2T/L, T_i = 2L and T_d = 0.5L. Substituting these into Equation (16), the Laplace transfer function becomes

$$\frac{U(s)}{E(S)} = \frac{0.6T(s+1/L)^2}{s} \quad (16)$$

Generally, the control system makes the hydraulic device active. So, the head-discharge relationship of an AHD is usually dynamically modified via its control system to change the opening or closing of its control valve. The generalised dynamic characteristics of an AHD are expressed as Equation (17) (Yong, 2009):

$$F\left(Q, H, Y, \frac{dy}{dt}, \ldots\right) = 0 \quad (17)$$

where Y corresponds to the solenoid of a hydraulic proportional valve. Electric signals from a PIDC are directed to the solenoid to either open/close the valve. Q is flow rate and H is the head.

The solenoid of the hydraulic valve was assumed to have first order dynamics (Roland, 2001) expressed by Equation 18:

$$\frac{V}{U}(s) = \frac{K_v}{1+T_i s} \quad (18)$$

Using standard manufacturer values for a PIDC (Munaf, 2008), the hydraulic proportional valve was simulated on MATLAB/SIMULINK interface as shown in Figure 9.

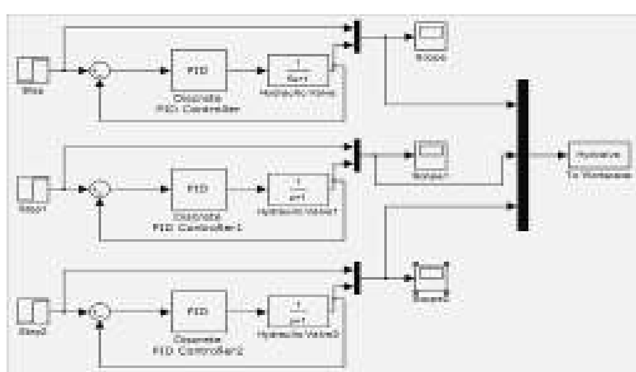

Figure 9. MATLAB SIMULINK block diagram for Hydraulic Valve Response

The values were varied to get different responses for the same hydraulic valve constant (Munaf, 2008):

Kc = [5, 5, 2], *Ti* = [5, 1, 1], Td = [2, 1, 2] and valve constant Kv = 1.0

Changing *Ti* from the valve dynamic equation also changed its response to the PIDC. Generally, signal flow through the whole model is as shown in Figure 10.

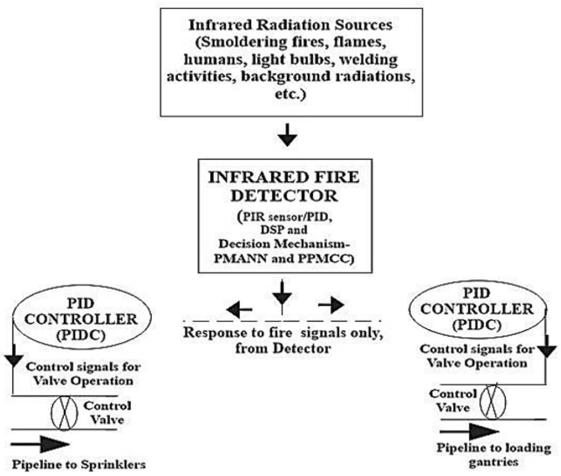

Figure 10. Signal Flow for whole model

4. Results and Discussion

Figures 11, 12 and 13 were obtained after infrared signals modeled at the flickering frequency (13Hz), and other frequencies for example 2Hz and 50Hz were simulated using the MATLAB/SIMULINK block for the PIR sensor/PID, respectively.

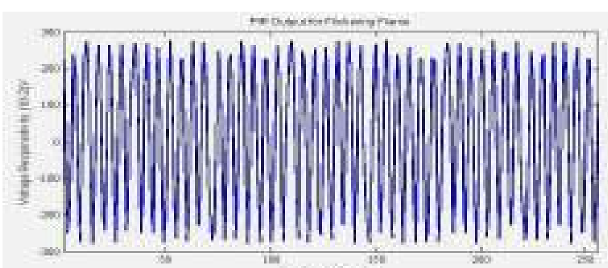

Figure 11. PIR Sensor/PID Output for fire at 13Hz

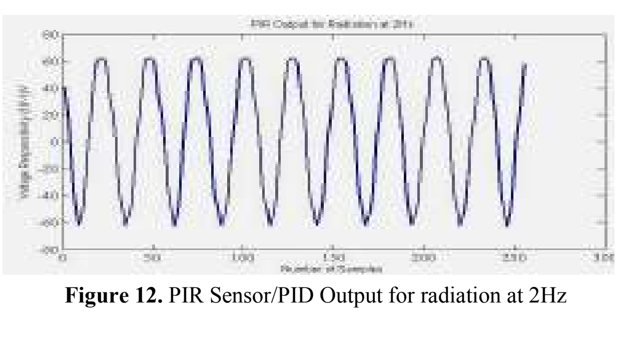

Figure 12. PIR Sensor/PID Output for radiation at 2Hz

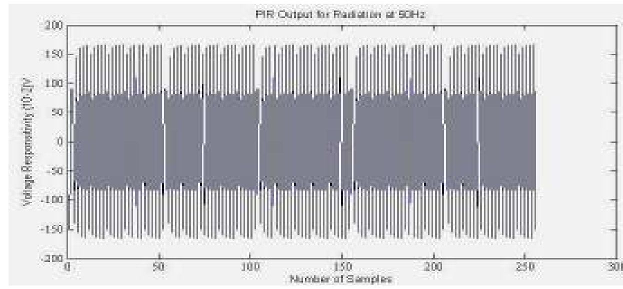

Figure 13. PIR Sensor/PID Output for radiation at 50Hz

From these figures, the difference among the various radiations can easily be seen. A step function, sequence interpolator and pulse generator (see Figure 4) were added together to generate the IR analog signals. This accounted for the oscillatory nature of the graphs. The fire radiation produced higher values (from -3 and 3 V) for voltage responsivity. If the model is to be implemented, the voltages are fed into a microcontroller with the Digital Signal Processing algorithm (DSP). A similar case was achieved when the voltages were fed into the MATLAB/SIMULINK interface containing the corresponding DSP blocks discussed earlier (Figure 4).

For a Hamming window length of N = 256 and wavelet filter implemented on SIMULINK as a discrete Finite Impulse Response (FIR) filter block, the 256 samples (or coefficients) considered by the window function were filtered and the recorded samples narrowed down to 52 samples (or coefficients). This further fine-tuned the detection process, for the results of the signal processing for a simulation time of 10 seconds. After DSP, each signal produced coefficients which were fed into the PMANN for the decision mechanism.

Out of the 52 samples (or coefficients) produced by the DSP algorithm, 18 were used in the training of the network (these contains recorded information i.e. non-zero samples as seen from Figures 14, 15 and 16). The other 34 samples (or coefficients) could be rounded up/down to zero; hence, they were not needed for the training. The DSP output from the model fire signal (13Hz) was our measured and expected output. Therefore, it was used to train our network. After training and classification, the other signals (2Hz and 50Hz) were then passed through the network for analysis. Below are the results for the training and analysis.

The blue graph is the expected (measured) output of PMANN, while green is graph for the signal under analysis (predicted). Figure 17 shows the training of the network, hence, perfect match between the predicted and measured. While Figures 18 and 19 are the results of the analysis.

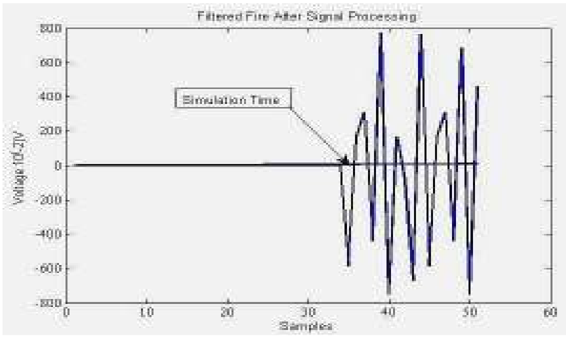

Figure 14. Radiation at 2Hz after DSP

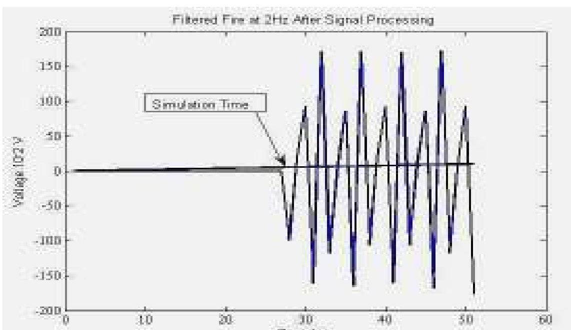

Figure 15. Radiation at 50Hz after DSP

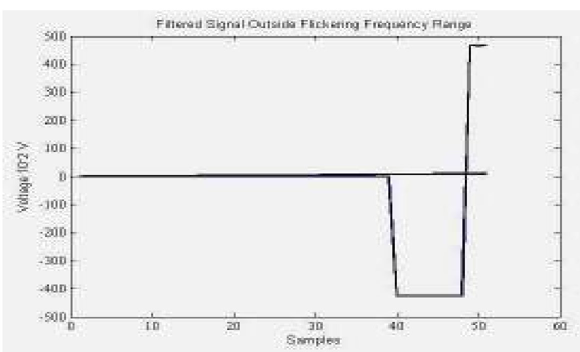

Figure 16. Fire Radiation after DSP

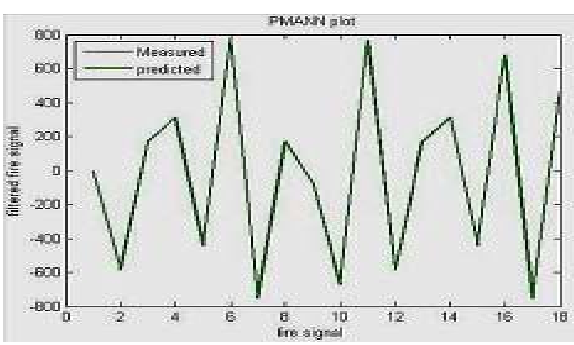

Figure 17. PMANN training of signal at 13Hz (ideal, hence the perfect match of both graphs)

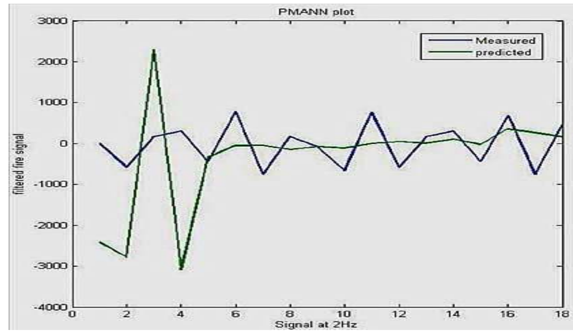

Figure 18. PMANN analysis of signal at 2Hz

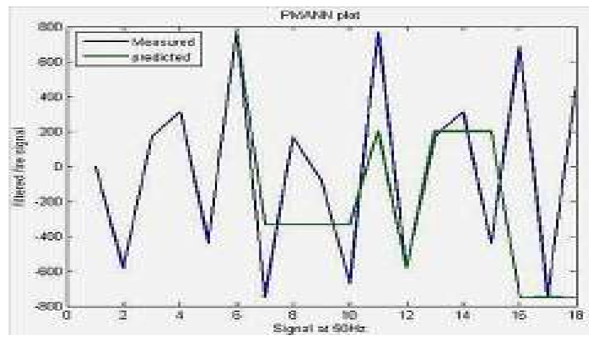

Figure 19. PMANN training of signal at 50Hz

Using the ICC, the samples (or coefficients) were analysed and decisions were made for "fire" and "non-fire" scenarios. Tables 2, 3 and 4 explain the decision rule. Our estimated reliability between the 13Hz sample signal and fire training signal gave 1, with 95% CI (1.00), which matches exactly. Hence, such a scenario is is recorded "fire" (see Table 2). As indicated in Table 3, our estimated reliability between the 2Hz sample signal and fire training signal gave an average of 0.004, with 95% CI (-1.660, 0.627), which is a miss-match. Hence, such a scenario is recorded "non-fire". Moreover, Table 4 shows that our estimated reliability between the 50Hz sample signal and fire training signal is an average of 0.144, with 95% CI (-1.222, 0.670), which is a miss-match. Hence, such a scenario is recorded "non-fire".

If the model is to be implemented in real life using appropriate electrical equipment, the detection mechanism will record only real FIRE cases, and send electric signals to the suppression valves. For the control of valves along suppression systems pipelines, the model hydraulic solenoid valve responded perfectly as expected in real life.

Figure 20 obtained was consistent with that obtained through experiments. Three cases of the PIDC are studied. The stepwise input simulated the digital nature of real life signals. The graphs perfectly correspond to a device connected to a PIDC under the Zeigler-Nichols' Process Reaction method of tuning, where the delay time

(L) is common for all the controllers and the time constant (T1, T2, T3) can be calculated from the slope of the graph for each PIDC. Hence, it will perfectly control depending on the nature of the pipeline to which it is connected to. From the graph, the 'PID' controller gives a normal forward control or open-loop control whereby the valves open and close. It is the most suitable PIDC for this application. Controllers 'PID1'and 'PID2', gave results for closed-looped control systems. Such systems experience some measure of damping (represented by the zigzag portion of the graphs). The damping is due to feedback and feed forward mechanisms as the PIDC tries to eliminate error. From the graph 'PID1' and 'PID2' have damping amplitudes (or ratios) within the range of 0.2-0.3, which are within the Zeigler-Nichols range of 0.21-4.0 (Roland, 2001).

Table 2. Intraclass Correlation Coefficient for 13Hz Sample Signals (e.g. open fires)

13Hz Sample Signal	Intraclass Correlation	95% Confidence Interval (CI)		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	1.000	1.000	1.000	1.946E19	18	18	0.000
Average Measures	1.000	1.000	1.000	1.946E19	18	18	0.000

Table 3. Intraclass Correlation Coefficient for 2Hz Sample Signals (radiations from sources like Humans)

2Hz Sample Signal	Intraclass Correlation	95% Confidence Interval (CI)		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	0.002	-0.454	0.457	1.004	17	17	0.497
Average Measures	0.004	-1.660	0.627	1.004	17	17	0.497

Table 4. Intraclass Correlation Coefficient for 50Hz Sample Signals (background radiations)

50Hz Sample Signal	Intraclass Correlation	95% Confidence Interval (CI)		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	0.078	-.379	0.504	1.168	18	18	0.373
Average Measures	0.144	-1.222	0.670	1.168	18	18	0.373

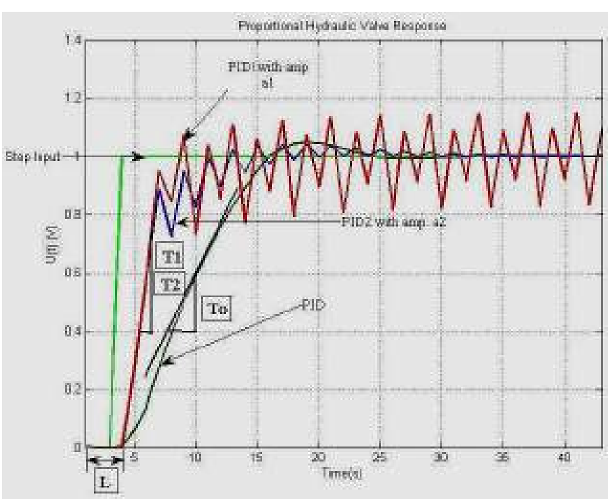

Figure 20. Hydraulic Proportional Valve Response.

5. Conclusion

An adaptive model for fire detection and suppression system has been discussed with emphasis on automatic fire detection and controlled suppression mechanism. First, the sensor was modeled using Laplace transforms and the fire signal detection mechanism was modeled using the Hamming window function and discrete wavelet transforms. Then using a PMANN and ICC as the decision rule, our detector could differentiate between fire and non-fire radiations. Using model equations of a PIDC and the standard dynamic equation for a proportional hydraulic solenoid valve, with valve constant being unity, the suppression mechanism was studied and simulated.

The results shows that under normal conditions the valve will control suppression systems (e.g. water sprinkler lines, foam injection lines and other similar fire suppression methods) and close pump lines in case of fire. We must note that sprinklers used in buildings are temperature activated. These are different from those used outside and in areas such as oil and gas storage sites. In Nigeria, most sprinklers used in loading gantries at oil and gas storage sites are perforated cone shape extensions of fire water lines. The detector controlled valves can be used to operate such sprinklers. Better approaches can still be used to devise more efficient models to mitigate the devastating effects of fire in petroleum storage sites.

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A Re-engineered Transmission Line Parameter Calculator

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Abstract: *This paper documents the development and testing of a Transmission Line Parameter Calculator (TLPC), which computes the impedance parameters for short and medium transmission lines. LPARA, an existing software at The Trinidad and Tobago Electricity Commission (T&TEC), has been taken as the standard for comparison, since it has been tested and proved consistent with Power World Software, as well as it has been satisfactorily employed for decades at T&TEC. Comparative testing of the newly developed TLPC with LPARA revealed a maximum percentage difference of 0.05%, 0.02% and 0.80% in Series Resistance, Series Reactance and Shunt Admittance Matrices, respectively. The package, when compared to its FORTRAN based predecessor, LPARA, has a user friendly Graphical User Interface (GUI) with an expandable database of support structures and conductors. The TLPC has interactive program help, error checking, and validation of all user inputs. It is tailored to T&TEC, but yet flexible enough for use by other similar electric utilities. The finished product has demonstrated a vast improvement in the overall speed of parameter calculations, the reduced susceptibility to input errors and it has addressed recent compatibility issues which LPARA experiences as T&TEC upgrades and transitions to 64-bit Operating Systems.*

Keywords: *Power transmission line, power system planning, transmission line theory, admittance impedance matrix*

1. Introduction

Transmission line oriented parameter software is readily available for most electric utilities to purchase, however many utilities opt for software which is custom developed to the requirements of their existing physical topological as well as software infrastructure. The Trinidad and Tobago Electricity Commission (T&TEC) employs a custom written command line interface which utilises a text file input and produces a text file output with the transmission line parameters for a given type of support structure. The input text file is manually created by the utility engineer and character spacing as well as character positioning is critical to prevent any errors from occurring when the input is supplied to the LPARA software. Moreover, the required inputs are only available after manual pre-processing of data to obtain the information required by the program. This renders the complete process for a line parameter calculation very tedious and the utility engineer exercise caution to prevent any errors from occurring when manipulating the input data. In recent times utility engineers at T&TEC have faced compatibility issues in the transition to 64-bit operating systems and thus T&TEC has expressed the need for a reengineered transmission line parameter calculation tool.

This paper details the theory, operation and validation of the developed TLPC to address the challenges presently faced. The primary transmission line parameters developed using TLPC include the line's series resistance matrix, the series reactance matrix and the shunt admittance matrix and using these matrices, several other line parameters, including sequence impedance parameters and sequence capacitance parameters can be derived. Studies by Galloway et al. (1964) allow these matrices to be calculated and quantities expressed in units per kilometer of overhead transmission line. LPARA, the existing software at T&TEC, has been verified using actual live line test data by Moorthy and Sharma (1988), as well as PSAF Software. LPARA has been employed by T&TEC for over 30 years with no reports of the unexpected triggering of protection relays. Thus, LPARA is used as the validation standard for comparison of the TLPC output.

2. Methodology

This section documents the processing done on the inputs supplied to the TLPC and the internal organisation of information. The main calculations which are performed utilise the work done by Galloway et al. (1964), and this theory is detailed in Appendix 1. Figure 1 shows a simple system overview of how information is processed by the TLPC and it also identifies the key processing modules present in the Line Parameter Package. The user must select a circuit configuration, after which the bundle parameters will be entered (only in the case of bundled circuits) and then the information is processed.

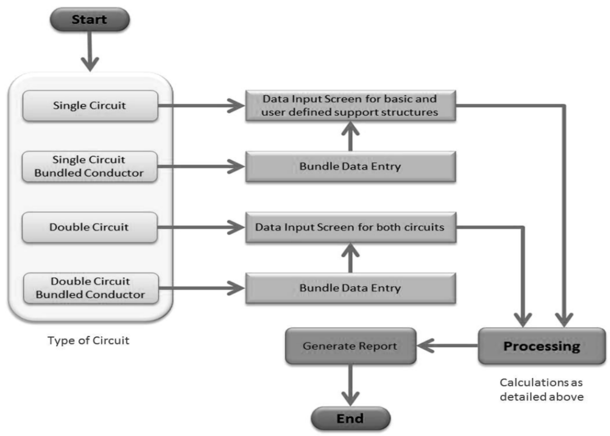

Figure 1. System flow diagram of the TLPC

Figure 2 identifies the series of processes which is done in the processing block of Figure 1, and upon completion; the TLPC will generate a Microsoft Excel 2010 Output Report. The report details both the user entered inputs and the calculated outputs. It shows the processing block of the TLPC consists of two separate processing paths, one for single conductor circuits and the other for bundled conductor circuits. Both paths are capable of handling both single circuits and double circuits. It shows that the Shunt Admittance Matrix is dependent only on the Conductor Coordinates, and the Series Impedance Matrix is calculated using Kron's Reduction on complex sum of the Self Impedance of the Conductor, the Impedance of the Earth Return Path and the Reactance due to Physical Geometry. When the Series Impedance Matrix is known, then further calculations can be performed to obtain the Derived Line Parameters. This is the general procedure for the Line Parameter Calculation, and if the transmission line consists of a bundled conductor, then an additional step must be performed to determine a revised Self Impedance of the Conductor. The Kron's Reduction procedure is then performed on the complex sum of the revised Self Impedance, the Impedance of the Earth Return Path, and the Reactance due to Physical Geometry matrices to determine the Series Impedance Matrix

3. Program Operation

It is evident that the system overview illustrated in Figure 1 and Figure 2 requires specific program inputs, and pre-processing of span length data, before the transmission line parameter calculations can be performed. These inputs include, but are not limited to:

- power system frequency,
- ambient and circuit operating temperatures,
- earth resistivity,
- line insulator length,
- aerial and phase line tensions,
- aerial and phase conductor types and specifications,
- sorted span lengths for each support structure, and
- support structure types and specifications

In the case where bundled conductors are selected, additional information is required which includes;

- number of conductors in the bundle, and
- conductor spacing.

All of these user inputs are validated by the program to ensure that the inputs are appropriate, before the user can proceed. Several, tips, warning, and error messages are also available to aid the user in navigating through the program and to rectify input errors.

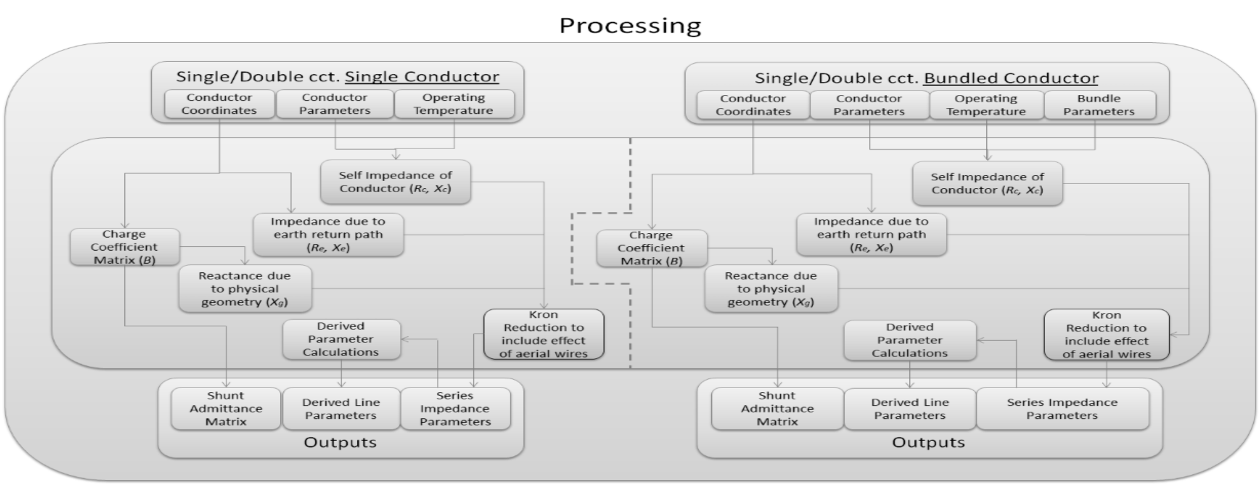

Figure 2. Processing block of the TLPC

4. Pre-processing

When the user has entered all of the required input data, the sequence of calculations documented in Equations 1 to 3 is performed. These Equations have been adapted from the Southwire Manual, (Southwire Company, 2007) and they allow the actual conductor coordinates to be determined using the user entered design coordinates. Firstly the conductor sag is calculated using Equation 1 and Equation 2.

Equation 1

$$Typical\ Span = Average\ Span + \frac{2}{3}(Max\ Span - Average\ span)$$

Equation 2

$$Sag = \left(\frac{Tension}{Weight}\right)\left(\cosh\left(\frac{Weight \times Typical\ Span}{2 \times Tension}\right) - 1\right)$$

Where

Tension = Tension of line conductor, and

Weight = Weight of line conductor

The conductor heights (y-coordinates) can then be determined using Equation 3, which is then paired with the x-coordinates to give the actual conductor coordinates.

Equation 3

$$Conductor\ Height = ConductorDesign\ Height - \frac{2}{3}(Sag)$$

In the event that the actual conductor coordinates are already known, the user shall enter these directly into the program with a high line tension and a short span length. Physically, the magnitude of these parameters represents the sag on the conductors, and such a combination of high tension and short span, results in negligible sag. Negligible sag hints that the actual conductor height is approximately equal to the user defined design height as can be seen from **Error! Reference source not found.**. This approach allows the program to handle calculated conductor coordinates and is illustrated in Figure 3.

These actual conductor coordinates are then passed to the main processing block of the program which performs the line parameter calculation as outlined in Galloway et al. (1964). This has been illustrated in Figure 1.

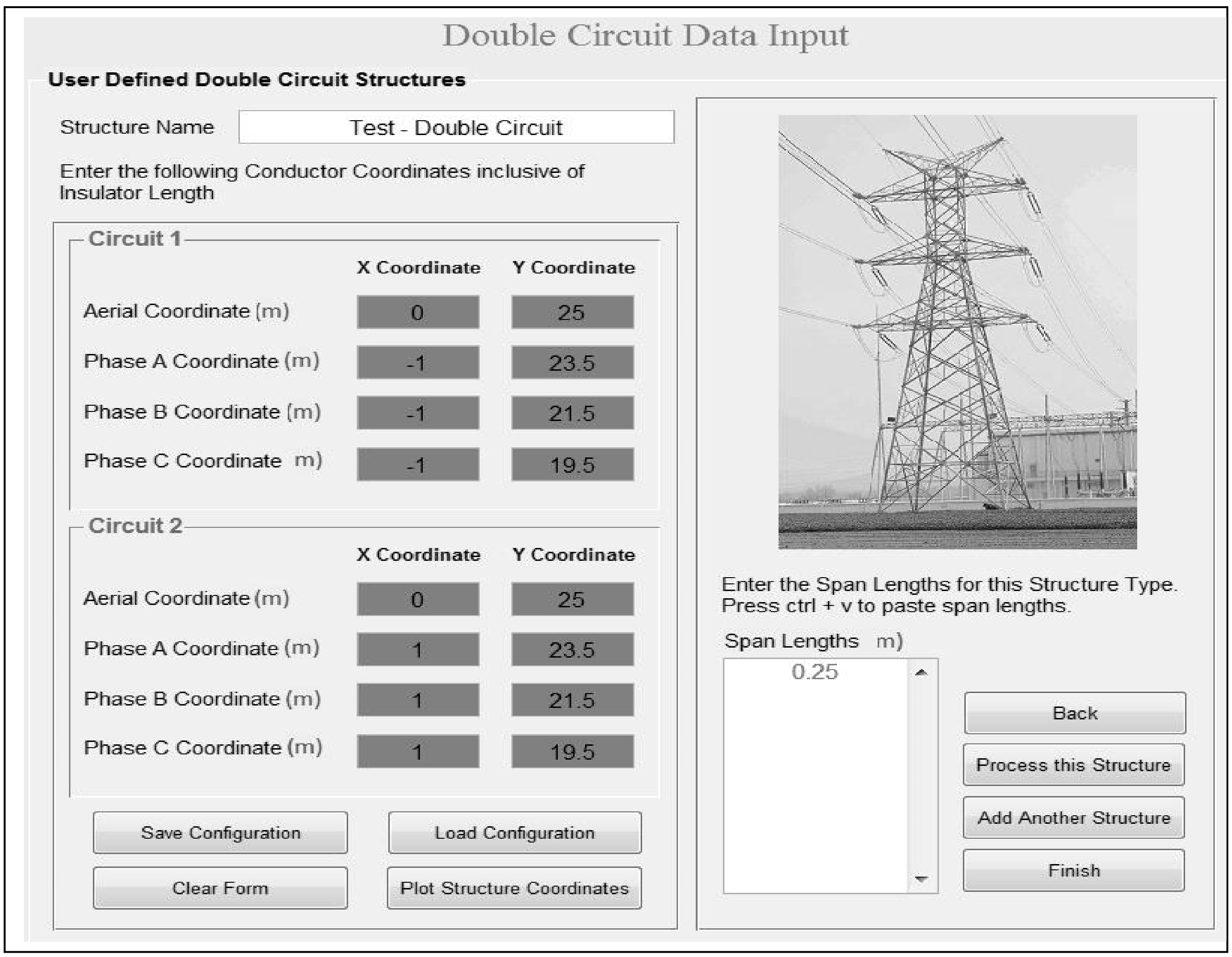

Figure 3. Entry of calculated conductor coordinates (with short span lengths)

5. Results

White box and black box testing was performed on each of the four separate processing paths (which each constituted a test case), *Single Circuit Single Conductor*, *Single Circuit Bundled Conductor*, *Double Circuit Single Conductor* and *Double Circuit Single Conductor*. The generated output of white box testing on a *Single Circuit Single Conductor* test case has been documented in this Test Results Section. The other three cases have not been included due to space restrictions but are available upon request. The inputs for Test Case 1 (*Single Circuit Single Conductor*) are shown in Table 1 and Table 2 and the outputs, with comparison to that of LPARA are shown in Table 3.

Combined these four test cases demonstrates the total functionality and accuracy of the TLPC when compared to LPARA. The maximum percentage differences of all four Tests are presented in Table 4.

Table 1. Test Conductor Coordinates for Single Circuit, Single Conductor

	X Coordinate (m)	Y Coordinate (m)
Phase A	0.9	12
Phase B	0.9	11
Phase C	0.9	10
Aerial Wire	0.0	14

Table 2. Properties for Single Circuit, Single Conductor

	Aerial Wire	Phase Wire
Conductor Name	Raven	Osprey
Cable Diameter (cm)	1.1011	2.2330
Manufacture Unit Resistance (Ω/km)	0.5338	0.1323
Manufacture Unit Reactance (Ω/km)	0.0321	0.0192
Number of Conductors (per bundle)	1.0000	1.0000
GMD of Conductor (cm)	1.1011	2.2330

Table 3. Comparative output matrices for series resistance, reactance and shunt admittance for the Test 1

Series Resistance Matrix: Max. Percentage Difference = 0.0448%					
LPARA Software (Ω/km)			*TLPC (Ω/km)*		
0.246213	0.109317	0.105852	0.246161	0.109268	0.105805
0.109317	0.237372	0.101871	0.109268	0.237326	0.101828
0.105852	0.101871	0.231172	0.105805	0.101828	0.231131

Series Reactance Matrix: Max. Percentage Difference = 0.0117%					
LPARA Software (Ω/km)			*TLPC (Ω/km)*		
0.691079	0.342884	0.298102	0.691106	0.342921	0.298137
0.342884	0.710364	0.359314	0.342921	0.710387	0.359347
0.298102	0.359314	0.724175	0.298137	0.359347	0.724195

Shunt Admittance Matrix: Max. Percentage Difference = 0.1873%					
LPARA Software (mS/km)			*TLPC (mS/km)*		
0.003546	-0.001068	-0.000548	0.003551	-0.001070	-0.000549
-0.001068	0.003742	-0.001091	-0.001070	0.003747	-0.001093
-0.000548	-0.001091	0.003484	-0.000549	-0.001093	0.003489

Table 4. Summary of comparative results for all Tests

Test Description	Maximum Percentage Difference (%)		
	Series Resistance Matrix	Series Reactance matrix	Shunt Admittance Matrix
Test 1 - Single Circuit, Single Conductor	0.0448	0.0117	0.1873
Test 2 – Single Circuit, Bundled Conductor	0.0010	0.0007	**0.7246**
Test 3 – Double Circuit, Single Conductor	0.0020	0.0028	0.2890
Test 4 – Double Circuit, Bundled Conductor	**0.0465**	**0.0135**	0.3922

6. Discussion

The results show a variation of less than 0.05% and 0.02% in the Series Resistance and Series Reactance Matrices, while the Shunt Admittance Matrix shows a variation of less than 0.8%. These variations are primarily attributed to the fact that there are significantly less user approximations made by the TLPC in the initial calculations, as compared to that of the LPARA System. These percentages are manifested as a small change in the output line parameters, which usually, is still within the range of tolerable values used in the utility engineer's power system design/study.

These results demonstrate functionality and accuracy of the TLPC. Major contributions of this reengineered TLPC are not necessarily its accuracy and functionality, but rather its:

- speed of line parameter calculation
- automation of calculation processes
- user friendliness
- flexibility in terms of saving and loading custom built structure types and conductors
- decreased susceptibility to human input errors when compared to its LPARA predecessor
- ability to integrate seamlessly with T&TEC's existing procedures
- economical advantage when compared to commercially available software.

6.1 Software Implementation and Requirements

To implement the TLPC it is important to note that it has been designed and built in Matlab version R2010b, (7.11.0.584) and was subsequently complied into a 32-bit standalone executable. This .exe requires Matlab or Matlab MCR (Matlab Complier Runtime Version 7.14) to be launched, but this does not mean that Matlab is needed. The MCR is included in the program files of the

TLPC and this allows any electric utility to use the calculator without the entire Matlab Environment. Other requirements for program operation include:

- Microsoft Windows XP or later version Operating System,
- 1920 x 1080 screen resolution, display font size set to medium,
- at least 512MB of RAM, and
- Microsoft Excel 2010 or later.

6.2 Assumptions and Considerations for Program Operation

Several assumptions are also made by the TLPC and the most important of these is that the TLPC was developed to calculate the line parameters for *overhead transmission lines* only. As such, there are critical expectations and criteria which must be satisfied for the program to function accurately. These include;

1) Single Circuits MUST consist of an aerial conductor as well as the three other line conductors required for three phase power transmission.
2) Double Circuits MUST consist of either one or two aerial conductors as well as the six other line conductors required for two three phase circuits.
3) The transmission circuit is balanced and each of the three phases is identically loaded. This implies that a) each phase is made of the same type of conductor with identical conductor parameters; and b) in the case of bundled conductors, each phase consists of the same number of conductors in each bundle of the circuit.
4) For Double Circuits, the span length between two support structures is the same for both circuits of the double circuit.
5) The temperature coefficient of a conductor is constant at any given temperature of operation.
6) It is a good approximation to model bundled conductors as a set of single conductors connected in parallel.

6.3 Limitations of the Calculator

The TLPC is limited to a maximum topology of a double circuit bundled conductor configuration, consisting of up to four conductors for any of the aerial or phase conductors. Every Single Circuit computation which is done using TLPC must consist of;

- One, aerial conductor (up to a four conductor bundle), and
- Three, phase conductors (each phase consists of a maximum of a four conductor bundle).

Every Double Circuit computation must consist of;

- One, or two aerial lines (up to four conductor bundle), and
- Two sets of three, phase conductors, for each of the two circuits in the double circuit (each phase consists of a maximum of a four conductor bundle).

The GMD calculation for a three conductor bundle is restricted to that of an equilateral triangular configuration, while that of a four conductor bundle is to a square configuration. The program is developed with a set of conductors and support structures which are preloaded into the existing database; however the option exists for the user to populate the database by defining their own conductors and support structures.

7. Conclusion

This paper highlighted the theory, operation and advantages of the reengineered Matlab based TLPC over the existing LPARA software. The inputs and outputs of the software are explicitly defined; and testing and verification of the functionality and accuracy of the TLPC has been performed and documented. The TLPC has been validated with the existing LPARA software yielding a maximum percentage variation of 0.05% and 0.02% in the Series Resistance and Series Reactance Matrices, while the Shunt Admittance Matrix yielded a variation of less than 0.8%.

This variation has been accounted for and numerous tests have shown consistency between both programs. Other advantages of the TLPC over LPARA have been observed and these include an improvement in the speed of performing a line calculation, the ease of use with the TLPC, as well as an improvement in the susceptibility to human errors. These characteristics of the TLPC make it a viable software option for almost any utility to calculate short and medium length transmission line model parameters.

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Appendix 1:

This is the theory used within the LPARA, and it is also used as the foundation of the reengineered TLPC. This method, published by Galloway et al. (1964), utilises Carson's solution and as a result, regards the earth as a plane, homogeneous, semi-infinite solid with constant resistivity. Furthermore, the axial displacement of currents in the air and the earth as well as the effect of the earth return path on the shunt admittance is neglected. The work is divided into three sections: Shunt Admittance, Series Resistance and Series Reactance Matrices.

Development of Shunt Admittance Matrix

The shunt admittance matrix, ***Y***, is a function only of the physical geometry of the conductors relative to the earth plane, and it is an imaginary matrix since the conductance of the air path to ground is negligible. The physical location of the conductors is defined with respect to a coordinate system, with the earth plane as horizontal reference axis and the axis of symmetry of the tower as vertical reference. This allows all conductors on a support structure to be referenced using *x* and *y* coordinates. Using these coordinates of the conductors and the conductor radii, elements of charge coefficient matrix ***B*** can then be calculated where the i,j^{th} element is defined as

<u>*Equation 4*</u>

$$B_{i,j^{th}} = \ln\left(\frac{D_{ij}}{d_{ij}}\right)$$

As used in Equation 4,

D_{ij} = distance between i^{th} conductor and the image of the j^{th} conductor
d_{ij} = distance between i^{th} conductor and the image of the j^{th} conductor for $i \neq j$ (of diagonal)
= radius of ith conductor for I = j (diagonal)

These quantities are shown schematically in Figure 4. The ***B*** matrix has order $3p + q$ where *p* represents the number of circuits and *q*, the number of earth wires.

If the charge matrix is represented by **ψ** and the voltage matrix by ***V***, then using Maxwell's equations,

$$V = \left(\frac{1}{2\pi\epsilon}\right).(B\psi)$$

And it follows that

$$\psi = 2\pi\epsilon B^{-1}V$$

However, ***V*** is a column matrix whose last *q* elements are zero (the voltage of the earthed or neutral wires), so that the last *q* columns of $\boldsymbol{B^{-1}}$ can be discarded. The last *q* rows of $\boldsymbol{B^{-1}}$ give the earth wire charges, and, as these are not generally required, these *q* rows are also discarded. The matrix obtained by discarding the last *q* rows and columns of $\boldsymbol{B^{-1}}$ is $\boldsymbol{B_A^{-1}}$ and has order *3p*.

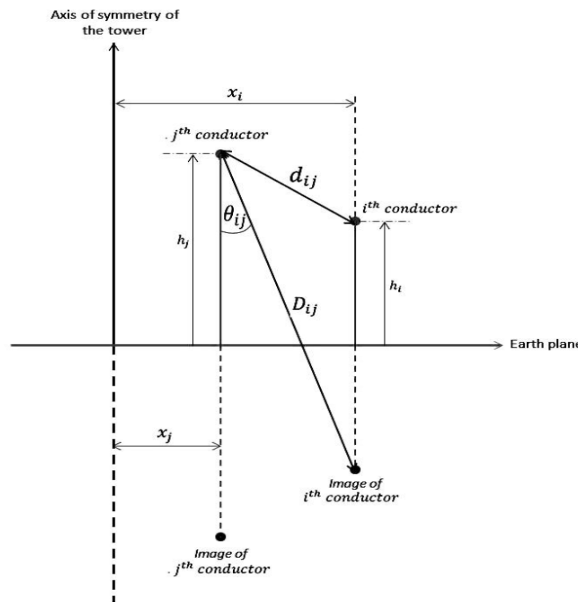

Figure 4. Schematic layout of two conductors

The shunt admittance matrix ***Y*** is defined by the general equation

$$I = YV$$

And since,

$$\Psi = 2\pi\epsilon B_A{}^{-1}V$$

$$I = \frac{d\Psi}{dt} = j\omega\Psi;$$

Then,

$$I = j2\pi\omega\epsilon B_A{}^{-1}V$$

And it follows that,

<u>*Equation 5*</u>

$$Y = j2\pi\omega\epsilon B_A{}^{-1}$$

Where ***Y*** includes for the effect of the earth wires

Development of the Impedance Matrix

The impedance matrix *Z'* consists of five components and is of the form

$$Z' = R_e + R_c + j(X_a + X_e + X_c)$$

Where the subscripts have the following significance

g = the contribution of reactance due to the physical geometry of the conductors
c = the contribution of the conductor
e = the contribution of the earth path

Reactance due to physical geometry

The reactance due to the geometry of the conductors is calculated directly from the charge coefficient matrix and is given by

$$X_g = \frac{\omega\mu B}{2\pi}$$

Where ***B*** is the identical matrix as derived for the ***Y*** matrix and is of order $3p + q$.

Determining the effect of the earth return path

The contribution of resistance and reactance, $\boldsymbol{R_e}$ and $\boldsymbol{X_e}$ due to the earth return path is calculated by using an infinite series developed by Carson. Real and imaginary correction component matrices $\boldsymbol{P}$ and $\boldsymbol{Q}$, respectively are calculated in terms if $\boldsymbol{r}$ and $\boldsymbol{\theta}$, two abstract parameters such that

Equation 6

$$r_{ij} = \sqrt{\left(\frac{\omega\mu}{\rho}\right).D_{ij}}$$

And θ_{ij} is the angle subtended at the i^{th} conductor, by the i^{th} image and the j^{th} image as illustrated in Figure 4. Galloway's work then involved rearranging Carson's formulas to suit computation as.

Equation 7

$$R_e = \frac{2\boldsymbol{P}\omega\mu}{2\pi} \; and \; X_e = \frac{2\boldsymbol{Q}\omega\mu}{2\pi}$$

Where, for $r_{ij} \leq 5$,

Equation Set 1

$$P_{ij} = \frac{\pi}{8}(1 - S_4) + \frac{1}{2}\log\left(\frac{2}{\gamma r}\right)S_2 + \frac{1}{2}\theta S_2' - \frac{\sigma_1}{\sqrt{2}} + \frac{\sigma_2}{2} + \frac{\sigma_3}{\sqrt{2}} \quad \text{and}$$

$$Q_{ij} = \frac{1}{4} + \frac{\log\left(\frac{2}{\gamma r}\right)(1 - S_4)}{2} - \frac{\theta S_4'}{2} + \frac{\sigma_1}{\sqrt{2}} - \frac{\pi S_2}{8} + \frac{\sigma_3}{\sqrt{2}} - \frac{\sigma_4}{2}$$

As shown in Equation Set 1, γ = Euler's constant ≈ 1.7811 and $S_2, S_2', S_4, S_4', \sigma_1, \sigma_2, \sigma_3, \sigma_4$ are the infinite series which are defined in Equation Set 2.

Equation Set 2

$$S_2 = \sum_0^\infty a_n \cos(4n+2)\theta$$

$$S_2' = \sum_0^\infty a_n \sin(4n+2)\theta$$

$$S_4 = \sum_0^\infty c_n \cos(4n+4)\theta$$

$$S_4' = \sum_0^\infty c_n \sin(4n+4)\theta$$

$$\sigma_1 = \sum_0^\infty e_n \cos(4n+1)\theta$$

$$\sigma_2 = \sum_0^\infty g_n (S_2)$$

$$\sigma_3 = \sum_0^\infty f_n \cos(4n+3)\theta$$

$$\sigma_4 = \sum_0^\infty h_n (S_4)$$

$a_n, c_n, e_n, f_n, g_n, h_n$ are as defined in Equation Set 3

Equation Set 3

$$a_n = \frac{-a_{n-1}}{2n(2n+1)^2(2n+2)}\left(\frac{r}{2}\right)^4, \qquad a_0 = \frac{r^2}{8}$$

$$c_n = \frac{-c_{n-1}}{(2n+1)(2n+2)^2(2n+3)}\left(\frac{r}{2}\right)^4, \qquad c_0 = \frac{r^4}{192}$$

$$e_n = \frac{-e_{n-1}}{(4n-1)(4n+1)^2(4n+3)}r^4, \qquad e_0 = \frac{r}{3}$$

$$f_n = \frac{-f_{n-1}}{(4n+1)(4n+3)^2(4n+5)}r^4, \qquad f_0 = \frac{r^3}{45}$$

$$g_n = g_{n-1} + \frac{1}{4n} + \frac{1}{2n+1} + \frac{1}{2n+2} - \frac{1}{4n+4}, \qquad g_0 = \frac{5}{4}$$

$$h_n = h_{n-1} + \frac{1}{4n+2} + \frac{1}{2n+2} + \frac{1}{2n+3} - \frac{1}{4n+6}, \qquad h_0 = \frac{5}{3}$$

For $r_{ij} > 5$, Equation Set 4 is used to calculate P_{ij} and Q_{ij};

Equation Set 4

$$P_{ij} = \frac{\cos\theta}{\sqrt{(2)}.r} - \frac{\cos 2\theta}{r^2} + \frac{\cos 3\theta}{\sqrt{(2)}.r^3} + \frac{3\cos 5\theta}{\sqrt{(2)}.r^5}$$

$$Q_{ij} = \frac{\cos\theta}{\sqrt{(2)}.r} - \frac{\cos 3\theta}{\sqrt{(2)}.r^3} + \frac{3\cos 5\theta}{\sqrt{(2)}.r^5}$$

Determining the internal impedance of conductor

At power frequency, if the skin effect for a conductor is negligible, then the resistance per unit length of the conductor, R_c is assumed to be equal to the d.c resistance per unit length. This is the case for most overhead conductors, and the d.c. resistance per unit length can be directly obtained from the cable manufacturer specification sheet. However if the skin effect is significant at power frequency, then the manufacturer's power-frequency value will be detailed in the conductor specification sheet and this value would be used as the resistance per unit length instead.

The internal inductance and hence reactance X_c is calculated by the standard concept of geometric mean radius (GMR) and geometric mean distance (GMD). That is X_c is given as:

$$X_c = 2\pi f L$$

Where L is given by

$$L = 2 \times 10^{-7} \ln\left(\frac{GMD}{GMR}\right) \; Hm^{-1}$$

And thus,

Equation 8

$$X_c = 4\pi f \times 10^{-7} \ln\left(\frac{GMD}{GMR}\right) \; \Omega$$

In the case of bundled conductors, the number of conductors and the distance between each conductor of a particular phase is used to determine the GMR of the conductor.

Effect of earth wires in Z matrix

In general, the Z' matrix calculated as detailed in Appendix 1, (Subsection Development of Z Matrix), will have order $3p + q$ where p is the number of circuits and q is the number of earth wires.

The equation relating series voltage drop and current is;

$$V = Z'I \quad or \quad I = Z'^{-1}V$$

As in the case of the ***Y*** matrix, the last q rows and columns of Z'^{-1} are discarded, and the modified matrix of order $3p$ is re-inverted to give the corrected Z matrix which allows for the effect of the earth wires.

Developing derived line parameters

This subsection demonstrates how the admittance and impedance matrices, previously defined, may be manipulated to calculate symmetrical component parameters (Impedance and Capacitance) at the power frequency.

Equation Set 5

Positive Sequence Impedance

For a single circuit network, the positive sequence impedance z_1 (and also the negative sequence z_2) is given by;

$$z_1 = \frac{(z_{11} + z_{22} + z_{33} - z_{12} - z_{13} - z_{23})}{3}$$

While for a double circuit network, the positive sequence impedance is given by;

Positive Sequence Impedance for Circuit 1

$$z_{11} = \frac{(z_{11} + z_{22} + z_{33} - z_{12} - z_{13} - z_{23})}{3}$$

Positive Sequence Impedance for Circuit 2

$$z_{12} = \frac{(z_{44} + z_{55} + z_{66} - z_{45} - z_{46} - z_{56})}{3}$$

Zero Sequence Impedance

For a single circuit network, the zero sequence impedance z_0 is given by;

$$z_0 = \frac{(z_{11} + z_{22} + z_{33} + 2z_{12} + 2z_{13} + 2z_{23})}{3}$$

While for a double circuit network, the zero sequence impedance is given by;

Zero Sequence Impedance for Circuit 1

$$z_{01} = \frac{(z_{11} + z_{22} + z_{33} + 2z_{12} + 2z_{13} + 2z_{23})}{3}$$

Zero Sequence Impedance for Circuit 2

$$z_{02} = \frac{(z_{44} + z_{55} + z_{66} + 2z_{45} + 2z_{46} + 2z_{56})}{3}$$

Zero Sequence Mutual Impedance *

The zero sequence mutual impedance z_{00} for a double circuit configuration is given by;

$$z_{00} = \frac{(z_{14} + z_{15} + z_{16} + z_{24} + z_{25} + z_{26} + z_{34} + z_{35} + z_{36})}{3}$$

Interphase Mutual Impedance

The interphase mutual impedance z_{pp} for a circuit is given by

$$z_{pp} = \frac{(z_0 - z_1)}{3}$$

Where ... ed in Equation Set 5 and consistent with e ... r a double circuit configuration.

Earth-Loop impedance

The earth loop impedance z_p for either single or double circuit is defined as

$$z_p = z_1 + z_{pp}$$

Where z_1 and z_{pp} are consistent with either a single or double circuit configuration.

Inter-circuit mutual impedance *

The inter-circuit mutual impedance z_{cc} in a double circuit configuration is given as;

$$z_{cc} = \frac{z_{00}}{3}$$

The following demonstrates how the shunt susceptance parameters are developed.

Let $A = Y^{-1}$ where A has elements a_{ij}, then;

Positive-sequence capacitance

The positive sequence capacitance c_1 is given by

$$c_1 = \frac{3}{\omega(a_{11} + a_{22} + a_{33} - a_{12} - a_{23} - a_{13})}$$

Zero-sequence capacitance

The zero sequence capacitance c_0 is given by

$$c_0 = \frac{3}{\omega(a_{11} + a_{22} + a_{33} + 2a_{12} + 2a_{23} + 2a_{13})}$$

Zero-sequence mutual capacitance *

The zero sequence mutual capacitance c_{00} is given by

$$c_{00} = \frac{3}{\omega(a_{14} + a_{15} + a_{16} + a_{24} + a_{25} + a_{26} + a_{34} + a_{35} + a_{36})}$$

Interphase mutual capacitance

The interphase mutual capacitance c_{pp} is given by

$$c_{pp} = \frac{3}{\frac{1}{c_0} - \frac{1}{c_1}}$$

Earth loop capacitance

The earth loop capacitance c_p is given by

$$c_p = \frac{1}{\frac{1}{c_1} - \frac{1}{c_{pp}}}$$

Inter-circuit mutual capacitance *

The inter-circuit mutual capacitance c_{cc} is given by

$$c_{cc} = 3c_{00}$$

* - Only applicable to double circuit topologies.

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Thermal Conductivities of Some Agricultural Soils in Trinidad as Affected by Density, Water and Peat Content

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Abstract: *The thermal conductivities of twenty-six (26) agricultural soils in Trinidad were measured in the field and the laboratory with a KD2 sensor and probe. The effect of compacting four of the soils (two clayey and two sandy) to five bulk densities (1.2 to 1.6 Mg m^{-3}) with zero and 4% peat content at four water contents (5, 12, 19 and 26%) on thermal conductivity was further investigated in the laboratory. The thermal conductivity measured in the field ranged from 0.73 to 1.69 W m^{-1} ^{o}C^{-1} and were within 0.11 W m^{-1} ^{o}C^{-1} of the corresponding laboratory-measured values for the individual soils. Thermal conductivity of the laboratory-compacted soils ranged from 0.25 to 2.00 W m^{-1} ^{o}C^{-1}, increased with increasing bulk density and water contents but decreased with the addition of peat. The clay soils exhibited lower values of thermal conductivity than the sandy soils, at given values of bulk density, water content and peat content. Good agreement was found between the laboratory and field measurements of thermal conductivity and the corresponding predicted values using the Campbell model of thermal conductivity. The results obtained are discussed in relation to pipe laying and agricultural operations in Trinidad and Tobago. Apart from soils with appreciable sand contents, most soils would require standard backfills during cable laying.*

Keywords: *Thermal, conductivity, peat, cable, soil, water, density*

1. Introduction

This paper reports the findings of the study and discusses the importance of the property of soil thermal conductivity which determines the ability of a soil to conduct heat (Bristow, 2002). It is required in many areas of engineering, agronomy and soil science. The engineering aspects include the design of underground telecommunication and power transmission cables (Campbell and Bristow, 2002) and underground thermal energy storage, as well as ground source heat pump systems (Spitler et al., 2000). In agronomic practice, seed germination, seedling emergence and establishment are affected by their surrounding climate, which is influenced by soil thermal properties (Ghuman and Lal, 1985; Abu-Hamdeh, 2000).

The thermal properties of soils have been studied in recent literature with a growing interest in laying cables in the ground as an alternative to running them overhead on poles or transmission towers. Sizing of cables for transmission towers is based upon the required current-carrying capacity. Electricity flowing in a conductor including cables generates heat and the resistance to heat flow between the cable and the surrounding environment that makes the cable temperature to rise. The thermal conductivity of the surrounding soils on which the cables are laid determines how much heat the cable is able to dissipate and whether or not or by how much the temperature rises (Campbell and Bristow, 2002; Ekwue et al., 2011). The ideal soil is one that has high thermal conductivity. A simplified solution to the problem is to assume the relevant soil properties and to oversize the cables so that temperature increases are avoided or reduced (Campbell and Bristow, 2002).

Another way of solving the problem is to lay cables in a relatively large trench surrounded with a backfill of stabilised soil or sand with high thermal conductivity. Both techniques are expensive, particularly in situations where cable lengths of many kilometers are planned. An alternative solution is the direct ploughing into a minimum width trench and backfilling with removed local soil. This latter approach could be economically preferable, provided that the thermal dissipation capabilities of the local soil can be guaranteed never to fall below certain minimum values when exposed to different bulk densities and water content. This, therefore, makes the determination of the thermal capacity of local soils to be very essential.

Information on the thermal properties of major soils in Trinidad is rare. Ekwue et al. (2011) started the process of providing information of thermal properties in Trinidad by providing the values for 12 soils. Knowledge of these properties is especially important in relation to underground pipe and cable laying as well as the agricultural needs of the country. This study continues to one started by Ekwue et al. (2011) and extends to 26 soils. This extended work is particularly necessary because of the increased underground pipe laying connected to the growing liquefied natural gas (LNG) industry in the Island. As far as agriculture is concerned, soil thermal properties dictate the rate and amount of heat flow throughout the soil.

The incorporation of organic materials into soils to improve soil physical and hydraulic properties is a common practice. Organic matter is known to reduce soil bulk density which affects soil thermal properties. Recent studies by Abu-Hamdeh and Reeder (2000) and Ekwue et al. (2005, 2006) found that peat decreased the thermal conductivity of soils. It is, however, unclear whether the reduction was as a result of the low conductivity of the peat material or because of its effect in reducing soil bulk density. Several models exist for estimating the thermal conductivity of soils. Some of these include the ones by Kersten (1949) and Campbell (1985). Ekwue et al. (2005, 2006, 2011) found that the Campbell model could be used to predict the thermal conductivity of the twelve Trinidadian soils they studied. It is not clear whether this will be also applicable for the rest of twenty six soils studied in this research.

The objectives of this study as a follow-up of the work by Ekwue et al. (2011) were:

- To measure the thermal conductivity of twenty six major agricultural Trinidadian soils both in the field and the laboratory.
- To examine the effects of bulk density and water content on thermal conductivity for four of these soils representing the range of textural properties.
- To define the effect of peat on soils compacted to the same water contents and bulk densities.
- To assess the adequacy of the well-known Campbell model for estimating thermal conductivity of a wide range of Trinidadian soils.
- To determine the suitability of the soils for use as backfill material in underground pipe laying.

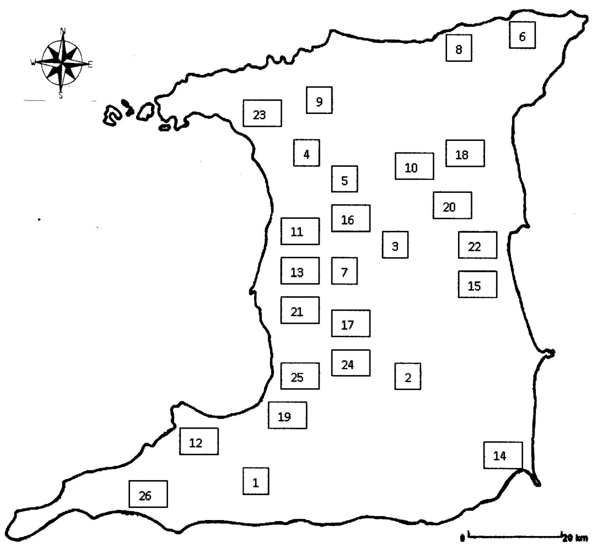
2. Materials and Methods

Twenty six soils representing some of the major agricultural soils in Trinidad were selected for the field and laboratory study of thermal conductivity (see Table 1 and Figure 1). The soils have a wide range of texture including sandy, sandy loam, sandy clay loam, clay loam and clay. Thermal conductivity was measured at existing water contents and bulk densities in the field using the KD2 sensor and probe described below.

Table 1. Classification, organic matter, and particle size distribution (%) of twenty six Trinidadian soils

Soil No.	Soil series	Classification[a]	Organic Matter content, %	Sand 2 – 0.05 mm	Silt 0.05 – 0.002mm	Clay < 0.002 mm	USDA soil textural class
1	Siparia	Typic Haplustults[1]	1.4	54.5	33.5	12.0	Sand
2	Cocal	Typic Quartzipsamments[2]	2.7	81.0	6.0	13.0	Sand
3	Brazil	Umbric Tropaquults[1]	4.8	67.0	20.0	13.0	Sand
4	River Estate	Fluventic Eutropepts[3]	0.9	67.3	15.8	16.9	Sandy loam
5	Piarco	Aquoxic Tropudults[4]	1.7	64.9	17.0	18.1	Sandy loam
6	Grand Riviere	Typic Tropofluverts[3]	1.5	58.0	22.0	20.0	Sandy loam
7	Moruga	Typic Haplustults[5]	2.6	57.3	15.4	27.3	Sandy clay loam
8	Matelot	Orthoxic Tropudults[3]	4.6	50.0	22.0	28.0	Sandy clay loam
9	Maracas	Orthoxic Tropudults[6]	4.7	44.7	24.7	30.6	Clay loam
10	Ecclesville	Aquentic Chromuderts[5]	1.4	50.0	14.7	35.3	Clay loam
11	Mc Bean	Typic Tropudults[5]	0.7	37.3	27.4	35.3	Clay loam
12	Delhi	Typic Tropudults[7]	1.5	39.2	24.8	36.0	Clay loam
13	Freeport	Aeric Tropaqualfs[5]	2.4	30.5	24.5	45.0	Clay
14	Guayagayare	Vertic Tropudalfs[5]	4.8	30.0	25.0	45.0	Clay
15	Plum Mitan	Aquic Tropudalfs[5]	8.8	33.0	21.0	46.0	Clay
16	Cunupia	Aquic Eutropepts[5]	1.7	24.0	30.0	46.0	Clay
17	Talparo	Aquentic Chromuderts[5]	2.7	25.4	28.3	46.3	Clay
18	Sangre Grande	Aeric Tropaquepts[5]	2.2	37.0	11.7	51.3	Clay
19	Debe	Entic Pelluderts[5]	3.4	20.4	23.4	56.2	Clay
20	Tamana	Typic Tropudalfs[7]	7.7	25.0	17.0	58.0	Clay
21	Brasso	Aquentic Chromuderts[7]	4.8	12.3	27.4	60.3	Clay
22	Navet	Aeric Tropaquepts[5]	4.2	13.3	19.4	67.3	Clay
23	Frederick	Vertic Tropaquolls[5]	4.1	6.2	26.5	67.3	Clay
24	Sevilla	Aquentic Chromuderts[7]	1.1	12.7	20.0	67.3	Clay
25	Princes Town	Aquentic Chromuderts[7]	1.9	17.3	11.4	71.3	Clay
26	San Francique	Entic Pelluderts[5]	4.9	4.0	22.5	73.5	Clay

Note: a - Classification according to the Soil Taxonomy System (Soil Survey Staff, 1999).
All values are means of three replicates. Numbers in superscript are soil mineralogy given by Smith (1983) and represent (1) siliceous, (2) uncoated, (3) micaceous, (4) kaolinitic clay, (5) mixed clay mineralogy, (6) clayey oxidic, and (7) montmorillonitic clay



* Notes::Trinidad (Soil numbers are detailed in Table 1.
The coordinates are shown in Table 2)

Figure 1. Soil sampling locations for the 26 soils in

Three replicate measurements of thermal conductivity were made within the top 20 cm of each soil. Three replicate soil core samples (collected with core cylinders 5.76 cm diameter and 6.72 cm height) were collected from the study sites and used to determine bulk densities and water contents (see Table 2) that existed in the field using the method of Blake and Hartage (1986). Table 2 also shows the coordinates of the soils. In addition, disturbed samples were collected from the study sites, air-dried and ground to pass a 5-mm sieve. These sieved soil samples were subsequently brought to the same water contents and compacted to the same bulk densities that existed in the field. Laboratory measurements of thermal conductivity were then made using the KD2 probe and sensor. Both field and laboratory measurements were adopted in order to test the authenticity of measuring thermal conductivity in the laboratory using disturbed soil samples.

Particle-size distribution analysis (see Table 1) was performed using the hydrometer method (Lambe, 1951). Organic matter content in the samples was measured using the Walkley and Black (1934) method. Four of the twenty six soils (Siparia sand, Brazil sand, Tamana clay and Frederick clay) were selected for more detailed compaction study designed to examine the effects of bulk density, water content and peat content on these soils. Each soil with zero or with 4% peat contents at different gravimetric water contents (i.e., 5, 12, 17 and 26%) was placed in cylindrical molds of 102 mm diameter and 116 mm height and compacted uniformly to bulk densities of 1.2, 1.3, 1.4, 1.5 and 1.6 Mg m^{-3} using a fly press machine. After compaction, thermal conductivity was determined.

Soil thermal conductivity was measured with a portable thermal properties sensor (KD2) manufactured by Decagon Devices Inc, Pullman, Washington, United States. The sensor measures thermal properties and calculates thermal conductivity by monitoring the dissipation of heat from a line heat source given a known voltage using the equation for radial heat conduction in a homogeneous and isotropic medium. This theory was well described by the KD2 User's Manual by Decagon Devices Incorporated (2006) and Ekwue et al. (2006) and was based on the solution to the heat conduction equation where a heat-pulse is applied instantaneously from a line source (Bristow, 2002).

Apart from the field and laboratory measurements, independent estimates of soil thermal conductivity were obtained for comparison with the KD2 measurements using the equation developed by Campbell (1985). These estimates were obtained for all the twenty six soils used in the field study (Table 1) as well as for the four selected soils with zero peat contents compacted at five bulk densities and four water contents in the laboratory.

Using the Campbell (1985), soil thermal conductivity can be empirically described using the equation:

$$k = A + B\,\theta_v - (A - D)\exp[-(C\,\theta_v)^E] \qquad (1)$$

where: k is soil thermal conductivity (W m^{-1} ^{o}C^{-1}), θ_v is volumetric water content and A, B, C, D and E are soil dependent coefficients. For many mineral soils where the quartz fraction can be neglected (as in the present soils, see Table 1 for soil mineralogy), Campbell (1985) gave the values of the coefficients as:

$$A = 0.65 - 0.78\,\rho_b + 0.60\,\rho_b^2 \qquad (2)$$

$$B = 1.06\,\rho_b\,\theta_v \qquad (3)$$

$$C = 1 + 2.6\,m_c^{-0.5} \qquad (4)$$

$$D = 0.03 + 0.10\,\rho_b^2 \qquad (5)$$

$$E = 4 \qquad (6)$$

Where ρ_b is soil dry bulk density in Mg m^{-3} and m_c is clay mass fraction. For the present study, the exponent of ρ_b in Eqn (2) above was changed from 2 to 2.5 as it better reflected the increase in k as bulk density of the soil increased during compaction.

3. Results and Discussion

3.1 Comparison of measured thermal conductivity in the field and the laboratory

Thermal conductivity measured in the field and the laboratory were closely related and varied within 0.11 W m^{-2} ^{o}C^{-1} for each of the soils (see Table 2 and Figure 2). This result demonstrates that the KD2 sensor is expected to measure soil thermal conductivity accurately in the laboratory once the field water contents and bulk densities are maintained during testing in the laboratory. The coefficient of determination of the comparing equation (see Figure 2) is significant at 0.1% level.

Table 2. Field moisture content, bulk density, soil coordinates and thermal conductivity

Soil No.	Soil series	Field moisture content (% dry mass)	Field density (Mg m^{-3})	Soil Coordinates		Thermal conductivity (W m^{-1} °C^{-1})		
				Latitude (N)	Longitude (W)	Field	Lab	Predicted *
1	Siparia	15.0	1.67	10°08.3′	61°30.0′	1.69	1.58	1.62
2	Cocal	41.0	1.20	10°16.0′	61°10.8′	1.13	1.16	0.99
3	Brazil	13.9	1.25	10°27.2′	61°11.5′	0.73	0.80	0.75
4	River Estate	21.5	1.38	10°38.3′	61°25.6′	1.01	0.91	1.04
5	Piarco	21.1	1.60	10°35.4′	61°19.7′	1.55	1.52	1.54
6	Grand Riviere	21.1	1.33	10°47.0′	61°00.0′	0.78	0.85	0.95
7	Moruga	18.3	1.41	10°24.5′	61°23.2′	1.24	1.14	1.06
8	Matelot	44.1	1.33	10°45.1′	61°07.0′	0.93	0.93	1.12
9	Maracas	14.7	1.59	10°42.2′	61°23.9′	1.52	1.47	1.37
10	Ecclesville	17.9	1.55	10°33.9′	61°10.8′	1.45	1.47	1.36
11	Mc Bean	24.6	1.57	10°28.2′	61°25.9′	1.22	1.29	1.33
12	Delhi	17.1	1.59	10°10.0′	61°36.0′	1.47	1.47	1.44
13	Freeport	18.3	1.58	10°24.5′	61°25.9′	1.27	1.31	1.42
14	Guayagayare	32.4	1.38	10°09.5′	61°06.0′	1.00	1.00	1.20
15	Plum Mitan	23.9	1.40	10°23.5′	61°05.2′	1.18	1.25	1.11
16	Cunupia	18.3	1.58	10°30.1′	61°23.2′	1.45	1.40	1.42
17	Talparo	38.3	1.19	10°23.8′	61°21.2′	0.87	0.86	0.91
18	Sangre Grande	18.3	1.41	10°35.3′	61°07.0′	1.03	1.05	0.97
19	Debe	28.4	1.43	10°12.5′	61°25.0′	1.13	1.21	1.25
20	Tamana	40.6	1.26	10°31.5′	61°06.5′	1.02	1.03	1.09
21	Brasso	34.1	1.31	10°24.3′	61°23.7′	0.99	1.03	1.08
22	Navet	50.7	1.15	10°27.2′	61°05.2′	0.90	0.91	1.02
23	Frederick	32.8	1.23	10°41.3′	61°30.0′	0.84	0.84	0.91
24	Sevilla	32.5	1.41	10°38.3′	61°25.6′	0.99	0.93	1.08
25	Princes Town	36.3	1.34	10°16.0′	61°25.9′	0.91	0.91	1.19
26	San Francique	33.0	1.36	10°04.0′	61°50.0′	1.03	1.09	1.17

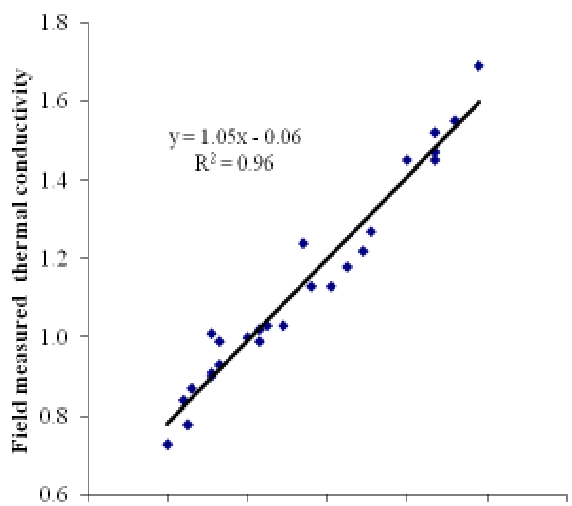


Figure 2. Measured values of thermal conductivity (W m^{-1} °C^{-1}) in the laboratory and the field

The values of the slope of the regression line (1.05) and the intercept (-0.06) were close to 1.00 and 0.00 respectively which demonstrate that there was little or no bias in the measurements. The values of thermal conductivity measured in the field ranged from 0.73 W m^{-2} °C^{-1} in Brazil sand to 1.69 W m^{-2} °C^{-1} in Siparia sand. As mentioned in the introduction section, there are two major options of power cable installation to avoid excessive increases in cable temperature which could shorten cable life. One is the use of designed backfill materials. Campbell and Bristow (2002) observed that a fluidized thermal backfill that has a thermal conductivity which varies from 1.33Wm^{-2} °C^{-1} when dry to 2 W m^{-2} °C^{-1} when wet can be poured in place. The second option is the direct ploughing of the cables into a minimum width trench and backfilling with removed local soil.

Campbell and Bristow (2002) suggested that the engineer should specify the density of a backfill material, and assure, through design and appropriate management, that water content does not fall below 5% water content by volume in sandy soils and 10 or 15% in clay soils. Below these minimum water contents, thermal conductivity is known to decrease considerably. These water contents correspond to typical minimum water contents in the root zone of growing plants. For the soils tested in the field (see Table 2), using the thermal conductivity of the fluidised thermal backfill mentioned above as a standard, only the Siparia sand, Piarco sandy loam, Maracas clay loam, Ecclesville clay loam, Delhi clay loam and the Cunupia clay fell within the 1.33 to 2.00 W m^{-2} °C^{-1} range where direct ploughing of cables can be allowed.

As shown in Table 2, these soils achieved the recommended thermal conductivity because of their high bulk densities which are greater than the maximum of 1.50 Mg m^{-3} that is normally required for adequate plant development (Soane, 1975). For most clay soils, their relatively low thermal conductivities in the field suggest that there is the need for standard backfill materials during underground pipe laying.

3.2 Comparison of predicted and measured values of thermal conductivity

Measured thermal conductivity values were compared with those predicted by Campbell (1985). Results are showed in Table 2 and Figure 3. The predicted and measured values were significantly correlated (R^2= 0.83; P = 0.001). The predicted thermal conductivity values were within 0.20 W m^{-2} $^{o}C^{-1}$ of the values measured in the field. Abu-Hamdeh (2000) reported that the model of Campbell (1985) accurately predicted the thermal conductivity of some Jordanian soils very closely. This result shows that, although Campbell and Bristow (2002) suggested that thermal conductivities should be measured in-situ, the model of Campbell (1985) would be useful for obtaining estimates of thermal conductivity of mineral soils in Trinidad once their bulk density, water content and clay content are known. This result also agrees with previous studies by Ekwue (2005, 2006, 2011) that the Campbell (1985) model could predict thermal conductivity values accurately.

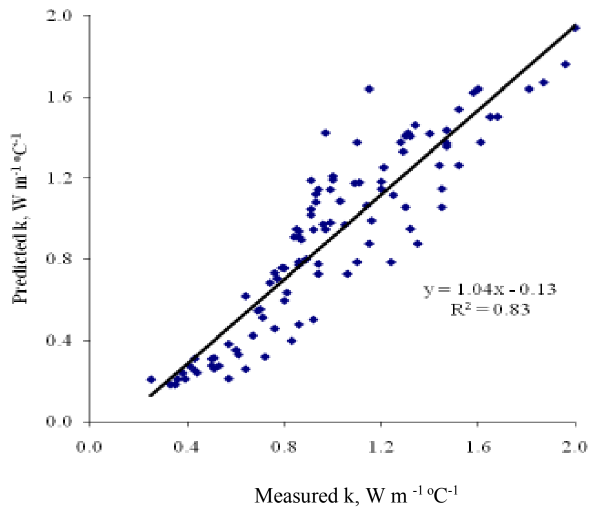


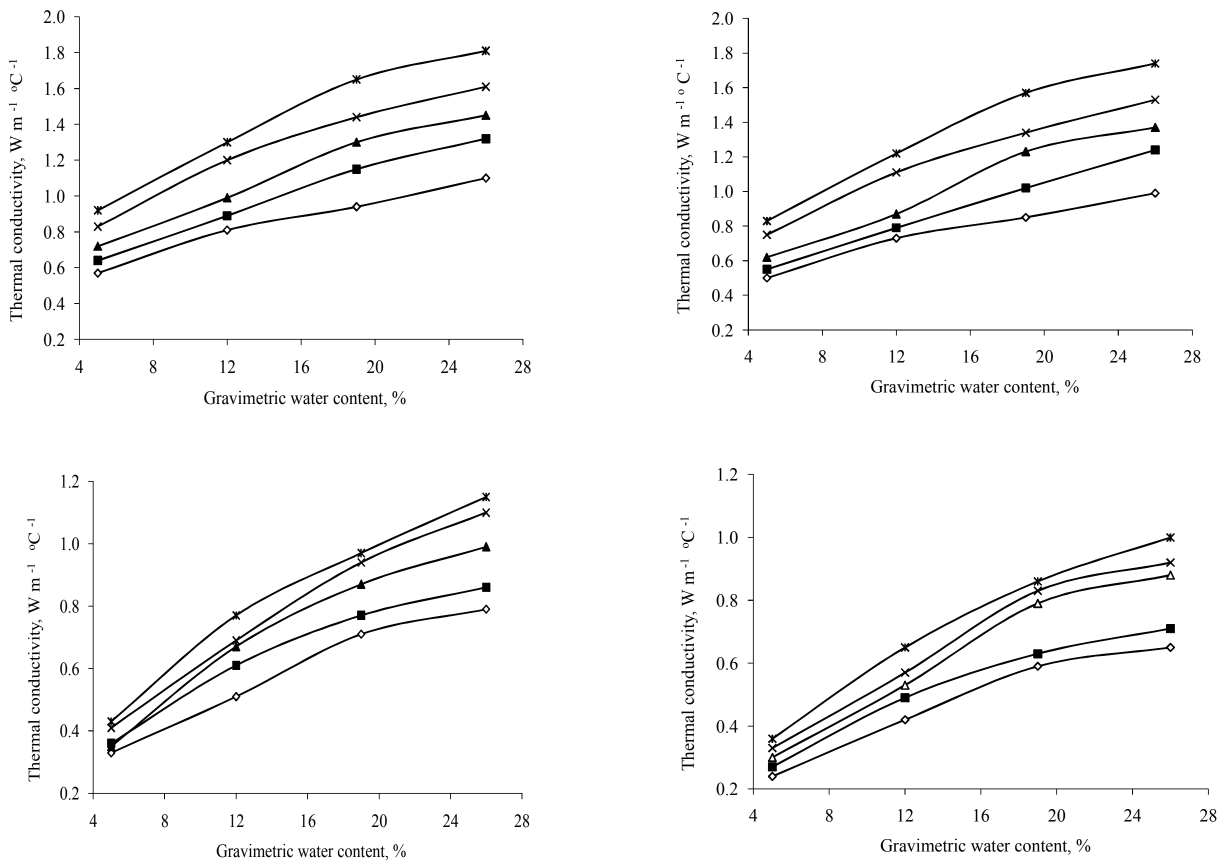
Figure 3. Measured thermal conductivity k versus values predicted by Campbell's model as a function of bulk density, moisture content and clay fraction

3.3 Factors Affecting Thermal Conductivity

Thermal conductivity for the four soils at different peat content and water contents compacted in the laboratory at different bulk densities are shown in Table 3. The plots for two of the soils are shown in Figure 4. Values of thermal conductivity in the compaction study ranged from 0.25 W m^{-2} $^{o}C^{-1}$ to 2.05W m^{-2} $^{o}C^{-1}$.

Table 3. Laboratory measured values of thermal conductivity, k (W m^{-2} $^{o}C^{-1}$) for different soils with or without peat at various moisture contents and bulk densities

Bulk density, Mg m^{-3}	Without Peat (Moisture contents, %)				With 4% Peat content by mass (Moisture contents, %)			
	5	12	19	26	5	12	19	26
Siparia sand								
1.2	0.57	0.81	0.94	1.10	0.50	0.73	0.85	0.99
1.3	0.64	0.89	1.15	1.32	0.55	0.79	1.02	1.24
1.4	0.72	0.99	1.30	1.45	0.62	0.87	1.23	1.37
1.5	0.83	1.20	1.44	1.61	0.75	1.11	1.34	1.53
1.6	0.92	1.30	1.65	1.81	0.83	1.22	1.57	1.74
Brazil Sand								
1.2	0.25	0.64	1.06	1.24	0.29	0.67	0.75	0.86
1.3	0.43	0.86	1.35	1.65	0.57	0.82	1.01	1.23
1.4	0.50	0.96	1.45	1.87	0.63	0.89	1.07	1.31
1.5	0.57	1.11	1.52	1.96	0.72	1.00	1.33	1.60
1.6	0.86	1.32	1.68	2.05	0.86	1.22	1.53	1.84
Tamana clay								
1.2	0.35	0.53	0.70	0.86	0.25	0.55	0.65	0.78
1.3	0.39	0.60	0.76	0.92	0.31	0.59	0.74	0.80
1.4	0.44	0.76	0.97	1.20	0.50	0.85	0.88	0.90
1.5	0.50	0.80	1.00	1.28	0.55	0.85	0.96	0.99
1.6	0.51	0.94	1.34	1.60	0.73	1.06	1.18	1.25
Frederick clay								
1.2	0.33	0.51	0.71	0.79	0.24	0.42	0.63	0.65
1.3	0.36	0.61	0.74	0.86	0.25	0.49	0.63	0.71
1.4	0.38	0.67	0.87	0.99	0.27	0.56	0.79	0.88
1.5	0.41	0.69	0.94	1.10	0.33	0.57	0.85	0.92
1.6	0.43	0.77	0.97	1.15	0.35	0.65	0.86	1.00



(c) Frederick clay – No peat; (d) Frederick clay with 4% peat

Keys:

*◊ 1.2 ; ■ 1.3 ; ▲ 1.4; x 1.5; and * 1.6 Mg m^{-3}*

Figure 4. Influence of moisture content on thermal conductivity of two soils - Siparia sand and Frederick clay at bulk densities

The plots for two of the soils are shown in Figure 4. Values of thermal conductivity in the compaction study ranged from 0.25 W m^{-2} °C^{-1} to 2.05W m^{-2} °C^{-1}. As expected, thermal conductivity increased with increasing water content and bulk density but declined with peat content. The "two sandy soils" had higher values of thermal conductivity than the "two clay soils" in line with previous work. From the results of the laboratory compaction study, since the minimum water content expected in the field should be ideally used in the design (Campbell and Bristow, 2002), if this is assumed as 12% water content by mass, then the direct ploughing can only be barely allowed for the excessive soil compaction level of greater than 1.5 Mg m-3 in the sandy soils using the 1.33 to 2.00 Wm^{-2} °C^{-1} range of thermal conductivity. It is apparent that no matter the value of bulk density or water content to which the clay soils are exposed, direct ploughing of cables cannot be allowed. The cable laying in the clay soils must be accompanied by adequate standard backfill materials. Based on the results of this study, standard backfills should be utilised during pipe laying in all the soils used in this study except for highly compacted sandy loam soils, when soil densities are very high.

The mean values of thermal conductivity for all the experimental factors are shown in Table 4. While thermal conductivity increased with water content and bulk density, it declined with peat content and increasing clay content in the soils. The analysis of variance showed that the main effects of all the experimental factors and their first and second order interactions significantly affected soil thermal conductivity. The main effect of water content was the highest followed by soil type, bulk density and peat content in that order. The most important first order interaction was between peat content and water content followed by soil type and water content. However, the interaction effects of the other first-order interactions and the second-order interactions were small compared to the main effects and the mentioned first-order interactions, and only the latter were therefore examined further.

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Table 4. Mean* values of thermal conductivity from the compaction study

Factor level	Mean thermal conductivity (W m-1 °C -1)
Soil type	
Siparia sand	1.09
Brazil sand	1.09
Tamana clay	0.80
Frederick clay	0.66
LSD (P = 0.001)	0.04
Peat Content (%)	
0	0.96
4	0.85
LSD (P = 0.001)	0.03
Moisture content (%)	
5	0.51
12	0.82
19	1.06
26	1.24
LSD (P = 0.001)	0.04
Bulk density (Mg m^{-3})	
1.2	0.66
1.3	0.79
1.4	0.91
1.5	1.01
1.6	1.16
LSD (P = 0.001)	0.04

* - Mean values for each factor were obtained by averaging the measured values over the levels of the other three experimental factors. Number of experimental points is 320 representing a factorial experiment with 4 soil types, 2 peat contents, 4 moisture contents, 5 bulk densities and 2 replications

Water has a thermal conductivity that is approximately 30 times that of air, but considerably smaller than that of the soil particles. Consequently, the thickness and the geometric arrangement of the water layer around the particles increase soil conductivity (Nakshabandi and Kohnke, 1965). As the bulk density of a given soil increases, the contact between the individual particles becomes more intimate, and results in increases in thermal conductivity (Nakshabandi and Kohnke, 1965). This facilitates greater heat movement through the soil. The interaction between the soil water content and soil type (see Figure 5) implies that the increases in thermal conductivity with water content would be more pronounced in sandy soils than in clay soils.

The higher mean values of thermal conductivity of the two sandy soils than the two clay soils were expected. This confirms the previous research by Nakshabandi and Kohnke (1965), Abu-Hamdeh (2000) and Ekwue et al. (2005, 2006) and is due to the greater particle size of sandy soils. The lower thermal conductivity of the clay soils means that they will experience greater surface temperature fluctuations than the sandy soils. The interaction between soil type and water content shows that the effect of soil type on thermal conductivity is more pronounced at higher rather than lower moisture contents (see Figure 5).

Thermal conductivity declined with increasing peat contents and this has been found in previous studies by Abu-Hamdeh and Reeder (2000) and Ekwue et.al. (2005, 2006). The latter authors attributed this to the decline in bulk density resulting from the greater pore space normally obtained when soils are amended with organic matter. They stated that since peat decreased soil bulk density it also decreased the soil thermal conductivity.

However, in this study, for all soils compacted to the same bulk density, soils with peat had lower thermal conductivity than the soils with no peat. This study, therefore, shows that in addition to peat decreasing bulk density, it decreases thermal conductivity because its material has a lower thermal conductivity than mineral soils (see Figure 6). Electricity flowing in a conductor generates heat. The ideal soil used as backfill material for the cables is the one with a high thermal conductivity, so that most of the heat generated can be dissipated (Campbell and Bristow, 2002). This means that soils that contain appreciable organic materials, particularly in form of peat, will not be suitable as backfill material for underground cables.

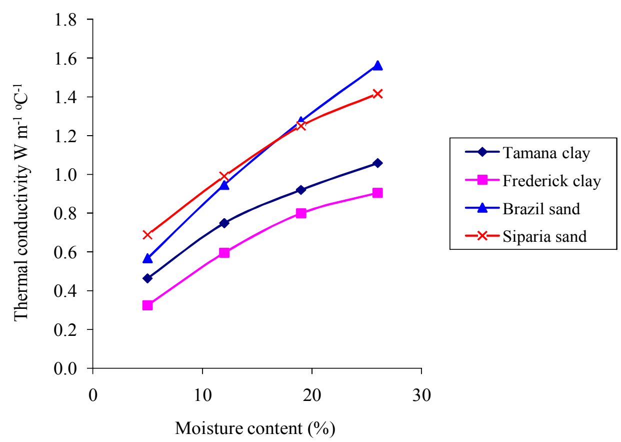

Figure 5. The effect of the interaction between soil type and moisture control on thermal conductivity

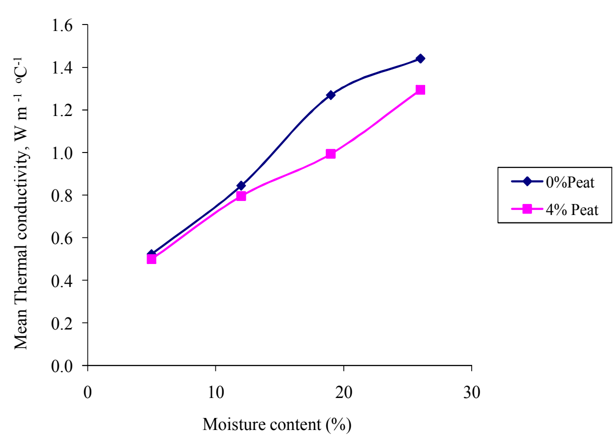

Figure 6. The effect of the interaction between peat control and moisture control on thermal conductivity

In situations where cables must pass through soils with appreciable organic materials, it may be necessary to dig a trench and fill it with large amounts of high thermal conductivity backfill materials such as sand, as explained by Campbell and Bristow (2002). The significant interaction obtained between peat content and water content means that at low soil water contents, the effect of peat content in reducing thermal conductivity would be minimal.

4. Conclusions

The thermal conductivities of 26 Trinidadian soils were measured in the field and in the laboratory. This was accompanied by a detailed laboratory compaction study in which four of the soils were compacted to five bulk densities, with or without peat, and at four moisture contents prior to the measurement of thermal conductivity. Field and laboratory measurements of thermal conductivity were similar for all the 26 soils. These similarities demonstrate that laboratory measurements of thermal conductivity could be used to accurately represent field measurements provided that soil bulk densities and water contents similar to those existing in the field are maintained.

Thermal conductivity increased with increasing bulk density and moisture content, declined with the addition of peat and was lower for clay soils than for sandy soils. The effect of peat in reducing thermal conductivity is achieved both by its role in decreasing soil bulk density and its lower thermal conductivity compared to mineral soils. Thermal conductivity predictions using the popular Campbell model correlated well with their corresponding measured counterparts thereby demonstrating the utility of this model in providing reliable estimates of thermal conductivity of Trinidadian soils. The major implication of this study is that most soils in Trinidad, apart from those with appreciable sand contents, would require standard backfills during underground cable laying. The highlights of the paper include:

i) Laboratory measured thermal conductivities are similar to those measured in the field as long as the density and water contents of soils are similar to those existing in the field.
ii) Campbell (1985) model can be reliably used to estimate the thermal conductivity of soils in Trinidad.
iii) Thermal conductivity values were lower for the clay soils than for the soils with high sand contents.
iv) Peat reduces thermal conductivity by reducing soil bulk material and because of its material which has a low thermal conductivity.
v) Most soils in Trinidad, apart for those with appreciable sand content would require standard landfills during undergraduate electric cable laying.

Future studies could examine the effect of actually laying electric cables in some of the soils with known thermal conductivity and monitoring the rise of temperature of the surrounding soil with time.

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Needs for Professional Hydrography in the Caribbean Towards Risk Reduction in Maritime Navigation

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Abstract: *With a focus on the Caribbean Sea, the needs of hydrography and national economic benefits are explored. Expectations in terms of data requirements are identified and components where shortage often exists are acknowledged. It is anticipated that shipping activities will increase in both density and size of vessels, the need for professional staff capable of functioning with accepted survey standards is then fundamental to maritime safety. While the majority of states that have territorial ownership of some part of the Caribbean Sea are signatories to the Safety of Life at Sea (SOLAS), questions arise as to whether the requirements for provision of hydrographic data to the international community are being maintained. The need for professionally qualified staff to maintain state services is identified, and there is also a need for surveying operations to be undertaken by professionals, where a professional refers to those having undertaken a recognised programme of study.*

Keywords: *Hydrography Caribbean Navigation Charting*

1. Introduction

In modern terms, the formal definition for the discipline of hydrography is given by the International Hydrographic Organisation (IHO, 2015a) as: *"Hydrography is the branch of applied sciences which deals with the measurement and description of the physical features of oceans, seas, coastal areas, lakes and rivers, as well as with the prediction of their change over time, for the primary purpose of safety of navigation and in support of all other marine activities, including economic development, security and defence, scientific research, and environmental protection"*.

The science originated from the need for charting as a requirement for safety of navigation with survey voyages being undertaken during the 19th Century to chart the coastlines of the World. Perhaps the most notorious voyage was that of HMS Beagle, which was made famous by the presence of Darwin, but the primary purpose of the mission was to chart the waters in the entrances to primary ports within the Southern hemisphere. Almost a century later, as a direct consequence of the tragedy of the Titanic in 1912, the international convention for the Safety of Life at Sea (SOLAS) was introduced. SOLAS today requires contracting states to take responsibility for aspects of safety of navigation within their territorial waters to include deployment of navigational marks, dissemination of navigational information, and to perform hydrographic surveys. In resolution A/RES/58/240, the United Nations (2003) recognised that hydrographic surveys are critical in navigation for safety of navigation at sea and hence in environmental protection.

By its nature shipping is international, so standards to which hydrographic data is acquired and the way in which resulting navigational information is presented to the mariner must be international. The IHO (2015b) exists in this capacity: *"The vision of the IHO is to be the authoritative worldwide hydrographic body which actively engages all coastal and interested States to advance maritime safety and efficiency and which supports the protection and sustainable use of the marine environment"* and offers standards and protocols to ensure the quality of hydrographic information provided to the international community meets this objective. Amongst the publications: IHO (2008) offers standards for conducting surveys; IHO (2000) provides transfer standards for digital hydrographic data; and, IHO (2012) addresses issues relating to production and distribution of data for modern electronic charting systems.

2. Shipping Density in the Caribbean

The location of the Caribbean Sea within Central America and the presence of the Panama Canal places primary international shipping routes within the region. Furthermore, the island nature of many states means that shipping is a requirement for movement of goods and the presence of natural resources within some territories makes shipping essential to the economy. The estimated number of internal shipping movements within the Wider Caribbean Region (WCR, which includes the Gulf of Mexico) for 2007/8 is shown in Figure 1, this excludes shipping beyond the region, hence Panama canal traffic is not included. Internal shipping accounts for about 73% of the total movements within the WCR. Density of traffic within the Caribbean Sea is highly focussed on locations as shown by shipping routes and density in Figure 2. The image from MarineTraffic (2015) clearly shows areas of particularly heavy traffic around Trinidad, Curacao and the entrance to the Panama Canal.

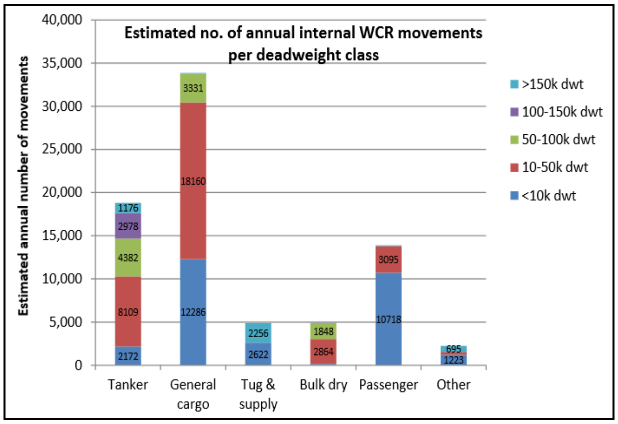

Figure 1. Internal shipping movements in the Wider Caribbean Region by class and type
Source: Algell, Bakosch and Forsman (2012)

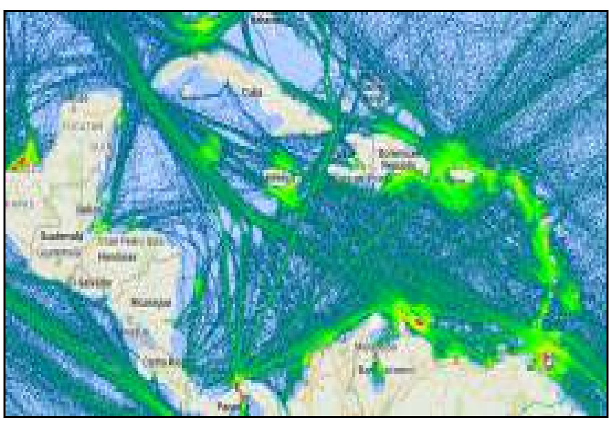

Figure 2. Shipping density in the Caribbean, for the second period of 2013. (Source: MarineTraffic (2015))

At one instant in December of 2014 a variety of shipping traffic was observed around Trinidad and Tobago (see Figure 3) with cargo vessels and tankers moving to the North using port facilities on the West coast of Trinidad and smaller vessels servicing the offshore industry to the East. An instantaneous snapshot from the Gulf of Paria provided in Figure 4 shows that the traffic includes vessels carrying dangerous goods (DG), vessels towing structures associated with the offshore industry and a high speed ferry servicing the Trinidad to Tobago route. There is a second high speed service between Port of Spain and San Fernando in Trinidad that has to make its way through the high density traffic on the west coast of the country. Maritime traffic around Curacao also consists primarily of tankers servicing the Isla refinery and cargo (see Figure 5).

Figure 3. Traffic around Trinidad and Tobago.
Source: MarineTraffic (2015)

Figure 4. Identification of traffic on the West coast of Trinidad at one instant

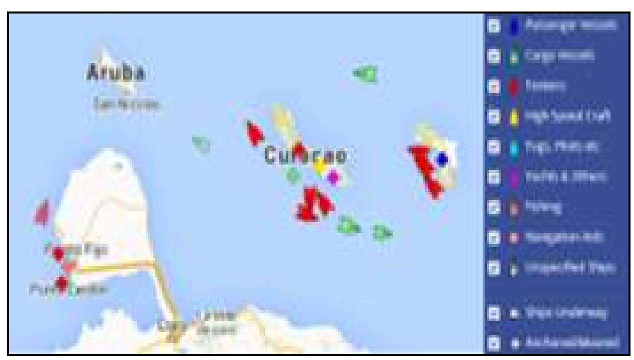

Figure 5. Traffic around Curacao. (Source: MarineTraffic, 2015))

In May of 2011, under the International Convention for the Prevention of Pollution from Ships (MARPOL), the Caribbean Sea was designated a special area with regulations governing the disposal of garbage by shipping. The Association of Caribbean States has established a Caribbean Sea Commission with the aim of ocean governance within the region (ACS, 2015).

3. Economic Basis for Hydrography

In their report for the Asia-Pacific Economic Cooperation, APP and Globalworks (2009) used economic models to suggest that there is always direct economic benefit from investment in hydrography. Further case studies are listed by the International Federation of Surveyors (2011). The level of return is dependent on factors associated with potential for shipping services and foreign trade with the return given by improvement in efficiency of services that encourages an increase in shipping traffic. Navigable waterways need to be maintained, and the depth of water available to access a port is important. For example, in terms of cargo vessels the change in tonnage per centimetre in draught (TPC) is given by $A \times d/100$ where A is the surface area of the vessel and d is the density of water. Considering the surface area of vessel typically passing through the Panama Canal, a change of 30 cm in navigable depth would accommodate an increase of about 2000 tonnes in cargo.

In addition to cargo vessels of various types, Brida and Aguirre (2008) estimate that the Caribbean accommodates 40% of the global cruise industry. A study of the economic impact of cruise spending for the 2011/12 cruise season in the Caribbean undertaken by BREA (2012) states that transit passengers spent $1.38 billion (an average of $93.21 per person) at each location, while spending at the home port was $104.4 million, $155.62 per person.

Shipping traffic in the Caribbean comprises cargo and tankers integrated with cruise liners and smaller vessels used in fisheries as well as local services. A wide range of sectors contributing towards the overall economy of the region are heavily dependent on shipping. Maritime disaster could have significant impact on both human life and on the environment, which is critical to the tourism industry. With the expansion of the Panama Canal (Canal de Panama, 2015) to increase the size of the locks allowing larger vessels to pass and the addition of a further lane that is intended to double capacity, the density and size of shipping traffic through the Caribbean is expected to increase.

Further developments are proposed with the addition of another canal through Nicaragua (Watts, 2015). These developments provide opportunity for economic growth in the Caribbean region, there is economic advantage in increasing the depth of ports to accommodate larger vessels. Nicholson (2015) explains how ports in some Caribbean States are already aligning with the development and considers the increase in risk of maritime disaster that comes as a consequence. A primary requirement for risk reduction is the provision of information to the mariner, the source of such data is derived from hydrographic services.

4. Hydrographic Requirements under SOLAS

The SOLAS convention broadly addresses the issues associated with safety at sea, with regular updates to requirements. Under SOLAS Chapter V, Regulation 9 refers specifically to hydrographic services with the following obligations:

1. *"Contracting Governments undertake to arrange for the collection and compilation of hydrographic data and the publication, dissemination and keeping up to date of all nautical information necessary for safe navigation.*
2. *In particular, Contracting Governments undertake to co-operate in carrying out, as far as possible, the following nautical and hydrographic services, in the manner most suitable for the purpose of aiding navigation:*
   a. *to ensure that hydrographic surveying is carried out, as far as possible, adequate to the requirements of safe navigation;*
   b. *to prepare and issue nautical charts, sailing directions, lists of lights, tide tables and other nautical publications, where applicable, satisfying the needs of safe navigation;*
   c. *to promulgate notices to mariners in order that nautical charts and publications are kept, as far as possible, up to date; and,*
   d. *to provide data management arrangements to support these services.*
3. *Contracting Governments undertake to ensure the greatest possible uniformity in charts and nautical publications and to take into account, whenever possible, relevant international resolutions and recommendations*
4. *Contracting Governments undertake to co-ordinate their activities to the greatest possible degree in order to ensure that hydrographic and nautical information is made available on a world-wide scale as timely, reliably, and unambiguously as possible."*

The first two items relate to acquisition and management of data and services while compliance with items 3 and 4 requires that staff associated with the provision of information to the maritime community work within international standards. There is not necessarily a requirement to host acquisition systems and acquire data within the state, services can be contracted out, but there is a need to manage data in house. Irrespective of how data is acquired, the State has responsibility for quality assurance of data and provision of information to the international community. There is then a requirement for professional staff within the State to manage operations.

Hydrographic surveys are expensive, the cost of a single fitment using modern survey equipment would exceed 250,000 USD and the purchase and maintenance of a vessel requires further capital outlay as well as ongoing costs. For these reasons it is also expensive to contract services. A survey undertaken for dredging of a small port in the Caribbean recently cost close to 10,000 USD. This was performed using lower cost equipment and without heed for quality assurance measures required under SOLAS. Numerous surveys of this type are conducted within the Caribbean, with contracts being issued by port authorities for engineering purposes (such as dredging or construction) and resulting data being used for this application alone. Surveys are conducted, but the data is not necessarily acquired to international standards and is not always being made available to improve safety of navigation.

5. Status of Hydrography in the Caribbean

Not all territories can be expected to provide the capacity to produce charts, particularly in instances where territorial waters are small. In such cases major charting agencies internationally take on the role of charting using locally acquired data. In the case of small territories of the Caribbean, the United Kingdom Hydrographic Office (UKHO) takes on the primary charting responsibility through publication of Admiralty charts. As a measure of quality of information provided on charts, the Admiralty details the age of data used in compilation, Figure 6 shows the situation for Admiralty Chart 474, Port of Spain and Approaches. Much of the data for the Gulf of Paria was acquired prior to 1940, and some in the 1960's.

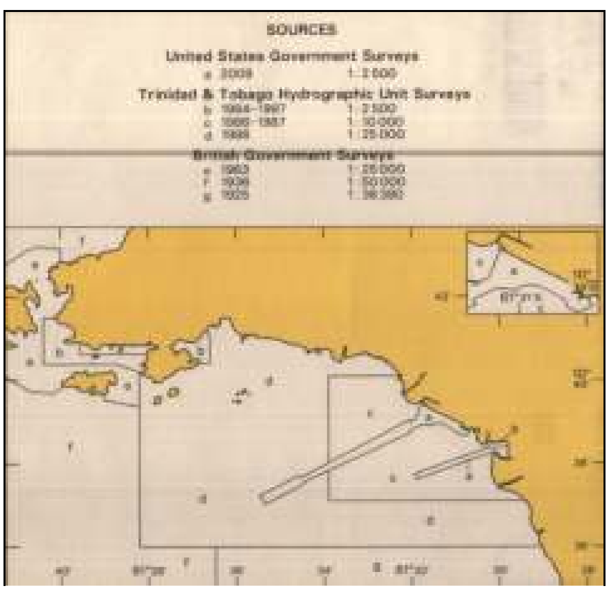

Figure 6. Age of data used in charting the Port of Port of Spain and approaches (Source: UKHO (2010))

A Hydrographic Unit that was established in the early 1980's under United Nations funding (Holden, 1986) and acquired data in more critical navigational areas through that decade. Loss of staff led to demise of the Hydrographic Unit. Prior to a visit to Trinidad by President Obama in 2009, the United States agencies surveyed the channels leading in to Port of Spain for evacuation purposes and this data consequently appears on charts. Otherwise, the charts may have still shown channel depths of 10 m, in spite of their having been dredged to 12.5 m in 1999, an operation that was undertaken to accommodate ships able to pass through the Panama Canal.

Depths are a dominant feature on a chart and for navigational safety reasons these are shown to the level of Lowest Astronomical Tide (LAT). Typically land survey datum, which is usually defined as Mean Sea Level (MSL) is used to establish a level for referencing hydrographic surveys, with the data then being reduced to the published offset from LAT. In many instances within the Caribbean, MSL itself was crudely determined using short term data sets, which has led to errors in charted depths. Masters of cruise liners reported incidents of ships touching the seabed on manoeuvring within a port in Grenada, the resulting investigation undertaken by Neale (2007) revealed a discrepancy between true MSL and that adopted as the land survey datum. In Bridgetown, Barbados, it was been established by Miller (2010) that an error of about 0.43 m was made in interpreting the observations that led to determination of MSL. Fortunately in this case the mistake erred on the side of safety. In developing a geoidal model of the Caribbean, Smith (1999) also comments on the lack of reliability in realisations of mean sea level throughout the Caribbean territories.

Due to natural movement of sediments, vertical displacement to topography and human disturbance, the seabed is dynamic. Survey data that details the seabed topography has a lifespan, and in many ports dredging is required to maintain depths. Charted depth in the channel can also be disturbed by obstructions, for example large objects that fall from ships unnoticed can restrict the depth of the waterway. In the approaches to a port and surrounding waterways the seabed can be littered with debris such as wrecks, remains of disused platforms, and so on, that can extend close to the sea surface. Further hazards to maritime activities such as fishing and anchoring of vessels exist due to installations on the sea floor. Figure 7 shows a sonar image of an abandoned platform within the Gulf of Paria, this was found while performing a debris survey that was conducted to identify obstructions prior to launch of a high speed ferry service. In spite of the finding this particular debris item in 2005, it is still shown on Admiralty Chart 483 with corrections to 2014 as a platform equipped with lighting; data acquired has never been forwarded to charting agencies. As electrical generation sources move offshore to harvest wind, current and wave energy the sea is becoming more cluttered with obstructions to navigation. Beyond initial surveys, the maintenance of hydrographic services for charting is a full-time role to monitor change, manage databases and ensure that corrections are propagated throughout the maritime community.

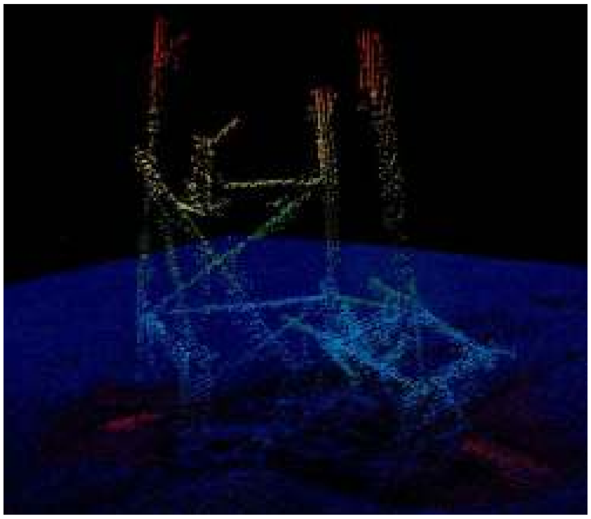

Figure 7. Sonar image of debris in the Gulf of Paria.

In support of their vision, the IHO are keen to promote the requirements for hydrography internationally, and to develop capacity building initiatives. Technical visits are offered to assess of the status of hydrography nationally and make recommendations for development. The UKHO cooperate with many territories of the Caribbean towards technical support. The last technical visits were made in 2006 and covered 14 territories in two phases. Reports from the UKHO (2006a and 2006b) found generally that services such as maintaining aids to navigation, publishing notices to mariners and matters relating to maintenance of ports were being carried out as required.

Otherwise, a number of particular problems were identified in:

- Montserrat - a grounding that had taken place outside of the channel had not been reported, volcanic ash encroachment into the sea had also not been documented for charting purposes and positions for two buoys marking an artificial reef were not adequately provided.
- Anguilla - chart coverage of a primary channel was based on lead-line data acquired more than a century old and three jetties had been constructed without communicating changes to charting authorities.
- Antigua and Barbuda - a number of coastal developments had taken place, including a new fishing harbour that remained uncharted.
- Turks and Caicos - access to a main cargo port was found to be in close proximity to uncharted banks with a few soundings shown and major construction work was underway on a new dock that even at that stage required notification for charting purposes.
- Cayman Islands - uncharted developments included a new wharf, extension to a jetty, additional berths and installation of submarine cables, also, a navigational light had been demolished by a hurricane.
- Grenada - a number of coastal developments including new jetties, a new marina, relocation of a shipping terminal and restrictions on anchoring were all unreported for charting purposes.
- St Vincent and the Grenadines - a number of changes had been made to navigational lighting, which had not been reported to charting authorities.
- St Kitts and Nevis - it was recommended that surveys be conducted in a number of areas to check the impact of a recent hurricane in terms of both depth and debris.
- Dominica - a substantial number of new developments had taken place along the shoreline that remained uncharted.

Surveys of primary channels within existing ports were considered as being up to date and checks on depths are typically being made using basic equipment. These findings are supported through a review of Admiralty Notices to Mariners. For example, UKHO (2015) refers to a chart of Grenada detailing alterations made to the port area and navigational marks, these were reported by the port authority for a survey where professional surveyors had been contracted to perform the work with their findings also detailed in the notice. These changes are incorporated into later editions of the corresponding chart.

However, during the UKHO technical visit the team noted that in numerous locations facilities had been developed both within and outside of port boundaries that remained uncharted. Information provided in technical reports is obtained from visual inspection and discussion with authorities, content then focuses on coastal development and engineering surveys conducted within the port, much of the bathymetry beyond that obtained for dredged channels dates back to surveys conducted decades ago. It is now nine years since the technical visits took place and more recent anecdotal evidence from the region suggests that changes to navigational features are still not being adequately reported. A subsequent visit by staff from the National Oceanographic and Atmospheric Administration (NOAA, 2011) to Belize revealed that a local hydrographic unit that had appeared promising in 2006 was suffering from lack of maintenance of equipment. In 2014 further visits were made by staff from the UKHO to many of the other locations visited in 2006, reports have yet to be published.

Success stories come from Barbados and Jamaica. Barbados Port Incorporated contract out their survey work and are commended by the UKHO on their delivery of data to the charting authority for updates to charts, whether this is due to staff within the port authority appreciating the need, or down to professional conduct of the survey company used is unclear. Jamaica is reported to have a strong team of qualified hydrographers working within the National Land Agency with equipment available, while they are covering the ports and passing information to the charting authority there was need for a national charting programme to cover areas beyond the ports. It appears that the key to success in Barbados and Jamaica is attributed to the use of properly qualified staff.

6. Standards of Competence

Acquiring and presenting quality data is fundamental to its use in navigation. Specialist courses exist within the discipline of hydrography, some accredited with professional bodies. Accreditation typically involves professional bodies or local accreditation boards awarding recognition to a programme on the basis of compliance within a general discipline. There is typically some flexibility for the programme team to provide an aim and objectives with reviewers considering content on its merits and requirements within the discipline. However, the international nature of the hydrography and nautical cartography mean that international standards are required and the process is different.

In support of educational requirements for hydrographers and nautical cartographers to work to internationally recognised practices, the International Board on Standards of Competence for Hydrographic Surveyors and Nautical Cartographers (IBSC) provides standards and offers recognition to courses that are found to comply with the standards. Membership of the IBSC is made up of ten (10) representatives, four from the International Federation of Surveyors (FIG), four from the IHO and two from the International Cartographic Association (ICA). Standards of competence are provided in terms of theoretical content and skills based components for programmes, and it is programmes rather than individuals that are recognised. Standards exist at Category A (professional) and Category B (technician) level for the disciplines of both hydrography and nautical cartography. The IBSC meets annually to review programmes that are submitted for recognition, programmes found to be in compliance with the standards are awarded recognition for a period of 6 years.

Lists of currently recognised programmes in hydrography and nautical cartography at Categories A and B are available from the IHO (2015c) website. Programmes are offered by three different types of ornagisation: (i) government agencies or navy establishments with national responsibilities for hydrographic surveying and charting; (ii) educational establishments such as universities with recognition being awarded to academic programmes; and, (iii) commercial organisations. Recognising the need for the disciplines of hydrography and nautical cartography the IHO (2015d) offer various capacity building initiatives. A number of government employed staff from the Caribbean region have travelled overseas to complete sponsored category B programmes, fewer have been awarded funding to undertake programmes at category A level. Using alternative funding sources (including self-funding) it is typical for one or two graduates from The University of the West Indies (UWI) each year to progress to a category A hydrography programme through enrolment on a university Masters' degree overseas, however, given lucrative opportunities in the offshore industry few return to the Caribbean to work. There is then a shortage of professionally qualified hydrographic surveyors working regionally in hydrographic services for applications in navigation.

7. Risk Reduction Measures

In support of hydrographic operations, data that is provided by shipping under the Automatic Identification System (AIS) is useful. Under SOLAS, vessels over 300 gross tonnes and all passenger ships are required to carry AIS, a system that provides at least identification, position, speed and direction of the vessel. It is primarily used within navigation to enhance radar targets acquired by other vessels and by Vessel Traffic Services (VTS). However, statistical analysis of historical AIS has proved beneficial in hydrography; Figures 2 to 5 herein are derived from AIS data.

Recognising the potential risk of maritime disaster to life and the environment in the Pacific, the Land Information New Zealand, under the New Zealand Foreign Affairs and Trade Aid programme, commissioned a study to assess areas of particular hazard. Riding, Webb, Rawson and Grover (2013) used AIS data as a primary source to examine shipping movements. Factors such as shipping density, confines of navigational waters and environmental vulnerability were used within Geographic Information Systems (GIS) applications to classify areas according to risk vulnerability. Results are used to identify priority areas for surveying and charting. There is further potential for such results to enhance navigational safety, for example in the definition of traffic separation schemes for shipping. Such schemes are often implemented in congested waterways to separate vessels heading in opposite directions, but no such schemes exist in the Caribbean Sea.

Risk of maritime disaster is being addressed within the Caribbean (Morinière and Réglain, 2012) and a web mapping system has been constructed with the support of MarineTraffic (2015) to display traffic flow. Use of data for risk assessment is a significant step, some of the flaws in AIS data have been recognised, but Riding *et al* (2013) found that a substantial amount of further information concerning ships and their cargo could only be obtained by visiting ports and searching records of movements.

8. Discussion

Maritime accidents in the Caribbean Sea have been rare events. In 1979 the largest ever ship-sourced oil spill occurred off the coast of Tobago when two full tankers collided, fortunately without significant environmental consequences. Such events make the headlines, otherwise there is under-reporting of incidents (Psarros, Skjong and Eide, 2010). A search of the International Maritime Organisation (IMO, 2015) database confined to the last 15 years to find incidents from the Caribbean related to navigation errors in ports or their vicinity found 20 groundings, 8 vessel to vessel collisions and 3 contacts with fixed objects. Details of the cause are often sparse, of those which are available many are attributed to human error, often associated with bad weather conditions, but two that are documented in detail are related to charting. In September of 2009 a bulk cargo vessel was punctured below the waterline while manoeuvring within a port. There had been three hurricanes during the previous year causing partial demolition of a pier and while the facility had been rebuilt, debris from the original remained in the water.

The other incident in 2005 involved the grounding of a vessel under pilotage on a mud bank. With a draught of 6.8 m the vessel should have had sufficient under keel clearance to enter the port, but soundings taken with a lead line from the bow of the stranded vessel showed a depth of 5 m. Both of these incidents occurred within the confines of a port with the hydrography at fault. IHO (2008) standards (and previous editions) require full seafloor searches within such areas to find obstructions and would be normal to conduct a survey after construction work. For the grounding, while the sea floor topography does change, and can do so rapidly in the confines of a large river, a reduction in depth of at least 1.8 m within a port of the Caribbean would not be expected.

Under SOLAS the contracting governments are responsible for the provision of hydrographic services within their territorial waters. Survey data, including bathymetry and aids to navigation, must be available for chart production and mariners notified of any changes through approved channels. In contracting out survey work, professional surveyors are aware of the requirements and normal practice would involve passing survey information on to relevant authorities. However, there is anecdotal evidence to suggest that contracts are being issued to commercial operators where staff do not hold recognised qualifications. This applies equally to state owned ports where surveys are often conducted for dredging purposes and to privately owned facilities.

It is also evident from UKHO (2006a and 2006b) visits that responsibilities within the majority of states within the Caribbean are divided between different agencies. While the port authority may have responsibility for hydrography within the port, the waters beyond the confines of the port fall within the jurisdiction of another agency. While these areas are generally deeper and less restrictive for manoeuvring, the methods used to acquire bathymetric data on which charts are based is now antiquated. Furthermore, there are changes taking place such as that shown in Figure 7 where an object once fitted with lighting as a navigational warning is now reduced to a set of crumbling steel members that protrude from the sea bed to a few metres below the sea surface. Hydrographic services are needed at national level to manage data associated with bathymetry and obstructions, this is a requirement under SOLAS and improvements to the efficiency of the service would encourage shipping activity, hence improve the economy.

Recognising deficiencies that exist in hydrographic services in particular regions globally, the IHO capacity building programme has gained support from governments of at least Japan, Korea, the UK, the USA, Brazil, Mexico and Norway with the provision of training programmes and technical support. As developments of the Panama Canal are underway some governments within the Caribbean are now preparing for an increase in shipping density and size, but there seems to be lesser acknowledgement of the associated requirement for improved hydrographic services. The Association of Caribbean States have made the connection between the vulnerability of the Caribbean Sea and increased risk in maritime accidents in the region, however as an organisation they have no responsibility for hydrographic services. A regional risk assessment programme should not be a precursor to justifying hydrographic surveys that are themselves a requirement of international convention. Such studies have a useful purpose in developing mitigation strategies towards risk reduction.

9. Conclusions

Hydrography is a specialised profession that has a wide range of applications in offshore and coastal operations. Within charting the hydrographer plays a key role in providing information to the mariner that is critical in the practice of navigation. As shipping is international the standards adopted in conducting hydrographic surveys, compiling data and presenting it to the user must follow international protocols. The International Hydrographic Organisation exists to define such standards and to ensure compliance standards also exists for the education of professionals. These standards are regularly updated to reflect developments in technology, and standards of competence are regularly revised for alignment with educational practice.

Within the Caribbean there is a shortage of professional hydrographers working towards charting, to some extent this is due to higher income opportunities that are available in other applications such as the offshore industry. Where hydrographic surveys are conducted they are typically for purposes such as dredging or coastal development with the engineer responsible considering the application alone and unqualified personnel undertaking the work, the results are rarely passed on to the relevant charting authority. Primary ports are then maintained by dredging to the specifications indicated on the chart with other developments within the ports and along other stretches of coastline going uncharted. There is however an obligation to deliver quality data to the international community, which raises a liability issue in case of accident and for this reason it is essential that recognition is given to international standards when awarding contracts for hydrographic surveys.

A lack of staff with internationally recognised qualifications working within the government sector regionally is the primary reason for non-compliance with SOLAS requirements. Compliance in communication with charting authorities is better in both Jamaica and Barbados where qualified staff have been retained. By contrast, in the cases of Trinidad and Tobago and Belize where specialised hydrographic units have been established using external support, these services have not been sustained. The economy of both of these territories is heavily dependent on shipping and economic studies have shown that effective navigational information can impact on shipping activity. There is a need to undertake risk assessment analysis as a priority at a regional level, to identify territories that are most vulnerable to maritime disaster and to develop a regional plan for improvement in hydrographic services accordingly.

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A Value Management Approach for Managing Social Project Risks of International Funding Discontinuity in Guyana

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Abstract: *It is not unusual for social development projects funded by International Development Partners to come to an end, without maintaining benefit flows after the funding period. The study aims to explore the efficacy of using Value Management (VM) as an approach to minimise the risks of the projects going into cessation after funding from International Development Partners (IDPs) is no longer forthcoming. A simulated "Value Statement" workshop was facilitated by VM experts to identify obstacles and examine factors affecting project sustainability. It included collecting and documenting the views of those integrally involved in the project on what is the meaning of sustainability, recording the experiences of the project to ensure the sustainability of project results beyond implementation, examining the project design, monitoring and implementation and its relatedness to the sustainability of outcomes. A VM-based strategic framework was developed. It was found that adopting VM at the initial stage of social development projects could bring impact on reducing the risks of projects being unsustainable when external funding ends. Risk management (RM) and Gateway (GW) methods could be synchronised with VM as parallel processes for successful project implementation. Future research could validate the value factors and VM criteria identified for managing social development projects.*

Keywords: *Value Management, Sustainability, Risk Management, Gateway, Guyana*

1. Introduction

Value management (VM) had originated in the manufacturing industry in North America and evolved to other industries, including the construction industry (Barton, 2000). The overarching goal of VM is to obtain the best functional balance between cost, quality, reliability, safety and aesthetic. This is a process seeking to create and explore options that deliver most value for the least money taking a whole of life perspective (Barton, 2012). This paper explores the efficacy of using VM approach to minimise the risk of projects becoming unsustainable after funding from International Development Partners (IDPs) has ceased in Guyana. It focuses on addressing the problem of sustaining social development projects, notwithstanding the fact that IDPs are no longer the primary source of funding.

In Guyana, social development projects lacked fundamental inputs from as early as identification and preparation stages of the project cycle. These were seldom addressed as the projects evolved, and this led to their cessation when the specified period of funding concluded (Busiinge, 2010; Patterson, 2014). Several factors have been attributed to this including the absence of social support and acceptability, lack of economic and financial stability, absence of technical soundness/ capacity for continuation and a lack of ownership of the process (Patterson, 2014).

There is a need to reduce the risk of social development projects being discontinued and to maintain the benefit flows of such projects in Guyana. The maintenance of such benefits continues to be a challenge. This paper explores how project sustainability could be improved, by integrating VM principles at the design stage. It is based on social development projects funded by international agencies in Guyana.

2. Literature Review

According to BS EN 12973: 2000, VM is a style of management, particularly dedicated to mobilise people, develop skills and promote synergies and innovation, with the aim of maximising the overall performance of an organisation (BSI, 2000). It is a system that brings together within a framework: management style; positive human dynamics; consideration of external and internal environment; effective methods and tools. Moreover, AS 4183: 2007 defines VM as a structured and analytical process in which a prescribed work plan is followed to achieve best value for money in products, processes, services, systems and organisations (Australian Standard, 2007). Noting that the process may be applied to management decision making at any level of an organisation, the AS 4183: 2007 emphasised that it is a powerful process "that could be used to develop agreement, understanding and commitment when applied to the resolution or optimisation of particular issues and situations". This is a new perspective to VM somewhat different from "engineering". This underscores value as an "attribute of an entity determined by that entity's perceived usefulness, benefits and importance" (Australian Standard, 2007). Figure 1 depicts the factors affecting the use of VM approach.

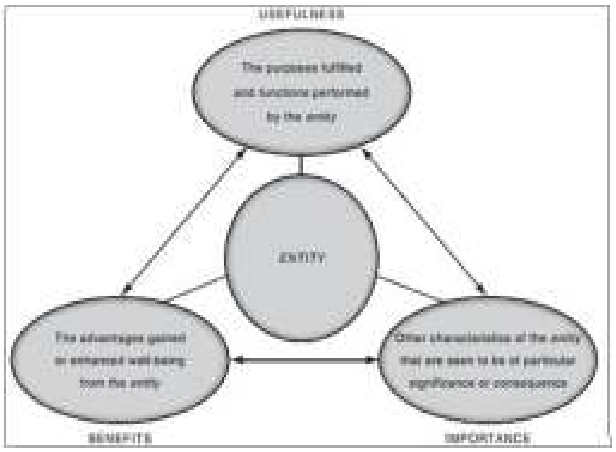

Figure 1. Factors influencing the VM Approach
Source: Australian Standard (2007)

The notion of 'hardness' and 'softness' in relation to VM, systems and problem solutions was advanced by Checkland and Scholes (1990). The 'hard' situations are those which could be well-defined, understood and could be clearly described within a well-defined system (Barton, 2000). For instance, a 'hard' problem may be choosing between broadening a two-lane stretch of road to a four-lane highway and construction of an access road through residential communities. The case requires 'hard' methodological assessment and conventional value engineering (VE) inputs. Technical experts would be required to work through the required phases of the VE job plan and based on life-cycle costing and function analysis, conclude which option delivers the most cost effective functions.

The 'soft' situations can be typified by such circumstances as those facing intractable situations (Barton, 2000). The issue is "knowing what to do" as distinct from knowing "how to do it". The situations are usually complicated and, they may present many conflicting values, viewpoints and interfaces (Barton, 2000). An example of a "soft situation" is what is to be done about a buildup of solid waste in a particular city. The problem situation may be complex, as numerous potential solutions may present themselves. These may require implementing solutions such as public education programmes aimed at attitude changes, a strategy to ensure that there are more waste disposal facilities around the city, increasing the number of vehicles as well as having a more rigid schedule of garbage collection in wards and the imposition of fines and other penalties for indiscriminate dumping of refuse. Large sections of the city could be affected by whatever decision(s) are made and the main problem rests in the answer to the question, *what to do about the situation* (Barton, 2000).

Kelly and Male (2001) contend that VM is sought to maximise the functional value of a project by managing its development from concept stage to that of operation through a multi-disciplinary value team. A high premium is placed on client value which is made explicitly clear at the conceptual stage of the project. VM is a divergence from other approaches in managing projects (BSI, 2000; Abidin and Pasquire, 2005). The view of this goal tends to lean towards the traditional 'hard' approach to VM (Barton, 2000; Kelly and Male, 2001). Hence, advocating modifications in the approaches to the 'soft' implementation of social development projects, as well-defined procedures and processes could be introduced to enhance the function of designs, services, facilities or systems at the lowest possible total cost (Patterson, 2014).

3. Conduct of "Value Statement" Workshop

A simulated Value-Statement Workshop involving a small group of project stakeholders drawn from Case 1(see below) was undertaken. The four other selected social projects were also incorporated into the study methodology. These projects were:

- Case 1: The School Retention and Child Labour Prevention Project (under the Ministry of Labour, Human Services and Social Security)
- Case 2: The Voluntary Mentoring Programme (by the Ministry of Education)
- Case 3: Support for the Low Income Housing Sector (by the Ministry of Housing and Water)
- Case 4: HIV AIDS Reduction and Prevention Project 1 (under the Ministry of Health)
- Case 5: The Sprinkles Project (under the Ministry of Health)

Some of the questions raised to address the deficiencies associated with social development projects in Guyana are:

1) What are some considerations for consolidating the extension of project gains after IDP funding has expired?
2) What follow up activities using locally mobilised resources (in terms of technical, professional and financial) are required for the project continuity?

The Workshop was facilitated with the assistance from professional VM experts from Australia. This was a necessary aspect of the methodology, especially because producing a value statement for an entity is one of the first tasks undertaken in any VM study (BSI, 2000; Australian Standard, 2007). Besides, appreciative inquiry was used to articulate stakeholders' experiences as they participated in the exercise. Notes of discussions were taken at the interviews and were used to inform the issues raised in the study.

Steps were taken to arrive at a value statement. The issue of risk was also explored, and a corresponding risk statement was established. Of significance to the study and certain importance, a VM approach was initiated for sustaining social development projects following discontinuity of international funding**.** The approach incorporated an institutional framework and the principles for the facilitation of the VM adoption.

4. Findings and Analysis

Based on the evidence from the selected case projects, the deficiencies emerging from the issues were identified. Firstly, there were inherent weaknesses in approaches in initiating the projects, as well as the steps along the implementation process. It was found that the VM techniques were omitted in the planning and design stages of these project cases. Those projects failed to benefit from processes which would have allowed for detailed planning to capture multiple stakeholder perspectives and build them into proposals for projects and programmes. The absence of this process is a major contributory factor to projects facing the risk of discontinuity when IDP funding ceases in Guyana (Patterson, 2014).

The narrow definition of projects by their outputs was recognised as unbeneficial to the process and was evident in the case examples. Those softer values that are inherent in social development projects such as those of a subjective nature (e.g., honesty, commitment, integrity, respect for others, a culture that support uprightness) were not captured in any of the case examples. Systemic connections and relationships were found in the educational and social networks (e.g., the Housing and School Retention Projects) and physical connections, as access to new communities and linkages, all fit together to make the project work

Several core 'value factors' were identified, and these collectively formed the 'value statement'. These value factors comprised 1) the useful purposes fulfilled by the project, 2) the beneficial outcomes from fulfilling those purposes and 3) those other features/characteristics of the project that are of particular importance or consequence. In combination, these factors would determine the value placed on the entity from multiple perspectives. Figure 2 highlights key points raised in arriving at the value factors for one selected project - The School Retention and Child Labour Prevention Project in Guyana. The project was funded by the European Union (EU), with technical support from the International Labour Organisation. The Ministry implementing the project on behalf of the Government of Guyana was the Ministry of Labour, as part of its social protection mandate (Patterson, 2014).

Figure 2. Understanding Value Factors on School

The value statement focused on the "cultural environment" of social and economic conditions, and invariably formed the nucleus of the project. Participants in the process were assisted to have a broader perspective of the process, and the matter of project sustainability was examined beyond the surface. Central issues addressing the purpose, the outcomes and important features of the project were examined from the perspective of multiple stakeholders, giving value to the process. At the level of the ministries involved, the assurance created and confidence which exuded among stakeholders from knowing that a transparent review process being undertaken was remarkable.

As evidenced from the selected projects under study, the absence of the application of VM principles and techniques would have caused the discontinuation of social development projects at the end of the funding period in Guyana. Therefore, active involvement of stakeholders (particularly at the startup of the project processes) would be crucial. Moreover, proper adoption of VM principles and techniques has the potential to facilitate the improvement of communication, commitment to project purpose, team building, reduced work, getting it right first time, as well as developing risk and crisis management procedures (Barton, 2000; Patterson, 2014). The findings also confirmed the point made by Gough (2005) that the use of VM tools and techniques could add value and increase the chances of success for high-risk projects. Adoption of a VM approach would ensure that the capacity built remained an integral part of the continuity plan. This would be the consideration for the institutional requirements and provision made to foster management support for the continuation of project operation that VM could offer.

5. Development of a VM Approach

Although VM focuses on the project's purpose, this should not exist in isolation. VM would play a broader role in fostering project sustainability if risk management (RM) and Gateway (GW) are applied in tandem with VM. VM is the central focus, with RM and GW, being presented in the broader context. Reference was made to Gateway (a Peer Review Health Check System) that is effectively utilised in Project Management. This is a procedural context of the Institutional Framework, which provides guidance and principles for projects to: 1) improve alignment of service delivery with available funds, 2) attain accurate project scope and estimates, 3) reduce time and cost overruns, 4) improve risk management, 5) reinforce agency responsibility and accountability for decision making, and 6) secure better results for the community (Patterson, 2014). Figure 3 shows the procedural components of a 4-stage VM study.

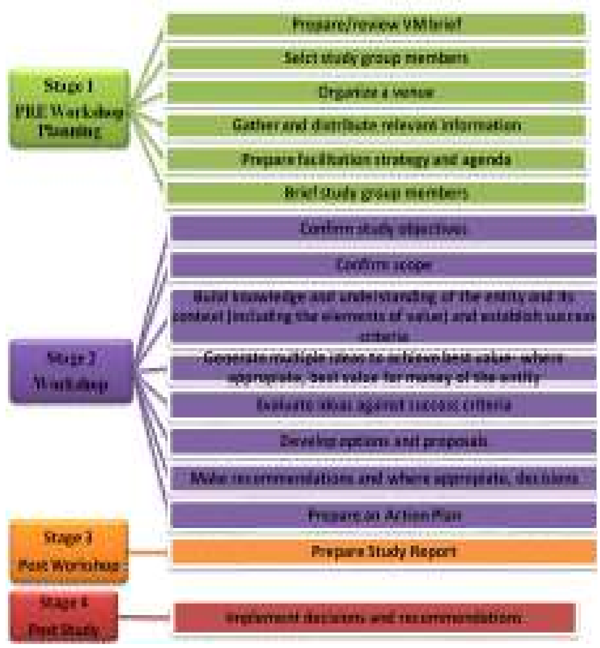

Figure 3. Procedural components of a 4-stage VM study
Source: Based on Australian Standard (2007)

The VM study institutes a critical step in developing a Strategic Framework for continuity. The organisational context fits well within the Gateway structure as it provides the checks and balances required for managing the respective project(s). With reference to the lessons learnt from the selected projects under study, a set of nine (9) principles was identified. These principles could be instituted into a VM-based strategic framework for continuity (see Table 1).

A significant benefit of the VM approach is that the requirement of "on-going sustainability" after funding ceases could be established at the beginning of the project and be monitored throughout the project cycle. Critical points for VM, RM and GW interventions were identified so as to reduce the risk of projects being discontinued at the end of funding in Guyana. Figure 4 depicts an outline of the various points on the building blocks where these interventions are being recommended. This covers various stages of the implementation from the beginning to the end of the project cycle (Patterson, 2014).

In the Conception stage (i.e., Block 1), the project goal is defined, and the broad areas of needs are explored. In particular, areas of focus are identified (for example, HIV/AIDS reduction, school retention and child labour prevention, and low cost housing, etc) and agreements are made by governments and the Official Development Assistance (ODA) body to the terms and conditions of the receipt of the funds (usually by signing Agreement Protocols or a Memorandum of Understanding). At this stage, VM and RM applications should be considered in the project roll out.

The second component of Strategy is the second building block. The key question here is: '*Does the project suit the service needs identified?'* The strategy employed is an important consideration in the paradigm since project implementation cannot be effectively assessed without examining the organisational setting or structure. It is about the set of formal tasks that are assigned to individuals and departments, formal reporting relationships, lines of authority, decision making responsibilities, hierarchical levels, span of managers' control, as well as the design of systems to ensure effective coordination. In order to achieve the project goals/objectives (such as people, communications, and jobs and resources), an enabling organisational structure is to be built to support project activities. The Gateway approach provides the checks and balances for the review system, in tandem with the VM methodology to reduce the risk of projects being discontinued when funding from an ODA/IDP ceases.

The Concept Design Stage is the third building block. The thinking of the project activities is beginning to take form and shape and the critical components are starting to emerge. It is at this stage that the 'Pre-Workshop' activities identified in the VM Four stage study must be considered. The preparation of the VM Brief, identification and selection of the study group members, information dissemination as well as agenda preparation and facilitation strategy should become areas of focus. Since VM and RM were initiated at the Conception stage, the Concept Design building block allows for the deepening of VM and RM. The activities, types of risks, description of their impact, internal controls and probability of risks without controls and questions of project cost would be raised at this stage.

Table 1. The Nine Principles of a VM-based Strategic Framework for Continuity

Principles	Descriptions
1.	**Value Management should be incorporated** into the development process, commencing at the earliest practicable time (preferably before a decision to proceed has been taken) and after that, at strategic points along the project's journey. For the purpose of this study, and the Development of a Strategic Framework for continuity, the use of the Work Plan from the Australian Standard AS 4183: 2007 is advocated. It is appropriate because of its applicability to a myriad of project types – including "soft" projects, which is the focus of this study. AS refers to the Information phase as "Build shared knowledge and understanding".
2.	**A 'Gateway' or similar system** should be put in place as one of the first organisational steps in the development journey. This 'peer-reviewed' system will help to ensure that the project is aligned with desired outcomes right from the start, and maintains that alignment throughout the development journey. As has been alluded to earlier in the study, the way the process works is that it has 6 "gates", which are passed during the procurement journey and 7 "success factors" are assessed to ensure the continuing health of the process. Gateway can be regarded as an extension of VM and as a response to institutional framework for sustainability.
3.	**Risk assessment** should be undertaken before a decision to proceed with the project is taken, and a risk management plan should be produced, monitored and regularly updated if and when the project proceeds. The assessment helps to support better decision-making through understanding the risks inherent in a proposal and their likely impact. Where considerations of important features as sustainability and risks are omitted from the dialogue of project processes, there are clear indications the projects yielded less value/ value that was not maximised and their continuity after funding was jeopardised.
4.	Mechanisms to ensure the **Project's financial viability** after funding from an Official Development Assistance (ODA)body ceases. During the VM Workshop stakeholders have an opportunity to see and learn about the various facets of the project and their interconnectivity, where matters of this nature are raised as a matter of significance and are scoped out. Particularly because the cessation of funding is a major contributory factor to the risk of projects being sustainable, the researcher submits that more emphasis must be placed on this issue and the VM Workshop creates an enabling environment for it to be captured in detail.
5.	Networking and collaboration in order to **Promote inter/intra ministerial agency/community /sectoral relations to achieve the best possible project outcomes**. Principle 1, the undertaking of a VM study would have some bearing here as the bringing together of multi stake holders for defining the scope of the value factors would lead to this collaboration. Just as VM encourages an approach that does not deal with programs and projects in isolation but as a whole system, this principle advocates a knowledge sharing among relevant entities, because they are "connected systemically" in order to facilitate an integrated approach to social development projects. The greatest benefit is reducing the risk of social development projects being unsustainable when funding ceases.
6.	The choice of **which Social Development Project should be undertaken**. Those initiatives not rated on the government's priority list as contributing to national development, appeared to be at high risk of becoming unsustainable at the end of funding. It appeared that they were undertaken because an ODA made funding available, but there was no long term thinking to derive value. Choices of projects should therefore be assessed based on a real need for intervention, as opposed to a felt need or simply a response to an ODA offer.
7.	**Introduction of an element of training or mentorship for those who would play integral roles in the entity and would be tasked with sustaining benefit flows.** Particularly in cases where specialist/ technical support was required to provide institutional support, mechanisms must be put in place to ensure that the requisite capacity is strengthened on the project management team, if and when that skill set is required to leave the process, so that implementation can proceed unimpeded, at the end of ODA funding.
8.	Implementation of a **Monitoring framework**. Reference has been made to the application of the Gateway approach as a useful tool in this Strategic Framework and critical questions that must be asked at each "gate". Additionally, seven (7) success criteria (service delivery, affordability - value for money, sustainability, governance, risk management, stakeholder management and change management) are used to assess the progress of projects, undertaken by a reviewer. These indicators guide the process and the key question is kept in mind at each "gate". The sponsor has a responsibility to link the "success factors" to the project.
9.	The use of **Participatory methodologies as an approach in the initiation as well as the management of projects**. In this regard, people are organised, skills are harnessed, singularly and collectively, synergies and creativity promoted and overall performance of the organisation is advocated. This advocacy has a positive impact in enhancing (organisational) performance.

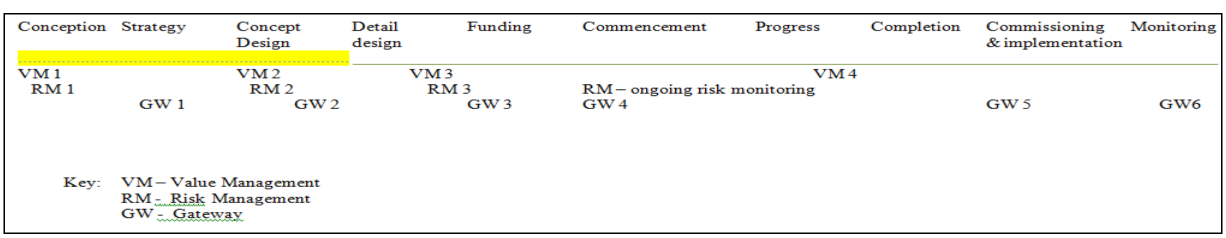

Figure 4. VM, RM and GW Interventions at Various Points in the Building Blocks

The Detailed Design Stage (i.e., Block 4) constitutes an intensification of multiple stakeholders (representing managers, donor, strategic partners, resource owners, regulators, communities, interest groups, and NGO) who are brought together at the VM Workshop. The primary purpose is to determine the value factors of the entity, comprising of the useful purposes fulfilled by the entity, benefits to be delivered, and significant characteristics. Hence, multiple perspectives of each of these, come into focus. Aims and objectives, outputs and activities are being defined and refined. Strategic decisions are made regarding the implementation process.

The VM adoption is to capture these multiple perspectives and build them into project proposals. Any omission could for instance lead to the failure of establishing the value factors of a project, that is, building shared knowledge and understanding amongst stakeholders and project team members, where emphasis is on learning and achieving unity of purpose. In other words, the absence of this building block could result in a poor definition of the entity that would govern the project delivery, the primary purposes, and benefits. The consequence of the absence of this building block would be disastrous, since measures to reduce risks of discontinuity were omitted. This would lead to the projects being placed at risk, and of becoming unsustainable at the end of the stipulated period of funding from an IDP.

With reference to RM, the questions raised pertain to activities, types of risks, description of their impact, internal controls and probability of risks without controls. A wider cross-section of participants is involved and is making inputs hence the use of GW at Block 4 would help to raise essential questions of the robustness of project scope and estimates. In order to reduce the risk of social development projects being discontinued following funding from an IDP, the Funding Application Stage (i.e., Building Block 5) is crucial. At this stage, the work plan has already been prepared. Funding becomes available for the project start up.

The Commencement Stage (i.e., Block 6) is characterised by ongoing RM and GW. GW addresses the state of readiness for commissioning. VM principles and techniques, particularly participatory methodologies in the form of ongoing workshops involving a myriad of stakeholders are kept as tasks are completed and stakeholders' roles in monitoring are deepened. During this period, there is preparedness for handing over or change management.

Progress of project achievements characterises Block 7 as deliverables are monitored and issues of time, quality and cost are kept in focus as far as possible. While progress is being monitored, delivering the best value for money across the whole system is addressed and in the workshops attention is given to details on aspects of the project. It is during this Block, the value factors established at the beginning of the VM journey continue to guide decisions and recommendations.

Block 8 marks the Completion and Close-out of the project activities, while Block 9 indicates commissioning and implementation. In these final steps, attention is on continued monitoring. Both achievements and production of services are outlined, and best practices and lessons learnt are reviewed and documented. This study has established that one major factor puts projects at risk of being discontinued after funding ceases. It was because the critical processes are excluded when VM principles are not included from the earliest stage of the project cycle.

7. Conclusion

Those well-structured and defined situations are seen as "hard" VM, while the "soft" VM suggests the methodology of addressing problem situations that are not easily structured or defined. The nature of a 'soft' problem situation is fundamentally different from that of a "hard" problem situation. Solutions which work well in addressing 'hard' problems might be inadequate in addressing 'soft' problems.

This paper explored the VM approach for managing social development projects and risks of their cessation following the discontinuity of IDP funding in Guyana. The client, specialists, end users, suppliers and other stakeholders put forward suggestions for discussion and investigation, and incorporated how the values contained there could be sustained beyond funding. It concludes that the application and evaluation of the VM framework is so integral, that it be incorporated in the Work Breakdown Structure of projects. The WBS reflects the entire project scope, planning process and assigned responsibilities to persons/ departments. In order to ensure RM/VM and GW implementation, their inclusion on the WBS is seen as the most strategic approach.

Public Private Partnerships (PPPs) and Cooperatives would be able to play critical roles in sustaining social development projects when funding from an ODA source comes to an end (Patterson, 2014). The fact is that the conventional/traditional means of project funding are contracting as many development agencies/ partners are cautiously identifying areas to provide funding. Projects therefore require astute management, considering their sustainability. It is anticipated that greater involvement of PPPs would be fostered for the undertaking of social development projects. Applying VM principles would enhance service delivery and reduce the risk of projects going into cessation with inputs from PPPs. Further work and exploration would be recommended focusing on a paradigm shift in the traditional approach based on the combination of ODA involvement with government.

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An Evaporative Cooler for the Storage of Fresh Fruits and Vegetables

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Abstract: *An evaporative cooler for the storage of fruits and vegetables was designed, built and tested. The system is an economical and efficient method used for the reduction of temperature and increase in the relative humidity for the storage of produce by applying the principles of the evaporative of water. The cooler comprised of two extraction fans, a cooling pad media, a plate-fin heat exchanger, a water tank, a storage and a cooling chamber. The optimal operational parameters were determined by operating the cooler for 180 minutes using three pad media (cedar, teak and coconut fiber), with three fan extraction speeds (4 m/s, 6 m/s and 8 m/s) at two periods of day (morning and afternoon) and the saturation effectiveness of the evaporative pad and temperature differences between ambient conditions and the cooler were measured. The mean saturation effectiveness was 64.42% (cedar), 63.56% (teak) and 53.47% (coconut fiber). The mean values for the temperature difference were 5.00 K (cedar), 4.63 K (teak) and 3.60 K (coconut fiber), showing that cedar was the best material for operating the cooler. The best fan speed was 8 m/s while the cooler operated better in the morning (9.00 a.m.to 12 noon). The evaporative cooler operated at 8 m/s fan speed using the cedar shavings pad was then used to store tomatoes over a 14 day period alongside two other storage methods (refrigeration and ambient conditions). The mean penetration depth of tomatoes was 13.43 mm, 13.82 mm and 18.26 mm for the refrigerator, evaporative cooler and the ambient conditions respectively. The pH and the total solubility solids of the tomatoes stored with the evaporative cooler were the lowest showing that while the refrigerator was the best in terms of maintaining the skin firmness, the evaporative cooler was the best storage method in terms of preserving the acidity of the tomatoes as well as their total solubility solids.*

Keywords: *Evaporative, Cooler, Saturation, Effectiveness, pH, Tomatoes*

1. Introduction

In today's society many individuals strive to maintain a healthy lifestyle consisting of a balanced diet of fresh fruits and vegetables. As the demand for such produce increases, so too does the rate of post-harvest loss, as a result of inadequate facilities to store such produce. It was estimated that the average post-harvest loss in fresh produce in most developed countries is 5% to 25% and 20% to 50% in the developing countries (Kader, 1999). Regionally, harvesting is done early in the morning in order to maximise the lower temperatures because under temperatures of 25°C to 35°C that typically exists in the afternoons, the respiration rate is high thus reducing the storage life. It is important that prompt pre-cooling of fresh produce is done as the produce can potentially deteriorate as much in one hour at 32°C as twenty-four hours at 10 °C (FAO, 2013). Undesirable effects of excessive temperature on produce include accelerated ripening, yellowing, spouting in potatoes and bitter taste in carrots which are directly linked to respiration, transpiration and ethylene production. This is due to the higher respiration rates (Odesola and Onyebuchi, 2009). There is therefore the need to decrease the temperature of the produce thereby decreasing its respiration rates, water loss, ethylene production and sensitivity to it as well as reduce microbial development. According to Odesola and Onyebuchi (2009), low relative humidity increases the transpiration rates, while at high relative humidity, the rate of water evaporation is low hence cooling is low. At high relative humidity, produce will generally maintain its nutritional quality, appearance and flavor with minimal effect on the softening and wilting (Odesola and Onyebuchi, 2009).

The most effective method utilised in storing produce involves refrigerated cool stores. However, many small scale farmers and vendors in the Caribbean region and in most developing countries are unable to incorporate such methods in preserving fruits due to its high cost with respect to installation, energy consumption and maintenance. Currently, the business revenue of many farmers in the region is limited due to the high loss in produce such as pineapples, carrots, tomatoes and guavas because of its perishable properties (Mohammed, 2001). A device can be designed and constructed in order to maximise the shelf life of the produce, thus reducing the losses endured by small scale retailers. This device will allow the appropriate cooling temperatures between 0°C to 21°C (Lerner et al., 2001) necessary to reduce the deterioration process. In order to create such a device, the requirements and parameters affecting the storage life of these produce must be analysed. A major contributing factor to the cooling process incorporates the natural resource, water in conjunction with the process of evaporation. The combination of the evaporation of water can be assisted by an external component such as a suitable air moving device (NAHB, 2001).

Evaporative coolers can be easily constructed using available local materials. They can be easily maintained compared to refrigerated systems as their major mechanical components, the motor, extraction fan and heat exchanger (optional) can be repaired at a low cost. They are environmentally friendly without pollution. Moreover, the refrigerant used is water, whereas existing refrigerated units utilise CFCs, sulphur dioxide and ammonia and these refrigerants are toxic and are contributors to the depletion of the ozone. Evaporative coolers are primarily based on the principle of evaporation which is affected by the flow of air within the system as well as the surface area. The humidity of air which is closest to the water surface is increased as water evaporates from a surface.

From a search of literature, six major types of evaporative coolers which were constructed were identified (see Table 1). Data was collected on the power consumption, speed of the fan, storage capacity, type of cooling pad, weight and the dimensions and the operational assessment of the devices. The main problem with all the previous designs is that most of them did not mention the material of the cooling pads apart from Thomson and Kasmire (1981) who used Aspen fibre. Diljohn (2010) started the use of local materials of cedar and teak in constructing evaporative coolers, but he operated the cooler at one speed of the fan and also carried out limited testing of the cooler to determine the optimal operating conditions. The main intention of this paper is to continue the work of Diljohn (2010) by designing, construction and testing of an evaporative cooler that could maximise the efficiency of storing produce at a low cost while simultaneously achieving its longevity that a more mechanically suitable device can offer. The design of such a device aims at finding an appropriate balance at increasing the storage life of produce based on the use of a low cost evaporative cooler made with local materials. The optimal conditions for running the cooler will be investigated and compared with the current methods of storing produce.

Table 1. Comparison of some existing evaporative coolers

Comparator	An evaporative cooler for vegetable crops (Thompson and Kasmire, 1981)	Evaporative Cooler (Diljohn, 2010)	EC220W (Amazon.com, 2013)	EXV 115 (Seeley International Pty Ltd, 2013)	PACKA53 (The Home Depot, 2013)
Power Consumption (kW)	1.620	0.026	0.220	0.870	0.150
Speed of Fan (m^3/s)	0.19 – 0.28	0.00273	0.78	2.60	0.22
Storage capacity	272 kg of produce can be stored in storage chamber in 1 to 2 hours	3 kg of produce can be stored in the cooling chamber	NS	NS	NS
Type of Cooling Pad	Aspen Fibre	- Cedar - Teak	NS	NS	NS
Area of Cooling Pad (m^2)	0.743	0.0103	NS	1.375 (2 Pads)	NS
Weight (kg)	NS	NS	9.9	111.1	11.3
Dimensions (W x Dx H) (m)	NS	0.508 x 0.483 x 0.854	0.692 x 0.438 x 1.049	1.016 x 1.219 x 1.168	0.411 x 0.391 x 0.701
Operational Assessment of Device	The device verified the effectiveness of evaporative cooling by testing various produce by varying several parameters.	The maximum efficiency was determined at an average temperature drop of 6.1°C, relative humidity as 24.3% and the overall efficiency as 4.88%.	A portable device, which is used to cool large areas up to $60m^2$. Device is durable as it is constructed from U-V ABS plastic.	Device is suitable for cooling commercial or industrial areas and consists of a centrifugal fan, a PSC-variable speed motor. The device uses 90% less electricity than traditional refrigerated systems.	A portable device which does not consist of a pump to moisten the cooling pad. Cools up to 350 square feet for residential purposes

Remarks: *NS: Not specified in the product literature.*

2. Description of the Construction and Operation of the Evaporative Cooler

The system primarily operates on the principle of indirect evaporative cooler. In in-direct evaporative cooling, air is allowed to cool freely, without the addition of moisture to its content, with a heat exchanger. The secondary air is then used in the cooling process of the primary air via the heat exchanger. The wet and dry bulb temperatures within this system are thus reduced (Wescor, 2011). It differs from the direct evaporative cooling where air is allowed to flow through a water soaked material thus allowing evaporation and cooling to occur. The wet bulb temperature and enthalpy are unaffected and the dry bulb temperature reduces as the specific humidity and relative humidity increases (Wescor, 2011). The direct cooling method was not adopted because of the inherent high humidity of local air which leads to very low dry bulb temperature drops.

Components of the evaporative cooler (see Figure 1) are a cooling chamber, 25 cm x 25 cm x 5 cm (10" x 10" x 2") plate-fin heat exchanger, 12.5 cm (5") connecting pipe, and a storage chamber. In the cooling chamber, there is an evaporative pad on one end and at the other end, a tapped section with a 25 cm (10") diameter extractor fan capable of reaching a maximum speed of 10 m/s. At the base of this cooling chamber, is a water storage tank pan with a submersible pump, which delivers water to the top of the evaporative pad via 1.25 cm (1/2") diameter PVC connecting pipe with 10 holes of diameter 0.8 mm (1/32"). The purpose of these holes is to moisten the evaporative pad to achieve an even distribution of water on the surfaces of the material. The extractor fan attached to the cooling chamber creates a vacuum which removes the water from the evaporative pad and distributes the cool moist air created through the plate and fins of the heat exchanger via a shroud. The shroud was used to ensure that all the cool air created at the cooling chamber was utilised in the cooling process which occurred in the heat exchanger and it prevented turbulent airflow from occurring. A variable transformer regulated the speed of this extraction fan between 4 m/s, 6 m/s and 8 m/s.

The storage chamber consists of three trays for storing produce. A hole of 5 cm (2") diameter was placed in the center of the base to allow the cool dry air to be created to enter the box via a connecting pipe. The door of the storage box is lined with a sealant material to ensure when the door is closed and the 7.5 cm (3") diameter extraction fan placed at the top of the storage chamber (see Figure 1) is turned on, there exists a vacuum. During the operation of the evaporative cooler, ambient air is blown through the inlet of the heat exchanger and this air is cooled by the moist air from the cooling chamber. It is at the heat exchanger that the heat transfer takes place between the moist cool air and the ambient air. Ambient air enters the inlet of the heat exchanger and exits at approximately 25^{o}C. The cool ambient air from the outlet of the exchanger is then pulled into the storage box and this is the air that is used to cool the produce.

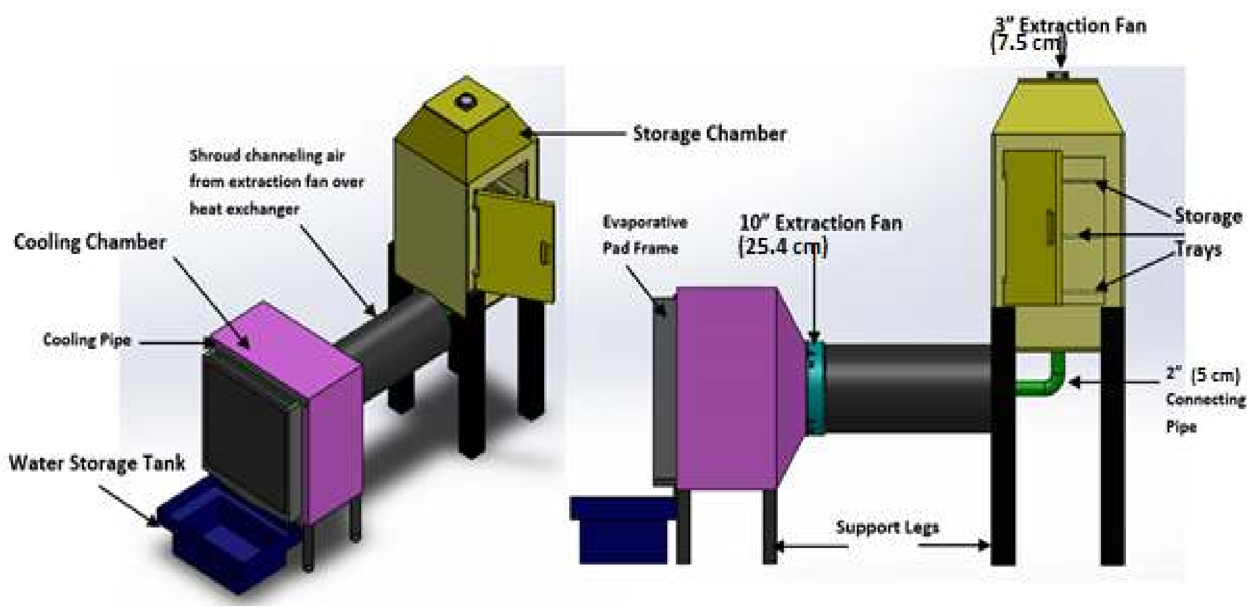

Figure 1. Views of the evaporative cooler with heat exchanger

3. Testing of the Constructed Evaporative Cooler

3.1 Purpose of the Tests

Two tests were carried out. The first test involved the use of a factorial experiment to examine the effect of three (3) types of materials (including cedar shavings, teak shavings and coconut fiber) for an evaporative pad, three (3) different speeds (i.e., 4 m/s, 6 m/s and 8 m/s) for the extraction fan based on the period of the day (morning and afternoon) and time of operation (0 to 180 mins) on two operational parameters of the evaporative cooler (saturation effectiveness of the evaporative pad and the temperature difference between the ambient conditions and the constructed evaporative cooler). This was done to obtain the optimal conditions for operating the evaporative cooler. In the second test, the performance of the evaporative cooler operating at the optimal conditions was compared with that of a refrigerator and traditional methods (storing at ambient conditions).

3.2 Procedure for Testing

Test 1

Cedar shavings, teak shavings and coconut fiber were easily attained from local saw mills. These materials were selected based on their water holding capacity, moisture content and bulk density. Cedar and teak shavings held the shape of the pad and offered little resistance to the development of mold, fungus bacterial growth and foul odors (Essick, 1945). Coconut fiber was selected as typical fibers of 7.70 x 10^{-4} m have a water absorption saturation efficiency of 85% (Toledo et al., 2005). The materials selected possess tolerable rotting resistance, thus a pad constructed of such materials could last for a considerable period (5 months minimum) of time without being changed. The shavings were first air dried for a week and then sifted so as to remove any foreign organic matter such as dried leaves or any other contaminants which could affect the properties of the materials. The following steps were involved:

1) The evaporative pad was inserted into the pad frame.
2) The water tank was filled using regular pipe borne water (T_{avg}= 28.6°C) and the pump was switched on.
3) A variable transformer (variac) was used to regulate the voltage and speed of the extraction fan. The airflow rate was simultaneously recorded with the anemometer from the extraction fan. It was ensured that there was a consistent vacuum in the cooling chamber for the cooling effect so as to reduce loss of heat transfer to the environment.
4) Five thermocouples were connected to the Picolog Software and were able to record the ambient temperature, the temperature exiting the cooling chamber, the temperature entering the storage chamber after being passed over the heat exchanger and mixed with ambient air blown through the inlet of the exchanger, the temperature in the middle of the storage chamber and the temperature exiting the storage chamber every 15 minutes over a time of 3 hours. The main reason for recording the temperatures at the various positions in the system was to effectively analyse and account for the temperatures which the produce would be stored at different levels, as there are three shelves in the storage chamber. A digital temperature and relative humidity probe measured the relative humidity of the ambient air and the storage chamber. A wet bulb thermometer measured the wet bulb temperature of the ambient air. After performing the first test in the morning period (9 a.m. to 12 noon), the system was switched off, the door in the storage chamber was opened and the system was left for an hour to reset. The experiment was then repeated in the afternoon period (i.e., from 1 p.m. to 4 p.m.). The experiments were conducted twice by applying the repeatability and reproducibility principles to evaluate the performance of the system.
5) Steps 1-4 were repeated using different materials at different speeds over a period of 9 days.
6) The saturation effectiveness of the evaporative pad was calculated by using the following equation (ASHRAE, 2007)

$$\varepsilon = \frac{t_1 - t_2}{t_1 - t'} \times 100$$

Where, ε is saturation efficiency (%),
t_1 is dry bulb temperature of entering air (K),
t_2 is dry bulb temperature of leaving air (K), and
t' is the wet bulb temperature of entering air (K)

Test 2

1) **Penetration depth:** Measuring the penetration depth of the sample was an indication of the skin firmness of the tomato and was carried out to compare the effectiveness of the various methods of storage. Measurements were made using the drop cone penetrometer (Hansbo, 1957). The tomato sample was placed on the level gauge, with the dial reading set at zero. The 30° cone was adjusted to move downward by alternating the adjuster on the side on the device until the tip of the cone was slightly touching the tomato sample. The thumb release knob was pressed for 3 seconds and then released. The depth gauge rod was then pressed without being forced in order to attain the depth of penetration of the sample. The samples were tested on the top (opposite end of the stem) as well as on the side (middle).
2) **pH Test:** pH was measured to observe how the acidity of the samples varied based on method of storage and number of days stored. This would assist in determining the most optimum conditions to store tomatoes. A pH meter was calibrated

accordingly before testing. The tomato sample was cut in half and blended in order to attain a solution to test the pH. A 10 cm^3 beaker was used to store the tomato juice and the probe of the pH meter was lowered into it. The reading was noted when the meter gave an indication of "ready" on the screen.

3) **Total Solubility Solids Test**: This physiological test corresponds to the percent of sucrose concentration in the solution. A hand held refractometer was utilized in this test. The scale of the device used is calibrated in ºBrix (0 to 32%) in this case based on the stage of development in the tomatoes) which is the measurement unit for dissolved solids. The refractometer was zeroed before testing by washing the glass prism with distilled water, which gave a reading of 0° Brix. The prism was gently wiped with a microfiber cloth and the tomato juice was sprinkled on it. Readings were recorded by looking through the eyecup and adjusting the focus control.

4. Results and Discussion

4.1 Determination of the Optimal Conditions for Operating the Evaporative Cooler

Values of the saturation effectiveness and temperature difference between the ambient conditions and the cooling chamber for the three operating media of the evaporative cooler with the extraction fan operating at three speeds for different periods of the day at different times of operation are shown in Tables 2 and 3, respectively. For most of three materials, the saturation effectiveness and the temperature difference increased with the operating speed of the extraction fans. The values for cedar were in most cases higher than those for the teak, which were also higher than values for coconut fibres. As expected, both parameters also increased with time of testing from 0 to 3 hours. The evaporative cooler operated better in the day than in the afternoon. The mean values of saturation effectiveness and temperature difference for the various experimental variables are shown in Table 4. Both parameters increased with increasing speed of the extraction fan and time of operating the evaporative cooler. Mean values were higher in the morning than in the afternoon and the effectiveness of the materials in the deceasing order was cedar shaving, teak shaving and coconut fibres.

'F' values were obtained from the ANOVA (see Table 5). It shows that the effect of the main effect for the experimental factors on saturation effectiveness and temperature difference was very significant. For both parameters, the time of testing (0-180 mins) was the most important factor that affected the values.

Table 2. Saturation effectiveness of the evaporative cooler with three cooling pad materials and extraction fans operating at three speeds at two periods of the day

Time of Testing (mins)	Cedar shavings with fans operating at			Coconut fibre with fans operating at			Teak shaving with fans operating at		
	4 m/s	6 m/s	8 m/s	4 m/s	6 m/s	8 m/s	4 m/s	6 m/s	8 m/s
0	1.8/5.7*	1.7/10.3	2.0/2.7	1.9/1.4	0.0/4.0	0.4/6.8	2.0/1.3	0.0/2.5	2.0/0.7
30	40.5/24.7	46.5/35.6	57.2/34.7	29.8/31.2	15.5/27.7	17.6/26.1	44.9/19.3	39.3/48.9	48.8/47.9
60	75.6/42.1	69.8/47.0	76.2/55.9	54.0/44.7	29.2/42.8	36.7/42.7	64.8/48.6	66.0/67.4	76.0/70.0
90	92.8/46.0	65.4/89.1	89.1/81.2	69.3/53.4	39.6/54.1	52.9/54.0	71.6/53.9	76.6/77.1	86.8/71.5
120	90.0/45.6	73.4/90.8	95.2/82.5	79.8/64.6	69.2/71.3	69.9/72.5	78.8/62.7	80.9/72.8	88.7/74.8
150	86.9/64.7	88.6/94.5	97.4/88.3	85.2/86.3	92.0/89.2	91.7/89.0	91.1/70.2	99.0/76.1	92.9/87.0
180	98.2/87.7	95.8/94.3	98.8/93.8	90.9/90.0	98.4/93.5	98.8/82.3	87.3/78.3	92.6/78.0	93.8/85.1

* - Values are saturation effectiveness (%) for the morning (9 a.m. to 12 noon)/afternoon (1p.m. to 4 p.m.). The relative humidity of the ambient air ranged from 50.2% to 64.9% while that of the air in the storage chamber ranged from 69.1% to 83.2% throughout the experiments.

Table 3. Temperature difference between the ambient conditions and the inside of the evaporative cooler with three cooling pad materials and extraction fans operating at three speeds at two periods of the day

Time of Testing (mins)	Cedar shavings with fans operating at			Coconut fibre with fans operating at			Teak shaving with fans operating at		
	4 m/s	6 m/s	8 m/s	4 m/s	6 m/s	8 m/s	4 m/s	6 m/s	8 m/s
0	2.6/0.5	0.1/0.9	0.1/0.2	0.1/0.1	0.0/0.3	0.0/0.5	0.1/0.1	0.0/0.2	0.1/0.1
30	2.6/2.2	2.8/3.2	3.1/2.5	1.5/2.4	0.8/2.2	0.9/2.1	2.5/1.5	2.2/3.8	2.4/4.0
60	5.5/3.7	4.7/4.4	4.4/3.6	2.9/3.7	1.6/3.4	2.0/3.5	4.1/3.5	4.3/5.4	4.6/5.7
90	6.4/3.9	6.3/6.1	6.2/6.4	4.4/4.4	2.3/4.2	3.1/4.3	4.8/4.2	5.1/6.0	5.4/5.7
120	6.9/3.7	7.2/6.4	6.8/6.5	4.5/5.3	4.1/4.9	4.2/5.2	5.4/4.8	5.7/5.7	6.3/5.7
150	7.4/5.0	8.3/7.2	7.4/7.4	5.5/6.6	6.0/5.8	5.8/6.1	6.3/6.6	7.1/6.1	6.9/6.5
180	8.1/6.5	8.7/7.1	7.8/7.2	7.3/5.5	7.5/5.6	6.7/5.1	7.2/6.1	8.0/5.8	8.0/6.2

*- Values are temperature differences (K) for the morning (9 a.m. to 12 noon)/afternoon (1p.m. to 4 p.m.). The ambient temperature ranged from 303 K to 307.4 K (30ºC to 34.4ºC) throughout the experiments

Table 4. [a]Mean values of the saturation effectiveness (%) and temperature difference between the ambient and evaporative cooler (K) for the different experimental factors

Factor Level	Saturation effectiveness (%)	Temperature difference (K)
Type of pad:		
Cedar shavings	64.4	5.0
Teak shavings	63.6	4.6
Coconut fiber	53.5	3.6
Speed of extraction fan (m/s):		
4	56.8	4.1
6	60.8	4.6
8	63.8	4.6
Time of testing (minutes):		
0	2.6	0.3
30	35.3	2.4
60	56.5	3.9
90	67.7	4.9
120	75.8	4.5
150	87.0	6.5
180	90.9	6.9
Period of the day:		
Morning (9 a.m. -12 noon)	64.4	4.5
Afternoon (1p.m. – 4 p.m.)	56.6	4.3

[a] - Mean values for each factor were obtained by averaging the measured values over the levels of the other three experimental factors.

For both parameters, the time of testing (0-180 mins) was the most important factor that affected the values. For the saturation effectiveness, this was followed by period of the day (morning or afternoon), type of pad and the speed of extraction fan. For the temperature difference, it was followed by the type of pad, speed of fan and period of the day. The most important interaction effects were between type of pad and period of day; speed of extraction fan and period of day and type of pad and speed of extraction fan in that order of importance (see Section 4.3.1).

4.2 Testing of the Evaporative Cooler at the Optimal Conditions

From the first set of results shown in Tables 2 to 5, it was determined that the optimal conditions for operating the evaporative coolers are using the cedar shaving as the media and the speed of operation of the extraction fan as 8 m/s. For comparative purposes, the evaporative cooler was used to store tomatoes for 14 days alongside the refrigeration method operating at 12°C (285 K), 90% to 95% relative humidity and storing at ambient conditions of 25°C (298 K) and between 80% to 85% relative humidity. Table 6 shows the values of the pH, total solubility solids (TSS) and depths of penetration of tomatoes using a penetrometer for the different days for the three methods of storage. Values showed that during the 14-day storage period, while the evaporative cooler more or less maintained the acidity and the TSS of the tomatoes, the refrigeration and ambient conditions made the fruits slightly more alkaline and increased the TSS. Also, the penetration depths of tomatoes stored in the evaporative cooler were slightly greater than those for the refrigeration method but were much lower than the tomatoes stored under ambient conditions.

Table 7 shows the mean values of pH, TSS and penetration depths for the three storage methods and days of storage. The three parameters increased with increasing days of storage. The tomatoes stored in the evaporative cooler had the lowest pH and TSS of the three storage methods. The 'F' values were obtained from the ANOVA (see Table 8). It shows that the effect of the main effect for the storage methods and the days of storage on pH, TSS and penetration depths were significant. For penetration depth, the method of storage was more important than the days of storage. For the pH and total solubility solids, the reverse was the case.

4.3 Discussion of the Results

4.3.1 Determination of the Optimal Conditions for Operating the Evaporative Cooler

The first stage of experiments was conducted to determine the optimal conditions for operating the evaporative cooler. The results for the parameters tested are discussed below.

Table 5. 'F' values in the analysis of variance for saturation effectiveness (%) and temperature difference between the ambient conditions and the evaporative cooler (K)

Sources of Variation	Degrees of freedom	Saturation Effectiveness	Temperature Difference
Type of pad	2	73.5	165.5
Speed of extraction Fan	2	24.3	17.3
Time (minutes)	12	347.1	314.2
Period of the day	1	89.8	4.5
Type of pad x speed of extraction fan	4	15.3	14.3
Type of pad x time (minutes)	24	6.8	3.0
Types of pad x period of day	2	29.0	31.3
Speed of extraction fan x time (minutes)	24	0.6	1.0
Speed of extraction fan x period of Day	2	28.7	30.1
Time (minutes) x period of Day	12	3.8	8.6

Table 6. pH, total solubility solids (ºBrix) and penetrometer depths (mm) for evaporative cooler operating at optimal conditions compared with refrigeration and storage of tomatoes at ambient conditions

No. of days	Method of Storage								
	Refrigeration			Evaporative cooler			Ambient conditions		
	pH	Total solubility solids (ºBrix)	Penetration depth (mm)	pH	Total solubility solids (ºBrix)	Penetration depth (mm)	pH	Total solubility solids (ºBrix)	Penetration depth (mm)
0	3.87	3.2	11.8	3.91	3.1	12.5	3.89	3.2	11.3
3	3.91	3.3	13.2	3.94	3.3	12.3	3.91	3.3	15.7
5	3.89	3.2	13.2	3.95	3.1	13.0	3.91	3.3	17.5
7	3.90	3.5	11.3	4.09	3.3	12.0	4.10	3.3	17.8
9	4.25	3.4	12.0	4.29	3.2	13.5	4.40	3.6	17.7
11	4.20	4.2	14.0	4.29	3.4	15.2	4.45	3.5	20.7
13	4.40	3.9	15.2	3.27	3.9	16.5	4.41	4.4	24.5
14	4.41	3.2	15.0	3.91	4.4	15.7	4.44	3.4	19.5

Table 7. Mean values for the pH, total solubility solids (TSS) and penetrometer depth (mm) for the different experimental factors

Factor Level	pH	Total solubility solids (ºBrix)	Penetration depth (mm)
Method of storage:			
Refrigerated	4.11	3.63	13.42
Evaporative cooler	4.05	3.46	13.82
Ambient conditions	4.22	3.53	18.26
Day of storage:			
0	3.89	3.15	11.98
3	3.92	3.28	13.72
5	3.91	3.20	14.56
7	3.98	3.36	13.72
9	4.32	3.41	14.39
11	4.30	3.70	16.61
13	4.40	4.07	18.72
14	4.04	3.65	16.72

Table 8. 'F' values in the analysis of variance for the pH, total solubility solids (TSS) and penetrometer readings (mm)

Sources of Variation	Degrees of Freedom	pH	Total Solubility Solids (ºBrix)
Method of Storage	2	19.18	3.54
Day of Storage	10	28.18	12.88
Method of Storage x Day of Storage	20	11.13	5.09

1) Type of Material Used to Construct the Evaporative Cooling Pad

The values of the saturation effectiveness and temperature difference were the greatest for the pad constructed from cedar shavings, followed by teak shavings and then coconut fiber. The results indicated that cedar shavings was marginally better than teak. The effectiveness of the evaporative pad depends significantly upon the material which has a clean wet surface as well as minimum air flow resistance. Cedar and teak shavings used in the experiment were approximately 1.12 x 10^{-4} m thick and 0.0381 m to 0.0508 m in length. From the experiments, cedar shavings were able to spread the water rapidly by capillary action and allowed a substantial percentage of air to enter than the other materials. Also, the surface area of the shavings and fibers which is exposed to moist conditions affects the rate of cooling the system that would experience. For a larger moisten surface area, a greater amount of cooling occurred.

The microscopic structure and orientation of the grains in the shavings can account for the ability of the materials to allow a considerable amount of heat transfer to occur which in turn produced a significant decrease in temperature. The grains in the cedar wood are straight and have a medium/ fine texture whilst teak has a considerably coarse texture and medium sized pores with grains being tangential (Green et al., 1999). Coconut fiber, however, offered considerable resistance to air flow due to the porosity and permeability of the fiber itself.

2) Time (minutes) for the Operation of the Evaporative Cooler

This was the most important experimental factor on the temperature difference and saturation effectiveness (see

Table 5). This trend is directly correlated to the variation of the wet bulb and dry bulb temperature with time. As time increased, the cooling effect increased within the system for the different materials. The maximum temperature difference which was attained was 8.72 K, at 180 minutes of operation. Also, the relative humidity inside the storage chamber increased with increasing speed for the cedar and teak shavings and decreased with the coconut fiber. The maximum relative humidity attained was from the cedar and teak shavings at 83.2% and 80.30% respectively. For teak, the maximum was 77.9%.

This is in accordance to the fact that achieving 100% relative humidity in evaporative cooling cannot occur as the pads are loosely packed thus allowing air to easily escape without having sufficient contact with the water (Xuan et al., 2012). This was observed with the coconut fiber pad, because of the texture of the coconut fiber, the contact time between the air entering the cooling chamber and the water from the pipe wetting over the pad was not long enough regardless of the system being in operation for 180 minutes. Thus, the heat and mass transfer was insufficient, which accounts for the low relative humidity attained contrary to the behavior of cedar and teak.

3) Speed of the Extraction Fan

The temperature difference increased for the pads constructed of cedar and teak shavings with an increase in speed of the extraction fan whilst the opposite occurred for coconut fiber (see Tables 2 and 3). Saturation effectiveness of the pad also increased for cedar and teak shavings. However, the saturation effectiveness for coconut fiber decreased with increasing speed. Increasing the speed of the fan was directly related to the rate at which water was removed from the materials and dispersed throughout the air. The increase in fan speed resulted of an increase in the water content in the air, which was directly related to the rate that water was removed from the shavings and the cooling effect which occurred. The coconut fiber was able to produce higher temperature differences and saturation efficiencies at 4 m/s because of the air voids present in the fiber itself, at a lower speed it was able to cool more effectively than it would at a higher speed as the rate of evaporation was less.

4) Period of the Day

The results for analysis variance are given in Table 5. This indicated that the period of the day was the second most important experimental factor on the saturation effectiveness. Period of the day however, had the least contribution to the temperature difference of the system. The results indicated that there was an interaction between the morning and afternoon periods for the behavior of the cedar and teak pads. The cedar material performed better during the morning period whereas teak produced the higher saturation effectiveness in the afternoon period. Thus, the ambient conditions throughout the day such as relative humidity, wet bulb temperature and dry bulb temperature affected the efficiency of the system in relation to the physical and microscopic properties of the materials. This trend was also observed in previous research conducted by Dağtekin et al. (2009), which indicated that the maximum temperatures attained inside as well as outside for the evaporative cooler was at 11.00 hours to 14.00 hours. The cedar pad provided the largest temperature difference in the morning period compared to the afternoon, whilst teak behaved in the opposite manner. This is as a result of the variation of the ambient dry bulb/wet bulb temperature over time. However, the overall ideal operating speed was at 8 m/s as this produced a substantially high saturation effectiveness than the other speeds and a reasonable temperature difference.

4.3.2 Testing of the Evaporative Cooler at the Optimal Conditions

The best method of storage affecting the firmness of the samples was the refrigerated conditions followed by the evaporative cooler and ambient conditions. It can be stated that for the refrigerated and evaporative cooler samples, the enzyme activity was in fact lower in comparison to those stored in ambient conditions. This finding was in accordance to the theory that the enzyme activity is a function of temperature (Cantwell, 2008). The storage temperatures for the refrigerator and evaporative cooler, were responsible for the decrease in the enzyme activity. The enzyme responsible for the breakdown of pectin in the cell wall is the peptidase enzyme. At these conditions the pectin in the cell wall was present which reinforced the cell wall fibers thus allowing it to remain firmer than those in the ambient condition. The tomatoes stored under ambient method of storage had the greatest penetration depths.

The pH content was greatly affected by the number of days the samples were left in storage followed by the TSS and the penetrometer readings. The pH content of the samples gradually increased as the storage period increased. However, the ambient conditions had the highest value of pH followed by refrigerated methods and the evaporative cooler. Thus, the evaporative cooler was the ideal method of storage in preserving the acidity of the tomatoes as well as its TSS content. The rise in the pH of the samples indicates the direct relationship that the acid concentrations in the samples decline with the level of maturity (Gordon et al., 2011). The decline in the level of acidity in the tomatoes is directly related to the increase in the sugar content as ripening increases as seen in the experiments conducted. The soluble content (°Brix) was used to assess the quality of the tomatoes. The physical color was visually observed and indicated that the tomatoes in the refrigerated and evaporative cooler were at development stages 5 and 6 throughout the test (90% surface covered was red-orange in color). However, the samples under ambient conditions quickly reached development stage 6 where the surface area of the tomatoes were 100% covered in a ruby red.

5. Conclusions

The following can be concluded from the study:

1) An effective way of storing fruits and vegetables could be the use of evaporative coolers using local materials like cedar shavings, teak shavings and coconut fiber as pad. It was found that Cedar shavings would be the best material in terms of saturation effectiveness and lowering the ambient temperature required for storage. The fan speed of 8 m/s produced the best results.
2) Tomatoes were tested under refrigerated, evaporative cooling and ambient conditions. The best method for storing produce in terms of skin firmness was the refrigerator followed by the evaporative cooler. The pH and the total solubility solids (TSS) of the tomatoes stored with the evaporative cooler were the lowest showing that while the refrigerator was the best in terms of maintaining the skin firmness, the evaporative cooler was the best storage method in terms of preserving the acidity of the tomatoes as well as their total solubility solids. Storage under the ambient conditions was the worst condition for the pH, TSS and penetration readings.

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Influence of Submicron Agro Waste Silica Particles and Vinyl Acetate on Mechanical Properties of High Density Polyethylene Matrix Composites

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Abstract: *Development of polymeric composites has invoked much interest in recent years. These fillers have great effect on the mechanical properties of polymers. The present study developed two groups of High Density Polyethylene (HDPE) matrix composites reinforced with silica particles extracted from rice husk ash (RHA) and Vinyl Acetate. The silica powder particles with average particle size of 0.489 μm were produced by Sol-gel process. HDPE based composites were prepared by melt compounding with 2, 4, 6, 8 and 10 wt. % of silica particles and 30 wt. % Vinyl Acetate with a Rapra single screw extruder and were produced by compression moulding. Mechanical behaviour and microstructure of the developed composites were studied. It was observed that the mechanical properties increased with an optimum value of 4wt. % of silica particles in HDPE. There was improvement in the mechanical properties of the siliceous HDPE composites when compared with Ethylene Vinyl Acetate (EVA) composites.*

Keywords: *Density Polyethylene, Ethylene Vinyl Acetate, Mechanical properties, Rice husk ash, Sol-gel process*

1. Introduction

Many of modern technologies require materials with unusual combinations of properties that cannot be met by the conventional metal alloys, ceramics, and polymeric materials. This is especially true for materials that are needed for aerospace, underwater, solar panels, electronics and transportation applications. For example, aircraft engineers are increasingly searching for structural materials that have low densities, are strong, stiff, and abrasion and impact resistant, and are not easily corroded. This is a rather formidable combination of characteristics. Frequently, strong materials are relatively dense; also, increasing the strength or stiffness generally results in a decrease in impact strength (Hull and Clyne, 1996).

Materials property combinations and ranges have been, and are yet being, extended by the development of composite materials. Generally speaking, a composite is considered to be any multiphase material that exhibits a significant proportion of the properties of both constituent phases such that a better combination of properties is realised (Chawla, 1998). According to this principle of combined action, better property combinations are fashioned by the judicious combination of two or more distinct materials. Property trade-offs are also made for many composites. A composite can also be described as a multi-phase material that is artificially made, as opposed to one that occurs or forms naturally. In addition, the constituent phases must be chemically dissimilar and separated by a distinct interface. Thus, most metallic alloys and many ceramics do not fit this definition because their multi-phases are formed as a consequence of natural phenomena.

In designing composite materials, scientists and engineers have ingeniously combined various metals, ceramics and polymers to produce a new generation of extraordinary materials. Most composites have been created to improve combinations of mechanical characteristics such as stiffness, toughness, and ambient and high temperature strength (Peters, 2008)

Many composites materials are composed of just two (2) phases; one is termed the matrix; which is continuous and surrounds the other phase, often called the dispersed phase. The properties of composites are a function of the properties of the constituent phases, their relative amounts, and the geometry of the dispersed phase. "Dispersed phase geometry" in this context means the shape of the particles and the particle size, distribution and orientation.

Due to exponential growth of photovoltaic (PV) industry, the demand for solar grade silicon (SoG-Si) has increased tremendously over the past decade due to their extraordinary properties and their existing and potential applications in science and technology, silica gel has a wide range of applications such as dessicant, as a preservative tool to control humidity, as an adsorbent, as a catalyst and as a catalyst support (Prasad and Panday, 2012).

At present, crude silicon known as metallurgical grade silicon, with 98-99% purity is obtained from quartz rocks by carbothermic reduction using electric arc furnace (Sarder, 2010). This silicon is further refined into high purity silicon through expensive and complicated purification process such as chemical vapor deposition (CVD) process which is used for production of electronic grade silicon. At the beginning of PV-activities in 1980s, the high purity scrap silicon from the micro electronic industry was used by the PV-industry (Muller *et al.*, 2006). However, increased demand that surpassed the limited supply of off-specification electronic grade silicon has created a thrust towards developing a dedicated technology for the production of solar grade silicon.

One of the approaches towards generation of SoG-Si is utilizing materials of very high purity to produce silicon. As an industrial waste, rice husk (RH) could be one of the potential raw materials for the production of solar grade silicon that can be used to develop siliceous particulate for use in solar panel assembly. Rice husk ash (RHA) is usually obtained by burning rice husk as fuel to generate energy from waste product. RHA is rich in silica (about 60%) and can be an economically viable raw material for the production of silica gel and powders (Chakraverty and Kaleemulah, 1991).

Although various uses for rice husk and RHA have been suggested in the literature, their disposal or utilization remains a major concern. Soluble silicates produced from silica are widely used in glass, ceramics and cement as a major component and in pharmaceuticals, cosmetics and detergents industries as a bonding and adhesives agents (Anon, 1997; Laxamena, 1982). Silica also has been used as a major precursor for variety of inorganic and organometallic materials which have applications in synthetic chemistry as catalysts, and in thin films or coatings for electronic and optical materials (Lender and Ruiter, 1990; Brinker and Scherer, 1990).

The use of silicon in solar panels has served to illustrate the unique properties of silicon in this particular application. While silicon is used in the manufacture of solar cells, silicone in the form of adhesives, sealants, coatings, encapsulants and potting agents are used in solar pane installation and assembly (Ancker *et al*., 1983). Within solar pane applications, silicone could be used as cell encapsulants to protect photovoltaic cells from delamination and corrosion and because of these, pure polycrystalline silicon metal is used in the solar cell construction.

The PV industry, generally speaking, is under significant pressure to reduce the cost of manufacturing PV modules. Before PV modules and the renewable energy they deliver can enjoy widespread adoption, the manufacturing process must be refined to a point at which the product, PV modules, has desirable price points as compared to conventional energy sources. In this current environment, there is great interest in new technologies that realized efficiencies in the module manufacturing process.

Encapsulants as a component in PV modules provide an opportunity to realise efficiencies in the module manufacturing process and overall module cost. The PV industry currently has a particular well-defined need for such improved materials. The PV industry has long – recognised the dramatic effect that corrosion has on module performance. Today PV modules typically include a polymeric encapsulant material to isolate the silicon components from the ever-present potentially adverse conditions created by various sources of water, including rain, snow and condensation. The isolation created by the encapsulant protects the PV components from corrosion and provides additional benefits, including mechanical support, electrical insulation and protection from mechanical damage (Lee *et al.,* 2008).

Polymeric encapsulants provide the desired isolation by bonding to a surface and limiting access to the protected areas or components. For example, encapsulants used in PV modules are typically bonded to one or more glass sheets to isolate the solar cells, or cell strings, from water in the module environment. The ability of a polymeric material to protect a surface is thus highly dependent on its ability to bond to a surface and limit access to corrosion sites. A strong correlation exists between corrosion protection and adhesive strength.

The dominant encapsulant used in the PV industry is based on a random copolymer consisting of about 67 wt.% polyethylene and 33wt.% polyvinyl acetate (Samuelson *et al;*1987); Polyethylene was chosen because it is very simple and inexpensive polymer. When used alone, however, it is typically an opaque or translucent (depending on the polymerization conditions) semicrystalline polymer with a modulus too high to mechanically protect a PV device. Polyvinyl acetate is a transparent, amorphous polymer, but it has a glass transition temperature (Tg.) of about 35ºC; making it too brittle or non-compliant under typical environmental exposure (Kempe *et al.,* 2007). Small amount of vinyl acetate is added to polyethylene to break up the crystallites, producing a semicrystalline, highly transparent material. Typically, 33wt.% of vinyl acetate is copolymerised with ethylene to get a good mix of properties such as a high optical transmission and a low Tg.

The adoption of Ethylene Vinyl Acetate (EVA) as a defacto standard occurred not because it had the best combination of properties, but because it was inexpensive and readily available. EVA was designed to be used on the front side of cells where high light transmission is required. It is also routinely on the back side of cells where light transmission is not necessary. In these applications, a white sheet of tedlar (or another reflective material) is commonly laminated to the back to improve performance by reflecting back the light that initially shines between the cells. This PV module construction method is common because sufficient research into inexpensive non-transparent alternative has not produced adequate materials that the industry trusts. Due to the nature of silicone chemistry, it is possible to produce a wide range of encapsulating materials with variations in colour, hardness, cure speeds and adhesion. Very soft silicone gels are chosen to provide a material that will accommodate extreme movement without inducing stress and also, facilitate the removal for repair or replacement of components. Harder materials will provide a more robust encapsulation (John, 2008).

Over the last several decades Ethylene Vinyl Acetate (EVA) has emerged as the dominant encapsulant material used in PV devices; early modules constructed with EVA demonstrated severe failure within a few years of putting the modules in use because of yellowing of the encapsulant (Yamada *et al.,* 2004). Improvement to EVA have been developed, including formulations with antioxidant and ultraviolet (UV) absorbers, that provide encapsulant materials that will not significantly yellow over the 20- to 30- lifeline of a module (Kempe, 2006).

Despite these improvements, EVA still has several drawbacks that affect its performance as an encapsulant material, particularly in PV module; for example, EVA suffers from non-ideal mechanical and thermal properties, a high diffusivity of water, and acetic by-product production (Barry *et al*., 2008). The newer thin-film technologies that are rapidly being developed in the PV industry may be more sensitive to the shortcomings of EVA. As crystalline silicon wafers become thinner, the mechanical properties of EVA may also prove insufficient. An alternative option would be to use an optically clear silica encapsulant with wide operating temperature range, excellent light transmission, repairable, ultraviolet stable, weather resistant, flexible and easy to use.

These special properties of silica were confirmed in the work carried out by Dorigato *et al;* (2010). Linear low-density polyethylene (LLDPE) based composites were developed by melt compounding LDPE with 1, 2, 3 and 4 vol. % of various kinds of amorphous silicon dioxide (SiO_2) micro- and nanoparticles. Dynamic rheological tests in parallel plate configuration were conducted in order to detect the role of the filler morphology on the rheological behavior of the resulting micro- and nanocomposites. A strong dependence of the rheological parameters from the filler surface area was highlighted, with a remarkable enhancement of the storage shear modulus (G') and of the viscosity (η) in fumed silica nanocomposites and in precipitated silica microcomposites while glass microbeads only marginally affected the rheological properties of the LLDPE matrix.

As the ability to isolate components and areas from potentially adverse condition is not absolute, there is a continuing need for improved encapsulant materials. A siliceous encapsulant providing even a minimal cost savings is expected to be well-received in the current environment, particularly if the encapsulant also provides beneficial technical properties. However, since the development of polymer based siliceous particulate composite from rice husk for solar cell applications looks feasible, a detailed investigation in this direction is therefore considered worthwhile.

The main objective of this work is to develop polymer based siliceous particulate reinforced composite using the silica extracted from rice husk ash as filler and study the mechanical properties of the composite.

2. Materials and Methods

Fine Silica powder of 0.489 μm particle size produced from rice husk ash by Sol-gel process was used in this research work; The rice husk was collected from a local rice mill in Ajaokuta steel city, Kogi State, Nigeria. Submiron particles of Titania powder supplied by Alfa Aesar High Purity Research chemicals, Vorna Valley, Republic of South Africa (RSA) were utilised as ultraviolet absorber. Maleic Anhydride Polypropylene (MAPP) supplied by Sasol Chemicals, Sasolburg, RSA was used as compatibiliser. High Density Polyethylene (HDPE) and Vinyl Acetate were supplied by DOW Chemicals, RSA. It has a melt flow index (MFI) of 8g/10min (XZ 89712-00 RD 10140182040), a molecular weight of 168,000g mol^{-1}, a melting point of 130^oC, and a density of 0.954gcm^{-3}.

2.1 Material Preparation

The rice husk was collected from a local mill in Ajaokuta Steel City, Nigeria (7.55611^{o}N6.65500^{o}E). It was thoroughly washed with water and dried in an oven at 80^{o}C for 24 hours to remove the water content. The rice husk was thereafter fed into an enclosed drum and burnt into ash, it was thereafter conditioned at a temperature of 650^{o}C in a muffle furnace. The obtained rice husk ash (RHA) was used in the experimental work.

2.2 Extraction of Silica gel from RHA

The Silica-gel was extracted from the RHA by sol-gel process. 10 grams of rice husk ash were added to various concentrations of sodium hydroxide (NaOH) solutions (0.5M -2.0M). The mixture was then heated in a shaking water bath at 100^{o}C in a beaker for one hour. The solutions were allowed to cool to room temperature, then, filtered through Whatman No 41 ashless filter paper and the carbon residue was washed with 100 ml of de-ionized water. Concentrated sulfuric acid was added to the obtained solution until pH 7.0 and incubated for

48 hours to promote silica gel formation. The silica gel produced was separated from soluble salt solution by vacuum filtration and washed with de-ionized water. Then silica gel was dried in an oven at 150ºC for 48 hours. The obtained white gel was pulverized into a powdery form and used for the experimental work.

2.3 Compounding of the Composite Materials

Predetermined proportion of HDPE, Silica powder (SiO_2), Titania powder (TiO_2) and Maleic Anhydride Polypropylene (MAPP) were mixed together in a tumbler mixer for 20 minutes in other to obtain homogeneous mixture. HDPE, Vinyl Acetate (VA) and MAPP were also mixed and designated as EVA. Each mixed samples was melt-blended together using a Rapra Single-Screw Extruder at a temperature of 200ºC -230ºC (Zone1=200ºC, Zone2=210ºC Zone 3=220ºC, Zone 4=230ºC) and rotor speed of 40rpm. The extrudates were ground with a grinding machine. Table 1 shows the proportions of constituents added in grams.

Table 1: Proportion of the Constituents added in grams

Sample Designation	wt.% of MAPP. (5%)	wt.% of TiO_2 (0.3%)	wt.%of SiO_2 (2,4,6,8 and10%)	Wt.% of VA (30%)	HDPE
Neat HDPE	---	---	---	---	1000 g
EVA (HDPE/VA)	50 g	---	---	300 g	650 g
2 Wt.% SiO_2/0.3 wt.%TiO_2/HDPE	50 g	3 g	20 g	---	927 g
4 Wt.% SiO_2/0.3 wt.% TiO_2/HDPE	50 g	3 g	40 g	---	907 g
6 Wt.% SiO_2/0.3 wt. %TiO_2/HDPE	50 g	3 g	60 g	---	887 g
8 Wt.% SiO_2/ 0.3 wt.%TiO_2/HDPE	50 g	3 g	80 g	---	867 g
10 Wt.% SiO_2/ 0.3wt.%TiO_2/HDPE	50 g	3 g	100g	---	847 g

2.4 Production of Siliceous HDPE Composites by Compression MouldingTechnique

The ground extrudates were poured in a tensile mould and a rectangular mould of dimension 150 mm x100 mm x4 mm. 10 g of the blend was used for the production of the tensile samples while 60g was used for the rectangular samples.

The filled mould was placed in between the lower and the upper plates of the Carver laboratory press at 230ºC for 10 minutes under applied pressure of 0.2 kPa. The materials were then water cooled at 20ºC min^{-1}. In this way, neat matrix and submicron composite samples filled with various volume of silica (2, 4 , 6 , 8 and 10 wt. %) at constant 5 wt. % Mapp and 0.3 wt.% Titania were prepared; EVA composite containing 30 wt.% Vinly Acetate, 5 wt.% MAPP and 65 wt.% HDPE was also prepared. Teflon sheet was used to cover the surface of the samples at the top and bottom part of the mould while silicone was sprayed at the inner edges of the mould for easy release after moulding.

2.5 Chemical Analysis of Silica gels

The silicon content of the samples was estimated using energy dispersive X-ray (EDX) spectroscopy (Kevex Instruments, Valencia, CA). This was done in other to select the powder with the highest silicon content for the experimental work.

2.6 Particle Size Analysis

The particle size of the powder was analysed using Horiba dynamic light scattering particle size analyser. The measurable particle size range of the instrument is 0.05-3000 μm and it is equipped with a small volume sample dispersion unit. A lens range of 300RF, a beam length of 2.4mm, and a presentation of 30AD with polydisperse analysis was used for this measurement. About 0.5 g of the silica powder was dispersed in de-ionised water in the sample dispersion unit of the instrument, vigorously mixed for about two (2) minutes at speed of 2100 rpm, and sonicated for 45 seconds. The ultrasonic waves were used to break or minimise any particle agglomerates that may be present in the suspension. Measurements were taken and the diffraction data and graphs recorded by the instrument software program.

2.7 Examination of the surface morphology of Silica gels

An AURIGA Scanning Electron Microscope (SEM) (Carl Zeiss Germany) with an accelerating voltage of 15kV was used to characterise the particle morphologies of the silica powder. Sample specimens were gold coated in a gold sputter coater for 90 seconds at 15 mA current output. The gold coating was necessary to ensure a conducting surface was obtained for electron bombardment and characterization. The Selected areas of interest were focused and micrographs were taken.

2.8 Mechanical Test

The composites cast samples were prepared for tensile test, charpy impact test, and micro hardness test. Scanning Electron Microscope was used to investigate the miscibility between the particulate and the matrix at the notched impact fractured surfaces of the composites.

2.8.1Tensile Test

Tensile tests were performed to determine the modulus, ultimate tensile strength and elongation at break of the samples using an Instron 5966 tester (Instron Engineering Corporation, USA), 2010 model, with a load cell of 10kN in accordance with ASTM D638-10 standards. Dog-bone-shaped samples prepared by compression moulding were tested in tension mode at a single strain rate of 5mm/min at room temperature 27 ^oC and relative humidity of 40 %. The test piece which is of gauge length 14mm was fixed at the edges of the upper and lower grip of the machine and the test commenced. As the test piece is being extended, graph is being plotted automatically and important tensile properties data were generated. The results presented are average of six individual tests sample.

2.8.2 Impact Test

Representative sample of neat polymer and composites were subjected to impact test on a Charpy V-Notch impact testing machine (Instron CEAST 9050), in accordance with ISO179-2:1997 and 1: 2011 standards. The pellets were moulded into a rectangular Charpy impact bar of dimension 80mm x 10mm x 4mm. The Notched samples were placed horizontally on the machine, the notched surface is directly opposite the swinging pedulum, the initial reading of the sample gauge length and the thickness were entered into computer system attached to the machine and the machine was switched on. The pendulum of the machine swung freely through angle 180^{o}C and fractured the sample. The results were printed out from the computer system. The results presented are the average of six individual tests sample.

2.8.3 Hardness

The hardness of the neat polymer and composites were measured with the aid of micro-hardness tester, model 900-390, in accordance with ISO 868:2008 standards. This machine measures the resistance to penetration by measuring the depth of impression. The test was carried out by indenting the sample with the instrument for about 5 seconds before taking the reading that was displayed on the manitor. Ten values were taken each for each sample from which the average was taken as the representative value.

2.9 Scanning Electron Microscopy Observation

The surface morphology of the samples was studied using an AURIGA Scanning Electron Microscopy (SEM) (Carl Zeiss, Germany) with an accelerating voltage of 15 kV. The notched impact fractured surfaces of the compression-moulded samples were mounted on aluminium stubs and were sputter coated with gold using EMITECH K950X sputter coater before being subjected to SEM analysis.

3. Results and Discussion

3.1 Chemical Composition of RHA and Silica Gel

To evaluate the effectiveness of the purification parameter and to confirm the presence of silica , EDX analysis was carried out on the silica powder extracted from RHA at different concentration of sodium hydroxide 0.5, 1.0,1.5, and 2.0M . The effect of NaOH is as shown in the EDX elemental spectra shown in Figures 1-5.

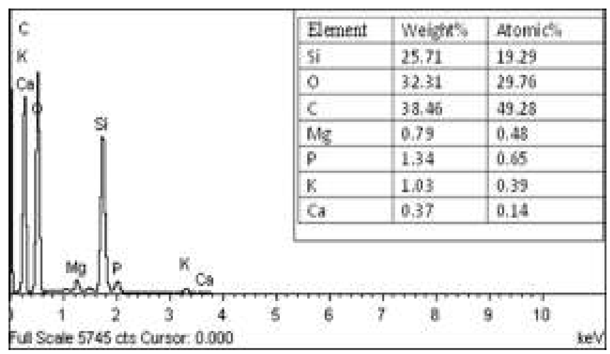

Figure 1. EDX spectrometric data of RHA

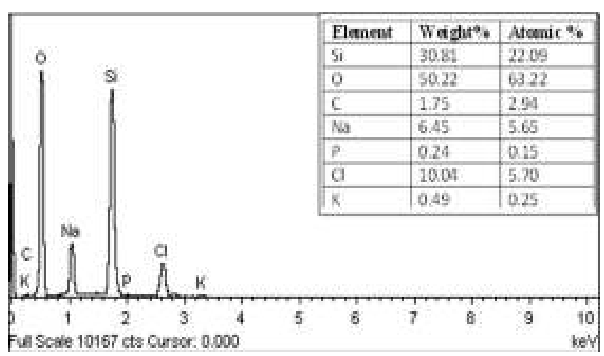

Figure 2. EDX spectrometric data of silica extracted from RHA with 0.5M NaOH

The major elements present are silicon and oxygen with other impurities such as sodium, carbon, phosphorus, chlorine and potassium. The elemental composition of silicon and oxygen increases with increase in NaOH concentration while the impurities decrease. The decrease in impurities mainly results from chemical reaction between acid metals, after which the metals are removed by filtration (Tzong-Horng, 2004). Figure 5 shows the EDX elemental spectra of the silica powder extracted from RHA with 2.0M NaOH concentration, which contains 65.35 wt% Si and 30.93 wt% O. The Si and O peaks that were observed confirm the presence of silica. The EDX spectra show that the content of Si and O is 96.28 in wt % and 97.80 in atomic %.

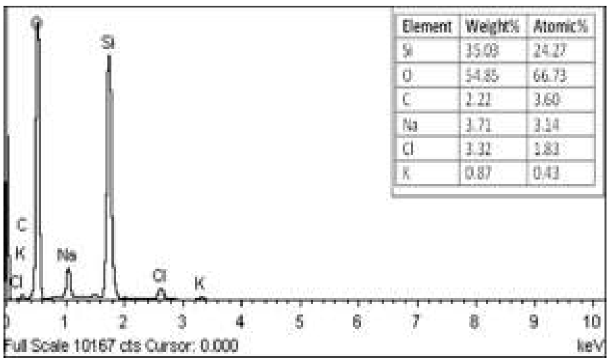

Figure 3. EDX spectrometric data of silica extracted from RHA with 1.0M NaOH

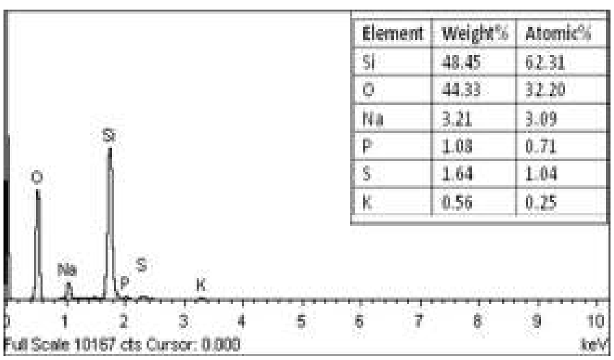

Figure 4. EDX spectrometric data of silica extracted from RHA with 1.5M NaOH

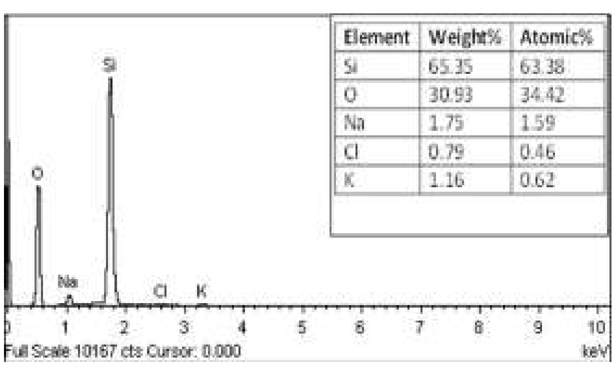

Figure 5. EDX spectrometric data of silica extracted from RHA with 2.0M NaOH

3.2 Particle Size Analysis

The chemical composition of silica powder extracted from RHA has been shown to be mainly silica (SiO_2). Since it is a known fact that particle size of filler materials has influence on the properties of composite, therefore, the cumulative particle size distribution of the powder with the highest silica content was analysed with Horiba dynamic light scattering particle size analyser as shown in Figure 6. The particle size distribution of the powder is approximately 0.489µm.

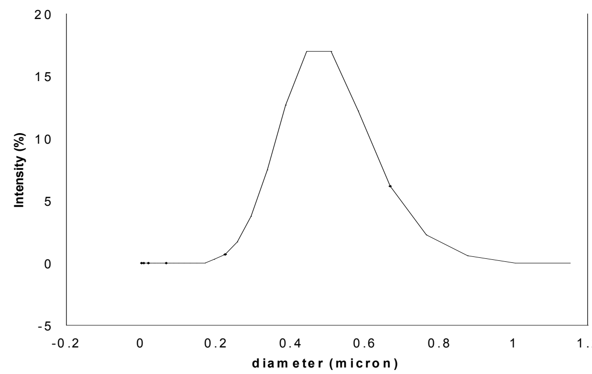

Figure 6. Particle size distribution by intensity produced by Horiba Dynamic Light Scattering Particle Size Analyser (The average Particle size is 0.489µm)

3.3 Examination of Surface Morphology of RHA and Silica Powder

The morphological features of the RHA and silica powder observed by scanning electron microscope (SEM) are shown in Figures 7-11. The SEM images were taken at a magnification of 500X. Figure 7 presents the image of as-received RHA which shows a porous and multifaceted particle shape and size. The honeycomb and porous morphology can be attributed to burning out of organic component in the rice husk during combustion. The hydrated silica subsequently polymerises to form a skeletal silica network which may explain the flaky and honeycomb-like structure in the SEM image of Figure 7.

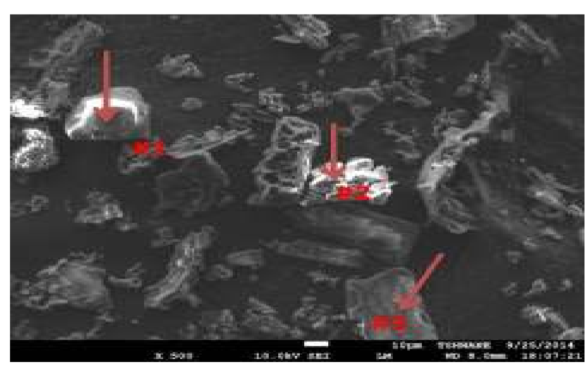

Figure 7. SEM Image of RHA with 0.5M NaOH

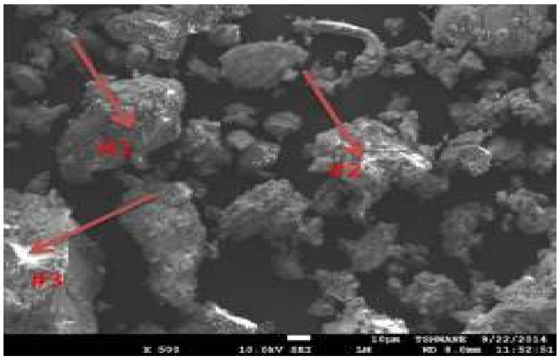

Figure 8. SEM Image of Silica gel extracted

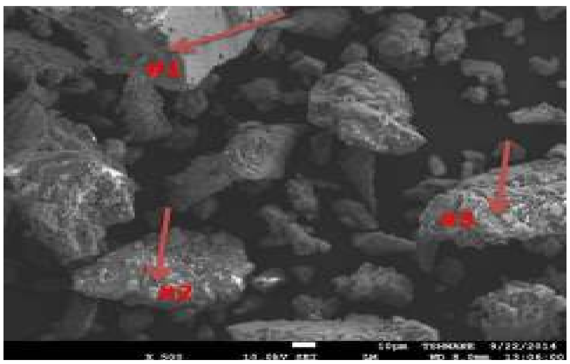

Figure 9. SEM Image of Silica gel extracted with 1.0M NaOH

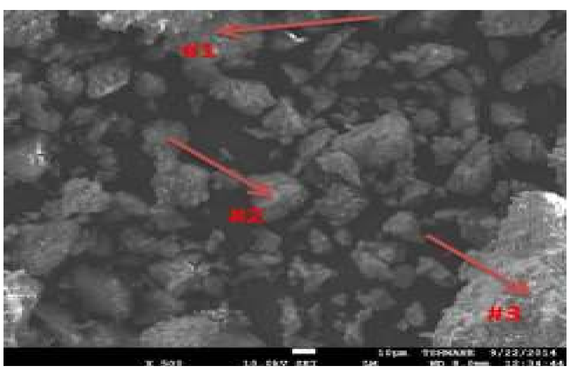

Figure 10. SEM Image of Silica gel extracted with 1.5M NaOH

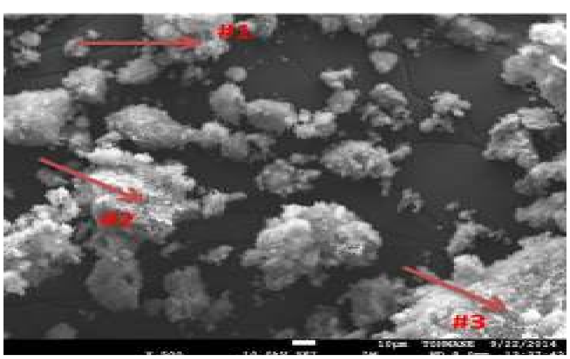

Figure 11. SEM Image of Silica gel extracted with 2.0M NaOH

The EDX analysis at points #1, #2 and #3 in Figures 8-11 shows the crusty and fibrous surface to be silicon-rich and was mainly SiO_2. The elemental composition for each silica powder produced was recorded by calculating the average of the elemental composition of point #1, #2 and #3, as shown in Figures 1-5.

3.4 Tensile Properties of the Composite

3.4.1 Ultimate Tensile Strength

Figure 12 shows the variation of the ultimate tensile strength for neat HDPE, HDPE/SiO_2/TiO_2 composites and Ethylene Vinyl Acetate (EVA). It was observed from the results that the strength of composites was more enhanced in HDPE/SiO_2/TiO_2 Hybrid composite than that neat HDPE and EVA. Clearly, composites developed with silica/titania particles exhibit the strengthening ability than EVA. However the best results were obtained with 4 wt% SiO_2 with a value of 60MPa. The ultimate tensile strength is a measure of the maximum stress a material can withstand before it fails. It is well known that the tensile strength of a particulate composite is usually reduced with dispersed phase particles content following a power law in the case of a poor filler/matrix bonding (Nicolais and Narkis, 1971).

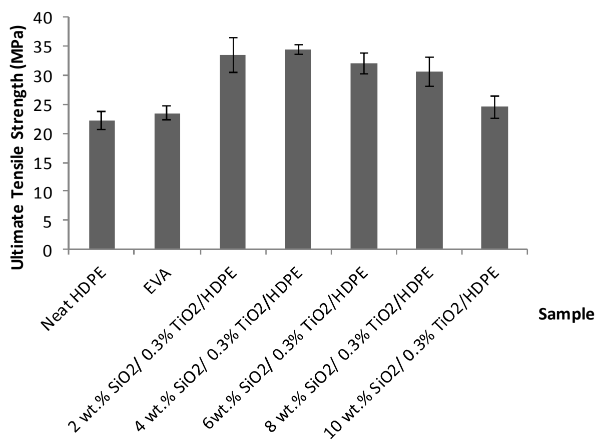

Figure 12. Variation of Ultimate Tensile Strength of Neat HDPE, EVA and SiO_2/TiO_2/HDPE Composites

The tensile strength is found to decrease with increasing particulate loading, as the particulate load increased, the weak interfacial area between the particles and the matrix increased, this consequently decreased the tensile strength (Yang, 2004, Lou *et al*., 2007, Jamil *et al*., 2006). This contradicts the results shown in Figure 12. In fact, when bonding between fillers and matrix is strong enough, the ultimate tensile strength of a particulate composite can be higher than that of the matrix polymer (Jancar *et al*., 1992).

The extremely effective improvement of tensile strength of the composites with the addition of submicron silica at lower weight fraction should result from chain inter diffusion and entanglement between HDPE and the silica particles. It is worth noting that when the amount of the submicron silica particles is greater than 4 wt.%, the silica particles agglomerate and the content of the HDPE chains is raised accordingly. The interlayer and the interfacial that stress transfer efficiency have to be decreased. An increase in the particulate content also increases the micro spaces between the particulates and the matrix, which weaken the filler matrix interfacial adhesion. This accounts for relatively low strength of HDPE/SiO_2/TiO_2 composites at higher particulate loading.

3.4.2 Young's Modulus of Elasticity

Young's Modulus is the ratio of the stress to strain in the linear region of the stress–strain curve. Young's Modulus of Elasticity for HDPE/SiO_2/TiO_2 composites, EVA and neat HDPE are illustrated in Figure 13. The neat HDPE and EVA have Young's Modulus of Elasticity of 719.83 MPa and 658.00 MPa respectively. On increasing the SiO_2 content, the modulus values increased. For the addition of 4wt% SiO_2 and 0.3wt% TiO_2, it was noticed that about 6.5% increase in Young's modulus occurred. The modulus value increases linearly up to 4wt% SiO_2 for HDPE/SiO_2/TiO_2composites; thereafter the value goes down. The increase in modulus is governed by the fact that the filler gives good reinforcement with the matrix. Furthermore, the particle size of the filler is small (489 nm) so that the aspect ratio is high. However, after 4wt% of SiO_2, the particles get agglomerated while processing the sample. Therefore, the dispersion becomes poor and the modulus decreases; the optimum filler loading is 4wt% for the best modulus with a value of 766.56 MPa.

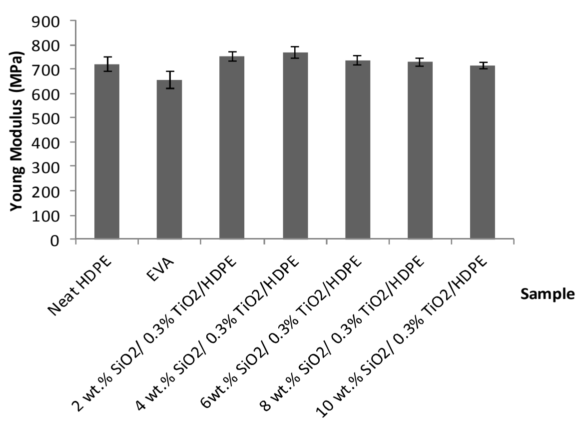

Figure 13. Variation of Young Modulus of EVA, Neat HDPE and SiO_2/TiO_2/HDPE Composites

3.4.3 Percentage Elongation at Break

Elongation at break values denotes the maximum extension of the samples while in tension. The elongation at break values depends on the filler/matrix interaction. Figure 14 revealed the variation of the percentage elongation at break of neat HDPE, EVA, and HDPE/SiO_2/TiO_2. The percentage elongation of neat HDPE and EVA are 210 % and 189 % respectively. From engineering point of view, percentage elongation at break is an important parameter describing the rupture behaviour of composite materials. The addition of particulates to polymers usually lowers its percentage elongation even though the polymer has high impact toughness (Chun *et al.,* 2002).

Figure 13 clearly indicates that this is not the case when submicron silica is used to reinforce the polymer matrix at lower weight fraction. From the graph, it was found that the elongation at break value is higher than the neat HDPE and EVA only at 2wt% of SiO_2 for the composites developed but decreases drastically when the filler weight fraction is greater than 2wt%. HDPE/SiO_2/TiO_2 composites with 2wt% of SiO_2 have the optimum value of 222 %.

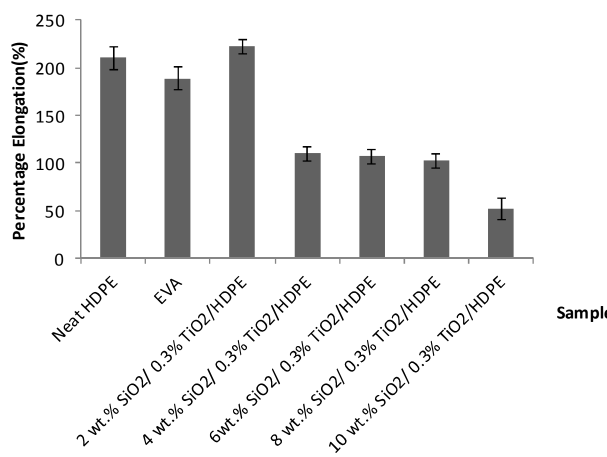

Figure 14. Variation of Percentage Elongation of Neat HDPE, EVA and SiO_2/TiO_2/HDPE Composites

3.4.5 Impact Properties

Impact strength is another important mechanical property that is difficult to predict in a filled polymer. The impact strength of a filled polymer also depends on the degree of polymer–filler adhesion, but in a more complex manner than the tensile strength (Thomas *et al.,* 2004). Other factors such as micro-scale morphological changes in a polymer that are caused by the filler, affect the impact strength of filled polymers. The presence of the filler may also cause a change in the fracture mechanism during impact from that commonly observed in the unfilled polymer. A polymer having good impact resistance should absorb most of the impact energy and propagate a crack very slowly.

One mechanism of slowing the rate of crack growth is the formation of crazes in the crack tip. Impact energy of the various compositions of submicron-composites, neat HDPE, and EVA were plotted against weight percentage of the filler in Figure 15. From the graph, the impact strength shows a light increase at 2wt% SiO_2 for $HDPE/SiO_2/TiO_2$ with values of 21.80KJ/m^2. Thereafter the values decrease linearly with increase in filler addition. Impact strength depends on the brittleness of the polymer matrix. The reason for the decrease in the property can be attributed to the poor adhesion or bonding at the interface between the matrix and the filler at higher filler addition. Similar observations were reported by Rozman *et al*; (1998) for the rubber wood-filled high density polyethylene composites.

There is a diminishing effect of the particulate on the impact strength due to a drastic decrease in break elongation because the particulate agglomerates and bridges the crack and increases the resistance of crack propagation (Liu *et al*; 2005, Sanadi *et al*; 1995). Addition of 5wt.% Maleic Anhydride Polypropylene as coupling agent allowed better filler/matrix adhesion which resulted into enhancement in the impact strength of the composites up to 6wt.% SiO_2 when compared with the neat HDPE. This observation was quite expected for filled composites and has been commonly observed. In the presence of the coupling agent, the interfacial bonding between the matrix and the filler increases and thus facilitates better transfer of stress.

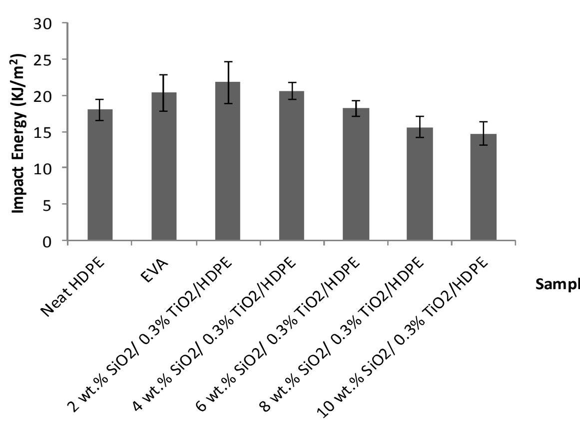

Figure 15: Variation of Izod Notched Impact Strength of EVA, Neat HDPE and SiO_2/TiO_2/HDPE Composite

3.4.6 Hardness Properties of the Composites

Figure 16 shows the variation of the hardness values for neat HDPE, EVA, and the siliceous HDPE composites developed. The test was carried out in accordance to ISO 868 standard using micro hardness tester. Ten readings were taking for each sample and the average was recorded as the representative value for each. From the graph, it was observed that 2wt% SiO_2 particulate reinforcement has the best hardness for composites developed, with values of 67.688 MPa for $HDPE/SiO_2/TiO_2$ composite. The hardness values of neat HDPE and EVA are 42.567 MPa and 44.426 MPa respectively. Hardness of a composite depends on the homogeneous dispersion of the particulate into the matrix (Premla *et al.,* 2002; Jamil *et al.,* 2006). Usually, the presence of a more flexible matrix causes the resultant composites to exhibit lower hardness (Jamil *et al.,* 2006).

The hardness of the siliceous HDPE composites showed an increasing trend with an increase in particulate content up to 2wt% but reduces drastically at higher particulate loading. The increase in hardness value at lower particulate loading may be attributed to the homogeneous dispersion of silica particles into the matrix with minimisation of voids and stronger interfacial adhesion between the matrix and the particulate while the reduction in hardness at higher particulate loading may be due to the agglomeration of particles which encourages voids formation and poor interfacial adhesion between the matrix and the particulate.

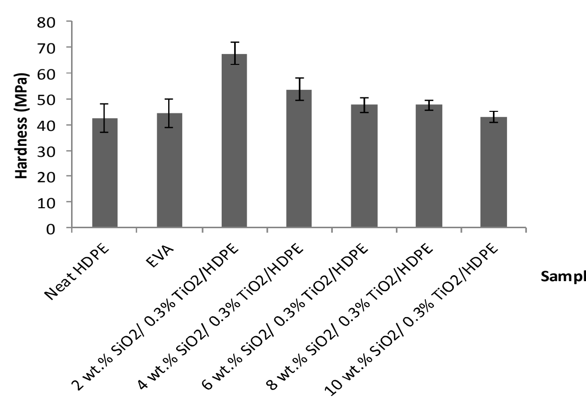

Figure 16. Plot of Hardness Values of EVA, Neat HDPE, SiO_2/TiO_2/HDPE and Composites

3.4.7 SEM Images of the Composites

A detailed investigation of the filler morphology within the matrix is a key parameter to impart desired mechanical properties of polymer-based composites. To have a clear images of the fractured patterns of the composites, SEM (Secondary Electrons) images of the notched impact fractured surfaces of the composites at different filler contents are shown in Figures 17-23.

Figure 17 revealed the notched impact fractured surface image of neat HDPE which has a relatively smooth fractured surface in association with terraced markings, indicating weak resistance to crack propagation. In the case of $HDPE/SiO_2/TiO_2$ composites with silica content of 2-4wt%, it is very clear that there is good dispersion of filler in HDPE matrix. The silica particles were uniformly distributed in the matrix with little agglomerates as shown in Figures 19-20. When the content of submicron silica approaches 6wt%, the morphologies of the composites' fractured surfaces become somewhat different. A number of agglomerates appear on the surface of HDPE/SiO_2/TiO_2 composites. These agglomerates are produced due to the debonding of the silica particles as illustrated by the arrow in Figures 21-23.

In general, an increased content of SiO_2 led to a larger agglomerates and hence greater debonding due to the poor interfacial adhesion at the particle – matrix interface. As there is not enough time for inducing matrix yielding after excessive particles debonding, the matrix beside the cavities seems

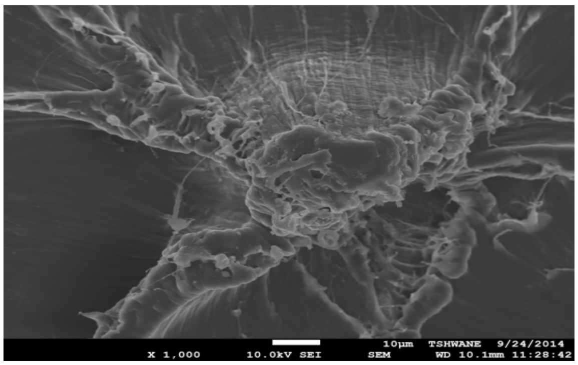

Figure 17: SEM of Neat HDPE

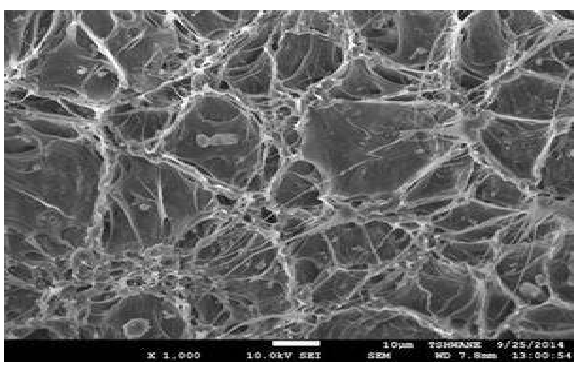

Figure 18. SEM of Fractured surface of EVA (30wt.% VA, 5wt.% MAPP and 65wt.% HDPE)

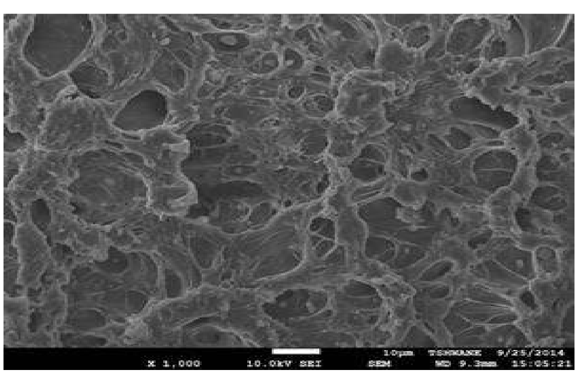

Figure 19. SEM of Fractured surface of the composite (2wt. % SiO_2)

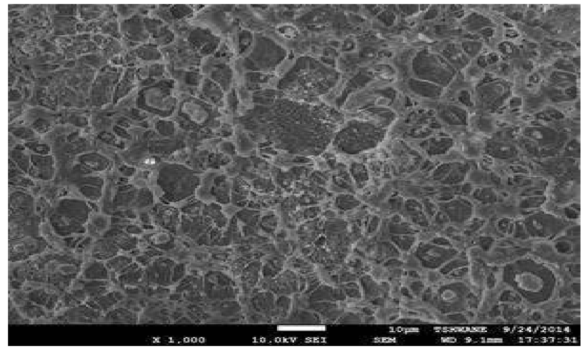

Figure 20. SEM of Fractured surface of the composite (4wt. % SiO_2)

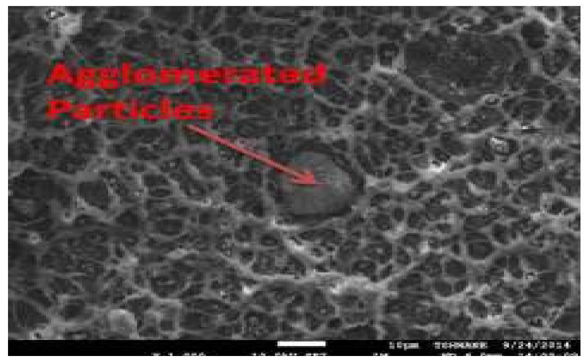

Figure 21. SEM of Fractured surface of the composite (6 wt. % SiO_2)

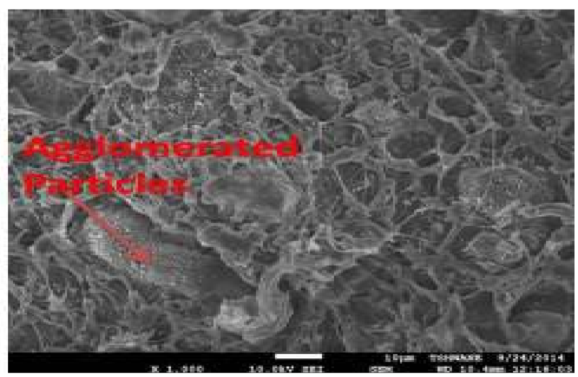

Figure 22. SEM of Fractured surface of the composite (8 wt. % SiO_2)

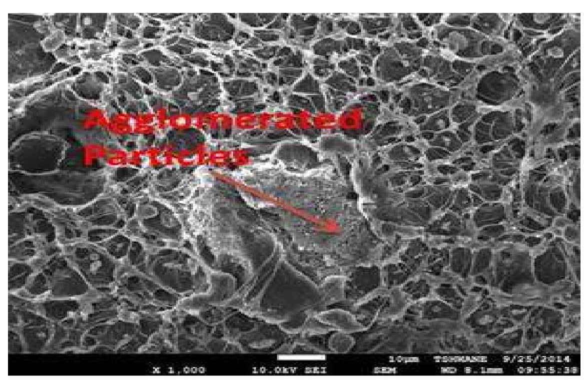

Figure 23. SEM of Fractured surface of the composite (8wt. % SiO_2)

to be rather flat; this coincides with the reduction of toughness of $HDPE/SiO_2/TiO_2$ composites at high SiO_2 loading.

4. Conclusion

Silica submicron particles were successfully produced by sol-gel process and were utilised for the production of $HDPE/SiO_2$ composites. From fracture surface analysis, it is clear that silica submicron particles, homogeneously dispersed in HDPE at lower weight percent loading as observed from white zones on the SEM images of the notched impact fractured surface. Moreover, it was observed that the addition of silica (SiO_2) submicron particles to HDPE causes an enhancement in the mechanical properties up to 4 wt.% SiO_2.

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Automated Money Detection Application for Trinidad and Tobago Currency Notes

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Abstract: *One of the challenges faced by visually impaired persons is the recognition of currency. Mobile phones are becoming more affordable and are being used by the visually impaired community to help them in their everyday lives. This paper investigates the Local Binary Patterns (LBP) as a method to recognise Trinidad and Tobago currency notes. A mobile application was developed and the effectiveness of the LBP algorithm was tested in terms of speed, robustness to illumination, scale and rotation. The LBP algorithm realised a recognition rate of at least 95 percent for Trinidad and Tobago currency. The recognition rates on mobile devices were compared for the LBP and the ORB (Oriented FAST and Rotated BRIEF) methods.*

Keywords: *Local Binary Pattern, Multiple Object Detection, Object Recognition, Visually impaired*

1. Introduction

The Visually Impaired community has been quite progressive in their approach to leading a normal life within the sighted world. One expanding technology that is being used by visually impaired persons is the mobile phone (Wong et al. 2012). Medium end mobile phones incorporate digital cameras and information gathered from the camera may be essential to real time applications. According to Dinh et al. (2013), data can be sent to a processing centre for further evaluation using the mobile capabilities of the phone for immediate responses. The use of mobile phone applications can be used to improve the lives of the visually impaired community by allowing them to easily identify currency bills, hence making monetary transactions quicker and easier. Applications such as Looktel (Sudol et al., 2010) are readily available for popular currencies such as the US Dollars, but there is a current challenge in the Caribbean to recognise regional currencies. None exist of acceptable quality. Furthermore, it would aid in the research for developing similar applications and increase awareness for the needs of visually impaired persons.

This is an image processing problem in object recognition. According to Gevers and Smeulders (1999), colour gives strong information for object recognition. A simple and effective algorithm is to match the colour histograms of the images. Wang and Lin (2010) proposed a currency recognition system based on colour and shape. For the colour recognition, background subtraction and histogram equalisation was used to improve accuracy. The images were taken using a scanner under constant lighting conditions. The RGB (red–green–blue) colour space was used and the mean for each channel was calculated. A lookup colour table was used to determine the primary colour of the currency. From the results, they achieved 100 percent accuracy under constant lighting conditions using new currency bills. However, the recognition rate dropped drastically under varying light conditions and the use of old bills. The system proved to be effective only under ideal conditions and fails in the real world environment.

Singh et al. (2011) suggested a currency recognition using template matching. The templates were cropped from the original image and the matching was done using cross correlation. Since template matching is scale and rotation dependent, they used pre-processing techniques to achieve scale and rotation invariance. Canny edge detection combined with simple trigonometry was used to calculate the angle of rotation of the currency. The currency was then rotated to align with the template image. In order to achieve scale invariance, the currency was scaled to the original image size (512 x 512) using nearest neighbour interpolation. The template matching was found to be computationally expensive on both laptop and mobile phone. To achieve real time recognition, Singh employed an optimised template matching on a Field Programmable Gate Array (FPGA).

According to Grauman et al. (2009), image recognition has made significant progress over the past decade through the development of local invariant features. Local invariant features is extracted from the image using Feature Detectors and represented using Feature Descriptors. In the developer's paper on Oriented FAST and Rotated BRIEF (ORB), Rublee et al. (2011) proposed a fast binary descriptor which is based on BRIEF. ORB uses variations to the popular keypoint detector FAST (Features from Accelerated Segment Test) and recent descriptor BRIEF. ORB claims to surpass older methods that rely on computationally costly detectors and descriptors. It is a computationally efficient replacement to SIFT that has similar performance but is less affected by noise. ORB also outperforms SURF while being two orders of magnitude faster. Their motivation was to enhance image recognition on low power devices without GPU acceleration. ORB also performed well against image transformations such as scaling, rotation, lighting and occlusion making it suitable for real world applications.

Pietikäinen (2010) stated that Local Binary Pattern (LBP) is a simple yet effective texture operator. The basic LBP works by thresholding the neighbourhood of each pixel in an image and creating a binary representation. Due to LBP simplicity and computational efficiency, it has become a popular algorithm in many visual applications such as Face Recognition. Ahonen et al. (2004), used a variation to LBP known as Circular LBP. This variation used a variable radius and sample points allowing it to be more robust to scaling. Also, the image was separated into blocks allowing the Circular LBP to capture not only fine grain details but macro structures. The algorithm was tested on the Facial Recognition Technology database and it outperformed other methods such as Principal Component Analysis and Elastic Bunch Graph Matching. Circular LBP was able to achieve recognition of 97 percent when recognizing faces with different facial expressions. The algorithm was also tested against varying illumination conditions and achieved a recognition rate of 79 percent. Given the advantages in robustness to scaling, speed and accuracy, current literature has not shown the use of LBP for currency recognition.

In this paper, LBP was used as the main recognition algorithm for the currency recognition system. The algorithm was implemented on an android mobile phone and was used to extract texture features from the bills. The texture features can be then be represented in a compact binary form which allows for easy storage and fast recognition rates. The algorithm was adjusted to allow for multiple object detection and object recognition. The objects chosen was the birds, since this was the key distinguishing feature of Trinidad and Tobago bills. Multiple object detection was used to detect and segment the objects and then the object recognition module was used to verify the object detected in order to increase accuracy.

2. LBP for Currency Recognition

Ojala et al. (1996) proposed the original LBP operator. The original LBP operator considered a 3 x 3 neighbour around each pixel in the image and threshold the neighbours against its centre pixels to produce a binary number. The binary number was converted to a decimal value where it was concatenated into a single histogram to retain spatial information. A formal description of the algorithm can be described below:

$$LBP(x_c, y_c) = \sum_{p=0}^{P-1} 2^p \, s(i_p - i_c) \quad (1)$$

The central pixel can be defined as (x_c, y_c) with intensity i_c and the neighbour pixel i_p.
s(x) is the sign of the function and can be denoted as

$$s(x) = \begin{cases} 1 & if\ x \geq 0 \\ 0 & else \end{cases} \quad (2)$$

From this description, very fine grain details can be captured from the image since the operator acts on a pixel level making it a very local descriptor. After the operator was published, it was found that a fix neighbourhood failed to encode details that varied in scale. Ahonen et al. (2004) extended the operator to use a variable neighbourhood. The basic idea was to use an arbitrary amount of neighbours and align them on a circle of variable radius. This method allowed Circular LBP to capture neighbourhoods such as spot, spot/flat, line, edge and corner which is shown in Figure 1.

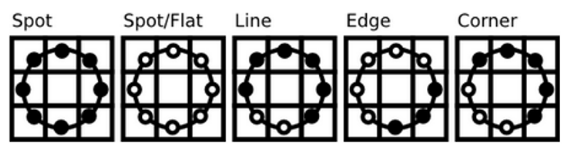

Figure 1: Circular LBP neighbourhoods
Source: Ahonen et al. (2004)

Any given point (x_c, y_c) in the image, the position of the neighbour (x_p, y_p), $\rho \in P$ can be calculated by:

$$x_p = x_c + Rcos\left(\frac{2\pi p}{P}\right) \quad (3)$$

$$y_p = y_c - Rsin\left(\frac{2\pi p}{P}\right) \quad (4)$$

R is given as the radius of the circle and P is the number of sample points.

This new operator is an extension of the original LBP and is called Circular LBP or Extended LBP. By using a variable circle, some of the sample points on the circle may not correspond to the pixel location and hence, the sample points get interpolated. There are many interpolation techniques; one that achieves good results with Circular LBP is bilinear interpolation. Bilinear interpolation can be represented by the function below:

$$f(x,y) \approx [1-x \quad x] \begin{bmatrix} f(0,0) & f(0,1) \\ f(1,0) & f(1,1) \end{bmatrix} \begin{bmatrix} 1-y \\ y \end{bmatrix} \quad (5)$$

The histogram of the labelled image $f_i\ (x,\ y)$ can be defined as:

$$H_i = \sum I\{f_i(x,y) = i\}, i = 0, \ldots, n-1 \qquad (6)$$

The number of different labels produced by the LBP operator is given by n where

$$I\begin{Bmatrix} 1, & A\ is\ true \\ 0, & A\ is\ false \end{Bmatrix} \qquad (7)$$

The histogram now contains local micro patterns of edges, spots and flat areas over the whole image.

Ahonen et al. (2004) also incorporated spatial information in the Circular LBP algorithm. This was done by dividing the LBP image into m local regions and obtaining the histogram of each. The overall representation of the image was found by concatenating all the histograms to form one histogram. The final histogram of the image contains three levels of locality which makes it effective. The first level gives us a representation of the patterns on a pixel level, the second level is the sum of the histograms of the local regions, and the third level is the concatenation of the regional histograms to form a global histogram of the image. In order to match the histograms of the images, similarity measures such as Histogram intersection, Log-likelihood statistic and Chi square statistic may be used.

Chi square statistic was chosen as the dissimilarity measure. (Lancaster and Seneta, 2005) states that the Chi square algorithm can be represented by:

$$x^2(S, M) = \sum_i \frac{(s_i - M_i)^2}{(s_i + M_i)} \qquad (8)$$

Ahonen et al. (2004) concluded from the results that the Chi square algorithm performed better than Histogram intersection and Log-likelihood statistic for face recognition. Using the "Olivetti Research Laboratory, Cambridge database of face images" they were able to obtain excellent recognition rates up to 98 percent. The database also contained images that were scaled up to 10 percent and rotation of 20 percent, meaning the algorithm showed robustness to scale and rotation.

According to Liao et al. (2007), LBP can also be used for object detection. They proposed a variation to the original LBP called Multi-scale Block Local Binary Pattern (MB-LBP). The original LBP uses a 3x3 operator on every pixel in the image, MB-LBP however uses a 9x9 operator. The algorithm to calculate the MP-LBP is given below:

1) Find the average block intensity of block zero by adding the all the pixels in the block and dividing by 9.
2) Repeat steps 1 for blocks 1-8.
3) Compare block 1 to the centre block 0, if the intensity of block 1 is greater or equal to the centre block, set block 1 to one. If block 1 intensity is less than the centre block, set block 1 to zero.
4) Repeat step 3 for blocks 2-8.
5) Concatenate the values for each block (1-8) in a numerical order and convert to a decimal number.

After all the labels for each block have been found, the uniform patterns are extracted. Uniform patterns can reduce the length of the feature vector and also makes the LBP robust to rotation. A local binary pattern is defined as uniform if it contains at most two bit wise transitions from 0 to 1 or 1 to 0 if the bit pattern is traversed circularly. The following is a group of uniform patterns "00000000 (0 transitions), 01110000 (2 transitions), 11001111 (2 transitions)". Non uniform patterns contains two or more transitions such as "11001001 (4 transitions) and 01010010 (6 transitions)".

This type of LBP is called Uniform LBP or Rotation invariant LBP. MB-LBP histograms were plotted using the FRGC ver2.0 face database. It was observed that the top 63 bins of the histogram corresponded to the uniform binary patterns. From this, a new definition of uniform local binary pattern can be establish as the top 63 bins where the non-uniform patterns can be represented as one bin or label. This shortens the histogram to 64 bins in total. This new representation was called Statistically Effective MB-LBP (SEMB-LBP).

Figure 2 shows a system overview of the various sub modules that form the implemented currency recognition system. The android camera captures one frame in an RGBA format. The Input Image module pre-processes the image to send it to the multiple object detection module. This pre-processing is a conversion of the image from a RGBA format to grayscale. The multiple object detection module checks to see if any objects are present in the given frame. If there is an object, the object is cropped and sent to the object recognition module However, if no object is present or more than one object is present, the input image module sends another frame. The object recognition module receives the cropped frame and matches the cropped image to the images in the database. If there are no matches the system goes back to the Input Image module, but if there are matches, the results are sent to the Voice Output module. The Voice Output module receives results from the Object Recognition module and it speaks the results to the user. The system is then repeated, starting from the Input Image module.

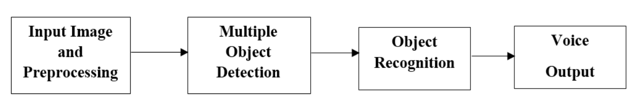

Figure 2: Sub-modules of the Currency Recognition System

3. Results

Each of the tests involved a different experimental setup. Table 1 shows the test used and its respective experimental setup. All of the testing was done using an

Intel 2.1 GHz dual core processor on a windows 7 OS. Each sub-section would contain the detail of the testing data and experimental setup. This section highlights the algorithm's performance in terms of robustness to illumination, speed, scale and rotation. The recognition rate of the algorithm was then compared to the popular ORB method from the developers' paper by Rublee et al. (2011). Figure 3 shows the testing data used in the experiments which consisted of Trinidad and Tobago currency. The images consisted of cropped images of the Front side of the Trinidad currency bills and each image shows a particular bird which is the object to be recognised.

Table 1: Experimental Setup

Test	Hardware/Software	Method
Original LBP Transformation Illumination Variations Colour Variations	Intel Pentium CPU B950 @ 2.10 GHz, 4Gb ram using Python 2.7 with OpenCV 3.0	The five and one dollar images from the dataset were imported using a Python script. The LBP algorithm was coded into a Python module and the binary LBP image transformation was performed.
Circular LBP: Radius Variation Chi-Square distance Added Noise Scaling and Rotation Variations	Intel Pentium CPU B950 @ 2.10 GHz, 4Gb ram using Visual Studio 2013 C++ with OpenCV 3.0 – Face Recognizer API	A sample one dollar was imported using C++ and converted to a LBP histogram and stored in a database. A copy of the sample dollar was used and altered according to the various tests. The copy dollar was then converted to a LBP histogram and compared to the original sample using Chi-Square.

Figure 3: Sample of Trinidad and Tobago Currency Notes used as Testing Data

Typically, training data contained 800 images per bill. The images consisted of cropped images of the birds on the bill in different lighting conditions. Four hundred images were taken at zero degrees and another four hundred images were taken of the object at 180 degrees. Figure 4 shows a sample of the Training data for one dollar bill.

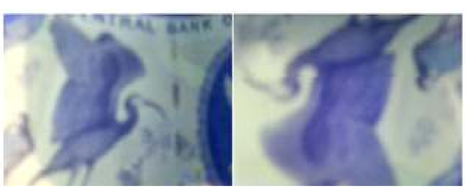

Figure 4: Sample of Trinidad and Tobago 1 Dollar Note used as Training Data

3.1 Robustness to Illumination

Figure 5 shows the verification of the Circular LBP robustness to illumination variations and validates the choice of the algorithm for a real world application. The dataset consisted of a sample one dollar bill, however the results can be replicated using other currency bills. The illumination was varied with Visual Studio C++ using OpenCV libraries. The altered image was then sent to a Python script where the Circular LBP is performed. The figure shows the transformation of the original image, the original image darkens and the original image brightens respectively. Comparing the Circular LBP transformations, it can be seen that they are relatively unchanged which shows Circular LBP robustness to illumination variations.

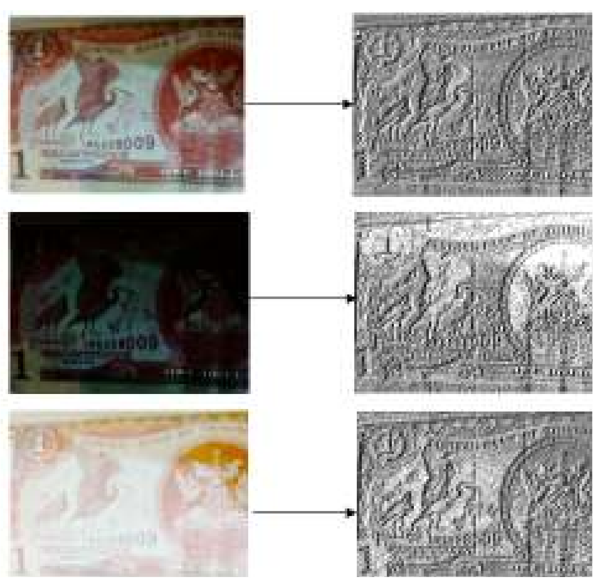

Figure 5: Example of LBP image transformation

3.2 Speed

Figure 6 shows the relationship between the Prediction time and the number of histograms in the database. The prediction time is the time to calculate the circular LBP of the input frame, convert to a histogram and compare it using chi-square to the histograms stored in the database. For 100 histograms in the database, the time taken would be 1.288 seconds. The graph also shows a linear relationship. Therefore, it can be said that the time complexity of the circular LBP plus the histogram comparison is proportional to the amount of histograms in the local database. When tested on the mobile device, prediction time was less than 20ms, making LBP suitable for real time performance.

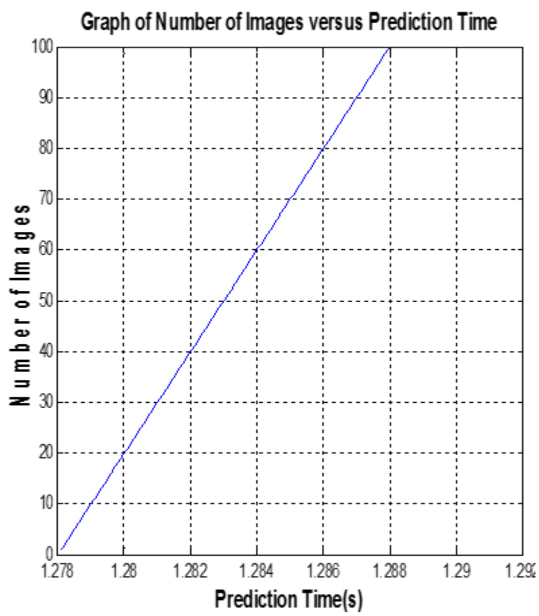

Figure 6: Number of images versus Prediction time

3.3 Scale and Rotation

Figure 7 shows Circular LBP robustness to scaling variations. It validates the choice of Circular LBP for this application where the currency is not at a fixed scaled. The test data consisted of a sample one dollar and a duplicate of the same one dollar except scaling and rotation variations were made. OpenCV libraries with Visual Studio C++ were used to vary the scale. The amount of scaling was varied and the Chi-square distance was observed. From the Figure 7, Circular LBP responds well to scaling, tolerating scale shifts up to 70 percent of the image with the Chi-Square distance remaining below 30. 100 percent represent no scaling.

Figure 8 shows how the Chi-Square distance responds to a changing angle of rotation. It validates the choice of Circular LBP for this application where the currency is not at a fixed orientation. From the data, the average confidence level is approximately 53. However the confidence level drops at the angles 90,180,270, and 360. This was due to interpolation, since at these angles no interpolation is performed.

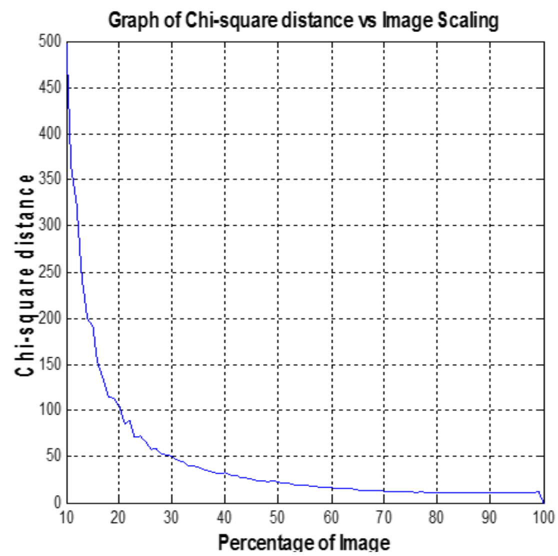

Figure 7: Figure 40-Graph of Chi-Square distance vs Image Scaling

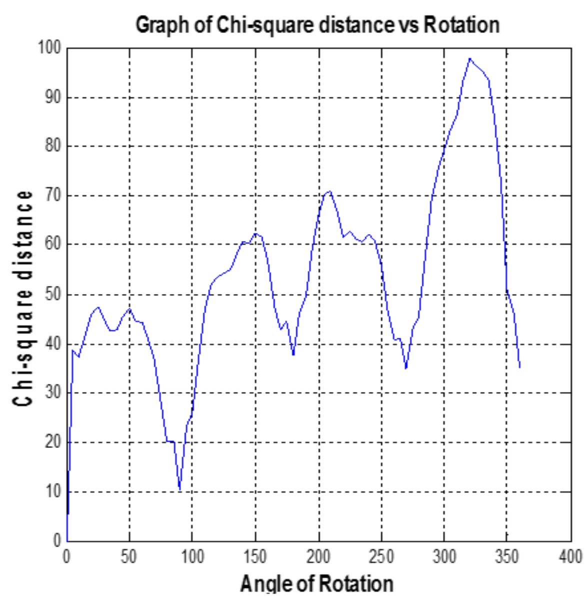

Figure 8: Graph of Chi-Square distance versus Rotation

In Figure 9, the recognition rate of LBP is shown. The dataset consisted of 100 images of the six currencies. The test was performed using Visual Studio C++. Both test for LBP and ORB were carried out separately but under similar lighting conditions, no scaling and no rotation. The Recognition Rate is a key factor in Currency Recognition. From Figure 9, it can clearly be seen that LBP performs on average above 95

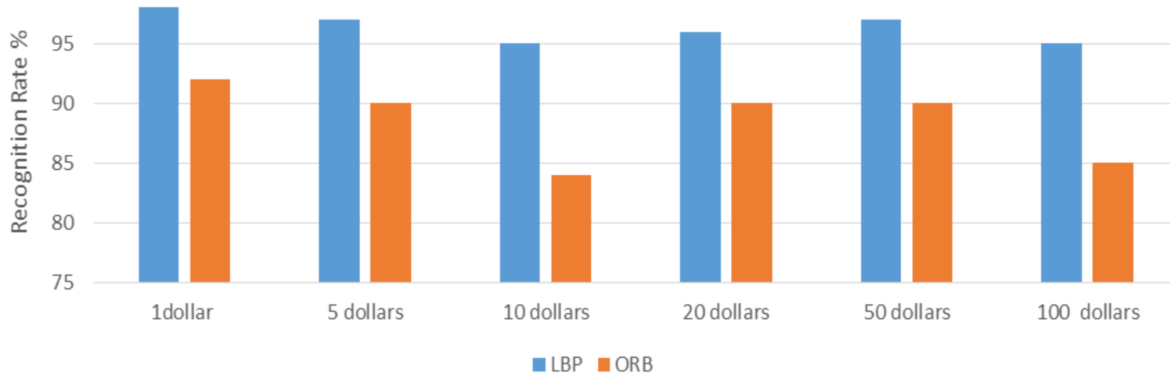

Figure 9: Recognition Rate of LBP versus ORB

percent in the Recognition Rate test compared to 85 percent of the ORB method.

4. Conclusion

LBP proves to be a simple yet powerful algorithm. LBP variations such as Circular LBP and Multi-scale Block LBP can accomplish object detection and object recognition. LBP effectively extracted fine grain texture features from the currency. These features were easily represented as a compact histogram which consumed little memory and allowed for fast histogram matching The low complexity of the histogram matching permitted real time and on-device matching on mobile phones.

From the results, LBP is computationally fast and achieves a prediction time of less than 20ms on mobile phones, allowing for real time currency scanning. Also, LBP showed high recognition rates of 95 percent and above, which is a key factor in currency recognition. LBP is also robust to various lighting conditions and exhibits excellent performance in poorly lit rooms. Also LBP is invariant to scaling and rotation making it practical for the currency recognition system as the visually impaired user would not know the exact distance from the bill or the orientation.

There were many limitations to this system; however, satisfactory results were still able to be obtained. Some major limitations were:

1. Lack of Resources- Training the Recognition System was a computationally intensive task. On a 2.1 GHz dual core CPU, training time took over half hour per currency bill.
2. Testing- testing was only performed on a Samsung galaxy S3 and a Samsung tab 3. The application compatibility with other android devices could not be tested due to time and resource constraints.

This paper presents a fast and accurate method to recognise Trinidad and Tobago currency notes. This method uses the LBP method for object recognition and proves to be robust to rotation and scale variation. It was implemented on an Android platform and provided a recognition rate of at least 95 percent which was better than the ORB method presented in (Rublee et al., 2011). Deployment of the work in this paper would greatly assist the visually impaired community of Trinidad and Tobago in making monetary easier cash transactions. In the future, this work may be extended to include other regional currencies.

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Notes and Guidance to Authors

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