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**PRESIDENTS OF THE ASSOCIATION OF PROFESSIONAL ENGINEERS OF TRINIDAD AND TOBAGO**

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<td>Rupert V.S. Aleong</td>
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**Note:** APETT's logo was designed by Derek Aleong.
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by Kit Fai Pun and Cilla Pemberton
Editorial

I. Notes from the Editors

The APETT Journal aims to provide a broad coverage of subjects relating to engineering. Preference will be given to papers describing original engineering work, or material of specific interest to engineers and those working in related fields, in Trinidad and Tobago (T&T) and the Caribbean region.

On 7th-8th December 2018, The Fourth Industrial Engineering and Management (IEM-2018) Conference was hosted by the DMME - Industrial Engineering Office, the Faculty of Engineering of The University of the West Indies (UWI), in collaboration with the Association of Professional Engineers of Trinidad and Tobago (APETT) and other local, regional and international engineering organisations. “Striving for performance excellence with quality management and industrial engineering management (IEM) practices” was the theme of the Conference.

The Conference offered a platform for academics, engineers, government officials and industry practitioners to share experiences, present research results, and review recent applications and developments in the IEM areas. This special issue of The APETT Journal included selected contributions of research work, according to their respective focuses and outcomes. These contributions encompassed the work carried out by researchers, professionals, and practitioners from a wide range of public and private-sector institutions, government and non-government organisations.

II. About This Issue

This Issue (Volume 47 Number 2) of the Journal includes five (5) articles and also an excerpted version of 34 abstracts/papers submitted to The IEM4-2018 Conference. The relevance and usefulness of the five articles are summarised below.

K.N. Hassanali, “Deploying Synergistic Standardisation and Optimisation Strategies within Coatings Manufacturing Plants across the Caribbean Region: A Case Study”, discusses a standardisation model for attaining financial and operational synergies within individual coatings manufacturing plant of ANSA Coatings Limited (ACL) throughout the Caribbean region. ACL was established from the integration of Penta Paints Caribbean Limited (Penta) and Sissons Paints Trinidad Limited (Sissons) in 2012 and then acquired Berger Paints Caribbean in 2017. With this acquisition came great opportunities to maximise profitability across all three (3) brands; Penta, Sissons and now Berger. There is a need to standardise and optimise operations throughout the region; BPTL, BPJL, BPBL, ACL and Sissons Grenada (GD). In this paper, he elucidates some of the main financial and operational contributions attained through the acquisition of the Berger brand.

Based on their work, “Developmental Requirements Implementing Industry 4.0 in Trinidad and Tobago Companies”, Jason R. Rameshw ar and Graham S. King, aim to design the strategic systems for small and medium-sized enterprises (SMEs) to evolve to I4.0 based on developmental requirements. The assessment of I4.0 literature developed I4.0 readiness tool and 23 qualitative open-ended semi-structured questions. Interviews were conducted with executives and tours of companies (namely, SoftCom, StickCom, PanelCom, ClothCom, MetalCom, FurnCom) assessed company’s present status and ability for implementing I4.0. The paper contributed to the development of new definition for I4.0 as “the evolutionary change in decentralised connected systems to enable the intelligent integration of the horizontal and vertical value chains of the organisation”. It also identified two key phases for SMEs to evolve into I4.0, namely 1) I4.0 readiness level tool and developmental requirements, and 2) Formation of an I4.0 Cluster Project Initiative.

K.N. Hassanali and K.F. Pun, “Modelling Productivity Dynamics of Manufacturing Capital Investment Projects in Trinidad and Tobago: A Study Agenda”, explore the productivity within the realm of project management (PM), and describe a study agenda with a conceptual model proposed for assessing the dynamics of productivity from project planning to project execution in Trinidad and Tobago (T&T). The research agenda would combine 1) an extensive literature review, 2) empirical survey and interviews, and 3) the development and evaluation of a Productivity Management Framework (PMF) for manufacturing firms. The novel contributions of this study are firstly, to identify key PM attributes and relate them to the design of project productivity (PP) metrics for capital investment (CI) projects, and secondly, to develop the PMF accompanied by an implementation guide for use in manufacturing firms in T&T.

In their paper, “Fault Characterisation System of Induction Motors Based on Vibration Signal Analysis Using Machine Learning Techniques”, M. Jodhan and J. Bridge investigate an automated machine learning approach for detecting and characterising faults in an induction motor based on accelerometer readings. The vibration waveforms are pre-processed using Fourier transforms and wavelets. Key statistical parameters of these curves are explored including the skewness and the kurtosis; these are then used to isolate identifying features for various common faults in induction motors. These features are then fed into a supervised machine learning algorithm and a fault classification system is built. The method described herein is validated with vibration data.
collected from a laboratory fault simulator. The performance of the system is discussed and its applicability to industrial situations is described.

A. Koonj-Beharry and K.F. Pun, “Transcitioning of Manufacturing towards Industry 4.0 in Trinidad and Tobago: A Proposed Framework with Discussions of the Role of Industrial Engineers”, review the evolution of innovation concepts and industrial revolutions and draw parallels of the contributions of Industrial Engineering (IE) in industrial developments, with particular reference to the manufacturing profile and business environment in Trinidad and Tobago (T&T). Incorporating the analysis of empirical data/findings acquired with desk research, a conceptual framework of Manufacturing Innovation Management (MIM) is proposed to integrate and guide the innovation activities of manufacturing firms. Discussions are made on the advocate of the framework, along with the IE provisions and challenges and the ‘enabler’ role of industrial engineers in T&T. It concludes by underlining the importance of IE and asserting that Industrial Engineers are equipped with the necessary skills-set embedded in safeguarding industrial developments and transition towards Industry 4.0.

III. Acknowledgements

On behalf of the Association, we gratefully acknowledge all authors who have made this issue possible with their research work. We greatly appreciate the voluntary contributions and unfailing support that our reviewers give to the Journal. Our reviewer panel is composed of academia, scientists, and practising engineers and professionals from industry as listed below:

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Finally, the views expressed in articles are those of the authors. This does not necessarily reflect the opinions or policy of the Association.

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November 2019
Deploying Synergistic Standardisation and Optimisation Strategies within Coatings Manufacturing Plants across the Caribbean Region: A Case Study

Kevin N. Hassanali

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(Received 03 January 2018; Revised 21 July 2019; Accepted 03 September 2019)

Abstract: ANSA McAL (ANSA) is a robust, stable and progressive business institution operating in Trinidad and Tobago (T&T) and the region. ANSA Coatings Limited (ACL) is a reputable and diversified manufacturer and supplier of paint and coatings in the Caribbean. ACL was established from the integration of Penta Paints Caribbean Limited (Penta) and Sissons Paints Trinidad Limited (Sissons) in June 2012. In 2017, ANSA acquired Berger Paints Caribbean which included Berger Paints Barbados (BB) Limited (BPBL), Berger Paints Jamaica (JM) Limited (BPJL) and Berger Paints Trinidad Limited (BPTL). With this acquisition came great opportunities to maximise profitability across all three (3) brands; Penta, Sissons and now Berger. However, to seize this opportunity implied an intrinsic need to standardise and optimise operations throughout the region; BPTL, BPJL, BPBL, ACL and Sissons Grenada (GD). This paper discusses a standardisation model for attaining financial and operational synergies within each coatings manufacturing plant throughout the Caribbean region, while elucidating some of the main financial and operational contributions attained through the acquisition of the Berger brand.

Keywords: Standardisation, Optimisation, Synergy, Manufacturing, Coatings, Caribbean

1. Introduction

In today's highly competitive global environment, companies are striving to remain in existence since the levels of competition have grown to greater heights. The manufacturing sector in many countries is in a state of transition, experiencing growth in emerging economies, while shrinking but becoming more productive in advanced economies. The new manufacturing giants with low wage economies tend to compete on cost, while the established players prefer to move up the manufacturing value chain to compete on technology and innovation. Lean manufacturing techniques which control costs and improve quality are pervasive. According to the Chartered Institute of Management Accountants (CIMA, 2010), the manufacturing sector faces several significant challenges: lack of loan funds, currency volatility, fears over the sustainability of supply chains and downward pressure on prices.

As such, Berger International Private Limited (BIPL), the Singapore-based indirect subsidiary of Asian Paints, sold its entire stake in Lewis Berger (Overseas Holdings) Limited (LBOH), BIPL's wholly owned subsidiary, to ANSA, a diversified conglomerate which operates across eight industrial sectors. With this major acquisition ANSA intended to capitalise on the potential synergies which inherently existed when integrating Berger into the Penta and Sissons business model. There was expected increases in manufacturing productivity where lean manufacturing techniques and optimisation strategies were simultaneously deployed.

Synergy is the concept that the value and performance of two companies combined would be greater than the sum of the separate individual parts. Synergy is a term that is most commonly used in the context of mergers and acquisitions (M&A). Synergy, or the potential financial benefit achieved through the combining of companies, is often a driving force behind a merger. Therefore, in addition to capturing a greater portion of the coatings market share in the Caribbean region, ANSA acquired Berger to also capitalise on the synergistic opportunities’ existent. M&A are made with the goal of improving the company's financial performance for the shareholders. Two businesses could merge to form one company that could produce more revenue than either could have been able to independently, or to create one company that is able to eliminate or streamline redundant processes, resulting in significant cost reduction (Investopedia, 2018).

Synergy is reflected on a company's balance sheet through its goodwill account. Goodwill is an intangible asset that represents the portion of the business value that cannot be attributed to other business assets (Investopedia, 2018). Synergies may not necessarily have a monetary value, but could reduce the cost of sales and increase profit margin resulting in future growth. In order for a synergy to have an effect on value, it must produce higher cash-flows from existing assets, higher expected growth rates, longer growth period, or lower cost of capital. This added value was realised with the integration of Berger with ACL. Post-acquisition of Berger implied an inherent need to integrate the operations of the ACL brands (i.e., Penta and Sissons) with the Berger brands to capitalise on synergetic profits. In this milieu, the objective of this paper is to discuss a standardisation model for attaining financial and operational synergies within coatings manufacturing plants in the Caribbean region.
2. Literature Review

2.1 Rationalisation and Standardisation Defined

Currently, there are a range of products that exist amongst all three (3) brands; Berger, Sissons and Penta, some of which are similar, some of which are exclusive to each specific brand and some of which are marked for discontinuation. Therefore, there exists a grave opportunity for product rationalisation and product standardisation. The number of stock keeping units (SKUs) is the standard measure of product variety in a company. Each of these SKUs may be stored in multiple locations, leading to geographical variety. Reducing either product variety or geographical variety generally would allow a company to maintain current customer service at a lower cost (or improve service without incurring additional costs). The fundamental mechanism underlying both approaches is equivalent, even if there are significant differences between them. In both cases, product rationalisation can be defined as a business strategy that consists of aggregating individual demands (Gerchak and Mossman, 1992). The concept of product rationalisation originated with Eppen’s (1979) and Eppen and Schrage’s (1981) work on multiechelon inventory systems with geographically dispersed stocking locations. In the coatings industry context, product rationalisation can be considered as the process of reducing the number of coating SKUs, thereby promoting the ability to invest more in the SKUs that make the most profit. The goal of product rationalisation is to reach a maximum number of customers with a minimum number of products thereby maximising revenue of all product SKUs.

Product standardisation and adaptation empirical investigations were performed since the 1970s (Leonidou, 1996), where, according to Doole and Lowe (2008), a product standardisation strategy refers to a uniform representation of all aspects of the product such as: the quality, the materials being used, product name, and packaging for all markets; regardless of location around the world. On the contrast, product adaptation is when changes and special modifications are made to adjust to each market in question. This project employed a hybrid of product standardisation and adaptation. In the context of the coatings industry, product standardisation would be considered as the process of setting generally uniform characteristics for all coatings SKUs. This includes standardisation of formulas for common ranges across territories coupled with the standardisation of raw materials (RMs) required for manufacturing.

2.2 Optimisation of Manufacturing Operations

In addition to the merits achieved in product rationalisation and standardisation, this paper also addresses the manufacturing operations of all brands throughout the four (4) territories; with their economic impact, while making product with the existing manufacturing processes. Optimisation is usually driven to satisfy: 1) Market demand (delivered: volume, quality); and 2) Economics (incurred: cost savings, resource utilisation).

These drivers represent the main impact of production on company profits, with short-term and long-term effects on the profit and loss (P&L) statement. The bottom line is that the most production processes are underutilised; and the use of mature, accessible mathematical technology unlocks that latent capacity, which is of significant value (Moreno, 2006). The best possible performance is “Optimal Operations”. In the process industry, it is called “Process Optimisation”. Other components that qualify for “lean” in the sense of avoiding waste (non-value-added), and not missing opportunities for improvements are: “Lean Design” (the most common emphasis today), “Lean Logistics – and Supply Chain,” “Lean Maintenance,” “Lean Scheduling,” “Lean Safety,” and “Lean Scheduling” (Moreno, 2006). While the concepts of lean and all its attributes are not within the scope of this paper, it is valuable to place mention of its attributes since ANSA intends to undoubtedly thread down the lean road in the very near future.

2.3 Design of a Standardisation Model Based on Market Research

Market research assists in the overall management of the marketing function. A Marketing Manager must prioritise the more important and pressing problems selected for solution, reach the best possible solution based on the information available, implement the solution, modify the solution when additional information so dictates, and establish policy to act as a ready made solution for any recurrence of the problem (Danaher et al., 2001). As suggested by Goeree (2008), marketing research often focuses on understanding the “Customer” (purchasers, consumers, influencers), the “Company” (product design, promotion, pricing, placement, service, sales), and could also be expanded towards the environment to include “Competitors” (and how their market offerings interact in the market environment).

Market research is a process of gathering, analysing and interpreting information about a market, about a product or service to be offered for sale in that market, and about the past, present and potential customers for the product or service; research into the characteristics, spending habits, location and needs of a business’s target market, the industry as a whole, and the particular competitors faced (Gupta and Benedetto, 2007). Market research provides relevant data to help solve marketing challenges that a business would most likely face - an integral part of the business planning process. In fact, strategies such as market segmentation (identifying specific groups within a market) and product differentiation (creating an identity for a product or service that separates it from those of the competitors) are impossible to develop without market research (Nevo, 2001).
Market research allows a company to discover who their target market is and what these consumers think about a product or service before it becomes available to the public Van Den and Joshi (2007). ANSA recruited the services of a third-party company to conduct regional market intelligence studies to determine brand positioning of the three (3) brands. The results of the market study led all standardisation and optimisation efforts across all brands.

3. Study Methodology

The methodology can be summarised, as follows:

1. **Desk Research** - In many projects, carrying out an initial desk research stage is strongly recommended to gain background knowledge to a subject as well as providing useful leads that would help to get the maximum from a research study. Specific literature related to rationalisation, standardisation, optimisation and the importance of market research and brand positioning was reviewed.

2. **Acquisition of Empirical Data from each Territory** – Essential data pertinent to cost, revenues, GPs, manufacturing formulations, RM listings and supply chain data were collated and utilised during the rationalisation, standardisation and optimisation exercises.

3. **Analysis of Empirical Data** - Both qualitative and quantitative analysis were used in the design of a standardisation model, utilising spreadsheets and Enterprise Resource Planning (ERP) software. However, due to the sensitivity of company financial and operational data, only some analytics were shared throughout the paper.

4. **Development of a Standardisation Model** – This model was utilised during the execution phase of the project at ANSA. The core parameters of the model include:
   a. Rationalisation of the product SKUs produced by the five (5) coatings plants: BPTL, BPJL, BPBL, ACL and Sissons GD.
   b. Standardisation of the coatings’ SKUs formulations, across all three (3) brands for all five (5) coatings plants.
   c. Standardisation of the coatings RMs across all three (3) brands for all five (5) coatings plants.
   d. Optimisation of manufacturing operations throughout all three (3) brands for all five (5) coatings plants.
   e. Determination of which plants would maintain manufacturing operations, and which would be converted to distribution centres.

4. Considerations of the Model Development and Results

With the results from the regional market intelligence, product rationalisation, formula standardisation and RM standardisation, the project ensued in the right direction. Figures 1 and 2 depict the conceptual model for the rationalisation and standardisation of the three (3) brands and the optimisation of manufacturing for these brands throughout the region, respectively.

**Figure 1. Conceptual Model for Rationalising and Standardising Brands across the Region**

**Figure 2. Conceptual Model for Optimising Manufacturing Operations throughout the Region**

### 4.1 Product Rationalisation

Rationalisation of all products was led by the finance department and critical thresholds were prescribed. All locally produced product SKUs exceeding two (2) years in the market and which existed in the bottom 0.5% of gross profit (GP) were earmarked for discontinuation from the SKU portfolio. The sales and marketing department was then elected to provide reasonable justifications for maintaining any SKUs found within this list marked for discontinuation. Additionally, any imported product over two (2) years in the market and which existed in the bottom 0.25% of GP were earmarked for discontinuation from the SKU portfolio. The sales and marketing department was elected to provide reasonable justifications for maintaining any SKUs found within this list marked for discontinuation.

An annual objective was then stipulated to continuously reduce SKUs over two (2) years old, as a perpetual best practice. This implied constantly reviewing SKU portfolio and removing counter-productive SKUs (continuous state of product rationalisation).
Table 1. ACL SKU Discontinuation Summary

<table>
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<tr>
<th>Territory</th>
<th>Criteria</th>
<th>Measure</th>
<th>TOTAL</th>
<th>KEEP</th>
<th>DISCONTINUE</th>
<th>% Keep</th>
<th>% Discontinue</th>
</tr>
</thead>
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<tr>
<td>ACL 2018</td>
<td>Total SKUs</td>
<td>Unit</td>
<td>1228</td>
<td>1063</td>
<td>165</td>
<td>86.56%</td>
<td>13.44%</td>
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<tr>
<td>ACL 2018</td>
<td>Total Volumes</td>
<td>Litres</td>
<td>2,224,238</td>
<td>2,167,313</td>
<td>56,925</td>
<td>97.44%</td>
<td>2.56%</td>
</tr>
<tr>
<td>ACL 2017</td>
<td>Total SKUs</td>
<td>Unit</td>
<td>1354</td>
<td>1190</td>
<td>164</td>
<td>87.89%</td>
<td>12.11%</td>
</tr>
<tr>
<td>ACL 2017</td>
<td>Total Volumes</td>
<td>Litres</td>
<td>4,585,717</td>
<td>4,476,655</td>
<td>109,062</td>
<td>97.62%</td>
<td>2.38%</td>
</tr>
<tr>
<td>ACL 2016</td>
<td>Total SKUs</td>
<td>Unit</td>
<td>1326</td>
<td>1152</td>
<td>174</td>
<td>86.88%</td>
<td>13.12%</td>
</tr>
<tr>
<td>ACL 2016</td>
<td>Total Volumes</td>
<td>Litres</td>
<td>5,031,380</td>
<td>4,975,974</td>
<td>55,406</td>
<td>98.90%</td>
<td>1.10%</td>
</tr>
</tbody>
</table>

Table 1 shows the results of the analysis performed in ACL. Several critical points were identified. For instance:

1. In 2018, of the 165 SKUs to be discontinued, 151 were ‘manufactured products’ (91.52%), while 14 were ‘imported products’ (8.48%).
2. In 2017, of the 164 SKUs to be discontinued, 160 were ‘manufactured products’ (97.56%), while 4 were ‘imported products’ (2.44%).
3. In 2016, of the 174 SKUs to be discontinued, 164 were ‘manufactured products’ (94.25%), while 10 were ‘imported products’ (5.75%).

At the end of the exercise, it was found that for ACL 1,428 SKU’s (i.e., 86 %) were tagged as “Keepers” and 238 (i.e., 14%) as “Discontinue”. Since the rationalisation exercise identified that high percentages of products marked for discontinuation were manufactured locally, this resulted in the availability of additional plant capacities throughout all manufacturing plants. This spare capacity was utilised in the manufacture of products that were in high demand, thereby increasing the gross profits on all products manufactured. Additionally, finished goods provisioning was significantly reduced and eliminated in some cases.

4.2 Formula Standardisation

Prior to formula standardisation, the same SKU was manufactured in each of the five (5) coatings plants using a different formula, which proved to be costly and inefficient. The technical personnel at Berger and ACL led the formula standardisation process. Across all brands, a comparative study was conducted to determine which product formula was superior amongst all brands, with further tests done between the ANSA brands and external competition. Some of the parameters tested included: warranty, odour, VOC g/l, stability, skimming, settlement, syneresis, abrasion resistance (100% removal at cycles), finish (visual), gloss at 60 degrees, viscosity Ku at 31°C +/- 1, alkali resistance, mud cracking, yellow index, opacity and whiteness.

4.3 Raw Material Standardisation

The RM standardisation exercise was segregated into colorant standardisation, resin and additives standardisation and paint pails labeling standardisation. A universal colorant is a concentrated dispersion of colour pigment that is used to tint a base paint. A line of well-designed universal colorants could be used for both water-based paints and solvent-based alkyd paints, most often for architectural applications. Modern universal colorants are solvent-free, water-based materials. The colour adjustment of the architectural paints could be done either in the production plant (In-Plant tinting) or in the shops where customers buy their paints (Point-of-Sale tinting). ANSA utilises both in-plant tinting and point-of-sale tinting.

Standardising the colorants across all brands allows for improved procurement and allows for aggressive price negotiations with colorant suppliers, since the volumes procured would then be much larger as all brands would now be consuming similar colorants. The same rule applied to the procurement of resins, additives and paint pail labels, in that standardised RMs allowed for larger volume requirements, which ultimately compelled suppliers to reduce their unit costs.

4.4 Optimisation of Manufacturing Operations

A detailed analysis was conducted by the financial and operations team at ANSA to determine the best locations for manufacturing operations. For elaboration on this analysis, one product SKU, ‘Everglow white GL’ was analysed. The calculation method adopted for this example was used for all SKUs in determining the most economically feasible location for the manufacturing hubs. It was found that BPJL displayed the lowest cost of production when compared to the other territories analysed; ACL and BPBL.

The cost to produce the total volumes of this SKU at BPJL was 11% less than the cost to produce the same volumes at ACL. As well as this, the cost to produce the total volumes of this SKU at BPJL was 6% less than the cost to produce similar volumes at the BPBL plant. In fact, there were calculated increases in the cost to produce this SKU’s volumes at ACL and BPBL by 11% and 6% respectively. It is essential to note that the cost of RMs, packaging materials, labour, overheads and shipping were included in the analysis. A complete calculation was conducted for all major product SKUs to determine at which location it was more feasible to produce that specific SKU.
Labour and shipping were the two (2) main factors which determined the location of the manufacturing hub, since all products and RMs would have been rationalised and standardised at this point. Product mix by territory was now realised which led to optimised regional batching across all brands. Within the territories selected for minimum manufacturing, the warehouses and manufacturing plants were converted to distribution centres for all brands.

5. Discussions

The transition Berger experienced post-acquisition by ANSA, has ultimately led to the entity thriving more economically, financially and operationally. It came at a time when the coatings industry has become extremely competitive with major players such as Sherwin-Williams and Benjamin Moore capturing increasing levels of market share regionally. Across the five (5) coatings plants, standardisation efforts yielded positive outcomes for ANSA in the form of financial and operational opportunities. These opportunities are almost axiomatic and can be summarised, as follows:

1. By integrating the ACL operations with the BPTL operations, all Berger SKUs could be manufactured under the overheads of ACL, thereby significantly reducing the cost of production for all Berger SKUs.
2. By standardising RMs across all brands (Berger, Sissons and Penta) throughout the five (5) territories (i.e., BPTL, BPJL, BPBL, ACL and Sisson GD) would allow for better pricing from suppliers as the quantities being ordered are larger.
3. Warehouse space requirements would ultimately be reduced significantly since product rationalisation reduces the number of SKUs across all brands and RM standardisation reduces the wide array of RM SKUs.
4. Manufacturing optimisation across all brands and throughout all territories would lead to reduced labour and shipping costs thereby reducing the overall cost of production.
5. Optimised re-ordering process with better lead time management – which ultimately results in fewer or zero stock outs of critical RMs required for production.
6. The overall cash flow management of ACL and Berger would be vastly improved due to optimised procurement procedures.

Figure 3 shows a before and after depiction pre- and post-integration of Berger with the Sissons and Penta brands, while the ensuing discussion points deliberated, provides a summary of the results obtained by territory.

5.1 T&T Integration Results

In T&T, the manufacturing operations of BPTL was integrated into the operations at ACL to derive significant synergies and cost savings. The integration of both manufacturing plants added a further 36% volume (Kilo Litres) capacity to ACL’s existing annual manufacturing plant capacity at the time.

To add this volume to ACL’s capacity, several considerations were undertaken. These included:

1. ACL budget for 2017 required the plant to produce 77% of its average annual plant capacity.
2. BPTL’s three (3) year average sales volume was 85% of its average annual plant capacity.
3. BPJL would manufacture Penta, Sissons and Auto coatings currently being shipped from ACL to Jamaica and Belize, therefore freeing up 12% of the plant capacity at ACL.
4. There was also a significant reduction in operational expenses.

Figure 3. Situation before and after integration
5.2 JM Integration Results
The operations of BPJL remained as a stand-alone company but was granted rights to manufacture and distribute ACL’s Penta and Auto-Refinish brands in JM. BPJL’s three (3) year average sales volume was 68% of its average annual manufacturing plant capacity. The manufacturing of Penta Paints, Sissons and Nexa Autocolor coatings increased plant volume by 22%, which increased the average annual manufacturing plant capacity to 83%.

To add these volumes to BPJL’s capacity, the following considerations were undertaken:
1. The operations of ANSA Coatings Jamaica Limited (ACJL) was absorbed into BPJL with ACJL becoming a division of BPJL.
2. Penta derived cost savings from eliminating shipping and administrative overheads by being manufactured in JM.
3. Penta continued to penetrate the market via hardware stores and the expansion of decorative and auto-refinish tinting network throughout the fourteen (14) parishes in JM.
4. Berger maintained its position as the local premium in JM, and
5. There was a significant reduction in operational expenses.

6. Future Work
The standardisation and optimisation strategies have thus far shown exceptional results in producing net positive synergies at ANSA. One possibility for future work, is to continuously improve operational optimisation of manufacturing plant throughput. BPBL’s average three (3) year sales volume is 64% of its average annual capacity. Hence, there is sufficient spare capacity to manufacture an additional 36% of volumes at the BPBL manufacturing plant.

Sissons GD’s budget for 2017 required the plant to produce volumes within this 36% spare capacity. Total sales volumes from BPBL and Sissons GD combined were computed to utilize approximately 98% of its average annual capacity, which strategically positions the BPBL plant to comfortably produce the GD volumes. However, to produce the GD volumes at the BPBL manufacturing plant, consideration must be given to the following:
1. An additional partial shift for peak production.
2. The transfer of essential Sissons GD equipment to BPBL to create additional capacity to cater for peak production, flexibility and growth.

The success of the manufacturing integration of Sissons GD with BPBL would depend on two (2) key components. These are:
1. There must be no disruption in product availability – increase plant capacity, ensure accurate sales forecasting, production planning and high efficiencies.
2. There must be no change or perceived change in product quality – maintain technical expertise for quality assurance (QA) and quality control (QC).

The already institutionalised standardisation strategies across various brands and throughout each territory would provide a strong foundation for facilitating the production of the GD volumes at the BPBL manufacturing plant. Additionally, there would be a resulting reduction in operational expenses which further enhances profitability.

7. Conclusion
This project presented the irrefutable need for standardisation and optimisation efforts within the manufacturing operations of the coatings plants at ANSA, with primary emphasis on the maximisation of positive synergies. It depicted the evolution from stand-alone operations in each manufacturing plant to an efficient operation in the Caribbean region. A synergistic standardisation approach was adopted to create the bedrock for fostering operational excellence.

A great deal of time was spent in reducing the number of dormant and uneconomic SKUs via product rationalisation. The remaining SKUs were considered economical which were found to add value to the coatings market throughout all territories. This was confirmed by the market intelligence study conducted by ANSA. Formula standardisation set a platform across all brands for ensuring uniform formulations, which led to improved quality to the customer. Additionally, formula standardisation resulted in RM’s standardisation, as a uniform formulation platform implied similar RM’s requirement across all brands. RM’s standardisation automatically fostered cost savings, due to a significantly lowered overall cost of production. Optimisation of manufacturing operations regionally resulted in labour and shipping cost savings, which essentially placed ANSA in a favourable position to manufacture the same existing product SKUs at a much lowered cost of production.

The project has demonstrated its success by the results achieved as described in the discussion section of this paper. It is anticipated that the contributions achieved from project standardisation at ANSA could be applied to other companies within the ANSA group. Future work would investigate the determinants and factors governing the manufacture of the GD production volumes at the BPBL manufacturing plant. Finally, the lessons learnt from ANSA’s synergistic standardisation and optimisation project, could be applied to other corporate firms throughout the Caribbean region.

References:
CIMA (2010), The Global Manufacturing Sector: Current Issues,
K.N. Hassanali: Deploying Synergistic Standardisation and Optimisation Strategies within Coatings Manufacturing Plants across the Caribbean Region: A Case Study

Chartered Institute of Management Accountants, available at: https://www.cimaglobal.com/Documents/Thought_leadership_docs/Global_manufacturing_report.pdf; Accessed October 2018


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Developmental Requirements Implementing Industry 4.0 in Trinidad and Tobago Companies

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Abstract: This paper is concerned with the development and use of a simplified Industry 4.0 (I4.0) readiness level tool. It aims to design the strategic systems for small and medium-sized enterprises (SMEs) to evolve to I4.0 based on developmental requirements. The assessment of I4.0 literature developed I4.0 readiness tool and 23 qualitative open-ended semi-structured questions. Interviews were conducted with executives and tours of companies (namely, SoftCom, StickCom, PanelCom, ClothCom, MetaCom, FurnCom) assessed company’s present status and ability for implementing I4.0. It was found that the top three I4.0-Developmental-Ready SMEs (i.e., SoftCom, StickCom, PanelCom) used to form an I4.0 Cluster Project Initiative with supporting companies (i.e., DesignCom and EduCom) based upon recommended I4.0 projects: Customer Product Configurator and Augmented Reality (AR) Operator Interface. Results showed that the participating SMEs represented Printing and Packaging, Assembly Type and Related Industries, Steel Products, Textiles and Garments. Other excluding manufacturing sectors included Food and Beverage, Household Products, Chemicals and Non-metallic, Wood and Wood-related. The study identified suitable candidates for I4.0 Cluster Projects, and proposed strategies for evolution to satisfy diverse consumers, who want similar base products with varying characteristics. Besides, there were implications on the potential to increase niche customer market globally to avoid competing on economies of scale with larger global manufacturers. This paper contributed to the development of new definition for I4.0 as the evolutionary change in decentralised connected systems to enable the intelligent integration of the horizontal and vertical value chains of the organisation. It also identified two key phases for SMEs to evolve into I4.0, namely 1) I4.0 readiness level tool and developmental requirements, and 2) Formation of an I4.0 Cluster Project Initiative.

Keywords: Industry 4.0; Mass customisation; Demand driven production; Real-time demand; Competitiveness; Value creation

1. Introduction

Small and medium-sized enterprises (SMEs) within Trinidad and Tobago (T&T) and the Caribbean region must compete on the global market in order to increase their revenue market base as their individual local environments are substantially smaller than the markets of the Americas (the USA, Canada), Europe, Asia and Latin America. As such, they are faced with both local competition (as other SMEs within their geographic borders) as well as those of the global environment. There is a need to quickly and accurately acquire customer needs information and to translate this in real-time into products and services that have a higher purchase preference to the other suppliers. Customers’ decisions are based upon lowest cost, highest quality, shortest time to delivery and ability to match their needs specifically.

Traditionally, low cost is achieved by economies of scale (of raw materials purchased and systems produced) and these savings are passed onto the customer to win orders. This process requires investment in large storage warehouses and product specialty systems that operate 24/7, as well as low-cost labour. It negatively affects the company from being agile and responding to subtle and fast market changes as well as increasing the losses due to unwanted stock items and systems that become obsolete.

Delivery time is a function of the production process and the specific routes between the manufacturer and the customer. For T&T, this is affected by both the distance to the larger market as well as the need to use air or sea to transport goods to the larger markets. This not only increases the time to market but also the cost of the product. As such, even if a local SME is able to produce a cost competitive product, the customer would opt for the manufacturer that has the lower delivery charge.

The Fourth Industrial Revolution (or Industry 4.0) proposes that these limitations could be alleviated through the use of technology and systems integration across specific value chains of SMEs in which benefits as low cost, real-time response to customers’ changing demands whilst maintaining high quality could be achieved.

This paper provides an initial exploration into the developmental requirements that the T&T SMEs should possess, by performing a case study in March-April 2017
with six (6) local companies, namely SoftCom, StickCom, PanelCom, ClothCom, MetalCom, and FurnCom.

2. Literature Review

2.1 Development of Industry 4.0 Definition

Sniderman et al. (2016) noted the definition made by the German Trade and Invest (GTAI), “A paradigm shift made possible by technological advances which constitute a reversal of conventional production process logic. Simply put, this means that industrial production machinery no longer simply “process” the product, but that the product communicates with the machinery to tell it exactly what to do”.

Industry 4.0 involves the use of intelligent and interconnected cyber-physical systems to change the current production system from one of mass production to mass customisation. The ability provides consumers with their customised products, irrespective of their geographic location, without increasing waste and increasing the company’s profit together with achieving a competitive advantage (Rameshwar, 2017).

A new definition of I4.0 is proposed and is based upon the key terms frequently used to describe critical systems of the concept (see Table 1). An evaluation of these key terms enabled a simpler definition of Industry 4.0. Thus it could be the evolutionary change in decentralised connected systems to enable the intelligent integration of the horizontal and vertical value chains of the organisation (King and Rameshwar, 2017; Rameshwar, 2017).

2.2 Design Principles of Industry 4.0

The principles from various authors outlined several similarities and are categorised to provide a simplified approach to the design aspect. This is illustrated in Table 2.

2.3 Enablers and Drivers for I4.0 Implementation

Recent developments by Bandara et al. (2019) evaluated eight I4.0 linked maturity models to develop “Maturity Dimensions” of “Products and Services”, “Technology and Resources”, “Strategy and Organisation”, “Operations”, “Customers”, “Governance”, and

<table>
<thead>
<tr>
<th>Industry 4.0 Key Terms</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connected systems</td>
<td>(Heng, 2014; VDI/VDE-Gesellschaft für Mess- und Automatisierungstechnik, 2015; Roblek, Mesko and Krapež, 2016)</td>
</tr>
<tr>
<td>“cyber physical system”; “Cyber Physical Production Systems”</td>
<td>(Wernicke, 2015; KUKA Aktiengesellschaft, 2016; Sniderman, Mahito and Cotteleeer, 2016); (Vogel-Heuser and Hess, 2016)</td>
</tr>
<tr>
<td>interconnectedness between the physical environment and the digital environment</td>
<td>(Bagheri et al., 2015; Ramanathan, 2015; Geissbauer, Vedso and Schrauf, 2016).</td>
</tr>
<tr>
<td>“Decentralised” systems</td>
<td>(MacDougall, 2014; Wernicke, 2015)</td>
</tr>
<tr>
<td>“Intelligent”</td>
<td>(Heng, 2014; Wernicke, 2015)</td>
</tr>
<tr>
<td>individual products controlling their own production</td>
<td>(Qina, Liu and Grosvenora, 2016)</td>
</tr>
<tr>
<td>feedback within the system</td>
<td>(KUKA Aktiengesellschaft, 2016).</td>
</tr>
<tr>
<td>Integration of value chains (both the horizontal and vertical)</td>
<td>(CFE Media, 2016; Prause and Wiegand, 2016)</td>
</tr>
</tbody>
</table>

Source: Abstracted from King and Rameshwar (2017, pp.5-7) and Rameshwar (2017, pp.10-11)

<table>
<thead>
<tr>
<th>Principles</th>
<th>Features</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand driven data</td>
<td>Specific, Virtual (digital)</td>
<td>CFE Media (2016); Matties (2016)</td>
</tr>
<tr>
<td>Communication between all internal and external systems</td>
<td>Open, Interoperable, Secure, Real-time, Modular, Standardised, Reliable</td>
<td>MacDougall (2014); CFE Media (2016); Matties (2016); Vogel-Heuser and Hess (2016)</td>
</tr>
<tr>
<td>Co-ordination of infrastructure and processes</td>
<td>Clear definitions of interfaces and protocols</td>
<td>Heng (2014)</td>
</tr>
<tr>
<td>Awareness of self, environment, context</td>
<td>Identification (Who am I?), Location (Where am I?), Data storage (What do I know?), Computing power (What can I do?), Connectivity (Who can I communicate with?), Analysis, Adaptable, Relevant</td>
<td>KUKA Aktiengesellschaft (2016); Qina, Liu and Grosvenora (2016); Vogel-Heuser and Hess (2016)</td>
</tr>
<tr>
<td>Knowing to provide feedback</td>
<td>Connections between aware systems (including human-human, human-machine, machine-machine)</td>
<td>KUKA Aktiengesellschaft (2016); Matties, (2016); Qina, Liu and Grosvenora (2016); Vogel-Heuser and Hess (2016)</td>
</tr>
<tr>
<td>Decentralisation</td>
<td>Functional across boundaries, Modular, Flexible, Multiple copies</td>
<td>Matties (2016); Vogel-Heuser and Hess (2016)</td>
</tr>
<tr>
<td>Integration</td>
<td>Horizontal integration, End-to-End integration and Vertical integration</td>
<td>Qina, Liu and Grosvenora (2016); Vogel-Heuser and Hess (2016)</td>
</tr>
<tr>
<td>Optimisation</td>
<td>Specific parameters, attributes, indicators</td>
<td>Vogel-Heuser and Hess (2016)</td>
</tr>
</tbody>
</table>

Source: Abstracted from Rameshwar (2017, p. 16)
2.4. Tools for Implementation of Industry 4.0

Zhan et al. (2015), Moustapha (2016) and Sherwin (2016) recognised that in order for an organisation to implement Industry 4.0, technology is a core component in achieving the design principles, which is also reflected in the frameworks of Bechtold et al. (2016) and Geissbauer et al. (2016). The various types of technologies are identified (King and Rameshwar, 2017; Rameshwar, 2017) as:

- Machine learning
- Data mining
- Mobility technologies (mobile devices)
- Cloud computing
- Augmented reality and wearables
- Big Data analytics and advanced algorithms
- Cybersecurity, authentication and fraud detection
- Autonomous robots
- System integration
- Internet of Things (IoT) platforms
- Simulation
- Additive manufacturing and 3-D printing
- Smart sensors
- Advanced human-machine interfaces
- Multilevel customer interaction and customer profiling (community)
- Location detection technologies

However, full implementation of Industry 4.0 occurs when the core definition is satisfied, and all other methods
(that only satisfy a part of the concept) are part of and contribute to the evolutionary change towards the concept.

2.5 Decision Framework for Industry 4.0

The contributions from 23 authors were analysed and the factors that facilitated I4.0 were extracted. The framework for I4.0 implementation first depends upon the needs of the organisation. Table 5 shows the four (4) highest concentrations are focused on Business drivers and enablers, Analysis of factors affecting the transition, Technologies needed to move towards Industry 4.0 principles and Understanding of Industry 4.0 concept, parameters and principles (Rameshwar, 2017).


Table 5. I4.0 Implementation factors and author percentage contribution

<table>
<thead>
<tr>
<th>I4.0 Implementation factors</th>
<th>Percentage contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business drivers and enablers</td>
<td>74</td>
</tr>
<tr>
<td>Understanding of Industry 4.0 concept, parameters and principles</td>
<td>35</td>
</tr>
<tr>
<td>Identification of RAMI4.0 (or other simplified framework definition) components</td>
<td>9</td>
</tr>
<tr>
<td>Assessment of the existing system</td>
<td>22</td>
</tr>
<tr>
<td>Migration strategy to the Industry 4.0 attribute of the specific parameter or component</td>
<td>22</td>
</tr>
<tr>
<td>Analysis of the factors affecting the transition</td>
<td>57</td>
</tr>
<tr>
<td>Technologies needed to move towards Industry 4.0 principles</td>
<td>39</td>
</tr>
<tr>
<td>Adoption model of technology</td>
<td>13</td>
</tr>
<tr>
<td>Priority of technology</td>
<td>17</td>
</tr>
<tr>
<td>Early or late adopter</td>
<td>17</td>
</tr>
<tr>
<td>Age of the company</td>
<td>9</td>
</tr>
<tr>
<td>Specialisation level of the company</td>
<td>9</td>
</tr>
</tbody>
</table>

Source: Abstracted from Rameshwar (2017, pp. 21–24)

2.6 Challenges to implementation of Industry 4.0

Challenges were identified through the analysis of the literature, as being critical factors affecting the implementation of I4.0: Communication and data; Labour workforce; Culture; Corporate vision; Financial investment; Government support; Change management (Rameshwar, 2017).

![Figure 1. Drivers and Enablers vs Challenges on Movement to I4.0](source: Rameshwar (2017, p.129))

2.7 Benefits of Industry 4.0

Although Industry 4.0 is in its early developmental stage, several authors (Heng, 2014; MacDougall, 2014; Zhan et al., 2015; Ramanathan, 2015; Wemicke, 2015; CFE Media, 2016; Geissbauer, Vedso and Schrauf, 2016; KUKA Aktiengesellschaft, 2016; Roblek, Meško and Krapež, 2016; Sherwin, 2016; Vogel-Heuser et al., 2016) have identified potential benefits to organisations evolving to the fourth industrial revolution. An assessment of their key phrases utilised in describing the benefits were used to identify keywords focusing on benefits. The thematic keywords revealed specific areas of foci of Industry 4.0 benefits, in the areas of customer, business and process as illustrated in Figure 2.

![Figure 2. Thematic representation of Industry 4.0 Benefits and the Relationships between the Customer, Process and Business](source: Abstracted from King and Rameshwar (2017, p.5) and Rameshwar (2017, p.35))
The interrelation between these thematic groups promotes “using a virtual environment to maximise customer choice and minimise delivery times points to an element of I4.0 that is driving and sustaining innovation in a rapidly evolving competitive environment. Four disruptions could be identified as driving I4.0: a massive rise in data volumes, computer power and connectivity; analytics and business intelligence; human-machine interfaces; and enhanced transfer of digital instructions to the real world, for instance in automation” (King and Rameshwar, 2017).

“Innovation can be achieved by developing a new product and/or service that is differentiated to provide a unique competitive advantage for the manufacturer. The Industry 4.0 concepts and design principles would be used to develop a framework for identifying pathways for innovation (in terms of products and/or services) as well as the identification and analysis of the specific I4.0 implementation tools needed for innovative systems.” (Rameshwar, 2017). Each of these could be accomplished in the Customer Product Configurator and the AR Operator Interface.

3. Research Methodology

Five local manufacturing companies have been identified based upon the following criteria:
- Registered as a business in Trinidad and Tobago
- Operates in Trinidad and Tobago
- Produces manufactured goods
- Sales composition is either 100% in Trinidad and Tobago or a combination of both local and export
- Companies identified with the potential for customisation
- Companies with whom the researcher has access to management for conducting interviews

A software development company was selected to understand a local software company’s ability to support the transition, as well as to understand their level of readiness in I4.0. The companies selected are known as StickCom, FurnCom, PanelCom, MetalCom, ClothCom and SoftCom.

The five core manufacturing companies do not reflect the diverse range of the local manufacturing sector as it only captures the first four groups of the identified categories of Printing and Packaging, Assembly Type and Related Industries, Steel Products, Textiles and Garments, Food and Beverage, Household Products, Chemicals and non-metallic, Wood and Wood Related (Trinidad and Tobago Manufacturers Association, no date).

The purpose of the case study was to develop a developmental requirement assessment to be applied to non-competitive entities that could form a cluster and a key focal point was the avoidance of identical manufacturing environments and products.

4. Development of Research Instrument

The assessment of the developmental requirements of the case study companies was performed through the administration (as well as an analysis and comparison of the companies’ answers) of twenty-three qualitative open-ended semi-structured questions, to assess the company’s present status as well as their ability for implementing Industry 4.0. The questions (as summarised in Table 6) were developed using the I4.0 Implementation Factors. These include:

1. Business drivers and enablers
2. Understanding of Industry 4.0 concept, parameters and principles
   a) Industry 4.0: The evolutionary change in decentralised connected systems to enable the intelligent integration of the horizontal and vertical value chains of the organisation
   b) Design principles
   c) Existing and planned technologies
3. Analysis of the existing system
   a) Tour of production system
   b) Review of the Design principles
   c) Existing and planned technologies
4. Analysis of the challenges affecting the transition
5. Adoption model of technology
6. Priority of technology
7. Early or late adopter
8. Age of the company
9. Specialisation level of the company

In order to facilitate a comparative response, the case study interviews were given face-to-face to the person in management that is able to influence the decision to implement the change to Industry 4.0. Typical positions identified are the “Production/operation manager and/or C.E.O. or Managing Director” (Syan and Ramoutar, 2008 and 2014) or the “senior management as senior executives, directors or managers” (Pun and Jaggernath-Furlonge, 2012).

This format enabled discussions on a variety of factors that affected the interviewees operations through analysis of the following categories:
- Company history and demographics
- Company’s business drivers and enablers
- Current and future technologies in the production system
- Horizontal and vertical value chains
- Challenges to transition to Industry 4.0

A comparative assessment of each company was developed to illustrate their commonalities with each other and the areas in which symbiotic relationships could be formed. This would be identified in the I4.0 frameworks of design principles, enablers and drivers, implementation tools as well as challenges of implementing Industry 4.0. The numeric values assigned to each company was based upon the researcher’s assessment of the interviews, the plant tour and relative comparison to each company using the categories. The use of the value ‘0’ will be where it does not exist or is
### Table 6. Summary of Research Questions and Company Information Extracted

<table>
<thead>
<tr>
<th>Question</th>
<th>Focus areas and summary of information to be extracted</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>Identifies the company’s experiential knowledge as a manufacturer as well as any changes in its methods and products.</td>
</tr>
<tr>
<td>#2, #3</td>
<td>Assess the organisation’s financial status and their employee demographics in terms of their ability to operate under the changing technological requirements required by I4.0. This is segmented into the areas of business and automation software and hardware systems for a manufacturing environment.</td>
</tr>
<tr>
<td>#4</td>
<td>This assess the areas and levels of specialisation of the company, in terms of manufacturing technology, customer data, and business systems integration as well as supplier and distributor data. It also examines the expected benefits of emerging technologies within their manufacturing environment.</td>
</tr>
<tr>
<td>#5, #6, #1</td>
<td>Examine the company’s ability to recognise, assess and adopt new technologies and products that provide benefits to their production and business operations.</td>
</tr>
<tr>
<td>#8</td>
<td>Focuses on the company’s ability to identify the value proposition for the customer that returns value to the company.</td>
</tr>
<tr>
<td>#9</td>
<td>Explores the company’s ability to create a digital production environment as well as utilise its benefits.</td>
</tr>
<tr>
<td>#10</td>
<td>Assess the company’s ability to customise orders.</td>
</tr>
<tr>
<td>#11, #12</td>
<td>Highlight the communication and collaboration between the manufacturer and their suppliers and customers.</td>
</tr>
<tr>
<td>#13</td>
<td>Linked to question #10 on customised orders and focuses upon the pricing strategy utilised by the manufacturer.</td>
</tr>
<tr>
<td>#14</td>
<td>Focuses on the vertical and horizontal value chains that the organisation can identify that are able to add value to their existing systems.</td>
</tr>
<tr>
<td>#15</td>
<td>Focuses on the manufacturer’s ability to recognise problems with their suppliers and their ability to switch to an alternate supplier.</td>
</tr>
<tr>
<td>#16, #17, #18</td>
<td>Highlight the value of the safety and security of data of the customer, business and process as well as identifying existing contingencies for losses and how the production system would be affected.</td>
</tr>
<tr>
<td>#19</td>
<td>Focuses upon the manufacturer’s understanding of the Industry 4.0 concepts and its importance to their corporate vision.</td>
</tr>
<tr>
<td>#20</td>
<td>Focuses on the company’s difficulty to transition into I4.0 as a result of the implementation challenges of communication and data, labour workforce, culture, corporate vision, financial investment, government support and change management.</td>
</tr>
<tr>
<td>#21, #22, #23</td>
<td>Examine the manufacturer’s current and future investment in technologies that enable the transition to Industry 4.0 as well as their level of commitment to move the organisation into the new industrial revolution.</td>
</tr>
</tbody>
</table>

Source: Abstracted from Rameshwar (2017, pp. 45-48)

The results of these analyses were used to create each company’s relative position in achieving the key concepts of I4.0 (e.g., evolution, integration of value chains, intelligence, communication and decentralisation) as well as their relative distribution in the system complexity of industrialisation (from Industry 1.0 to Industry 4.0). A brief plant tour of the key manufacturing systems also provided an understanding of the technological ability and limitations of the organisation to evolve and integrate various elements of their value chains, which was illustrated with recommended pathways to create and strengthen specific vertical and horizontal levels.

The second phase of involved the identification of the most suitable SMEs to develop an I4.0 Cluster Project Initiative based upon those that have the potential to evolve the fastest and demonstrate specific benefits in the Caribbean. The selection of SoftCom, StickCom and PanelCom were based upon their relative positions in the I4.0 Key Concepts in Figure 3. An initial macro-analysis of their vertical and horizontal value chains revealed two initial I4.0-based project concepts: Customer Product Configurator and an Augmented Reality (AR) Operator Interface. The introduction of two additional entities, DesignCom and EduCom to the cluster group were based upon the initial areas of speciality in providing value to the cluster group. DesignCom has experience in AR systems design and implementation. EduCom focuses on providing novel research and analysis in evolving industries.

### 5. Findings

#### 5.1 I4.0 Key Concepts

The Industry 4.0 Key Concepts development (as illustrated in Figure 3) is developed based on the following:

- Mathematical calculations is the first step and based upon linkages (as identified in Table 7), in which the average of the linked values are then assessed in the comparative analysis step, and
- Comparative analysis of the members within the potential cluster group using drivers, challenges, plant
## Table 7. Relationship between I4.0 Key Concepts and Design Principles

<table>
<thead>
<tr>
<th>I4.0 Key Concepts</th>
<th>I4.0 Design Principles</th>
</tr>
</thead>
<tbody>
<tr>
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In the first phase, the relative position of each company in reference to the key concepts of Industry 4.0, in the areas of evolution, connected systems, decentralised, intelligent and integration of value chains is illustrated in Figure 3.

This radar diagram provides a useful visual tool to focus on companies that have desired key concept qualities, as in the case of SoftCom, as well as identifying the concepts of other companies that need improvement.

SoftCom’s use of cloud computing enabled them to achieve the highest relative position in the key concepts. StickCom and PanelCom have demonstrated stronger positions in the areas of evolution, integration, intelligence and connected systems. Only ClothCom is able to take advantage of a component of the decentralised system, in the form of their outsourced Canadian manufacturing partner. This stronger position by StickCom and PanelCom has been reflected in the other areas as fewer challenges to transition, higher average investment in current and future technologies, stronger average influence by drivers and enablers and higher levels of adoption of the principles of I4.0.

FurnCom is the only organisation that did not identify a current position or need for connected systems and also scored the lowest in the other categories, except in decentralisation, in which it is on par with the StickCom, PanelCom and MetalCom.

The results of focused one-on-one interviews with the second phase cluster group revealed that each member (including SoftCom, StickCom, PanelCom, DesignCom and EduCom) agreed with the initial assessment to develop an I4.0 cluster group as well as noted a willingness to invest in the development of the infrastructure and product that would enable them to achieve I4.0 systems as a specific test case. Key limitations identified were the project’s return on investment (ROI) must be clearly identified based on each member’s involvement, as well as the project must not adversely affect their existing revenue streams.
5.2 I4.0 Developmental Requirements

There are multiple pathways of evolution that each company can follow to raise their level of the key concepts. The assessment of the interviews identified a recommended set of systems (such as technologies and training). These technologies were based upon the following criteria:

- Lowest cost (as compared to the other implementation technologies)
- Shortest timeframe required to utilise the system
- Infrastructure available to install the equipment
- Direct and immediate impact that adds value
- Mitigation of common issues amongst the companies such as the current lack of horizontal integration, the existing technology that limits the ability to vertically integrate and the lack of decentralisation

I4.0 technological developmental requirements that would create the greatest value, are: Multi-level customer interaction and customer profiling; System integration; Cloud platform; Mobile devices; Data mining. The I4.0 training developmental requirements focused upon the companies’ education to extract and create value as well as their need to build and strengthen relationships within their horizontal and vertical value chain.

The needs addressed by the Phase I systems would focus on common drivers and enablers as customer growth, communication and the power position of influence (King and Rameshwar, 2017; Rameshwar, 2017). These include:

- Cloud platform would provide access to information and enable the intelligent real-time analysis, as well as decentralisation, integration and communication.
- Technology to communicate and network legacy systems and to provide the capability to these systems that do not exist.
- Implement customisable and configurable dashboard HMIs that could be deployed on mobile devices that are connected via the cloud platform.
- Training in the areas of education to use the systems incorporated with relationship building seminars with customers, suppliers and staff that would change the culture.
- Utilising the cluster to manage the change initiated in the companies to ensure their individual drivers and enablers outweigh the challenges to continue evolving towards the I4.0 tier.

6. Conclusion

The developed I4.0 readiness tool compared six local SMEs in the areas of evolution, connected systems, decentralised, intelligent and integration of value chains. Only one of the case companies, SoftCom, could currently be considered to be I4.0 ready.

However, significant competitive benefits could be achieved for each of them by transitioning to an I4.0 operational framework. The approach to making this transition is of importance here. All five (5) manufacturing companies studied would gain competitive benefit from evolving: 1) Multi-level customer interaction and customer profiling; and 2) cloud platform to enable them to continue to vertically integrate with their suppliers and their Business-to-Business (B2B) customers. FurnCom and ClothCom would achieve the additional benefit of creating and strengthening their Business-to-Customer (B2C) connections, respectively.

Horizontal integrations, facilitated through the formation of clusters, could enable PanelCom to create new products and increase the utilisation of its equipment; and enable ClothCom to achieve lower procurement costs through economies of scale, by aggregating primary products with other manufacturers. System integration involving I4.0 components is key to each continuing the transition, except for ClothCom, whereas data mining would only be a focus for StickCom, PanelCom and MetalCom. The use of mobile devices as an implementation tool would be utilised by StickCom, PanelCom and ClothCom. Training would be required for each manufacturer to ensure that new value, thus innovative systems, is both extracted from their existing network and created from their integrations, as well as ensuring that these vertical and horizontal relationships are maintained to enable them to continue satisfying the I4.0 key concepts. Assessment of each manufacturer’s equipment and financial analysis was beyond the scope of the current project.

A Cluster Project Initiative was formed between three of the original SMEs (including SoftCom, StickCom, PanelCom) that demonstrated the highest ability to transition to I4.0 and the additional two specific members (i.e., DesignCom and EduCom) to focus on developing a specific I4.0 based system that would be used as a test case for the development of SMEs in the Caribbean region.

References:


CFE Media (2016), 2016 Digital Report the Industrial Internet of things (IoT), CFE Media.


Heng, S. (2014), Industry 4.0 Upgrading of Germany’s industrial
Capabilities on the Horizon. Germany: Deutsche Bank Research.
KUKA Aktiengesellschaft (2016), Hello Industry 4.0, We Go Digital. Germany: KUKA.
Moustapha, H. (2016), Aerospace 4.0, Canada: AÉROÉTS École de technologie supérieure.
Rameshwar, J.R. (2017), Getting Ready for Industry 4.0 in Trinidad and Tobago: An Assessment of Developmental Requirements of Case Study Companies. MSE Project Report, The University of the West Indies, Trinidad and Tobago.
TTMA (no date), Business Directory Search, Trinidad and Tobago Manufacturers Association Available at: http://ttmanufacturers.memberzone.com/list/ (Accessed: 8 January 2019).
VDI/VDE-Gesellschaft für Mess- und Automatisierungstechnik (2015), Status Report Reference Architecture Model Industrie 4.0 (RAMI4.0). Düsseldorf: VDI e.V.

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Graham S. King: Developmental Requirements Implementing Industry 4.0 in Trinidad and Tobago Companies
Modelling Productivity Dynamics of Manufacturing Capital Investment Projects in Trinidad and Tobago: A Study Agenda

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Abstract: In Trinidad and Tobago (T&T), the manufacturing sector has been facing pressure to increase its capital investment (CI) spending on projects related to plant upgrades, machinery and equipment. Productivity studies within the field of project management (PM) have been sporadic. Recent studies suggested that existing counter-productive PM practices would lead to failed CI projects in a turbulent manufacturing environment. Incidentally, the principles identified in existing productivity models within other sectors were useful, but none demonstrated a unique measure for determining overall productivity at the project level. This paper explores productivity within the realm of PM, and describes a study agenda with a conceptual model proposed for assessing the dynamics of productivity from project planning to project execution in T&T. The research agenda would combine 1) an extensive literature review, 2) empirical survey and interviews, and 3) the development and evaluation of a Productivity Management Framework (PMF) for manufacturing firms. The novel contributions of this study are firstly, to identify key PM attributes and relate them to the design of project productivity (PP) metrics for CI projects, and secondly, to develop the PMF accompanied by an implementation guide for use in manufacturing firms in T&T.

Keywords: Project Management, Productivity, Manufacturing, Capital Investment Projects, Trinidad and Tobago

1. Introduction

Over the past 50 years, the core reasons for project failure have been well documented. However, despite this large number of empirical evidences, many project practitioners, inclusive of leadership and executives, continue to replicate the mistakes made on past projects. For instance, according to the statistics of the Project Management Institute (PMI) in 2015, sixty-four percent (64\%) of projects met their goals, while seventy percent (70\%) of companies recorded at least one failed project, and more than two-thirds of all large projects resulted in failure (PMI, 2015). Poor project management (PM) practices have negatively affected capital investment (CI) projects in manufacturing, due to resulting project delays, cost variances and overall poor-quality project delivery.

A firm’s manufacturing CI project is defined as a project aiming to achieve either one (1) or both of the following: revenue growth and/or cost savings, with the intent of increasing the firm’s profitability. When a manufacturing CI project is delivered late, the firm’s opportunity to gain the expected revenue growth and/or its cost savings is delayed, thereby impacting the firm’s business plan. When a manufacturing CI project’s scope is compromised, and scope creep sets in, this would result in the aggregate effect of the pitfalls suffered from both late delivery and cost over-runs. Cost over-runs would ultimately place the firm in an unfavourable position as the budgeted cost to accomplish the specific business rationale would have been compromised. In practical terms, a manufacturing CI project is intrinsically required to be completed within its baselined scope, schedule and budget; to realise maximum financial and operational benefits.

A possible source of manufacturing CI project failure is attributable to the absence of productivity management within its lifecycle. For the purpose of this study and from a PM perspective, productivity management would be defined as the application of key project productivity (PP) techniques and metrics to project parameters (scope, schedule and budget) and includes analytics on how these parameters are affected during the manufacturing CI project’s planning and execution phases. Incidentally, an inherent gap exists between project success and project failure, and this gap is exacerbated by inadequate project planning. Moreover, the lack of measurable productivity indicators during a CI project’s execution phase could further erode its chances of successfully achieving its baselined plan.

In Trinidad and Tobago (T&T), many manufacturing CI projects include a considerable degree of construction works while ultimately providing a service to a customer; therefore, productivity related to construction project delivery is an essential facet of this research. Low productivity in the construction industry is as a result of diverse identifiable reasons such as; high reduction in skill level of construction workers, shift work, shortages of materials and equipment, change orders, labour shortages, adverse weather conditions and low level of monitoring and control of projects. These factors constitute the gap in achieving manufacturing CI project success. This paper
proposes a study agenda focusing on the utilisation of a productivity management approach to bridging this gap.

2. Managing Manufacturing CI Projects in T&T

A manufacturing CI project entails heavy construction and engineering practices where the result is a service to the customer, who in effect, would be the actual manufacturing company sponsoring the project. In T&T, a possible source for the problems related to manufacturing CI project failure could be due to the absence of effective productivity management practices within the project’s planning and execution phases. Within the planning phase of a manufacturing CI project, poor activity duration estimations could lead to inadequate scheduling of work activities; resulting in the development of unrealistic project schedule baselines. Similarly, poor estimation of worker requirements could encourage over-staffing or under-staffing of project work activities; ultimately resulting in either over- or under-budgeting. Moreover, the productivity of workers and by extension the work activities themselves, which make up the project schedule, are negatively affected due to these tenuous estimations in the planning phase.

By the time the project enters the execution phase, these impractical schedules and budgets become improbable to achieve. Scope creep eventually sets in and could result in scope, schedule and budget variances; which adversely compromises a CI project’s success at delivery. Considering this, there is an opportunity to foster productivity practices within the planning and execution phases of manufacturing CI projects.

To improve the success rate of manufacturing CI projects, there is an axiomatically critical need to bridge the gap between success and failure; particularly in many small island states, like T&T. Strategies such as: effective project planning, productivity measurement, avoidance of construction site congestion, motivation of workforce and good communication among project stakeholders could contribute to the success of a manufacturing CI project. As such, key project factors which could control the operations and continual existence of a manufacturing CI project; could be broadly classified and grouped to include: 1) project workforce, 2) project organisation, 3) job planning, 4) motivation, and 5) material availability. These five (5) success factors would be rigidly tested using empirical and statistical methods, and would then be incorporated within the proposed PMF.

The impact of these factors could be measured using Earned Value Method (EVM). Based on desk research, project performance researchers were unanimous that this conventional EVM is an effective tool to calculate project cost performance; however, they have divergent opinions about EVM’s capacity to provide reliable schedule performance metrics. Many authors (e.g., Anbari (2003), Brandon and Daniel (1998), Sou et al. (2006), Rodney, (2000), and Bower (2007)) argue that the EVM is not a reliable predictor of project duration and even recommend that EVM, relating to project schedule performance, should be used only as a warning mechanism and not as a real tool to analyse how the project is performing in time. A project team is to be equipped with the right tools to achieve the baselined scope, schedule and budget. With identification of key productivity performance (PP) metrics, this would provide early indications of project variances which could foster a proactive dynamic approach to managing a manufacturing CI project.

Planning and execution are two (2) critical PM phases. Project planning plays an essential role in helping guide stakeholders, sponsors, teams, and the project manager throughout later project phases. Planning is needed to identify desired goals, reduce risks, avoid missed deadlines, and ultimately deliver the agreed product, service or result. Therefore, without careful planning, project performance is almost certainly guaranteed to suffer.

Project execution is to develop and produce the project’s expected deliverables that must be delivered on time and within budget; and must meet the agreed upon scope and fulfil customer quality requirements. To be sure that the PP metrics are practical; they must be measured against realistic, well thought-out project baselines. This paper initiates a study that would explore a productivity management approach in safeguarding the baseline scope, schedule and budget of CI project delivery, in both the project planning and execution phases.

3. Literature Review

3.1 Modelling Project Productivity and CI projects in Manufacturing

System dynamics is a methodology for studying complex systems, and was advocated by Forrester (1971) in the 1960s. A system is defined as the collection of various elements which continuously interact with each other, over time to form a unified whole. The structure of a system is concerned with the underlying relationships and connections between its components. The term dynamics refers to change over time. By extension, system dynamics could be defined as a methodology used to study and understand how systems change over time. The behaviour of the system could be perceived as the way elements and variables comprising a system change over time.

The application of system dynamics in the field of project and productivity management is not new. The first PM model was developed to examine the dynamics of research and development projects (Roberts, 1964). Thereafter, the benefits of system dynamics in PM gained prolific recognition (Rodrigues and Bowers, 1996). Coyle (1996) defined systems dynamics as a method that deals with the time-dependent behaviour of the managed systems. Qualitative and quantitative methods could be
used with the aim of describing and understanding the behaviour of systems dynamics.

3.2 The PMBOK Methodology and Phases

The Project Management Body of Knowledge (PMBOK) methodology would be benchmarked when defining the manufacturing CI project scope. According to Canon (1994), from the ten (10) knowledge areas, four (4) of them (scope management, schedule management, cost management and procurement management) have outputs that are specific and measurable, otherwise known as hard elements. The remaining elements (risk management, quality management, integration management, communications management, stakeholder management and human resource management) are directly related to people within an organisation or project environment. A project’s scope, schedule and budget are critical elements that are specific and measurable, otherwise known as hard elements.

3.2.1 Planning a Manufacturing CI Project

Planning is described by PMBOK (PMI, 2008) as those processes and practices performed to establish the total scope of the project. The project’s purpose is clearly defined and consistently refined during the planning phase. An essential result of planning is the development of an unambiguous course of action required to meet the project’s aims and objectives. Activities in the planning phase include the design and development of the project plan, the development of a scope requirements plan, creation of the work breakdown structure, development of an achievable project schedule consisting of the required activities and the development of realistic budgets. Other essential areas of planning include the development of a proper quality management plan, a strong human resource management plan, a communications management plan, a risk management plan, a stakeholder management plan and a procurement management plan.

Thomas et al. (2008) state “the most effective team cannot overcome a poor project plan” and projects started down the wrong path could lead to the most spectacular project failures. Morris (1998) argued that “the decisions made at the early definition stages set the strategic framework” and further states that “get it wrong here and the project would be wrong for a long time”. Munns and Bjerim (1996) state that for a project that is flawed from the start, successful execution may matter only to the project team, while the wider organisation would see the project as a failure. Bloquist et al. (2010) also state that “plans are a cornerstone of any project; consequently, planning is a dominant activity within a project context”.

3.2.2 Executing a Manufacturing CI Project

Project execution refers to the actual completion of work that is outlined in the project plan. The primary output of the project execution process is completed deliverables (PMI, 2008; Houston and Bove, 2007; Schwalbe, 2010). Most of the project expenditures would also take place during project execution (PMI, 2008). Once the work has commenced, changes to the project have an increased cost associated with them because they might result in rework. During the execution process, resources and people are coordinated and the project team is brought together (Houston and Bove, 2007). According to Smith (1999), a project invariably fails or succeeds during the execution of the project plan. From a PMBOK perspective, executing a project is characterised by the implementation of all activities defined within the planning phase with the intent of meeting the strategic objectives and goals of the project (PMI, 2008).

3.3 Productivity with Labour Focus

Productivity and subsequently performance measurement have been regarded as a prerequisite for continuous improvement (Kaydos, 1991). When focusing on the industrial, national, and international levels; many approaches have been designed by economists such as the total factor productivity (TFP), or Bureau of Labour Statistics (BLS) multifactor productivity techniques (Duke and Torres, 2005). The use of delay surveys (Tucker et al., 1982) to establish causal factors of labour productivity have been common hitherto. Borcherding and Garner (1981), for instance, reported results of a longitudinal study, which employed the craftsmen questionnaire survey technique on over 1,000 carpenters, electricians and pipe-fitters. Other researchers (e.g. Olomolaiye et al. (1988), Zakeri et al. (1996), and Kaming et al. (1997)) employed surveys to investigate the work content factors influencing construction labour productivity in Nigeria, Iran and Indonesia respectively. Throughout these studies, material and tool unavailability, rework due to design changes, weather or poor workmanship, crew interference due to scheduling problems, craftsmen turnover and absenteeism were recurrent problems that curtailed productivity.

In the construction industry, productivity exhibited a decline over the past few decades (Brisco, 1988; Christian and Hachey, 1995). Some microeconomic studies reported the contrary (Allmon et al., 2000). Irrespective of productivity trends, a relatively recent research cautioned against unreliability in labour productivity raw data, and the uncertainties inherent in the methods used for its estimation and interpretation (Eddy and Peerapong, 2003). Though extensive research has been done on parameters influencing productivity, most have focused on determinants that have mid- or long-term impacts on labour productivity (AbouRizk et al., 2001; Crawford and Vogl, 2006; Lam et al., 2001; Moselhi et al., 1997; Thomas and Zavriski, 1999). Hence, a smaller number of studies have targeted individual; not multiple factors, that cause daily or short-term variations in productivity (Hancher and Abd-Elkhalek, 1998; Koehn and Brown,
3.4 Earned Value Method Reporting and Deficiencies

The EVM approach was developed in the 1970s and is widely used to measure the progress of a project. According to Anbari (2003), earned value is a useful PM tool that helps identify the project's scope, time, and cost. Fleming and Koppelman (1998) traced the origin of earned value from its beginnings in industrial engineering in the late 1800s. They presented a detailed account on development and applications of “Cost/Schedule Control Systems Criteria (C/SCSC)” into earned value theory in industries. EVM history is divided into several stages, namely: 1) industrial engineering origins; 2) Program Evaluation and Review Technique/Cost (1962-1965); 3) C/SCSC (1965-1996), and 4) the criteria outlined underlying EVM systems (since 1996).

At any time during a project, the earned value is the amount that should have been spent on production. The earned value of the production performed is found by multiplying the estimated percentage complete of the production by the planned cost for that production (Meredith and Mantel, 2006). The formula gives the amount that would have been spent on the production at that point in the project. However, a precise estimate of the percentage completed could be difficult to determine.

This percentage could be estimated in several ways, either by measuring the activity level or by breaking the project into smaller work packages and then following three (3) optional rules (Carmichael, 2006). These are:

1. Applying a 50-50 rule when the activity/package is considered 50% complete if it has begun and allocating the remaining 50% when the activity/package is fully finished;
2. Following a 0-100 rule when the activity/package is only considered complete if it is finished. This rule would understake the percentage complete because, at any given time, there would be activities/work packages that are in progress and;
3. Estimating the percentage complete by 'eye' or judgment relies on the nature of the work and the usefulness of dependent activities/packages stating percentage completeness of anything less than 100%.

Lipke (2003) argued that two schedule performance indices, namely the schedule variance (SV) and the schedule performance index (SPI) could cause misinterpretation. The SV measures the volume of work performed versus the volume of work planned. However, the SV is expressed in a monetary unit, which obscures the meaning of schedule variance and often causes misunderstandings. When the SV < 0, a lower volume of work has been completed than planned, meaning the project is behind schedule. When the SV > 0, a higher volume of work has been completed than planned and this means that the work is ahead of schedule. When the SV = 0, the work is exactly as planned. At the end of a project, the PV = BAC (budget at completion), and hence, the SV always equals zero. Two (2) results could be obtained if the SV = 0 and cannot reflect the real condition at completion. Thus, it shows that the SV is an unreliable measure of performance.

Two (2) studies presented by Christensen and Rees (2002) and Christensen and Templin (2002) measured the accuracy of the cost performance index (CPI) throughout the life of a project. For instance, the cumulative CPI value (stabilised by the time) of a project was approximately 20% complete, that is, the final CPI did not vary by more than 0.10 from the value obtained at the 20% point. The CPI value tends to be worse from the 20% point of stability until project completion. The estimate at completion (EAC) is not a stable index due to the poor accuracy of the CPI. Christensen (1993) also argued that no single EAC formula is consistently the most accurate. The CPI-based EAC depends on project-specific factors, which creates a reasonable lower boundary for the final cost of a contract.

Several other deficiencies have been identified as follows:

1. Anbari (2003) outlines an issue in determining the percentage completion of a project. The task becomes more demanding when dealing with new, emerging or software technology projects.
2. Brandon and Daniel (1998) note that the complicated EVM methodologies and procedures, as well as the massive effort involved in data gathering, reporting and performing an integrated information analysis; are the reasons why the EVM technique is underused.
3. Sou et al. (2006) identify one deficiency in the traditional EVM that relates to cost and schedule performances being evaluated only at the report date without considering the time sequence. Generally, the traditional EVM indicates only a single cost and schedule status at a specific report date together with a completion forecast to represent the project’s performance. The variation in individual performance values is not directly evaluated in most cases. The persistent performance variations and their consequences are not derived in the traditional EVM.
4. Rodney (2000) suggests that the estimated cost to completion and the original forecast of project completion cost are based on past performance. They may be incorrect in certain situations because future work may be completely unrelated to the work that is already completed.
5. Bower (2007) summarises the deficiencies into eight (8) categories, namely: isolation from procurement, integration of cost budget and time schedule, evaluation of work in progress, schedule variance units, schedule of anomalies in the progress, failure to
recognise milestones, failure to isolate project phases, and an inability to chart forecast trend lines.

Most of these deficiencies are implicit, and therefore cannot be eliminated. The original problems of EV always exist if the extensions of the EVM cannot overcome the basic and inherent deficiency in EV theory and if they continue to use unreliable indicators, such as the SV and SPI, in the new formulas. The results are meaningless when the earned value indices consist of formulas that lack practicality.

3.5 Service versus Construction Sector Perspectives

The service sector demands a more holistic approach as compared to that of the manufacturing sector, as it relates to customer satisfaction (Blois, 1985; Gronroos, 1990). According to Giarini (1991), quality and productivity cannot be separated in the case of services as both should work harmoniously with each other. From a productivity standpoint, there is a growing need for a critical analysis of the productivity concept in the context of services (Vuorinen et al., 1998). It is also important to identify what data is to be captured in measuring productivity in the service industry before making any attempt to measure it (Gummesson, 1992).

According to McLaughlin and Coffey (1990), measuring productivity in service organisations would be affected by the complexity of inputs and outputs of project activities. The main objective of productivity measurement is productivity improvement, and appropriate measures provide an analytical tool geared towards the achievement of this goal. Productivity measurement is a management control device, which identifies the characteristics of the services which are particularly critical for productivity gain (Ballantine et al. 1998; Modell 1997).

The quantity and quality dimensions of a service sector project should not be treated in isolation. Since a clear inter-relationship exists between quantity and quality, it may not be easy to separate the impact of a service process on productivity from its impact on service quality. Both the quantity and quality aspects would provide a combined impact on the total productivity of the service firm. Adam et al. (1995) put forward six (6) general requirements to guide the formulation of a service productivity concept. These include:

1. Service output must be the value for the customer and from the perspective of the customer.
2. Service output must be defined by its quality level.
3. The customer must become a part of the productivity concept.
4. Measures of productivity must be more customer-related.
5. Dynamic indicators of productivity must be used instead of static output/input measures.
6. Situation specific measures must be available to allow for the complexity and diversity of service operations.

For a detailed measure of service productivity, Vuorinen et al. (1998) suggested that there is a need to operationalise quantity and quality aspects of service productivity. This operationalisation must then be executed in alignment with a well-defined unit of measurement. The possibility of aggregate effects should be accounted for during measurement. Moreover, Sahay (1997) advocated the participative methodology to determine the productivity metrics. Figure 1 shows the logic flow of multi-factor productivity measurement in organisations.

![Figure 1. A Methodology for Multifactor Productivity Measurement in Organisations](Source: Abstracted from Sahay (1997))

The methodology includes:

1. Analysis of corporate mission, objectives and functions of the organisation.
2. Study of various departments/sections and finding out goals and key result areas.
3. Design of a multi-factor productivity model.
4. Selection of relevant productivity indices.
5. Calculation of productivity indices and validate results.
6. Development of action plan for implementation and monitoring of the model.

On the other hand, construction projects utilise a large percentage of national resources and account for a sizeable proportion of the gross domestic products (GDP) of most developed and developing countries (Tucker 1986). For instance, in many developed European countries, construction may account for 10% of the GDP and possibly higher in many developing countries (Hassan and McCaffer, 2002). This percentage implies a strong need for successful construction project deliveries. However, construction is expensive, dangerous and affected by many internal and external factors which could be within or outside the control of the stakeholders and the core project team. The client would need to balance the cost, time and quality of construction, with the benefits which would amass because of the work.

When the capital investments in construction projects are high, this implies that there would be less money remaining to operate and maintain the facilities post-construction. The less spent on construction projects, results in slower development, which could affect the quality of the facilities provided; resulting in lesser benefits accompanied by a reduced opportunity for improvement. To end this cycle, an improvement initiative is needed for better project costing and budgeting.

4. A Research Agenda

It is essential to understand how current manufacturing firms in T&T view productivity as an integral tool for project delivery improvements. An empirical study would engage a sample of manufacturing firms, where the selection criteria include the following: 1) The firm is one that operates as a manufacturing entity and has implemented or is currently implementing small, medium or large-scale manufacturing CI projects; 2) The firm is one that has implemented manufacturing CI projects both successfully and with challenges which resulted in project failures; and 3) The firm’s manufacturing CI project team is available to participate in the specified surveys and interviews. These firms would constitute the sample size; provided that they abide by the selection criteria stipulated. The empirical evidence would determine qualitatively, salient project factors related to manufacturing CI project success. From these empirical findings, parameters for successful design of a proposed Productivity Management Framework (PMF) could then be ascertained.

4.1 Acquisition and Analysis of Empirical Data

A series of surveys and interviews would be conducted by the researcher to project team members, project managers and other key stakeholders within the selected sample of manufacturing companies. For the study, two (2) main forms of collecting primary/empirical data would be utilised, these are selfcompletion questionnaires and semi-structured interviews. The design of the questionnaires would be structured to reflect appropriately the manner intended for its use. There would be questionnaires developed for two (2) main areas of this study, and they are as follows: 1) The identification of the main project factors for successful delivery of manufacturing CI projects within the selected sample of manufacturing companies, and 2) Evaluation of the proposed PMF post-implementation, with performance metrics and an implementation guide, within the selected sample of manufacturing companies in T&T. A hybrid research methodology approach would be considered for this study i.e. blending qualitative and quantitative methodologies.

4.2 Development and Evaluation of the Proposed PMF

By consolidating the findings from the surveys and interviews, a generic framework of productivity management would be developed. Existing frameworks identified and discussed in the Literature Review would provide essential information for the development of the proposed framework. An implementation guide would also be developed to demarcate firm steps for application of the framework within a manufacturing CI project. Moreover, PP metrics, attributes, and success criteria would accompany the procedure to enable effective performance measurement of the post-implementation process. Figure 2 shows the key PMF elements in the planning and execution phases of a manufacturing CI project’s lifecycle.

Evaluation of the framework would: 1) demonstrate performance, 2) determine where improvements could be made to design or delivery methods and practices, and 3) identify good practice and lessons. To elaborate on the formative evaluations, it is intended to postulate the acceptance of the framework as a viable methodology for improving project delivery. Areas for re-design would be ascertained and actioned accordingly, via the use of a questionnaire.

5. Discussion

Many productivity formulas were highly theoretical. The Sahay’s (2005) model is an example of this, where the case study showed how different factors of static, dynamic and development parameters were considered to calculate the total productivity of an organisation. For this study, a systems dynamics approach would be utilised in the design of the PMF by being able to measure a project’s performance at any point in time during the execution phase.

This study focuses itself on labour, more specifically worker productivity, as the common denominator in both the project planning and execution phases. It is critical to
consider how the project’s scope, schedule and budget change over time. Inferences and interventions could be made due to variances in the project’s scope, schedule and budget baselines, if the need arises. It is anticipated that:

1. The proposed PMF would facilitate project delivery, thereby promoting improved project performance i.e. completed within the baselined scope, schedule and budget.
2. The Schedule of the project could be determined based on estimating proper timelines using reputable past data from successful projects, similar to the project under study.
3. The Cost of a project would be determined based on a well-defined scope. The PMF would comprise productivity metrics which would allow for the development of an achievable project budget. This would prevent under-budgeting or over-budgeting of projects.
4. Scope creep would be reduced if not eliminated. The PMF would highlight critical focal points from the PMBOK Guide which would assist Project Managers in the scope development of a manufacturing CI project. Scope productivity metrics would be applied during the execution phase, for assurance that scope creep is effectively managed.

6. Conclusion

Many manufacturing CI projects include a considerable degree of construction works, while ultimately providing a service to the customer. There have been lacking solid metrics developed for measuring productivity throughout the stages of a project’s life-cycle. There is a need for a stringent measure of productivity for applications in manufacturing. Considering this, the study depicts the evolution from a ‘reactive’ comparative studies approach to analysing productivity factors that affect project performance, to a high-performance model geared towards a proactive approach in measuring productivity within the planning and execution phases of a manufacturing CI project.

The novel contributions of this study are firstly, to identify key PM attributes and relate them to the design of PP metrics for CI projects, and secondly, to develop the PMF accompanied by an implementation guide for use in manufacturing firms in T&T. Improved project success utilising the PMF within manufacturing CI projects would be extrapolated to projects in other sectors such as oil, gas, government, services, financial, and banking. Therefore, future research could validate the efficacy of the PMF approach to foster the PP efforts in CI projects across various sectors in T&T. It is anticipated that the research work would contribute to the next update to the PMBOK Guide, and the proposed PMF would be applied to other internationally recognised PM methodologies.

References:


Harper & Row, New York, NY.


Schwalbe, K. (2010), Information technology project management. Course Technology, Cengage Learning, Boston, MA


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Kit Fai Pun is Chair Professor of Industrial Engineering (IE) and the coordinator of IE Research Group at The University of the West Indies, St Augustine, Trinidad and Tobago. He is a Chartered Engineer and Chartered Marketer in the UK, as well as Registered Professional Engineer in Australia, Europe, Hong Kong, and The Republic of Trinidad and Tobago. Professor Pun is the Chair of the Local Members Community of The American Society for Quality (ASQ), Trinidad and Tobago, and has been serving as the Chairperson of the Technology and Engineering Management Society Chapter of the IEEE Trinidad and Tobago Section. His research activities include industrial and systems engineering, engineering management, quality management, performance measurement, and innovation.
Fault Characterisation of Induction Motors based on Vibration Signal Analysis Using Machine Learning Techniques

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Abstract: Vibration measurements have been used widely in industry to determine the state of health of machinery. Appropriate use of vibration monitoring can result in early detection of impending problems thus preventing unscheduled shutdowns of operations. However, the effectiveness of vibration based condition monitoring is integrally tied to the use of an expert to interpret the data provided. In this work, an automated machine learning approach for detecting and characterising faults in an induction motor based on accelerometer readings is presented. The vibration waveforms are pre-processed using Fourier transforms and wavelets. Key statistical parameters of these curves are explored including the skewness and the kurtosis; these are then used to isolate identifying features for various common faults in induction motors. These features are then fed into a supervised machine learning algorithm and a fault classification system is built. The method described herein is validated with vibration data collected from a laboratory fault simulator. The performance of the system is discussed and its applicability to industrial situations is described.

Keywords: Machine Learning, Vibration Monitoring, Fault Detection, Induction Motors

1. Introduction

Vibration based condition monitoring is a well-established maintenance tool in industrial settings. Condition based predictive maintenance (CBM) utilises periodic or continuous asset monitoring in order to gauge the condition of an asset. Some plants take continuous vibration data from important equipment and track the changes in the vibration signals to alert them to impending failures. Other companies have scheduled operational vibration measurements. In the past, these vibration signals had to be interpreted by experts in the field in order to accurately diagnose the types of faults that were developing within the machines. However, this analysis can be costly, time-consuming, and sometimes the diagnoses presented by distinct specialists for the same signal differ. While there are many CBM technologies that can be used in the field, focus will be placed on vibration analysis as it provides the foundation of many CBM programs in an industrial setting.

The vibration characteristics of a machine can be used to determine its condition i.e. to ascertain whether any mechanical problems are present and if so, to diagnose the types of faults that are present. Indicators of the condition of a machine can be derived from data in the time domain, the frequency domain or the time-frequency domain. A fast Fourier transform (FFT) of the vibrational response provides frequency information about the component under examination. It also gives information on the overall vibration energy as well as the amplitude or vibration energy at certain frequencies generated by the system that can be used to detect and isolate faults. These vibration characteristics include:

- **Amplitude** - The amplitude can be expressed either as displacement, velocity and acceleration which relates to stress, fatigue and forces of vibration, respectively. The amplitude is an indicator of the severity of the fault.

- **Frequency** - The vibration created from the faulty part will have its own characteristic frequency spectrum. Typically, different faults result in several frequencies of vibration which are multiples of the operating speed.

- **Phase** - The phase between vibrations of the same frequency is used for balancing of a part quickly and precisely.

Faults in induction motors yield characteristic information in their FFTs. Table 1 gives some examples of faults in motors and the characteristic trends in the frequency spectra, especially with regards to the peaks at associated multiples of the operating speed (N) of the motor (usually given in RPM). The table reveals that sometimes the characteristic features for two different faults are similar; for example, both bowed rotor and rotor unbalance nominally have the same key feature – a high radial vibration measurement at 1N. As a result, the effectiveness of fault detection using vibration analysis is highly dependent on the use of an expert to interpret the data provided. Traditionally, this expertise has been supplied by a human, but in recent times, machine learning techniques have been implemented in interpreting vibration data.
Machine Learning (ML) refers to the process by which a computer learns how to or improves its ability to perform specific tasks without explicitly programming software to do so. Instead, the system utilizes pattern recognition and inference to accomplish the task given. The algorithm is built by using input (training) data to create a mathematical model, which is then used to predict an output. Importantly, a ML algorithm is able to adapt as predictions from new data sets are stored, which can then be used in future analyses.

Machine learning methods typically fall into one of three major categories: supervised, unsupervised and reinforcement learning (Alpaydin, 2014). In supervised learning, the algorithm is trained using a dataset for which both the input and output are known. The relationships identified are then used to predict the output for new data (James et al., 2013; Alpaydin, 2014). Unsupervised learning algorithms are not trained with a known output. Instead, deep learning is used to explore the data to detect structure and generate categories (James et al., 2013; Alpaydin, 2014). Finally, in reinforcement learning, the environment reacts to the machine activities with a series of error or reward prompts thereby guiding the computer to learn the optimal responses (Alpaydin, 2014).

Applying machine learning to fault detection will allow the user to detect problems in mechanical systems by feeding the algorithm data gathered from a machine. Using a fault simulator, datasets with specific faults can be gathered to train the algorithm using supervised learning to classify the data. Once classified, datasets with new inputs and unknown outputs can be filtered through the ML algorithm to present a prediction of whether one or more faults are present as well as the type of fault. This prediction is then used to validate and fine-tune the algorithm for future reference.

In recent years, there has been an upsurge in research into automatic fault detection and diagnosis. Several artificial intelligence algorithms have been proposed for the design of fault classification systems of various components. Liu et al. (2018) summarise the theoretical framework and the industrial applications of various machine learning techniques including artificial neural networks, naïve Bayes, K-nearest neighbours (KNN), deep learning and support vector machines. Dou and Zhou (2016) compared four different fault classification methods for diagnosing bearing faults: KNN, probabilistic neural network, support vector machine and a rule-based method. Yin and Hou (2016) review several fault diagnosis methods and indicate that support vector machines are especially useful since they can be easily generalised. There has also been much interest in the type of features used to identify the faults. Deep learning techniques have been applied to statistical parameters of vibration measurements in either time, frequency and/or time-frequency domains. For example, Sharma et al. (2016) use several statistical features including the standard deviation, kurtosis and skewness of the vibration waveform. Similarly, Li et al. (2016b) explored the viability of using a combination of statistical features from the time, frequency and time-frequency domain to identify anomalies in equipment. Machine learning techniques have been applied to fault detection in ball bearings (Kankar et al., 2011; Dou and Zhou, 2016), gearboxes (Li et al., 2016a; Jing et al., 2017), induction motors (Pezzani et al., 2018) and rotating machinery. In some algorithms, the system is trained using supervised feature learning (Sepulveda and Sinha, 2018) while others conduct unsupervised feature learning (Lei et al., 2016).

In the current work, four machine learning algorithms (complex trees, support vector machine, fine k-nearest neighbour and boosted trees) were applied to vibration signals from a machine fault simulator in order to determine how well each one characterises induction motor faults. A combination of features in the time and spectral domain was extracted and used to classify the vibration signals of the simulator operating in its normal, unbalanced rotor, misaligned, faulted bearings, phase unbalance, bowed rotor and broken rotor bars fault conditions. Conventional wisdom suggests that the more information is available about a system, the easier it will be to identify its faults. However, this comes with high computational costs. This work seeks to determine the minimum information an operator can measure yet still be able to diagnose faults within the system.

The remainder of the paper is organised as follows. In Section 2, the experimental rig and the sensors used are described while Section 3 outlines the data analysis including the key features used to train the machine learning model, the different machine learning methods used to train the computer and the manner in which the classification error is calculated. The results are presented in Section 4, while the implications of the results are discussed and conclusions drawn in Section 5.

### 2. Acquisition of Experimental Data

<table>
<thead>
<tr>
<th>Fault Characterisation of Induction Motors based on Vibration Signal Analysis Using Machine Learning Techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Table 1. Frequency Characteristics of Faults in Induction Motors</strong></td>
</tr>
<tr>
<td><strong>Fault</strong></td>
</tr>
<tr>
<td>Bowed Rotor</td>
</tr>
<tr>
<td>Broken/Cracked Rotor Bars</td>
</tr>
<tr>
<td>Rotor Unbalance</td>
</tr>
<tr>
<td>Parallel Misalignment</td>
</tr>
<tr>
<td>Angular Misalignment</td>
</tr>
</tbody>
</table>
The experiments were conducted on the SpectraQuest Inc. machine fault simulator (see Figure 1). The system was studied under six different motor conditions. The first is the nominally healthy condition while the other six (6) motors consist of the following fault conditions:

- Rotor unbalance
- Misalignment
- Faulted bearings
- Bowed rotor
- Broken rotor bars
- Voltage unbalance and single phasing

were taken for twenty (20) seconds each; for seven (7) different motor speeds ranging from 500 rpm to 3,500 rpm at increments of 500 rpm. This process was then repeated to acquire the data for the inbound and outboard bearings.

Figure 2 shows the experimental and signal processing setup. The reading from the accelerometer was conditioned via the signal conditioner to prepare the signal for conversion into digital values. The low pass filter on the signal conditioner was set to a cut off frequency of 1,000 Hz to prevent aliasing of the signal.

The Data Acquisition System (DAQ) acts as the interface between the accelerometer and computer. The analogue to digital converter (ADC) was used to convert the analogue voltage obtained from the accelerometer into a digital signal. The gain of the signal conditioner was set to 100. LabVIEW was used to adjust the settings of the DAQ (sampling frequency/number of samples) and record the data from the accelerometer. The sampling frequency ($f_s = 10$ kHz) was greater than twice the largest frequency ($f_{max}$) considered (in this case, 58.3 Hz) according to the Nyquist rate which states that $f_s > 2f_{max} = 2B$ (where $B$ is the bandwidth of a bandlimited periodic signal). This helps to prevent the occurrence of aliasing.

Figure 1. The SpectraQuest Machine Fault Simulator (Magnum)

Vibration signals were acquired at a sampling rate of 10,000 Hz using a PCB PIEZOTRONICS triaxial accelerometer (Model Number 356B11) located on the motor, inbound bearing and outboard bearing. A thin film of wax was used to fix the accelerometer onto motor and bearings. For each motor, a total of ten (10) readings in the radial horizontal, radial vertical and axial directions were taken for twenty (20) seconds each; for seven (7) different motor speeds ranging from 500 rpm to 3,500 rpm at increments of 500 rpm. This process was then repeated to acquire the data for the inbound and outboard bearings.

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Figure 2. Experimental Setup for Acquiring and Recording Vibration Data

Table 2. Features extracted and used for training the machine learning algorithms

<table>
<thead>
<tr>
<th>Time domain features</th>
<th>FFT domain features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root mean square $X_{rms} = \sqrt{\sum x_i^2 / N}$</td>
<td>Mean vibration energy $F_1 = \sum x_i / K$</td>
</tr>
<tr>
<td>Standard deviation $\sigma = \sqrt{\sum (x_i - \mu)^2 / (N-1)}$</td>
<td>Fatness of tails in FFT $F_2 = \sqrt{\sum f_i^2 s_i / \sum f_i^2}$</td>
</tr>
<tr>
<td>Skewness $\sum (x_i - \mu)^3 / (N-1)\sigma^3$</td>
<td>Maximum amplitude $Maximum s_i$</td>
</tr>
<tr>
<td>Kurtosis $\sum (x_i - \mu)^4 / (N-1)\sigma^4$</td>
<td></td>
</tr>
<tr>
<td>Mean $\mu_i = \sum x_i / N$</td>
<td></td>
</tr>
<tr>
<td>Maximum Value $Maximum x_i$</td>
<td></td>
</tr>
<tr>
<td>Minimum Value $Minimum x_i$</td>
<td></td>
</tr>
</tbody>
</table>
3. Data Analysis

3.1 Assessing the quality of the data
The quality of the data obtained from the simulator was evaluated using two analytical tools: the signal to noise ratio (SNR) and the stability of the waveforms. The signal to noise ratio (SNR), a means of comparing the level of the signal to that of the background noise, varies with the signal to noise ratio (SNR) and the stability of the waveforms. The signal evaluated using two analytical tools: the signal to noise ratio (SNR) and the stability of the waveforms. The signal evaluated using two analytical tools: the signal to noise ratio (SNR) and the stability of the waveforms. The signal evaluated using two analytical tools: the signal to noise ratio (SNR) and the stability of the waveforms. The signal evaluated using two analytical tools: the signal to noise ratio (SNR) and the stability of the waveforms.

\[
SNR_{\text{voltage}} = \frac{\text{RMS Signal Voltage}}{\text{RMS Noise Voltage}}
\]

Convergence of the variance of the vibration data was used as a measure of stability of the signal.

3.2 Signal Processing and Feature Extraction
Several features of the vibration waveforms (see Table 2) were extracted for subsequent use in the machine learning exercise. Seven features were extracted from each untransformed waveform sensed by the triaxial accelerometer. A further three features were also extracted from the Fourier Transform of each measured acceleration. A total of ten (10) classification features had been identified per signal, while each dataset consisted of acceleration readings in three directions (axial, radial horizontal and radial vertical) at three locations on the machine (motor, inbound bearing and outbound bearing), making a total of 90 classification features per dataset. In the table, \( x_i \) represents the waveform, \( x_i \) represents the height of the Fourier spectrum at the relevant dominant frequency and \( K \) is the number of dominant frequencies in the FFT.

3.3 Machine Learning Algorithms
Three machine learning algorithms were applied to the data for the classification of various fault conditions. The system was analysed using different training scenarios, as shown in Table 3.

**Decision Tree (fine) Algorithm** - The first algorithm was the fine decision tree. The decision tree is a hierarchical structure consisting of an increasing number of nodes and branches. Each node corresponds to a classification indicator (Bishop, 2006). Depending on the value of this indicator, the feature is assigned to a different branch i.e. classification path. Supervised training of a classifier using this algorithm essentially uses the original data set to find the optimal values for each classification branch. Decision trees are relatively easy to understand and so have developed into a major machine learning tool for classification of data.

**Support Vector Machine Algorithm** - The support vector machine (SVM) algorithm was also used as a method of classification as it has been proven to work well in pattern recognition (Bishop, 2006). In our case, each vibration signal is characterised by \( N \) features, where \( N \) depends on the scenario examined as per Table 3. We can therefore consider the universe of our signals to be an \( N \)-dimensional space. The aim of classification is to place each dataset in the appropriate region of this space with enough margin between points in different sets. The traditional SVM algorithm identifies a typical observation as one of two classes (binary). Given two sets of data, the margin is the distance between the two closest points (support vectors) in the two datasets. The SVM algorithm divides the \( N \)-dimensional universe into subspaces by determining the optimal hyper-planes (decision boundaries) for distinguishing between such distinct types of data. It does so by maximising the margin between them. To extend the SVM method for classification of multiple classes, the algorithm solves a series of binary SVM subproblems, using a One-versus-all method.

**k-Nearest Neighbour (kNN) Algorithm** - For execution of the kNN algorithm, the location of each training dataset is determined. When a new dataset is introduced into the \( N \)-dimensional space, it is assigned to the classification with the greatest number of elements in the region consisting of its \( k \) nearest neighbours. There are different methods for measuring distance (and consequently determining the nearest neighbours). In this work, we used Euclidean distance. As \( k \) increases, the training error increases. The validation error is high for small values of \( k \), decreases until it reaches a minimum value and then starts to increase again. In this work, \( k = 5 \) - the value at which the local minimum occurs most frequently over the different training and validation datasets.

3.4 Evaluation of Classifier Performance
A total of 490 observations were made (ten runs of seven faults each operated at seven speeds). Eighty percent of the observations (i.e., 392) were used to train the classifier while the remaining twenty percent (i.e., 98) were used for testing how well the classifier worked.

For classification problems, the accuracy of a trained model is determined by the number of observations (datasets) that it correctly classifies. To prevent the model from being overfit to the training data, it was subjected to 10-fold cross-validation (Alpaydin, 2014). This means that the training data was randomly partitioned into 10 distinct groups of data and subjected to 10 training exercises. For each fold, one of the groups was chosen to form the in-fold observations while the remaining nine groups composed the out-of-fold observations. The model was trained using the out-of-fold data and then its performance was assessed against the in-fold observations. The error of each fold was calculated by dividing the number of correctly classified observations by the total number of observations. Finally, the average of the cross-validation errors of the 10 folds was calculated and used as the overall error of the trained model.
To determine the test error, the overall model was used to classify a new (untrained) set of observations and the error thus obtained was recorded.

Any model chosen for fault diagnosis needs to be robust i.e. the predicted outcomes should be relatively insensitive to the observations used to obtain the training sets. If the model is stable, then it is expected that the variations in the output of the algorithm will decrease as the number of observations in the training set increases (Liu et al., 2017). The hypothesis stability bound is a common method of determining the robustness of a learning algorithm (Bousquet and Elisseeff, 2002). If we denote the original training set by $S$:

$$S = \{ z_1 = (x_1, y_1), z_2 = (x_2, y_2), \ldots, z_m = (x_m, y_m) \}$$

where $x$ represents the feature measurements and $y$ represents the fault assigned, and we create a new set, $S'$ by removing the $i^{th}$ observation in the training set,

$$S' = \{ z_1, z_2, \ldots, z_{i-1}, z_{i+1}, \ldots, z_m \}$$

then the learning algorithm is said to exhibit hypothesis stability $\beta$ with respect to the loss function, $V$, if

$$V_i \in \{1, 2, \ldots, m\}, E_{z \in S'} (V(f_S, z) - V(f_{S'}^i, z)) \leq \beta$$

When choosing between classifiers, the one which yields the lowest $\beta$ is the most stable. In this work, the exponential loss function is used; incorrect classification results in a large contribution to the loss term.

### Table 3. Sample feature scenarios examined using the Machine Learning Algorithms

<table>
<thead>
<tr>
<th>Features</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Both time and frequency domain features (10) in all three measurement locations (3).</td>
<td>90</td>
</tr>
<tr>
<td>Only time domain features (7) in all three directions (3) at all three measurement locations (3).</td>
<td>63</td>
</tr>
<tr>
<td>Only frequency domain features (3) in all three directions (3) at all three measurement locations (3).</td>
<td>27</td>
</tr>
<tr>
<td>Both time and frequency domain features (10) in all three directions (3) at only two measurement locations (2).</td>
<td>60</td>
</tr>
<tr>
<td>Only time domain features (7) in only two directions (2) at only two measurement locations (2).</td>
<td>28</td>
</tr>
<tr>
<td>Only frequency domain features (3) in all three directions (3) at only two measurement locations (2).</td>
<td>18</td>
</tr>
<tr>
<td>Only time domain features (7) in all three directions (3) at only one measurement location (1).</td>
<td>21</td>
</tr>
<tr>
<td>Only frequency domain features (3) in all one direction (1) at only one measurement location (1).</td>
<td>3</td>
</tr>
</tbody>
</table>

### 4. Results

Figure 3 shows the distribution of the SNRs and the best fit normal distribution through the values. They varied from 1.61 dB (for the vertical acceleration measurement of the simulator experiencing rotor unbalance with the motor operating at 500 rpm) to 62.6 dB (for the axial acceleration due to faulty bearings for the motor running at 3,500 rpm). All the signal to noise ratios are positive and only three waveforms had signal to noise ratios less than 5, indicating that the actual acceleration measurement is well differentiated from the noise. The sensitivity of the learning algorithm used will normally depend on the sampling technique used to choose the training set and the noise in the measurements. Since Figure 3 results show that the SNR is relatively high for typical measurements, the robustness of the learning algorithm obtained will depend primarily on the training set selection.

Tables 6-8 examine how accurately machine learning based on the time domain only, the frequency domain only, and combination of frequency and time domains can classify the specified faults, given readings in various combinations of mutually perpendicular directions (Figure 1): horizontally (x-axis), vertically (y-axis) and axially (z-axis). These different directions were also examined under various motor, inbound and outbound bearing configurations for the three (3) classifiers. Table 5 provides the legend for Tables 6 - 8.

### Table 5: Legend to the symbols in the results tables

<table>
<thead>
<tr>
<th>Keys:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Complex Tree</td>
</tr>
<tr>
<td>2</td>
<td>Linear SVM</td>
</tr>
<tr>
<td>3</td>
<td>kNN (k=5)</td>
</tr>
<tr>
<td>M</td>
<td>Motor</td>
</tr>
<tr>
<td>I</td>
<td>Inbound Bearing</td>
</tr>
</tbody>
</table>

### 4.1 Choosing between Different Classification Methods

In this section, we examine the accuracy of the different training algorithms. The kNN algorithm trains the material with the highest accuracy. For example, when all 90 features are used in the analysis (row 1, grouped column 1 of Table 6), the kNN algorithm achieves 99.7% accuracy, compared to 99.2% and 91.1% respectively for the SVM and fine decision tree algorithms, respectively. The same trend holds true whether the number of features...
are reduced by removing one/two accelerations (comparing grouped columns in Table 6), by decreasing the number of locations at which the measurements are taken (comparing rows in Table 6) or by including only time domain features (comparing like terms in Table 7) or only frequency domain features (comparing like terms in Table 8). The lowest accuracy (71.4%) occurs when using frequency domain features only obtained from axial measurements obtained on the outboard motor; this corresponds to only three features per observation.

When the number of features being analysed is greater than 30, on average, the SVM provides a better fit to the training data than the fine tree algorithm. However, if the number of classification indicators is less than 30, there is a distinct fall off in the accuracy of the SVM and the fine tree algorithm is then more accurate.

### 4.2 Determining the Appropriate Acceleration Data

Before the acceleration measurements can be input into the machine learning algorithm the data must be processed, i.e. the classification indicators have to be calculated. Typical acceleration waveforms are in the order of tens of thousands of points, so calculating the indicators can be computationally intensive. Ultimately, the fault classification systems will be real-time systems, so it is important to determine what is the least amount of data that can be analysed yet still provide accurate information on the state of the machine. Consequently, we examine the effect of just looking at acceleration measurements in one/two direction(s) instead of in all three directions.

Applying the kNN algorithm to the scenarios for which all the time and frequency domain features from triaxial data are used in the classification process, we note that the accuracy of fit of the training data lies between 99% and 100% with a mean value of 99.5%. The corresponding accuracy for the biaxial acceleration measurements in the xy, yz and zx directions are 99.3% and 99.4% respectively, as seen in the 3rd column of Table 9. A similar order is noted for time domain only measurements and frequency domain only measurements as elaborated in columns 4 and 5 of Table 9. Thus, amongst the three types of biaxial domain analysis, measurements in the xz direction give the best fit with minimal decrease in accuracy (99.4% compared to 99.5% for features from both domains and 98.3%}

### Table 6: Percentage Accuracy of Time and Frequency Domain Features in mutually perpendicular directions for the training data

<table>
<thead>
<tr>
<th>Configurations</th>
<th>Axes</th>
<th>Classifier</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>xy</td>
<td>x</td>
</tr>
<tr>
<td>MLO</td>
<td>91.1</td>
<td>99.2</td>
</tr>
<tr>
<td>LO</td>
<td>88.8</td>
<td>97.2</td>
</tr>
<tr>
<td>LM</td>
<td>92.1</td>
<td>97.4</td>
</tr>
<tr>
<td>LM</td>
<td>94.1</td>
<td>98.9</td>
</tr>
<tr>
<td>LM</td>
<td>86.7</td>
<td>92.6</td>
</tr>
<tr>
<td>O</td>
<td>89.8</td>
<td>86.5</td>
</tr>
<tr>
<td>M</td>
<td>94.1</td>
<td>88.3</td>
</tr>
</tbody>
</table>

### Table 7: Percentage Accuracy of Time Domain Features in mutually perpendicular directions for the training data

<table>
<thead>
<tr>
<th>Configurations</th>
<th>Axes</th>
<th>Classifier</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>xy</td>
<td>x</td>
</tr>
<tr>
<td>MLO</td>
<td>89.3</td>
<td>96.7</td>
</tr>
<tr>
<td>LO</td>
<td>88.8</td>
<td>95.5</td>
</tr>
<tr>
<td>LM</td>
<td>92.1</td>
<td>96.4</td>
</tr>
<tr>
<td>LM</td>
<td>87.5</td>
<td>90.8</td>
</tr>
<tr>
<td>I</td>
<td>88.0</td>
<td>84.7</td>
</tr>
<tr>
<td>O</td>
<td>82.9</td>
<td>61.5</td>
</tr>
<tr>
<td>M</td>
<td>83.9</td>
<td>79.3</td>
</tr>
</tbody>
</table>

### Table 8: Percentage Accuracy of Frequency Domain Features in mutually perpendicular directions for the training data

<table>
<thead>
<tr>
<th>Configurations</th>
<th>Axes</th>
<th>Classifier</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>xy</td>
<td>x</td>
</tr>
<tr>
<td>MLO</td>
<td>91.8</td>
<td>92.1</td>
</tr>
<tr>
<td>LO</td>
<td>89.8</td>
<td>86.0</td>
</tr>
<tr>
<td>LM</td>
<td>91.8</td>
<td>85.7</td>
</tr>
<tr>
<td>LM</td>
<td>92.5</td>
<td>81.6</td>
</tr>
<tr>
<td>I</td>
<td>85.2</td>
<td>69.9</td>
</tr>
<tr>
<td>O</td>
<td>87.8</td>
<td>62.5</td>
</tr>
<tr>
<td>M</td>
<td>90.8</td>
<td>72.4</td>
</tr>
</tbody>
</table>

...
compared to 98.7% for features from the time domain only).

When uniaxial accelerations are used to train the system, the drop in the accuracy of the fit is significant, with an appreciable spread in the accuracy about the mean value. Hence, the use of single accelerometer readings using the classification indicators in this research is not recommended.

4.3 Determining a suitable location for the acceleration measurements

Finally we determined suitable location(s) for acceleration measurements. The original data included acceleration readings at the motor, the inbound bearing and the outbound bearing. Table 10 summarises the accuracy of the kNN classification for different accelerometer location scenarios. Applying the kNN algorithm to the scenarios made at two points (the inbound and outbound bearing and the motor), the corresponding bearings, the inbound bearing and the motor, and the outbound bearing and the motor), the corresponding accuracies are 99.1%±0.4%, 99.2%±0.4% and 99.3%±0.4%, respectively. Table 10 shows the percentage accuracy for the different acceleration location scenarios. Note that there is a significant reduction in the accuracy of the model when accelerations are sampled at only one location.

4.4 Determining the Appropriate Domain of Features

Finally, the accuracy of the results is investigated with reference to the feature domains. Table 9 shows that the time domain features outperformed the frequency domain features in classifying faults in two ways, the average values for the accuracy were higher and/or the range of the percentage accuracy was smaller. Similarly, Table 10 shows that the accuracy of classification using the time domain features is greater than the accuracy obtained using the frequency domain indicators.

Based on the observations described in Sections 4.1 – 4.4, it is apparent that a kNN algorithm based model trained with time domain features obtained from radial (horizontal) and axial acceleration measurements at the inbound bearing and motor should provide satisfactory accuracy in classification of new datasets. This hypothesis is tested using the test data (the 98 observations not used to train the classifier).

4.5 Efficacy of the model in classifying new data

The performance of the chosen scenario is discussed using appropriate confusion matrices which compare the fault assigned to an observation using a specified model to the actual fault (Ting, 2017). One dimension of the confusion matrix indicates assigned classification (the column in this

### Table 9: Summary of accuracy for kNN classification for different acceleration direction scenarios

<table>
<thead>
<tr>
<th>Acceleration direction</th>
<th>Features from both domains</th>
<th>Features from time domain only</th>
<th>Features from frequency domain only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triaxial measurements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>x, y, z</td>
<td>99.5%±0.5</td>
<td>98.7%±0.5</td>
<td>97.9%±1.3</td>
</tr>
<tr>
<td>Biaxial measurements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>x, y</td>
<td>99.2%±0.8</td>
<td>97.4%±1.8</td>
<td>96.0%±3.3</td>
</tr>
<tr>
<td>y, z</td>
<td>99.3%±0.4</td>
<td>97.3%±2.2</td>
<td>97.3%±2.4</td>
</tr>
<tr>
<td>Uniaxial measurements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>x</td>
<td>97.4%±2.1</td>
<td>93.9%±5.1</td>
<td>87.9%±8.8</td>
</tr>
<tr>
<td>y</td>
<td>97.8%±1.7</td>
<td>92.9%±5.6</td>
<td>91.0%±11.2</td>
</tr>
<tr>
<td>z</td>
<td>97.6%±1.9</td>
<td>90.8%±4.4</td>
<td>87.3%±11.4</td>
</tr>
</tbody>
</table>

### Table 10: Summary of accuracy for kNN classification for different acceleration location scenarios

<table>
<thead>
<tr>
<th>Acceleration direction</th>
<th>Features from both domains</th>
<th>Features from time domain only</th>
<th>Features from frequency domain only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three positions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M, I, O</td>
<td>99.7%±0.3</td>
<td>98.8%±0.8</td>
<td>98.8%±0.8</td>
</tr>
<tr>
<td>I, O</td>
<td>99.1%±0.6</td>
<td>98.0%±1.7</td>
<td>95.7%±3.5</td>
</tr>
<tr>
<td>I, M</td>
<td>99.2%±0.7</td>
<td>98.4%±1.1</td>
<td>96.8%±2.7</td>
</tr>
<tr>
<td>O, M</td>
<td>99.3%±0.7</td>
<td>97.5%±2.0</td>
<td>96.6%±2.9</td>
</tr>
<tr>
<td>Two positions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>97.8%±1.7</td>
<td>93.6%±4.9</td>
<td>86.9%±15.2</td>
</tr>
<tr>
<td>O</td>
<td>97.2%±2.0</td>
<td>91.5%±6.7</td>
<td>84.9%±9.5</td>
</tr>
<tr>
<td>Single position</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>97.8%±1.7</td>
<td>91.6%±6.9</td>
<td>93.3%±4.8</td>
</tr>
</tbody>
</table>
work) while the other dimension (the row) indicates actual classification; therefore, an element in the M^{th} column and the N^{th} row of the confusion matrix indicates the number of observations in the dataset which predict that the fault is type M when it is actually type N. Figure 4 shows the confusion matrix for a classifier trained using the kNN algorithm with vibration measurements in the three mutually perpendicular directions at the three locations for features from both the time and frequency domains. Each observation therefore has 90 features, i.e. 10 features per acceleration with 3 (vertical, horizontal and axial) accelerations taken at each of 3 locations (motor, inbound bearing and outbound bearing). The system performs perfectly; it correctly classifies all the faults in the test data. Figure 5 shows the confusion matrix for the recommended classifier. It too assigns all the observations to the correct fault. Note, however that this classifier only requires 28 features, less than a third of the original set. This is a benefit both in terms of computational effort and storage of the classifier parameters. Table 11 provides the legend for the confusion matrices.

We compare the accuracy of these models to the accuracy of the support vector machine algorithm 28-feature-trained classifier, i.e. 7 time domain features per acceleration with 2 (horizontal and axial) accelerations taken at each of 2 locations (motor and inbound bearing). Of the 98 observations, 90 (92%) were correctly classified (see Figure 6).

The confusion matrix reveals that the classifier correctly identified the normal motor, faulted bearings and the motor with voltage unbalance. Of the 14 observations of motors with rotor unbalance, 13 were correctly identified while one was misidentified as a motor with broken rotor bars. Similarly, all but one of the misaligned motors was correctly assigned; the other observation was mislabeled as a faulted bearing. The SVM classifier performed with least accuracy in assigning motors with a bowed rotor. Only 10 were correctly identified; two were mis-labelled as broken rotor bars, and one each was mislabelled as a motor with no faults and as a misaligned motor.
4.6 Stability of the Models

The calculated stability bounds for 392 training observations are displayed in Table 12. It is important to note that the stability bound $\beta$ measures how sensitive the learning algorithm is to changes in the training data. The model with the lowest $\beta$ is generally the most robust. So for the 90-feature model, the kNN ($k=5$) method yields the most robust learning algorithm (about 0.8% of the time, the fault identified by this algorithm with a variation in the training data will differ from the fault identified by the original training set).

Table 12: Stability bounds for some training algorithms based on the exponential loss factor

<table>
<thead>
<tr>
<th>Classifier</th>
<th>90-Feature</th>
<th>28-Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine Tree</td>
<td>0.010613</td>
<td>0.008163</td>
</tr>
<tr>
<td>kNN ($k=5$)</td>
<td>0.009361</td>
<td>0.005442</td>
</tr>
<tr>
<td>SVM</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The stability is relatively small for the chosen 28-feature kNN ($k=5$) classifier shown in Figure 7. When the number of training observations increases, the stability bound will decrease. This implies that the learning algorithm is stable (Liu et al., 2013).

5. Discussion and Conclusions

Several machine learning algorithms (i.e., fine decision tree, support vector machine and k nearest neighbours) were used to train classifiers for diagnosing faults in induction motors. It was noted that the kNN algorithm consistently gave the most accurate detection and classification of faults. The model was examined to determine the effect of reducing the number of features in a data set by (a) reducing the number of features per acceleration waveform, (b) decreasing the number of acceleration components taken at each location and (c) decreasing the number of locations at which accelerations are taken. The data suggested that a 28-feature model could achieve comparable goodness of fit levels to that of the original 90-feature model; the model consists of the time domain features obtained from axial and radial acceleration (horizontal) data at the inbound bearing and the motor. This is borne out by the confusion matrix assigning every observation correctly. The small stability bound, which suggests relative insensitivity to the training set chosen also bolsters this choice and suggests that the model has potential for further development into a system which may be used for fault classification in real-life industrial situations.

However, there are several limitations to the work reported in this article. First, the number of observations used to train the classifiers was rather limited (i.e., 392). Machine learning models are able to classify faults more effectively when they are trained with large enough data sets. Future work will address this. The classification error is very low for the system described. However, the training data was taken from an experimental test rig. In an actual industrial scenario, the data would be more random. An enhanced model requires data from industrial settings to be used to train and test the model.

A major limitation of the algorithm discussed is that it can only characterise motors with a single fault. Another area of future research is being able to classify equipment condition when there is more than one fault. Finally, the system is able to categorise the faults within the system but does not yet quantify the magnitude of the fault. These limitations give rise to avenues for further research.

References:


Li, C., Sanchez, R. V., Zurita, G., Cerrada, M., Cabrera, D., and Vásquez, R. E. (2016a), “Gearbox fault diagnosis based on deep random forest fusion of acoustic and vibratory signals”,

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Transitioning of Manufacturing towards Industry 4.0 in Trinidad and Tobago: A Proposed Framework with Discussions of the Role of Industrial Engineers

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Abstract: The current economic environment demands a different skills-set from engineers in order to achieve meaningful growth and development in Trinidad and Tobago (T&T). The traditional role of the engineer is no longer sufficient to sustain a growth trajectory on par with global benchmarks. This would extend the role of the engineer from a strict problem-solving mindset to incorporate an entrepreneurial mindset. In such context, this paper reviews the evolution of innovation concepts and industrial revolutions and draws parallels of the contributions of Industrial Engineering (IE) in industrial developments, with particular reference to the manufacturing profile and business environment in T&T. Incorporating the analysis of empirical data/findings acquired with desk research, a conceptual framework of Manufacturing Innovation Management (MIM) is proposed to integrate and guide the innovation activities of manufacturing firms. Discussions are made on the advocate of the framework, along with the IE provisions and challenges and the ‘enabler’ role of industrial engineers in T&T. It concludes by underlining the importance of IE and asserting that Industrial Engineers are equipped with the necessary skills-set embedded in safeguarding industrial developments and transition towards Industry 4.0.

Keywords: Industrial Engineering, innovation management, Industry 4.0, Trinidad and Tobago

1. Introduction

Nowadays, most developed nations are forging at the frontiers of the industrial revolution, while many developing countries are trying to catch up with innovation initiative towards sustainable development. The Fourth Industrial Revolution (4IR), like its predecessors, brings with it a unique set of opportunities and challenges which have significant implications for industry, labour and governments (Schwab, 2015). Despite global technological advancements, innovation in developing countries, such as the Caribbean, emerges from “behind the technology frontier” as defined by leading industrially advanced countries (IACs) (Hobday, 2005).

The Republic of Trinidad and Tobago (T&T) is the southernmost island country in the Caribbean. Trinidad and Tobago has the third highest gross domestic products (GDP) per capita based on purchasing power parity (PPP) in the Americas after the United States and Canada (IMF, 2017). It is recognised by the World Bank (2007) as a high-income economy. Unlike most Caribbean nations and territories, which rely heavily on tourism, the Trinidadian economy is primarily industrial with an emphasis on petroleum and petrochemicals (Wikipedia, 2019a). The growth and development of T&T’s economy has since the 1960s hinged on the endowed oil and gas resources and the energy sector. This led to a high demand for engineers to service the sector along with other industry sectors, like manufacturing and associated services.

The volatility of industrial development coupled with the emergence of Industry 4.0, is forcing a shift in the structure of the revenue-generating base of the T&T economy. A more innovative regional manufacturing sector is advocated as a means of diversifying the regional economies and promoting sustainable economic growth and development. In this context, a conceptual framework of Manufacturing Innovation Management (MIM) is proposed to integrate and guide the innovation activities of manufacturing firms in T&T.

The field of engineering is subdivided into several major disciplines. Industrial Engineering (IE) is a people-oriented and customer-focused discipline that stresses the technical and human aspects of quality and productivity (Pun and Yiu, 2010; Pun, 2011). It integrates knowledge and skills from several fields of science, namely, technical, economic, human and information sciences (KMS, 2007). ‘Systems world view, productivity and efficiency’ are words that describe the distinctive attributes of industrial engineering (IIE, 2019). IE practices focus on the design of products, processes and systems that cuts across other major engineering disciplines and associated engineering management (UWL, 2015). Industrial engineers are the professionals trained as productivity and improvement specialists. The IE profession comprehends knowledge and professional skills in applying scientific analysis, technical design, management techniques, financial appraisal and human relations principles in order to improve quality,
productivity, investment and human development in operations (KMS, 2007; Pun and Yiu, 2010).

Over the past few decades, IE has become a fast-growing engineering discipline not only in advanced nations (e.g. the United States of America (USA), Canada, Japan and Germany), but also developing countries (like, China, Korea, Thailand, and Columbia) (Pun and Yiu, 2010). However, a quite different scenario of the IE popularity has been prevalent in T&T, and many people including employers and practitioners have been underestimating the contributions of Industrial Engineers in respective organisations (Parsotan, 2005; Pun and Yiu, 2010; Pun, 2011). There is a pressing need to break such the prevalence by restating the IE roles and contributions to industry and the transitioning of manufacturing towards Industry 4.0.

This paper begins with a brief review of evolution of innovation concepts and industrial revolutions. It then presents the main findings of a recent study on transitioning of manufacturing towards Industry 4.0. Discussions are made on the advocate of the conceptual MIM framework, along with the IE provisions and challenges and the role of industrial engineers in T&T. It concludes by underlining the importance of IE in safeguarding industrial developments and transition towards Industry 4.0.

2. Evolution of Innovation Concepts and Industrial Revolutions

Technological innovations have been the driving force of industrialisation. This is evidenced by four (4) major technological breakthroughs that have influenced the mode of production in the global manufacturing sector (Naudé, and Szirmai, 2012). These developments have led to the successive progression of four (4) industrial revolutions since the second half of the eighteenth century. Figure 1 maps the innovation-industrialisation relationship from the perspective of technological innovation leading industrialisation.

![Figure 1. The Four Industrial Revolutions](image)

The Fourth Industrial Revolution (also known as Industry 4.0) brings with it a unique set of opportunities and challenges which have significant implications for industry, labour and governments (Schwab, 2016). It is important for actors to understand the context of their operating environment and the reciprocal relationship that exists between innovation and industrialisation. While technological innovations have set the pace for industrialisation, the converse is also true. Industrialisation has in turn stimulated innovation as a result of new technologies and technological developments, as well as new combinations of existing technology (Nicolov and Badulescu, 2012).

Verloop (2004) asserts that innovation existed even before the onset of the industrial revolution. According to Verloop (2004), innovation during the pre-industrial era was ad-hoc and lacked scientific and technological applications. However, the onset of the industrial era changed the innovation landscape by introducing technology-driven processes which have since transitioned into opportunity-driven processes. Opportunity-driven innovation is the mainstay of the Industry 4.0 resulting from exponential increase in speed and scope of impact from technological breakthroughs (Schwab, 2016). The development of the industrial innovation process based on Verloop’s (2004) concept is depicted in Figure 2.

![Figure 2. Development of the Industrial Innovation Process](image)

Rothwell’s (1994) seminal work on the ‘fifth-generation innovation’ concept has pioneered the characterisation of innovation models throughout the industrial era (Hobday, 2005; Tidd, 2006). Rothwell (1994) charted five generations of innovation models as illustrated in Figure 3. Hence, Hobday (2005) argues that the transition from one generation to the other does not imply a discontinuation of models from the previous generation but rather an expansion of models that co-exist and intersperse.

![Figure 3. Five Generations of Innovation Models](image)
Based on Rothwell’s (1994) classification, innovation was considered as a linear process during the first and second generations however, the focus of the first generation was on technological development (i.e., technology-push) while in the second-generation emphasis was placed on market demand (i.e., need-pull). The third-generation innovation process saw a “coupling” of the push-pull factors along a “logically sequential, though not necessarily continuous process, that can be divided into a series of functionally distinct but interacting and interdependent stages” (Rothwell, 1994).

Complexities within the innovation process started to build during the fourth generation as firms became more interactive by forging external network alliances while at the same time pursuing internal cross-functional activities. This period coincided with the Third Industrial Revolution which made such interactions possible through information and communication technology (ICT) and extended into the fifth generation where attention was placed on instituting electronic systems to manage the growing knowledge base to improve the speed, flexibility and efficiency of organisational output leading into the Fourth Industrial Revolution.

Industry 4.0 coincides with activities described in the fourth and fifth generation innovation models. The fourth generation is described as the ‘interactive’ era which promotes integration and collaboration among firms while the fifth generation is characterised by ‘electronification’ and use of information technology (IT) tools and knowledge management (KM) strategies (Rothwell, 1994).

According to Hobday (2005), innovation in developing countries emerges from “behind the technology frontier” as defined by leading IACs. Innovation process models across these five generations are presented from the perspective of the research and development (R&D)/technology developers, usually from the developed economies, and does not take into account the distinct innovation process of R&D/technology adopters, such as T&T being one of the developing countries in the Caribbean (Koonj Beharry, 2019).

4.1 Firm Age, Size and Ownership

Based on the respondent profile, it was found that 85% of manufacturing firms across T&T are at the mature phase of their business life cycle having been established for over five years. Based on a regionally contextual definition of firm size, 50% of respondent firms represented micro, small, and medium enterprises (MSME) with less than fifty employees, while 50% represented large firms with more than fifty employees.

In terms of ownership of these firms, 85% represented local privately-owned firms, 10% represented internationally-owned firms and 5% represented jointly owned firms. Inter-firm collaboration was found to be a significant source of innovation for mature firms while outdated technology was found to be a barrier for younger firms. IP protection was found to be of greater concern for younger firms compared with mature counterparts. These factors align with the theory that mature firms have greater accessibility to resources than younger firms (Mazzarol et al., 2010).

Results showed that there exists a positive correlation between foreign ownership and innovation. For international and jointly-owned firms, the parent firm was found to be a significant source of innovation while government was considered a significant enabler of innovation. This may be explained by the need for international firms to possess a superior asset base to develop differentiated products and build economies of scale in order to successfully compete with local firms in...
their own territory and offset relatively higher costs of operating in foreign markets (Martin, 2008).

4.2 Industry and Primary Business Activities

It was found that the manufacturing sector has spanned a diverse range of industries with the largest being food and beverage, representing 30% of respondents. Other industries included construction representing 25% of respondents, consumer goods, pharmaceutical/medical products, and printing/packaging/publishing each representing 10% of respondents and to a smaller extent, automotive, computer/electronics and petrochemicals/chemicals. These firms were also found to be engaged in a diverse range of business activities including mass production, batch production, job production, original design manufacturing (ODM) and contract manufacturing.

4.3 Target Markets

100% of respondents confirmed that their primary target market was the local market while secondary markets extended to the Caribbean with 65% of respondents and 5% each to Latin America, Europe, the USA, and the United Kingdom. 15% of firms indicated that they did not service a secondary market.

5. Discussions

5.1 Recency of Acquisition of Technology

Survey findings showed that the more recent the acquisition of technology by a firm, the more significant the need for resource allocation to enable innovation using this technology. This has been justified since newer technology might require different resources such as raw materials and skills-set to function effectively. In addition, it was found that knowledge of customer needs has been a significant contributor to the recency of acquisition of new technology which would be attributable to changing customer needs. As customer needs evolve, manufacturers would need to invest in new technology to meet these demands.

5.2 Internal Research and Development

For manufacturers engaged in internal R&D as a primary source of innovation, management and university/research institutions were found to be statistically significant contributors. This follows that management policy would govern research strategy and resource allocation for research. Insufficient pricing power was considered a significant barrier to innovation. This would be as a result of the relatively high capital expenditure associated with internal R&D and the high cost of offsetting these expenses. Competitor analysis was found to be a significant enabler. Moreover, the features of technology were a significant consideration in choosing a technology transferor for firms engaged in internal R&D. Analysis showed that many manufacturers concerned about alignment of transferred technology with their R&D needs and output.

5.3 Equity Link between Firm and Technology Transferor

It was found that inadequate physical infrastructure has been a significant barrier to innovation more so for firms with no equity link with the transferor. This would result from disparities between the physical infrastructure norms and requirements and between the transferor and transferee countries. As a result, features of the technology were found to be significant considerations in choosing a technology transferor.


A consolidation of empirical findings with desk research was considered in the development of a proposed framework of Manufacturing Innovation Management (MIM). The basic MIM structure is based on the Triple Helix configuration of university, industry and government collaboration (Etzkowitz and Leydesdorff, 1995; Laursen and Salter, 2004) with industry. In this context, the manufacturing sector would be the primary stakeholder, and be supported by various entities. Figure 4 shows a diagrammatic view of the conceptual MIM framework.

Empirical findings highlighted the university/research institution as a source of innovation. Knowledge of customer needs was considered as an integral component of the process. As such, the model advocates the operation
of Market Research Agencies linking the industry and research institutions in the product development process. In addition, Technology Transfer Agencies are proposed to facilitate the search and acquisition of appropriate technologies to fit the needs of the industry. These agencies liaise between the firm and the technology developer to ensure that transferred technology is supported by appropriate infrastructure and resource allocations.

In order to facilitate inter-firm collaboration as a source of innovation as endorsed by mature firms, the MIM framework recommends prudently managed cluster networks moderated by a qualified Cluster Facilitator who facilitates collaboration among partners, lobby for support on behalf of members, direct resources and entities within the network and promote transparency between partners.

Funding Agencies play a critical role in the innovation process. These institutions should provide funding for R&D initiatives, equipment and infrastructural upgrades as well as patent financing. It is recommended that these agencies adopt a more risk-accepting approach than traditional lending institutions. Such an approach releases the fear of failure thereby encouraging a culture of innovation that allows for learning from failure. While a Legal Council is recommended to provide legal advice and services to regional manufacturing firms covering issues.

Moreover, the MIM framework prescribes that the role of government focuses on the provision of an enabling environment with a Consultations Agency serving as liaison between government and other stakeholders. The mandate of the Consultations Agency should be to provide regular feedback and progress updates and to engender transparency and parity among stakeholders (Koonj Beharry, 2019).

6. The Role of Industrial Engineers on Transitioning Manufacturing towards Industry 4.0

The discipline of IE had been changing and the need for Industrial Engineers around the world has been growing (Pun and Yiu, 2010). Industrial Engineering stresses the design of products, processes and systems that cuts across other major engineering disciplines and associated engineering management (UWI, 2015). Pun and Yiu (2010) contend that IE draws upon a wide base of knowledge and skills in mathematical, physical and social sciences together with principles and methods of engineering analysis and design to determine and evaluate the results to be obtained from such systems. According to Bajpai and Akhtar (2017), industrial engineers optimise processes and systems through strategic manipulation of the manpower, machinery, materials, methods and money.

The IE skills and methodologies are applicable to different industrial systems found everywhere such as manufacturing plants, services companies (e.g. hospitals, banks, and insurance) and government organisations. Pun (2011) argued that IE skills and applications would lead to flexibility and allow the industrial engineers themselves to act, make decisions or solve problems by drawing from various areas of knowledge.

However, there has been lacking understanding of IE applications in organisations across various sectors in T&T (Pun and Yiu, 2010; Pun, 2011). The inappropriate impressions, which employers/practitioners held of Industrial Engineers, have been affecting the IE employment and hindering the competitiveness of many industrial organisations, including both large manufacturers and MSME in T&T. One recommendation was to urge employers/practitioners to look critically into the capabilities of hiring Industrial Engineers and how they have aided in their operations advancement. The university sector (like, The University of the West Indies (UWI) and The University of Trinidad and Tobago (UTT)) should ensure the anticipated growth in IE workforce for the nation to be met with sufficient supply of qualified IE graduates (Pun and Yiu, 2010).

As discussed in Sections 4 and 5 above, the proposed MIM structure necessitates a high degree of interaction amongst a diverse range of specialised entities. The versatile applications of IE could be an asset for industrial organisations, irrespective of their business nature, size and locations. It is contended that industrial engineers and associated professionals could play an 'enabler' role to bridge between management goals and operational performance.

At the industry level, industrial engineers are equipped with the requisite tools to venture into entrepreneurship. They could support entrepreneurs by using optimisation and planning techniques. With their broad knowledge-base of technical, computational, financial and managerial/social grounds would make industrial engineers suitable for any functions as advocated in the MIM framework. Moreover, industrial engineers would also act as connectors between specialised functional entities drawing on their wide-ranging knowledge-base, thereby increasing the efficiency in collaboration between the various functional entities.

7. Conclusion

Over the course of four industrial revolutions, five generations of innovation models have evolved (Rothwell, 1994). Industry 4.0 coincides with activities described in the fourth and fifth generation innovation models. The fourth generation is described as the ‘interactive’ era which promotes integration and collaboration among firms, while the fifth generation is characterised by ‘electronification’ and use of IT tools and KM strategies (Rothwell, 1994; Koonj Beharry, 2019).

The proposed MIM framework is operationalised in the context of the current industrial era. At the turn of the century, the industrialised world began a transition into the Fourth Industrial Revolution or Industry 4.0 (Schwab,
This shift is leading to the burgeoning of ‘smart factories’ characterised by the use of cyber physical systems and powered by the internet (Umachandran et al., 2019). This enables communication with and control of physical systems using computational modalities (Lee et al., 2015). Resultant collaborations between evolving technological and social entities (Kagermann et al., 2013) present an added dimension to Schumpeter’s innovation theory of ‘new combinations’ (Schumpeter, 1982). It is projected that innovation management in Industry 4.0 therefore requires a holistic strategic approach which fits into the domain of the IE.

The conceptual MIM framework is hinged on collaboration amongst various entities with diverse skillsets and collective activities that facilitate a seamless transition of the T&T manufacturing sector into Industry 4.0. Industrial engineers possess the requisite knowledge and skillset and serve as conduits across various links in the proposed framework. They have a broad-based understanding of multiple disciplines that interact in the execution of collective activities. Moreover, industrial engineers could serve to bridge the knowledge gap amongst entities, and act effectively in any capacity stipulated in the framework.

Future research could acquire empirical evidences to validate the building blocks with key players, and verify collective interactions and activities as advocated in the MIM framework. Comparative evaluations and case studies are suggested to examine the ‘enabler’ role of industrial engineers and associated professionals in large enterprises versus MSME of varied operations nature, across various manufacturing sub-sectors, separately and collectively, in fostering industrial developments and transition towards Industry 4.0.

References:


Parson, A. (2005), Employers’ Perception of the Role of Industrial Engineering in Trinidad and Tobago, Final-year Project Report (unpublished), Department of Mechanical and Manufacturing Engineering, The University of the West Indies, April.


UWI (2015), Information Brochure: Industrial Engineering, DMME - Industrial Engineering Office, University of the West Indies, Trinidad and Tobago, Version 5, May


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**Kit Fai Pun** is Chair Professor of Industrial Engineering (IE) and the coordinator of IE Research Group at The University of the West Indies, St Augustine, Trinidad and Tobago. He is Chartered Engineer and Chartered Marketer in the United Kingdom, as well as Registered Professional Engineer in Australia, Europe, Hong Kong, and The Republic of Trinidad and Tobago. His research activities include industrial and systems engineering, engineering management, quality management, performance measurement, and innovation.
# Abstracts of The Fourth Industrial Engineering and Management Conference

**Theme:** “Striving for performance excellence with quality management and industrial engineering management practices”, 7th-8th December 2018

Kit Fai Pun and Cilla Pemberton

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34. Industrial Engineering: Championing the Change to Industry 4.0
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1. Achieving Developed Nation Status through Education, Innovation and Change Management

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Abstract: Among the United Nations, World Bank and the International Monetary Fund there appear to be no fixed definition of what constitutes a developed country. The indices that are generally considered in determining the status of economic development tend to include Gross domestic product (GDP), Gross national product (GNP) per capita income, level of industrialisation and infrastructure. More recently non-economic factors such as the human development index (HDI) are considered in the evaluation. The HDI basically quantifies a country’s level of education, literacy and health into a single figure. Analysis does show however that the countries that place major emphasis on education, innovation and change management tend to rank highest in all the economic indices and are well-known for sustainable growth and development. Countries that are well known as part of this trend include the USA, France, Canada, the United Kingdom, Germany and Japan. It is important for Trinidad and Tobago as a people and as a nation to recognise therefore that being recognised as a developed country is not only about having a high per capita GDP but rather putting in place the simple building blocks of education, innovation and change and understanding the process to be followed to achieving this objective. These are the ultimate catalysts for long term and sustainable economic and social prosperity.

Keywords: Education, innovation, change management

2. Urban Redevelopment Post Vision 2030: Spatial and Economic Framework

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Abstract. The approach of urban redevelopment has been argued to be more sustainable to national development policy. The Urban Development Corporation (UDC), Jamaica has traditionally taken the normative approach to development over the past five decades. Despite this, there is a gap between the improvement development metrics of successive waves of development programs and contiguity with overlapping policy. This paper addresses this gap and will examine a descriptive approach of urban redevelopment, using spatial planning and economic policies that provide lifetime (50 year) concept planning and long-term 10 to 15 year master planning in conjunction with medium term plans. A qualitative review is done of the results of this approach by similar economies in particular Singapore’s Urban Redevelopment Agency (URA). Underpinning legislative statues and supporting policies for land administration, economic planning, along with social policies that drive the urban redevelopment are examined. The paper will present a conceptual model for redevelopment for the UDC and utilise quantitative data measuring development from both approaches of the URA and UDC over their existence.

Keywords: Urban redevelopment, spatial planning, economic development, land administration

3. The Changing Nature of Industrial Engineering: Implications for the Region

Oneil Josephs
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Abstract. Global manufacturing and service operations have been experiencing extensive change over the last two decades. These sectors are now benefiting from extensive use of robotics, artificial intelligence, Big Data, integrated systems and the use of Internet of Things (IoT) to solve routine and complex operational and systems problems. More and more, Industrial Engineers (IEs) are having to interact with IT based systems, smart systems and embedded systems, to name a few, as against the traditional tools of operations. The implications of these advances on the traditional roles of Industrial Engineers will be
identified. The paper will rely on best practices from known universities, through benchmarking, to gauge the significance of the changing nature of the IE discipline with a view to place IEs in the Caribbean on a path of excellence through continuous improvement. This paper seeks to bring its own perspective on the long debate about the relevance of Industrial Engineering and to provide regional universities with the basis for reviewing and strengthening their curricula. It will also allow industry players to realize the significant benefits to be gained in their operations from the discipline of Industrial Engineering.

Keywords: Industrial Engineering, Industrial Engineers, university curricula, Caribbean

4. Disaster Management, Disaster Preparedness and Business Continuity for Utilities in the Caribbean

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Abstract. A wide range of topics of national interests is relevant and appropriate considering the volume of large projects being undertaken in various sectors of the country, namely Oil and Gas, Utilities, Manufacturing, Construction and Service sectors initiated mainly by the Government and the private industries. Presently in Trinidad and Tobago (TT) and the wider Caribbean, there is a demand for increased productivity and efficiency in Project Management in relation to general infrastructure projects and Disaster Management and Recovery. In 2018, this has been a very active climatic season with several Caribbean countries and TT still recovering from several natural events that has caused severe flooding with damages to private and public infrastructure. The assessment, recovery, rebuild and mitigation management efforts require technical acumen, experience and capital expenditure in conjunction to a review of our current project management practices. In tandem with this is the number of failed and idle Energy Sector Projects that have not contributed to our economy with no indication of ever being operated. This presentation focuses on Project Management Practice within the Disaster Management field for a Utility and the Preparedness with Business Continuity requirements for Corporate Governance.

Keywords: Project Management Practices, productivity, efficiency, Corporate Governance

5. Customising Lean for Rapid Organisational Success

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Abstract. After racking up a huge loss in 2008 of USD$680k a Jamaican manufacturing firm sought to find its way out of the rut. They sought the help of the Jamaica Productivity Centre (JPC). A new approach to operating was adopted which utilised a hybrid of lean, six sigma and kaizen techniques and required innovation and the commitment of the employees to conceptualise, implement, sustain and replicate the solutions. A customised and simple approach was utilised to ensure quick education of the staff, creation of cross-functional implementation teams as well as reward systems. The business case outlines how the Jamaica Productivity Centre had helped this company, utilising industrial engineering and management techniques, address their business concerns, the benefits of the project as well as the lessons learnt. The result of the intervention resulted in the company recording a profit in 2009 in excess of USD$2M due to reduced variability, increased employee engagement among other benefits while maintaining product quality. The methodology has since been replicated to other industries including education with much success.

Keywords: Hybrid, Lean, customised, employee engagement, education
6. A Value Management Approach to National Education Management by the Ministry of Education, Trinidad and Tobago
Roashion Persadie
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Abstract. After over 56 years of Independence and 44 years as the Republic of Trinidad and Tobago, many challenges plague the education system. Challenges include suboptimal return on investment (ROI), efficiencies, planning and execution as well as the alignment of the Ministry of education past, current and future developmental, productivity, individual as well as societal needs. This feature address seeks to view, assess existing paradigms and systems against a Value Management (VM) approach focusing on needs alignment, outcomes and ROI for the individual and society. It captures some contemporary internal and external considerations and uses a VM approach to present methodologies and ideas aimed at increasing return on scarce resources while noting the significant the Ministry of Education (MOE), Trinidad and Tobago annually. Outcome measures are more holistic than pass rates. It acknowledges than education, dominant culture, emerging culture as well as strategic planning and execution have impacted significantly on the current society as a whole as well as seeding the future state. It was noteworthy to incorporate the processes of the 2016 and 2018 MOE public consultations, the new White Paper which is main focus latter consultation, as well as the overarching Strategic planning document, Vision 2030 – National Developmental Strategy 2016–2030.

Keywords: Value Management, Quality Management, Wealth Creation, Education, and ROI. MOE, Trinidad and Tobago

7. The National Quality Policy for Trinidad and Tobago and the Potential to Impact Competence-based Services
Karlene C. Lewis
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Abstract. The National Quality Policy for Trinidad and Tobago was launched on 2018-Apr-24 and is a 12-year plan to: (i) foster quality intelligence; and (ii) promote a culture of quality. There are strategies required to be implemented to achieve this goal. One of these critical strategies is the fostering of quality in the businesses and operations of Trinidad and Tobago. Most persons and organizations are familiar with ISO 9001 and other management systems that are certified. However, the critical area for development is in the area of competence-based management systems that can be accredited. This paper discusses these specific needs and compares the “fit for purpose” quality solutions of accreditation and certification.

Keywords: National Quality Policy, Competence-based Services, Trinidad and Tobago

8. An Introduction to ISO 45001: 2018 and the Benefits of Implementation
Klenworth R. Jones
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Abstract. In today’s world of work employee health, safety, welfare and well-being are paramount. Organisations are legally required to ensure this in most jurisdictions. The International labour Organisation declares that 2.78 million deaths and 374 million non-fatal illnesses and injuries occur at work annually, at a combined cost (direct and indirect) 2.99 Trillion USD. Third-party certified occupational health and safety management systems operate on the premise of facilitating improvement in all aspects of health and safety management. Formally launched in March 2018 ISO 45001: 2018 Occupational Health and Safety Management Systems (OHSMS) is the world’s first International Standard for occupational health and safety (OH&S). This standard is a significant addition the suite of management system standards developed by the International Standards Organisation. ISO 9001: 2015 Quality Management Systems and ISO 14001: 2015 Environment Management Systems are already established and widely used. ISO 45001: 2018 provides a defined framework to increase safety, reduce workplace risks and enhance health and well-being at work for companies that conform to the requirements. Specifically the standard emphasizes inter alia an understanding of the organisation and its context, the integration of OH&S management system requirements into the organisation’s business processes, increased worker involvement and participation and expanded top
management involvement in the implementation of the OHSMS. Benefits to implementing the standard include enhancing the organisation’s ability to respond to regulatory compliance requirements, a reduction in the overall costs of incidents, increasing company-wide awareness of OH&S risks, reducing downtime, the costs of disruption to operations and reduced cost of insurance premiums.

**Keywords:** Occupational health and Safety Management Systems, ISO, compliance requirements

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**9. The Anatomy and Evolution of the Industrial Revolutions**

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**Abstract.** The paper begins by presenting the evolution of the Industrial revolutions in granular and qualitative form. It lists the critical contributing factors that form the unique calculus of technological development for convenience from the pre-industrial period (1500 CE) to the present. The paper presents the four industrial revolutions over separate but consecutive chronological periods 1750 to 1900, 1900 to 1960, 1960 to 1990 and 1990 to the present. What appears as arbitrary dates will emerge as specific markers of discrete periods of intense new and separate industrial activity. The initial intent was to study the evolution of the industrialisation process in the Caribbean region. But the author soon realised that to properly handle the subject one had to investigate the global phenomenon of industrialisation and that it is only in so doing one can return to the initial subject matter of the quest, and answer the question, at what stage of the industrial process in the Caribbean Region and identify what are the central tasks facing the region if it is to assume any role in twenty first century industrial and hence economic development. Each period, beginning with the Pre-industrialised period, began with a Time Scale that covers critical historical events that define and shape the period, giving it both context and mile stones of critical events. The paper then attempts to identify dominant centres of Industry, a description of the Global Political/ Economic Stage and Centres of learning (Scientific and Engineering/Technology. It lists a few of the prominent individuals making significant contributions (ideas). It then lists the dominant forms of energy and developing machinery; critical are the dominant economic activities and concludes with a list of the principal foci of the global Industrial Sectors. The central thesis of the paper is that concentration of wealth at any place and time (country) is the necessary condition which provides the context and opportunity for ideas to germinate from abstract theoretical thought or experimental dabbling. These ideas require a further enabling of leadership (commitment and financing) to permit the transformation of ideas and concepts into things and processes. This must be wedded to market strategies if we are to convert objects to market products. The cycle is complete when these are transformed into wealth. This is the Industrialisation/Innovation Cycle. This is the central thesis of paper.

**Keywords:** Industrial Revolutions; Industrialisation/Innovation Cycle; wealth creation

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**10. Embracing AGILE: Improving Organisational Quality through Agile Project Management Philosophies**

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**Abstract.** In today’s fast paced world, organisations must continually improve to achieve or maintain their competitive advantage if they are to remain relevant. For most organisations, as part of their strategic intent, this continual improvement revolves around meeting and exceeding customer expectations through the provision of high-quality products and services. Project management through its people, processes, tools and techniques has and continues to be the key vehicle used by organisations to achieve strategic quality goals. However, traditional project management philosophies and practices have not generally yielded the expected results as evidenced by numerous reports highlighting high project failure rates. AGILE project management philosophies however, seek to address the issues faced by project management practitioners using traditional project management. AGILE project management techniques employ an iterative approach that is heavily customer focused and centres around the concept of continuous improvement which also aligns with Total Quality Management (TQM) philosophies. It is in this context that this presentation develops the argument that through the use of AGILE project management, organisations may achieve their TQM goals.

**Keywords:** AGILE project management, Total Quality Management, Lean, strategic management
11. Integrating Change Management and Project Management: A Joint Value Proposition

Kisha Williams

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Abstract. Project management and change management are generally viewed as discrete approaches to managing organisational transformations. The discipline of project management provides the structure, processes and tools to make the targeted change happen, for example a new construction or the implementation of new technology. Change management - a people-sided focus, ensures that the change is embraced, adopted and utilised by those who now have to do things differently as a result of the project. In a business context that requires specific efforts from organisations to better achieve their transformations, project managers are more and more involved and engaged in mandates that integrate both the project and change management disciplines. This presentation will discuss the approach and demonstrate the benefits that can be gleaned by integrating change management with project management activities, in support of benefits realisation, speed of adoption, ultimate utilisation and user proficiency. It will also demonstrate that, to truly maximise the value they bring to these transformations, project managers must become change leaders. That is, they should not only drive the process and technology changes, but also support all the stakeholders in their transition from the current to future state as well.

Keywords: Project management, change management, organisational change management, transformation, integration, project, change, current state, future state, PMO, CMO, OCM

12. Strategic Development of the Corn Industry in Trinidad and Tobago Catering Towards Food Security and Sovereignty through Innovative Industrial Engineering Technologies

Karen Ottley

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Abstract. Approximately 958 million tonnes of corn are harvested annually and traded on the global market for human and animal consumption and more recently for the production of biofuel namely ethanol. The diversion of corn to biofuel has altered the equation of international corn trade dynamics; the major shift being in the volumes/route movement. China now claims a significant share in the new corn trading environment with its advances in alternative energy technology and clear policy to reduce their carbon footprint. The emerging scenario presents a major challenge to none corn-producing Small-State Economies that depend on trade arrangements to meet their corn needs for human and animal consumption. The corn trade environment is further impacted by the debilitating effects of climate change re the la Nina and el Niño phenomenon, rapid emergence of pest and diseases and frequent unexplained crop failures; these result in decreased annual production. The advent of genetically modified, pest, disease, and climate resilient seed stock has shown positive results. Trinidad and Tobago corn imports averages of $276,158,140 annually. The imports represent corn in various forms for human consumption and animal feed stock. Two of its main source countries are the United States of America and Brazil. However, it is noteworthy that the United States of America has adopted the policy to use 25% of its production toward biofuel. This presentation examined the merits of indigenous grown corn and the application of sound Agro Industrial Engineering Technology as a viable option to imports by Trinidad and Tobago. The vision 2020 and 2030 documents as well CARDI sponsored research papers on corn were sources for desk reviews. It was established that Food Security and Sovereignty are achievable in Trinidad and Tobago. However, Strategic Policies supported by Sound Industrial Engineering Technology are critical pillars.

Keywords: Food security, Corn production, Trinidad and Tobago

13. Observed Safe Practices amongst Finishing Sander Woodworkers in Trinidad and Tobago

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Abstract. This study assessed the ergonomic practices of finishing sander woodworkers within sixty-seven woodworking establishments in Trinidad and Tobago (T&T). This was a quantitative, cross-sectional study conducted using a questionnaire and the Rapid Entire Body Assessment (REBA) Employee Assessment Worksheet as its data collection instruments. These two instruments captured data of one hundred and twenty-six workers. The objective of the study determined the relationship between “Risk” and observed “Safe Practices” when using the finishing sander in T&T. The passive observation using the REBA Employee Assessment Worksheet showed that 89 (70.4%) participants exhibited “High Risk” (REBA scores ranging from 8-12) which implies that corrective measures are required to be implemented immediately. Additionally, SPSS identified thirteen categories of unsafe practices (“Safe Practice 6 to 18”) which identified that all the participants engaged in at least three unsafe practices from the twelve surveyed. Furthermore, the results of the Spearman’s Correlation Test between REBA Risk Scores (“Risk” and ‘Safe Practice’) displayed a positive correlation coefficient (rs (124) = .395, p = .000), thus indicating, there is an inverse relationship between REBA Risk Score and observed Safe Practices when using the Finishing Sander. The study recommends that the State should develop and implement a Safety Management System (SMS) for woodworking establishments, enforcement of health surveillance as prescribe by the Occupational Safety and Health (OSH) Act, redesign of the process to reduce musculoskeletal disorders (MSDs) symptoms, implement education and training programmes to develop ergonomic awareness and to ensure that workers are properly supervised.

Keywords: Ergonomic Practices; Finishing Sander Woodworkers; Trinidad and Tobago; REBA

14. Engineering Entrepreneurship in the Caribbean

Cilla Pemberton¹ and Oneil Josephs²

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Abstract. Programmes in the Caribbean have traditionally focussed on preparing their graduates for careers in the process, utilities, construction, mining and manufacturing industries and students in these programmes have selected their programmes based on the potential for well-compensated employment in these areas. In contrast, prominent engineering programmes in developed countries such as the United States of America (U.S.) and Canada have been channelling their graduates toward entrepreneurship or entrepreneurial thinking with the sustainable economic development of their societies as the goal. Students are supported through programmes, courses, business incubators, and access to investment opportunities, made available either within the engineering departments, or as co-curricular activities. With major economic challenges to the institutions and industries of the Small Island Developing States of the Caribbean, regional institutions are becoming more entrepreneurial in their thinking and seeking to have their students do the same. This study, as a subset of a larger body of research on Engineering Entrepreneurship in the SIDS, looks at the entrepreneurial intent of current engineering students in Trinidad and Tobago (T&T) and Jamaica, using desk research, interviews and a survey tool. A previous study by Benjamin looked at the nature of entrepreneurial motivations of engineering students in T&T. It concluded that they demonstrated higher order motivations for potential entrepreneurial behaviour such as the need for achievement or pursuit of a lucrative opportunity more often than lower order motivations such as job loss or dismal job market. That study, however, did not investigate the actual intent of students to become entrepreneurs after graduation. These Caribbean engineering entrepreneurship studies are important as it has been already been shown that with respect to entrepreneurial patterns, Caribbean engineering students may not mirror students majoring in other disciplines or engineering students in other societies. It is therefore essential to understand the attitudes of regional engineering undergraduates with respect to entrepreneurship.

Keywords: Engineering, Entrepreneurial Intent, Trinidad, Jamaica

15. An Automated-Human Interface Approach to HSE Risk Assessments

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Abstract. Risk has its roots embedded in chance and probability on the belief that a desired outcome will emerge without much loss on investment. While a low risk investment with high probability of financial returns is a favourable outcome one does have the option to make a high risk investment in the hope of better returns in the money market. Health and safety however affords no such luxury and there is no choice but to reduce the risks to exposure to hazards in order to protect worker life and limb. No
risk assessment would be complete if it did not also address man-made hazards that affect the environment and violence against workers. Violence at a site is a latent hazard that compromises worker safety, morale and productivity which must be measured and monitored to ensure complete worker well-being especially in a time of world destruction and terrorism. The way forward is to align HSE risk assessments to 21st century status through accurate data measurement, data recording, statistical analysis and reporting procedures for which scientific based decision making can be achieved. A holistic approach encompassing all four variables of health, safety, environment (natural and man-made disaster) and worker protection against violence through a HSE risk assessment for organisations is proposed. To accomplish the task this paper advances a human – electronic detector device interface model for developing and managing HSEP risk assessments through the implementation of tailor-made electronic hazard detectors that collect, measure, monitor and report real time field information from remote points and communicate to management and staff through the use of mobile applications. The final risk assessment model so constructed uses a simple principle-of-moments concept to calculate risk exposure to a hazard. The first moment is the prevalence or spread of the hazard, while the second moment is the pervasiveness or intensity of the hazard. The probability of obtaining values between the lowest and highest readings gives the prevalence while the probability of exceedance above the threshold or exposure limit as set by a Standard gives the pervasiveness. These are both taken from the best-fit model distributions using statistics of extremes for the data readings obtained from the field. The risk to exposure is the product of pervasiveness and prevalence.

_Keywords:_ Risk, health and safety risk assessment, human-detector interface, HSEP, hazard detectors, prevalence and pervasiveness.

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16. Investigation into the Suitability and Effects of Establishing a Project Management Office at a State-owned Utility

**Gyasi Ambrose**

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_Abtract._ The purpose of this paper is to investigate whether the establishment of a Project Management Office (PMO) at a state utility would be feasible based upon the project management maturity of the organisation. The paradigm followed is that of a grounded theory research design where the data is to be collected using surveys and interviews while additional data would be analysed based upon literature reviewed. This paper puts forward the idea that the establishment of a PMO at a state utility is both influenced by and has an impact on the project management maturity of the organisation’s staff. The work being presented in this paper is of particular interest to the author due to similar research conducted at a Government Ministry. Preliminary findings are derived from the review of similar research. The data sources are somewhat limited and the sample is somewhat small which may result in lack of sufficient statistical power. This is mainly due to limited availability of and accessibility to project personnel. This study contributes to the current body of knowledge about project management maturity and how projects are conducted in a non-projectised environment. The importance of project management maturity and its effect on project performance and by extension project success will also be considered. The value that can be derived from this study includes better project governance, stakeholder and human resource management.

_Keywords:_ Project governance, PMOs, human resource management, project management maturity.

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17. The Case for a University-Based OEDM in the Regional Cocoa Industry

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_Abtract._ The University of the West Indies is evolving to survive and be more relevant to its core stakeholders. One of the main transformations is an emphasis on entrepreneurial activities based on university birthed innovations which could lead to economic opportunity for researchers, the university and the region served by the institution. Following its mandate to respond to the needs of the society, a team of researchers from the Mechanical and Manufacturing Engineering Research Committee (MMERC), embarked on a project to fill gaps in the fledgling Caribbean fine cocoa industry by creating prototypes of equipment to assist cocoa producers and chocolate makers. This research was initially funded by the European Development Fund through the Ministry of Education, Government of the Republic of Trinidad and Tobago. An important part of the exercise was considerable industry research and a feasibility study which revealed that the initial concept for the project was much too narrow and there was an urgent need for cost effective, energy efficient, right-sized innovations for the regional fine cocoa
industry. However, it was obvious that the university’s current structure and infrastructure was not well-positioned to respond to this need in any meaningful way. Challenges experienced in creating basic prototypes and protecting intellectual property highlighted potential roadblocks in any strategy deployment of this nature. This paper presents a framework for commercialising university innovations using the MMERC project as an initial case. It comprises a typical Original Equipment Design and Manufacture (OEDM) framework combined with the teaching hospital model where a semi-commercial entity is intricately linked to the university and offers an incubator and testing ground for research as well as training of undergraduates and graduates. It is argued that if adopted, this framework could be synergistic in leading to new generations of entrepreneurially minded engineering graduates, with economic benefit to the university, and the wider Caribbean region.

Keywords: Cocoa, UWI, Caribbean, University Innovation, Original Equipment Design and Manufacture

18. Strategies on Managing Teams and People in Organisations: Some Thoughts
Cherisse Lashley
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Abstract. An organisation is made up of different departments and further teams directly or indirectly to perform specific functions which are distributed among them. Within these teams are groups and individuals which require proper management and work ethics in order to receive the best performance from them. Proper management will yield efficient function of the organisation. Metaphorically, an organisation is like an organ, made up many cells where each cell has role and must all work together for the organ to function at its best. There are strategies and ethics that will assist in handling people and situations that frequently arise within developing teams known as team dynamics. This was a topic of great concern because too often in most organisations an individual ‘just do their job’ as their job has become work to pay bills. This results in little appreciation for the job that they do, hence their best performance is submerged by system culture. This paper intends to identify strategies to manage teams and people, the barriers which oppose effective management and the mechanisms and that will improve this role. Suitable strategies depend on structure of the team and the purpose of the team. Possible barriers may include communication and accountability, individual values and norms and other features that can arise. Mechanisms assist in becoming a better manager and results increase team performance. Another key aspect is organisational behaviour which predicts how people and groups interpret event, react and behave. An organisation’s success is judged primarily by its clients and customers.

Keywords: Organisation, managing, teams, people, behaviour

19. Developmental Requirements for Implementing Industry 4.0 in Trinidad and Tobago Companies
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Abstract. This paper determines the Industry 4.0 (I4.0) readiness level and developmental requirements of six local companies to satisfy diverse consumers, who want similar base products with varying characteristics. It assesses their flexibility and ability to satisfy demand driven markets globally, in real-time, through mass customisation which improves competitiveness and profitability. This ability facilitates transition into I4.0 to compete globally against larger organisations that utilise economies of scale. Each company was evaluated in the I4.0 categories (evolution, decentralisation, connected systems, intelligence, integration of value chains) and the findings show that I4.0 enables local companies to be innovative and competitive utilising mass customisation, for both local and export sales, to remain profitable in the global environment. It produced a new definition for Industry 4.0: the evolutionary change in decentralised connected systems to enable the intelligent integration of the horizontal and vertical value chains of the organisation.

Keywords: Industry 4.0; Mass customisation; Demand driven production; Real-time demand; Competitiveness; Value creation
20. Determining Effective Management Approaches for Mechanical Engineering
Student Group Work at The University of The West Indies, St. Augustine Campus
Kathryn Christopher¹ and Marisha Arjoon²
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Abstract. Engineering students are often asked to form teams to complete projects. Many students dislike the idea of doing teamwork because of the uneven distribution of tasks and the presence of “loafers” within teams. Complaints are frequently made about team members not contributing, leaving one person to bear the brunt of the workload. Furthermore, students are unaware of how to properly handle these situations and delegate duties, leading to unsatisfactory performances. Thus, this paper seeks to establish which leadership styles are most effective in student group work by examining the current leadership styles employed by students and how it influences their overall performance, the distribution of tasks amongst members and the number of loafers per team. This will be done by gathering data through a questionnaire instrument and performing a descriptive analysis. The results will thus show which leadership style(s) to employ in student group work.

Keywords: Engineering Students, UWI, St. Augustine Campus, management leadership styles, group work, performance; loafer

21. Reviewing the Impact of Corporate Social Responsibilities and Ethics
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Abstract: When considering corporate social responsibility, it is interesting to think about which group holds the most influence over a business’ practices and guidelines. Is it the responsibility of the corporation to set ethical business standards, or is it the responsibility of the government to create regulations? Does public interest and ethics play a major role? Corporate Social Responsibility (CSR) can be interpreted in many ways. The term may convey legal responsibility or liability, or it can indicate socially responsible behaviour in terms of ethics. To some, it can also be determined as ‘responsible for’ in a casual sense, as well as it can be equated with a charitable contribution or being socially conscious. An alternative approach is to propose a classification in four groups of theories based on six criteria (motive, relation to profits, group affected by decisions, type of act, type of effect, expressed or ideal interest). Others critique that CSR may not solve societal and environmental issues but can in fact be an illusion that hinders systematic change. These programmes do more to collect information than solve problems. Businesses may choose to comply with minimal standard requirements and neglect more feasible and sustainable solutions. CSR is a very broad and ambiguous term that can be difficult to track and identify. In this light, businesses, instead of society, can determine what their “responsibility” is. Thus, a company may engage in a form of CSR and still engage in harmful practices.

Keywords: Corporate Social Responsibility, public interest, ethics, sustainable

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Abstract. Vibration measurements have been used widely in industry to determine the state of health of machinery, especially rotating equipment. In particular, they have been used for various forms of fault detection including damage to bearings, rotating unbalance and misalignment. Appropriate use of vibration monitoring can result in early detection of impending problems thus preventing unscheduled shutdowns of operations. However, the effectiveness of vibration based condition monitoring is integrally tied to the use of an expert to interpret the data provided. In this work, an automated machine learning approach for detecting and characterising faults in rotating machinery based on accelerometer readings is presented. The vibration waveforms are preprocessed using Fourier transforms and wavelets. Key statistical parameters of these curves are explored including the skewness and the kurtosis; these are then used to isolate identifying features for various common faults in rotating machinery. These features are then fed into a supervised machine learning algorithm and a fault classification
system is built. The method described herein is validated with vibration data collected from a laboratory fault simulator. The performance of the system is discussed and its applicability to industrial situations is described.

**Keywords:** Machine Learning, Vibration Monitoring, Fault Detection

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**23. Study of CBM Approach for Improving Fault Diagnosis of Centrifugal Pumps**

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**Abstract.** Centrifugal Pumps (CPs) are an integral part of most industries today. The large numbers of mechanical components within a CP results in the existence of various failure modes for these assets. Vibration Analysis is one of the most widely applied Condition Based Maintenance (CBM) technologies for diagnosis of pump failures. However, there are various factors such as operational speed, system complexity, data collection errors etc. that affect the accuracy of fault diagnosis under a CBM technique. As such, the work done in this paper investigates the use of CBM for effectively diagnosing CP faults. The study is designed by initially defining the system boundaries and subsequently selecting and ranking the most critical failure modes through the use of Pareto and FMECA techniques. A series of tests are then designed considering key factors such that experimental data is collected on a developed test system. Two sets of blind testing procedures allowed for the selection of different faults from which the collected data was analysed and each fault diagnosed. A final fault Classification Accuracy of 67% was attained. Furthermore, the process was adapted to a Case Study of CPs in the Oil and Gas industry. Bearing vibration data was collected and extrapolated to formulate the Potential Failure (PF) curve and thus estimate the planning interval for maintenance. The results illustrated a 6-month interval as most appropriate for bearing replacement. Future work will investigate the impact of greater complexities on the diagnosis accuracy as well as the use of improved classification techniques.

**Keywords:** Condition Based Maintenance, Centrifugal Pumps, Vibration Analysis, Failure Modes and Effects Criticality Analysis, PF Curve

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**24. Developing a Method for Evaluating Human Factors Risk at the Design Stage of Oil and Gas Projects**

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**Abstract.** Examination of major accident data in the upstream oil and gas sector, reveals that in the majority of cases, the initiating cause of catastrophic accidents is attributable to human error. Due to the devastating effects of these failures on people, property and the environment, current engineering design practices in the sector need to be explored in order to ascertain the shortcomings leading to neglect of key human factors design considerations. This paper aims to review current practices which influence the drivers that affect engineering design and practices in the sector and how they can be improved. A quantitative search and analysis of literature pertinent to human factors in design in the oil and gas industry was carried out. From the literature obtained, common human factors models, approaches and frameworks in engineering design were reviewed. The study then evaluated the applicability of the methods in the context of its integration into existing engineering processes and the gaps in human factors in engineering design. The paper will propose a framework which can be adopted by industry to address human error as early as possible in the design phase and thus prevent major accidents in the upstream oil and gas sector.

**Keywords:** Human Factors Risk, Design Stage, Oil and Gas Projects
25. Exploring Corporate Social Responsibility and Ethics on Sustainable Development in Organisations
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Abstract. The reputation and opinion of stakeholders is imperative for successful longevity of a company. It is clear consumers will disregard their favourite companies if they are not taking a stand for societal and environmental issues. A company’s strategy on corporate social responsibility (CSR) is a big factor in where today’s top talent chooses to work. One must build a socially responsible business to make an impact in the world. This paper examines how CSR and ethics contribute to the social, economic and environmental benefits of a business’s sustainable development. Case studies are used to illustrate the impact of CSR on businesses as well as factors which can be practiced were investigated. The paper also discusses effective ways of executing the ideas to best impact both society and the company. It focuses on environmental efforts, philanthropy, ethical labour practices and volunteering strategies.

Keywords: Corporate Social Responsibilities, Ethics, productivity

26. Deploying Synergistic Standardisation and Optimisation Strategies within Coatings Manufacturing Plants across the Caribbean Region Utilising a Project Management Approach: A Case Study
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Abstract. ANSA McAL (ANSA) is one of the most robust, stable and progressive business institutions in Trinidad and Tobago (T&T) and the region. ANSA Coatings Limited (ACL) is one of the most diversified manufacturer and supplier of paint and coatings in the Caribbean. ACL was established from the integration of Penta Paints Caribbean Limited and Sissons Paints Trinidad Limited in June 2012. In 2017, ANSA acquired Berger Paints Caribbean which included Berger Paints Barbados (BB) Limited (BPBL), Berger Paints Jamaica (JM) Limited (BPJL) and Berger Paints Trinidad Limited (BPTL). With this acquisition came great opportunities to maximise profitability across all three (3) brands; Penta, Sissons and now Berger. However, to plunge at this opportunity implied an intrinsic need to standardise and optimise operations throughout the region; BPTL, BPJL, BPBL, ACL and Sissons Grenada (GD). This paper would outline a model for attaining financial and operational synergies throughout the region and would utilise a sound project management (PM) approach for implementation of the conceptual model within the plants throughout the Caribbean region.

Keywords: Standardisation, Optimisation, Synergy, Coatings, Manufacturing, Project Management

27. Modelling Productivity Dynamics within Manufacturing Capital Expenditure Projects in Trinidad and Tobago: A Study Agenda
Kevin N. Hassanali1 and Kit Fai Pun2
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Abstract. In recent times, the manufacturing sector in Trinidad and Tobago (T&T) has increased its capital expenditure (CE) spending, specifically on projects related to plant upgrades, machinery and equipment. Project Management (PM) in T&T’s turbulent manufacturing environment is premised too much on counter-productive PM practices which can ultimately lead to failed CE projects. While the productivity movement has been around for the past fifty (50) years, productivity studies within these CE projects have been sporadic. Recent studies suggested that the principles identified in existing productivity models within other sectors were useful, but none demonstrated a unique measure for determining overall productivity at the project level. This paper aims to explore productivity by the qualitative and quantitative design of measurable productivity metrics geared towards improved PM practices within manufacturing CE projects in T&T. It describes a study agenda with a conceptual model proposed for assessing the dynamics of productivity within each phase of a project’s life-cycle, which includes project initiation, project planning, project execution, project monitor and control and project closure.
28. Impact of a National Accreditation Programme on Organisational Capabilities at the North West Regional Health Authority in Trinidad and Tobago: A Case Study

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Abstract. Increasing demand for better, high-quality and more responsive public services have prompted recent government administrations to embrace new frameworks for achieving public service transformation. The aim of this shift has been to facilitate enhanced service delivery, while delivering value for money and enhancing citizen satisfaction with public services. In 2013, a new framework implemented as a national service accreditation programme was launched. This programme focused on achieving change at the organisational level with emphasis on building and strengthening capabilities, connectedness and culture. This paper examines the impact of participation in the national service accreditation programme on eight specific organisational capabilities at the North West Regional Health Authority. Organisational self-assessment surveys were completed by members of the North West Regional Health Authority’s leadership team in 2014 and 2015. Results from these surveys showed that participation in the national accreditation programme resulted in an overall improvement of 29% across the eight organisational capabilities from 2014-2015. The most significant improvements were noted in culture and values, business processes, people and engagement, technology, and communication. Analysis of the results highlighted additional capabilities that were not well addressed by the accreditation programme, but are important elements of both public service and health care delivery. These include planning and leadership, and management of financial resources and accountability. It is anticipated that the findings presented will be of value to healthcare leaders and public policy makers.

Keywords: Caribbean, leadership, organisational development, culture and values, public service transformation, healthcare

29. Deploying a Simulation-Based Sensitivity Analysis Approach for the Justification of a Capital Expenditure Project in a Chlorine Manufacturing Company

Kevin N. Hassanali

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Abstract. ANSA McAL (ANSA) is one of the most robust, stable and progressive business institutions in Trinidad and Tobago (TT) and the region. ANSA McAL Chemicals Limited (AMCL), a subsidiary of ANSA, is the largest producer of sodium hypochlorite commonly known as bleach, in the English-speaking Caribbean. The company produces over 2.5 million litres of bleach per month and exports to all countries in the CARICOM Single Market and Economy (CSME) as well as the French and Dutch Dependencies and into Central America. In addition to owning the four (4) leading brands in the region; Clean & White, Trichloro, Spotless and Supreme, AMCL also contract manufactures other leading brands such as Clorox, Sparklean, Hi-Dee, Supa, Kleen, Home, Sno White and Ajax. AMCL also produces chlorine gas and sodium hydroxide for water treatment plants and other industries, inclusive of the food and beverage sectors, municipal water plants and other industries across the region. AMCL exports liquified chlorine to Jamaica (JM) in drums and cylinders. The landed cost in JM however, does not allow AMCL the ability to compete with the existing chlorine gas suppliers in JM. Based on analysis, it was found that by shipping isotainers (large standardised containers of liquified chlorine used for efficient shipping and handling), to JM and then trans-filling into the cylinders and drums in JM, would significantly reduce the landed cost per metric tonne (MT) of chlorine in JM. Therefore, a project was developed to operationalise a chlor-alkali transfilling hub in JM. To ensure the project would be viable in JM, a deep understanding of the Jamaican market was required. This paper would outline simulation scenarios based on AMCL’s ability to grow market share in JM by postulating a series of market segment scenarios. Based on the financial and economical metrics calculated, it is anticipated that the simulation exercise will justify the capital expenditure (CAPEX) spend needed to operationalise the trans-fill hub in JM. The justification will be part of the business case element within the initiation phase of the project lifecycle. It is expected that the results of the simulation exercise will provide AMCL with the right information that will ultimately determine the potential success of the chlor-alkali plant in JM.

Keywords: Simulation, Sensitivity Analysis, Project Initiation, Manufacturing, Capital Expenditure, Jamaica
30. Improvement Strategies in Equipment Maintenance and Reliability in the Industries in Trinidad

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Abstract. This paper explores strategies utilising models to fully implement improvement recommendation relating to physical assets in the Industries in Trinidad. These models have been used with success both in the Refining Industry and as some of the core models in the Engineering Asset Management Programme of the Faculty of Engineering at The University of the West Indies. The models look at the stages in the development of organisations requiring characteristic changes, the use of the condition monitoring techniques, root cause analyses, and quality systems coupled with a Computerised Maintenance Management System (CMMS) driven by a Planning and Scheduling system. The paper also describes the management accounting system, driven by leading and lagging key performance indicators (KPI’s), which are the keys to success in ensuring sustainability in the implementation of the improvement recommendations in the maintenance and reliability systems in these industries. This paper emphasises the need for Reliability and Maintenance Engineers in the industry to play key roles and to exercise the passion inherent with the “Ownership” of their assets so that they can be the ones deciding when and for how long equipment shall be taken out of service. They must remember that there is “no silver bullet” which can achieve the required goals since this can only be achieved by “placing their shoulders to the wheel” and working with the passion for their focused goals. They need to celebrate and learn from their successes and be innovative and critical thinkers to efficiently and effectively surmount any barriers in their way.

Keywords: Maintenance, reliability, models, recommendations, management accounting

31. Association between Finishing Sander Woodworkers’ Demography, Tenure and MSDS Symptoms in Trinidad and Tobago

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Abstract. This study assessed the demography, tenure and musculoskeletal disorders (MSDs) symptoms of finishing sander woodworkers from sixty-seven establishments in Trinidad and Tobago (T&T). This quantitative, cross-sectional study was conducted using a questionnaire which captured data of one hundred and twenty-six finishing sander woodworkers. The objective of the study determined the association between workers’ age, body mass index (BMI), tenure and MSDs symptoms. The mean “age” of the 126 participants was 42.91 years with a standard deviation of 11.93 years. Additionally, the mean “BMI” was 26.85 kilograms with a standard deviation of 3.74 kilograms and the Mean “Years of Experience” as a woodworker was 24.3 years with a standard deviation of 13.15 years. All three Chi-square tests of association between workers’ age, BMI, tenure and MSDs symptoms revealed p =.000 which suggested that the worker’s age, body mass index and tenure were associated with MSDs symptoms. The study recommends that the State should have enforcement of health surveillance as prescribed by the Occupational Safety and Health (OSH) Act and implement education and training programmes to develop ergonomic awareness.

Keywords: Demography; Tenure; Musculoskeletal Disorders (MSDs) symptoms; Finishing Sander Woodworkers; Trinidad and Tobago

32. Expanding Online Functionality of The West Indian Journal of Engineering for Research and Publications

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Abstract. The West Indian Journal of Engineering (WIJE) is an international journal which publishes research in the engineering sciences, with specific relevance to the Caribbean region. First published in 1967, WIJE has its 41st volume in 2018, and has a static repository of approximately 800 peer-reviewed articles. There has been a pressing need to revamp WIJE Online functionality. A WIJE Website Project was initiated in 2013, with some progress in digitising of the journal’s paper archives. With the approval of support from the Campus Research and Publication Fund, an extended phase of website project (ref. CRP.10.MAR15.45) was commenced in September 2016. This extended project aimed to: 1) determine the challenges and difficulties imposing the WIJE on expanding its limited functionality online, 2) redesign the online interface that allows improved access to content and readership of the Journal, and 3) promote engineering research in the Caribbean via the dissemination of research findings online via WIJE. This paper describes the methodology employed for executing the project, and provides a summary of the project progress and milestones.

Keywords: Online functionality, Dissemination, Research findings, Journal Management System

33. Salience Model Analysis of the Trinidad and Tobago Cocoa Industry
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Abstract. The Trinidad and Tobago (T&T) cocoa industry is experiencing revitalisation after almost a century of decline and dormancy. Spurring this growth is the focus on value added final products which were never a part of the industry in its previous incarnation. This paper is one in a series that seeks to define the modern local and regional cocoa industry. It deals specifically with the roles of stakeholders, dividing them into major groups including: Governmental Agencies, Research Centres, Cocoa Growing Communities, Cocoa Farmers and Farmers’ Associations, Chocolate Makers and Non-Edible Cocoa Product Producers (NECPP) and retailers, among others. Interviews, site visits and desk research were used to inform the ranking of stakeholders according to Mitchell, Agle and Woods’ stakeholder salience methodology, and the respective role and importance of each of the stakeholders was defined. The value of this research lies in its potential contribution toward an informed, comprehensive approach to developing the industry which is not as homogeneous or geographically contained as other key industries developed in T&T over the past 100 years.

Keywords: Cocoa, Trinidad and Tobago, Salience Model

34. Industrial Engineering: Championing the Change to Industry 4.0
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Abstract. The current economic environment demands a different skills-set from our engineers in order to achieve meaningful growth and development across the region. The traditional role of the engineer in the Caribbean context is no longer sufficient to sustain a growth trajectory on par with global benchmarks. These standards extend the role of the engineer from a strict problem-solving mindset to incorporate an entrepreneurial mindset. This paper draws parallels between Industrial Engineering and the evolution of the engineer’s role in society across the four industrial revolutions. The paper asserts that Industrial Engineers are equipped with the necessary skills-set embedded in the M5I management approach to transition the local and regional economies into Industry 4.0.

Keywords: Industrial Engineering, industrial engineer, M5I, Industry 4.0
### Association of Professional Engineers of Trinidad and Tobago

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The Journal of The Association of Professional Engineers of Trinidad and Tobago

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Professor Kit Fai Pun, c/o Faculty of Engineering, The University of the West Indies, St Augustine, Trinidad and Tobago, West Indies. Tel: 1-868-662-2002 ext-82068/82069; Fax: 1-868-662-4414; E-mails: KFai.Pun@sta.uwi.edu and office@apett.org.

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The journal aims to provide a broad international coverage of subjects relating to engineering. It welcomes the submission of papers in various engineering disciplines and related areas. Emphasis is placed on the publication of articles which seek to link theory with application or critically analyse real situations with the objective of identifying good practice across different engineering and related disciplines. Preference will be given to papers describing original engineering work, or material of specific interest to engineers and those working in related fields, in Trinidad and Tobago and the Caribbean region.

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Manuscripts should be in English and submitted in double line spacing with 2.5 or 3.0 cm margins, with all contributions being subject to a double blind review process. Manuscripts must be sent electronically in Word document to the Editor. There should be a separate title page giving the names and addresses of the authors. The author(s) should not be identified anywhere else in the article.

Notes or Endnotes should be used only if absolutely necessary and must be identified in the text by consecutive numbers, enclosed in square brackets and listed at the end of the article.

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

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