Adoption of an Effectiveness-Centered Approach to Improve Maintenance Operations: a Case Study

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Abstract: Nowadays, organisations are under great pressure to continuously enhance their operational capabilities to create value to stakeholders. Maintenance, as a support function in businesses, plays an important role in backing up any emerging business and operation strategies. An effectiveness-centered maintenance (ECM) approach stresses the function of the asset or equipment with concerns on reliability, safety, operations and customer services. This paper investigates into the present maintenance practice and explores the adoption of an effectiveness-centered maintenance (ECM) approach in the development and implementation of a maintenance management system (MMS) for an energy-sector organisation in Trinidad and Tobago. Empirical data was collected to determine the deficiencies in the existing maintenance practice of the company. Several key components of a MMS were identified. These include 1) the maintenance management (MM) philosophy; 2) MM strategies; 3) organisational structure and staffing; 4) materials and inventory management; 5) computerised MM processes, and 6) effectiveness-centered improvements. In this paper, various phases and associated activities of the ECM approach are presented along with a discussion of the efficacy of the MMS development and implementation for the company.

Keywords: Maintenance management, system, physical assets, Trinidad and Tobago

1. Introduction

The global business environment is very competitive and any downtime in a company’s manufacturing and production operations can reduce the competitive edge. Most production and manufacturing facilities strive to operate without failure. The consequence of a major equipment or process failure could be devastating enough to literally put a company out of business. Thus, there is a need to ensure that production and engineering equipment is adjusted, repaired and in good operating condition. The reason for the requirement for having equipment in perfect operating condition is not only to avoid interruptions to production but also to keep production costs low, keep product quality high, maintain safe working conditions, and avoid delays in product delivery (Levitt, 2009; Sookdeo et al., 2006).

Trinidad and Tobago (T&T) is one of leading industrialised countries in the Caribbean with a population of approximately 1.3 million people. The country has earned a reputation as an excellent investment site for international businesses and holds one of the highest growth rates and per capita incomes in Latin America. Recent growth has been fueled by investments in liquefied natural gas, petrochemicals, and steel. Additional petrochemical, aluminum, and plastics projects are in various stages of planning (Nations Encyclopedia, 2009). Trinidad and Tobago is the leading Caribbean producer of oil and gas, and according to the International Monetary Fund’s January 2008 Report, it has the second highest Gross Domestic Product (GDP) per capita in Latin America and the Caribbean. The IMF further
noted that, the energy sector accounts for over 40 percent of GDP, about 90 percent of exports, and about 60 percent of government’s revenues (IMF, 2008).

This paper presents the findings of a recent study on evaluating the present maintenance practices of and investigated into a new approach for improving the MMS development and implementation of a leading oil and gas operating company in Trinidad and Tobago (referred to in this article as TTGO to maintain confidentiality). Maintenance of the physical assets is regarded as an essential business function of the Company. Physical assets include offshore and onshore structures, processing equipment, and transportation equipment.

The management of the Company has realised the need to build its maintenance capability to ensure reliability and cost effectiveness of its operation. With the objective of protection of people, property, and the environment, the company also identified several problems associated with its existing maintenance management system (MMS). There were no formal procedures or guidelines for a systematic development and implementation of the system. Another problem is that no formal performance audits of the MMS have been conducted. This study aims to determine the requirements, and evaluate the implementation and operational performance of the MMS system against the expectations of the Company. The adoption of an effectiveness-centered maintenance (ECM) approach is explored for enhancing the MMS implementation and performance for asset development of the company.

2. A Review of Maintenance Approaches

Maintenance is a means of preserving, or keeping an item of equipment in a specified operating condition. Once a system or a piece of equipment has been purchased, it must be maintained. The decisions made at purchasing always determine the type of future maintenance to be carried out (Levitt, 2009). It is a set of activities or tasks used to restore failed equipment in a normal operating condition. Performing such activities would extend the useful life of the equipment. Tsang et al. (2000) argue that experience, judgement, vendor recommendations and “the more the better” syndromes are among the common bases for determining the content and frequency of a maintenance task.

Some recent studies (Pun et al., 2002; Sherwin, 2000) suggest that maintenance activities were moving from a reactive and expensive mode (e.g. breakdown maintenance, failure-finding maintenance and corrective maintenance) to a proactive-based, cost-effective and high service level type of maintenance. New maintenance techniques and approaches were developed and adopted by organisations in one form or another. For instance, the use of preventive maintenance (PM), predictive maintenance (PdM) and condition-based maintenance (CBM) reduces the maintenance service level, downtime cost and improves the reliability of equipment (Brook, 1998). Time-based maintenance (TBM) motivates the indiscriminate use of overhaul or preventive replacement procedures in many maintenance programs, whereas computer-aided maintenance (CAM) also promotes the use of advanced monitoring sensors to keep track of the condition of equipment (Pun et al., 2002; Sherwin, 2000).

Proactive maintenance (PaM) focuses on identifying and solving specific maintenance problems. Total productive maintenance (TPM) maximises equipment effectiveness through employee involvement, and incorporates the use of autonomous maintenance and small group activities to improve equipment reliability, maintainability and productivity (Nakajima, 1989; Pun et al., 2002). Profit-centred maintenance (PCM) insists on the reduction of the need for maintenance and the re-engineering of maintenance practices, thereby eliminating non-value-adding activities and reducing maintenance costs.

Moreover, reliability-centered maintenance (RCM) is the logic-based methodology for determining what PM is required to maximise the reliability of equipment and systems (Moubray, 1997; Pride, 2005). Continuous maintenance (CM) stresses the programmatic and technical aspects of maintenance to improve equipment readiness with less resource. The CM approach also utilises the knowledge base of the entire work force to improve equipment and process design to lower both maintenance and operation costs (Pun et al., 2002). Tsang et al. (2000) argue that the appropriate maintenance tactics need to be developed through a thorough and rigorous decision process in response to varied focus and strategies of maintenance (e.g. cost-constrained, capacity-constrained and/or compliance-oriented operations). A brief comparison among PaM, RCM, CM, TPM and PCM is depicted in Table 1.
Table 1. Comparison Among Selected Maintenance Approaches

<table>
<thead>
<tr>
<th>Criteria:</th>
<th>Proactive maintenance (PaM)</th>
<th>Reliability-centered Maintenance (RCM)</th>
<th>Continuous Maintenance (CM)</th>
<th>Total Productive Maintenance (TPM)</th>
<th>Profit-centered Maintenance (PCM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Maintenance costs reduction</td>
<td>Improving the life cycle management of the system</td>
<td>Optimising the required maintenance interval</td>
<td>Addressing the programmatic and technical aspects of maintenance</td>
<td>Improving overall equipment effectiveness and resolving equipment-related problems</td>
<td>Optimising the physical function of maintenance and resolving the recurring maintenance problem</td>
</tr>
<tr>
<td>2. Equipment or maintenance productivity</td>
<td>Focusing proven, corrective and preventive maintenance technologies; by identifying equipment maintenance processes</td>
<td>Improving the reliability of equipment</td>
<td>Maintaining and improving readiness with fewer resources</td>
<td>Increasing the value-added per person; increasing the rate of operation, and reduction in equipment breakdown</td>
<td>Reducing the need for maintenance and reduction in breakdown</td>
</tr>
<tr>
<td>3. Overall equipment effectiveness (OEE)</td>
<td>Emphasising equipment and system effectiveness</td>
<td>Emphasising systematic approach and the use of appropriate run-to-failure, planned, preventive and condition-based strategies according to consequence of system failure</td>
<td>Emphasising the measurement of maintenance performance and making use of both readiness and total maintenance costs</td>
<td>Improving OEE by attacking the six losses: breakdown; set up and adjustment; idling and minor stoppages; reduced speed; reduced yield from start up, and defects</td>
<td>Emphasising culture change to make decisions based on value; re-engineer the administration of maintenance, and use of available maintenance information technologies</td>
</tr>
<tr>
<td>4. Continuous improvement</td>
<td>Having little consideration of continuous improvement</td>
<td>Having little consideration of continuous improvement</td>
<td>Achieving the continuous improvement by incorporating PaM and RCM techniques</td>
<td>Achieving continuous improvement by extensive use of standardisation, workplace organisation, and visual management</td>
<td>Emphasising continuous process, administrative improvement, and optimisation</td>
</tr>
<tr>
<td>5. Anticipated duration of implementation</td>
<td>3-6 months</td>
<td>3-6 months</td>
<td>6-12 months</td>
<td>1-3 years</td>
<td>1-3 years</td>
</tr>
</tbody>
</table>

Nevertheless, for organisations with various types of systems, it is difficult for them to rely solely on certain common maintenance approaches to handle problems based on the customer service, productivity, system availability and reliability (Pun et al., 2002; Levitt, 2009). For instance, corrective maintenance is usually less economical than PM. Improper use of PM may however waste a lot of resources in doing unnecessary tasks that will not improve equipment or system availability. PM tasks that involve intrusion into equipment or overhaul tasks are also potentially risky (Tsang et al., 2000). TPM and RCM advertise vast savings for little investment, which are not obtainable if the organisation is already efficient. TPM does not exclude PM, but there is no specific strategy in it to allow PM to be planned. Besides, RCM also offers no corrective mechanism as front-line staff can make subjective judgements. As the age-reliability pattern is not straightforward in many systems, this may add further difficulty in proactive maintenance tasks assigned.

Objective judgements from experienced engineering staff are often a must at different levels to develop maintenance strategies and continuous monitoring of the performance. Moreover, it is not easy to maintain the self-discipline for quality improvement in the long run. In order to achieve maintenance optimisation without degrading the system availability, it is a prerequisite to have proper maintainability built into the existing systems. Instead of simply managing the results, it is necessary to control the equipment conditions that produce the results (Pun et al., 2002).

Tsang et al. (2000) argue that maintenance priorities, strategies and tactics should align with corporate priorities. In most circumstances, maintenance needs to maximise the profitability of the organisation by performing activities which retain working equipment in an acceptable condition, or return the equipment to an acceptable working condition (Shenoy and Bhadury, 1998). Effective asset maintenance management comes with the coordination within the groups of the maintenance organisation, the use of a suitable maintenance approach and utilisation of manpower resources (Wilson, 2002).

Pun et al. (2002) advocate an effectiveness-centered maintenance (ECM) approach that stresses the function of the asset or equipment with concerns on reliability, safety, operations and customer services. Similar to the main focus of PCM, the ECM approach puts emphasis on 1) culture change to make decisions based on value, and 2) re-engineering the administration of maintenance. It adopts the function of TPM philosophy and the principles of the RCM techniques to achieve maintenance optimisation. The ECM approach identifies equipment failure modes that can defeat system functions, prioritise the importance of these modes, and stresses life cycle profits and maintenance efficiency and effectiveness by optimising the scheduled preventive maintenance. Overall system effectiveness and individual system effectiveness are employed to monitor the ECM implementation. As compared with TPM and RCM, the ECM approach is more comprehensive and is composed of elements of maintenance strategy development, people participation and training, maintenance performance measurement, and continuous quality improvement (see Figure 1).

Nowadays, various maintenance management systems (MMS) are designed to ensure that proper maintenance activities are performed by providing organisations with a method of managing assets and a mechanism to achieve maintenance tasks (Levitt, 2009). As the emphasis shifted from the reactive-based maintenance to proactive and effectiveness-centered approaches, this allows the maintenance to be performed in a deliberate manner (Pun et al., 2002). Sookdeo et al. (2006) argued that among the core components of an MMS are 1) the maintenance management (MM) philosophy; 2) MM strategies; 3) organisational structure and staffing; 4) spare, materials and inventory management systems; 5) the work processes. Several key performance indices (KPIs) regarding reliability, availability and productivity have been advocated and widely used in
3. A Maintenance Case in Trinidad and Tobago

3.1 Company Profile and Maintenance Operations

TTGO is a new oil and gas operating company in Trinidad and Tobago. The company is involved in the exploration and production of hydrocarbons on the North East Coast of Trinidad and Tobago. The company commenced oil and gas production in January 2005 from new facilities that were constructed during the period 2003 to 2005. Oil and gas are presently produced from wells on offshore platforms and are processed by a central processing platform to the required product specifications. Processed oil is exported to an onshore storage facility by a pipeline that links the central processing platform to the onshore facility. The processed crude oil is exported to North American markets via marine tankers. Any gas produced is re-injected into the reservoir to maintain pressure and aid in oil recovery.

Maintenance of the physical assets within TTGO is recognised as a complex, costly, and essential business function. It was the global objective of TTGO to successfully develop new businesses and operational capability with the development of physical assets. The physical assets consist of structures such as platforms, pipelines, oilfield processing equipment, electrical, mechanical, rotating, and instrumentation equipment.

Maintenance operations are a critical function to ensure the safety and reliability of the entire operation. The production operations can be regarded as high risk since any failure of equipment or process can result in a hydrocarbon release resulting in damage to people property, and the environment. The development and implementation of the existing MMS commenced in the design phase of the asset development prior to the commencement of operations. The timelines and major activities of the project are summarised in Table 2.

Initially, there were no formal guidelines and no previous evaluation records to verify whether the activities in the design phase were completed. For the pre-commissioning phase of the project in 2004, the key deliverable was the development of the Plant Maintenance module for a CMMS. The Company has then commissioned the CMMS in January 2005. However, evidence showed that some of the project activities in design and pre-commissioning stages were not completed prior to the commencement of its operations. Improper implementation of the system at both stages has caused the operational deficiencies. There is a need to conduct a performance evaluation for the maintenance operations of the system.

3.2 Conduct of an MMS Performance Study

This is a need to improve production, safety, environmental protection, and at the same time reduces the cost of maintenance. In order to strategise the requirements into more useable steps, the focal areas of the study were to 1) design a MMS checklist/set of guidelines and 2) evaluate the performance status of key MMS components. The evaluation was conducted on these components using the checklist and guidelines developed.

The checklists and guidelines were developed incorporating the information acquired via a review of existing documentation, processes, and discussions with maintenance and operations personnel of the company. A set of documented process was also devised for measuring KPIs, with regards to 1) the type of measures used, and 2) the frequency of reporting (i.e., how often is the KPI measured, progress tracked, and reported). With regards to the company’s operation, deficiencies, and requirements, six (6) key MMS components were identified for performance evaluation. These were:

1) Maintenance Management (MM) Philosophy – i.e., the setting of criteria or requirement on the beliefs, mission, and vision for effective maintenance and asset management within the organisation.

2) MM Strategies – i.e., the methods (e.g. asset register, asset risk ranking, job planning, and reliability-centered maintenance studies) of formulating strategies for supporting the MM philosophies.

3) Organisational Structure and Staffing – i.e. the definition of organisational structure (e.g., roles and responsibilities of the company personnel and any third-party contractors for performing the maintenance activities on the facilities) and determination of manpower/staffing development (e.g., adequacy of personnel for maintenance operations, and methods of competency development and learning used).
Table 2: Project Phase Major Activities and Deliverables

<table>
<thead>
<tr>
<th>Project Phases</th>
<th>Main Activities</th>
<th>Deliverables</th>
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</table>
| Phase 1: Project Preparation (September 2003) | • Initial Project Planning  
• Project Procedures  
• Training Project Preparation Phase  
• Project Kick-off  
• Technical Requirements Planning  
• Quality Check Project Preparation Phase | • A mobilised team  
• Initial Project Plan and Schedule |
| Phase 2: Business Blueprint (November 2003)  | • Project Management  
• Organizational Change Management  
• Project Team Training Business Blueprint Phase  
• Develop System Environment  
• Organizational Structure Definition  
• Plant Maintenance Master Data and Business Process Definition and Configuration Planning  
• Quality Check Business Blueprint Phase | • PM Master Data Configuration Plan (such as functional locations, equipment, and bills of materials)  
• Maintenance Task List Plan  
• Maintenance Processing Configuration Plan  
• PM Information Systems Configuration Plan |
| Phase 3: Realisation (December 2003)  | • Project Management  
• Sustain Change Management Processes  
• Team Training  
• Baseline Configuration and Confirmation  
• System Management  
• Final Configuration and Confirmation  
• Develop Conversion Programs  
• Develop Application Interface Programs  
• Develop Enhancements  
• Determine Reporting Requirements  
• Create Forms  
• Establish Authorization Concept  
• Establish Data Archiving  
• Final Integration Test  
• Quality Check Realisation Phase | • Configured and tested system |
| Phase 4: Final Preparation (May 2004)  | • Project Management  
• Training Final Preparation and Realization  
• System Management  
• Cutover  
• Quality Check Final Preparation Phase | • Trained Personnel  
• Ready-to-use System  
• Go-live Plan |
| Phase 5: Go Live (June 2004)  | • Production Support  
• Project End | • Live System |

4) Materials and Inventory Management – i.e. the methods for spare parts identification, linking the maintenance tasks with material requirements, materials procurement and inventory management (e.g., moving and flow of materials, warehousing operations, re-ordering spares inventories, and ordering of new spares).

5) Computerised MM Processes – i.e., the use of the CMMS for managing maintenance-related activities (such as maintenance work identification, work planning, scheduling, execution, history recording, and data analysis), and evaluation of feedback loops and the MM processes.

6) Effectiveness-centered Performance Improvement – i.e. the identification of KPIs and the monitoring of maintenance efficiency and effectiveness (including the evidence of failure reports, lessons learned documentation) for operations improvements.

3.3 Highlights of Main Findings
It was found that the MMS was functional with some deficiencies identified. There were no formal guidelines on the sequential development and
implementation requirements, workflow, integration, and transition of the MMS from the project to the operational phase of the asset development. Incomplete activities constituted most of the deficiencies in the MMS development from the design to the operations phase. Besides, no evaluations or audits were conducted on the system after commencement of operation to determine performance and identify any shortcomings of the MMS development and implementation. Based on the assessment of key MMS components, among the main findings are discussed below:

1) MM Philosophy - The philosophy of designing the physical assets and developing the maintenance function was a key focus area in meeting the requirements of reliability and maintainability. This was evident by the presence of a hierarchical management system where systems and documentation are intended to support the higher levels. Based on the evaluation criteria, there was also a mission and vision statement for the maintenance function within the organisation. The mission statement described the contribution that the maintenance function provides to the business and the vision articulated the common theme and direction where employees in the organisation would follow.

2) MM Strategies - the development of the maintenance strategies adopted by the organisation was adequate and included reactive maintenance for breakdowns, preventive maintenance, conditions monitoring, and a corrosion management strategy. There were incomplete job tasks and job plans for maintenance jobs uploaded into the CMMS. There were inconsistencies in the scheduling and execution of condition monitoring maintenance tasks by third party vendors due to improper contractual arrangements, and lack of coordinating and interfacing by the engineering and operations teams. Other problems found included the non-identification of some critical equipment on the asset register and thus the non-creation of preventive maintenance tasks, inaccurate job tasks, lack of formalised procedures and strategies, and missing vendor technical information.

In order to tackle these deficiencies, an objective review of equipment with functional locations and tags on the asset register will be needed. This would allow proper maintenance schedules to be developed and spare parts procured for any future repairs required. The job plans and tasks should be updated and uploaded accordingly. It is also critical to assure condition monitoring program be executed as per schedule to detect equipment abnormalities and failure before they occur.

3) Organisational Structure and Staffing - The company’s organisational structure was found to be adequate for the maintenance operations. The role and responsibilities for key personnel involved in the maintenance activities are depicted in Table 3. The main deficiency found was unclear roles and responsibilities of personnel involved in maintenance operations across departments.

<table>
<thead>
<tr>
<th>Position</th>
<th>Key Responsibility</th>
</tr>
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<tbody>
<tr>
<td>Operations Manager</td>
<td>Accountability for Implementation and execution of the maintenance management</td>
</tr>
<tr>
<td></td>
<td>philosophies and delivery of the Company’s maintenance KPI’s for the offshore and</td>
</tr>
<tr>
<td></td>
<td>on-shore facilities.</td>
</tr>
<tr>
<td>Field Manager</td>
<td>Implementation and execution of the maintenance management philosophies an delivery</td>
</tr>
<tr>
<td></td>
<td>of the Company’s maintenance KPI’s for the offshore and on-shore facilities.</td>
</tr>
<tr>
<td>Engineering Manager</td>
<td>Technical support and engineering expertise in maintenance.</td>
</tr>
<tr>
<td>Operations Team Leader</td>
<td>Implementation and execution of the maintenance management philosophies an delivery</td>
</tr>
<tr>
<td></td>
<td>of the Company’s maintenance KPI’s for the offshore and on-shore facilities.</td>
</tr>
<tr>
<td>Field Engineer</td>
<td>On-site technical engineering support on maintenance issues.</td>
</tr>
<tr>
<td>Maintenance Planner</td>
<td>Planning, scheduling, and coordinating maintenance tasks.</td>
</tr>
<tr>
<td>Materials Coordinator</td>
<td>Ensuring availability of spare parts and materials for tasks.</td>
</tr>
<tr>
<td>Technicians</td>
<td>Executing maintenance tasks and history recording of activities.</td>
</tr>
<tr>
<td>Reliability Engineers</td>
<td>Reviewing equipment failure history and improving maintenance processes.</td>
</tr>
</tbody>
</table>
There is a lack of training on the CMMS that assures proper understanding of the CMMS and its interdepartmental integration. Most personnel were hired at the later part of the pre-commissioning stage and thus were not received the technical training provided from vendors, resulting in difficulties to navigate and find required parts, and complete work order closeout, history recording, and maintenance data analysis. This necessitates the need for on-going training that would enable personnel to effectively and efficiently manage maintenance activities, and particularly, using the CMMS.

4) Materials and Inventory Management (MIM) - The company had an inventory policy of spares stored at various warehouse locations. However, there were no formalised procedures for inventory control, spare parts procurement, and spare parts flow processes. A lot of critical spare parts were missing or misplaced during the design phase, never procured, improperly catalogued and not uploaded on the inventory, or never catalogued and in stock but unknown to maintenance personnel. The deficiencies therefore included the non-purchase of spares for some critical equipment due to non-identification on asset register, missing spares, long lead times for procurement and delivery of spares, and lack of an accurate inventory of spares.

Moreover, there are difficulty in navigating in CMMS to locate spares due to improper identification and cataloguing to associated equipment, and a lack of inventory management, spares identification, and materials workflow procedures. A full review of the materials and inventory management, and spare procurement process should be conducted. The cataloguing process should be revised to link spares and materials to associated equipment. An inter-departmental collaboration and agreement on the best workflow processes is necessitated.

5) Computerised MM Processes - The CMMS is used for all maintenance activities such as work identification, planning, scheduling, execution, closeout, and history recording and data analysis. However, there were no formal procedures or guidelines for maintenance planning or scheduling, execution, and closeout of tasks within the operation. Therefore, a lot of the deficiencies were attributable to improper development of the computerised MM processes. These included a lack of maintenance tasks on the CMMS for certain equipment (i.e., due to non-identification on the asset register initially);

inaccurate maintenance tasks for equipment in terms of duration and activities required; difficulty in locating spare parts for maintenance work orders from the inventory management system; incomplete job plans, and a lack of understanding in the use of the CMMS by maintenance and operations personnel.

Moreover, there is a lack of procedures and guidelines for job planning improvement, planning and scheduling, and maintenance budgeting and cost control. Therefore, formal procedures should be developed to formalise the planning, scheduling, maintenance work processes (execution, closeout, and history recording), failure analysis, and integrated use with the MIM system for maintenance tasks.

6) Effectiveness-centered Improvement - the company had developed maintenance KPI’s on an annual basis. These indicators included plan attainment, backlog man-hours, routine versus non-routine work, and plant operability for delivery of gross production. However, the maintenance budgets and tracking of KPI’s were not consistently measured. The main deficiency found was the lack of a formal procedure or process for the measurement and tracking of KPI’s. There were other minor deficiencies in the system. These deficiencies resulted in inefficiency in the system. Any corrective action on a daily basis required resources, additional budgets, re-work, and time. Most of the corrective actions were handled by the present operations and maintenance personnel in addition to their basic responsibilities.

In order to determine the workload among the maintenance and operations personnel, a multi-disciplinary team (consisting of specialists in maintenance, materials, procurement, and planning) should be formed. Besides, the maintenance budgets and performance against KPI’s should be tracked on a fixed basis to ensure compliance with set performance targets.

4. Development of an ECM Model

Evidence shows that most of the Company’s maintenance problems are related to the absence of formalised guidelines and poor development and integration of the MMS. The company has realised the pressing need to tackle these problems. The intent is to adopt an ECM approach that can eliminate some of the deficiencies experienced in the company. The approach needs to analyse the MMS
and its processes with the primary objective of preserving system functions, and guiding organisations towards their targeted system availability, quality and productivity in a cost-effective manner.

By its nature, ECM encompasses the concepts of TPM (e.g. people participation, autonomous maintenance and motivation) and continuous quality improvement (Pun et al., 2002). ECM attempts to incorporate the RCM analysis to improve the system availability and optimise the maintenance workload. This can help screen out unnecessary maintenance and save resources, so that the maintenance tasks can be properly assigned.

A proposed ECM model is depicted in Figure 2, incorporating the key features and components advocated in literature (Pun et al., 2002; Sookdeo et al., 2006). It shows an overall maintenance strategy and a development process that integrates activities across various phases of MMS development (i.e., from concept and feasibility, via design and execution to pre-commissioning and operations). The overall maintenance strategy would call for culture change, continuous improvement, people participation and training. The development process should involve various parties and personnel involved (such as the design team, commission team, operations and maintenance personnel, engineering teams, procurement and finance teams, and vendors). These teams should work together to 1) reduce the workload on the maintenance and operations personnel, and 2) assure that the design and/or acquisition of equipment meets the assets reliability and maintainability requirements, as well as the compliance with any health, safety and environmental (HSE) standards.

![Figure 2: A Proposed ECM Model](image)

### 5. Phases of ECM Development

The proposed model stresses effectiveness-centered evaluation of activities in maintenance operations for TTOG. The three respective ECM phases and associated activities are described below.

#### 5.1 The Concept and Feasibility Phase

At the Concept and Feasibility Phase, the basis of design document is the starting point of the ECM development. It would conceptualise the project in terms of facilities design, operations, and
maintenance. The maintenance philosophies could then be developed. This would include the desired reliability and maintainability of the facilities required based on the conceptual equipment type, quantities, and operating modes developed on the basis of design document.

With the maintenance philosophies and plans in place, maintenance and specific equipment strategies (such as reactive maintenance, preventive maintenance, condition-monitoring requirements, and corrosion management) could be conceptualised, and the maintenance budgets could be made. These budgets would be used to ensure the development of the reliability and maintainability requirements for new plant and equipment designs.

In this Phase, vendor data and technical requirements would be incorporated into tender and procurement documents. These included, for instance, equipment specifications, functionality, reliability, condition monitoring, safety requirements, recommended spare parts listings, equipment operating and maintenance manuals, and equipment maintainability. A list of equipment requirements and specifications would be formed as the basis of asset register. The selection, procurement, installation, development, testing, and commissioning of the CMMS would also be developed. These activities constitute the inputs of the process of Engineering, Procurement, and Contract Management (EPCM).

5.2 The Design and Execution Phase
The activities of the Design and Execution Phase involve the detailed engineering, procurement, construction, and subsequent commissioning of the facilities. The phase stresses the recruitment of ‘right’ maintenance and operations personnel to drive the ECM development. There are extensive involvements of the vendor’s technical expertise along with project, operations, and maintenance personnel. Contracts with vendors should be developed. Throughout the phase, efforts would be put to develop various plans and methods/procedures to facilitate proper execution of ECM activities. These include:

1) Equipment operations and maintenance plans and budgets (i.e., based on material costs and requirements, job durations and labour rates).

2) Job plans (including maintenance task procedures, task durations, equipment isolation procedures, job safety procedures, tools, materials, spares, and support services required).

3) Condition-Monitoring Plan (including measurement locations, frequencies, and tasks required).

4) Lubrication Management Plan – Protecting equipment from damage via ensuring lubricant and coolant quality.

5) Spares Review and Selection – Selecting spares based on vendors’ Recommended Spares Listing and/or on selection criteria (such as criticality, lead time for ordering and delivery, stock levels, cost, and frequency of use), and working with vendors in the assessment/validation of the spares procurement.

6) Maintenance Service Agreements - including maintenance schedules, labour rates, and materials required, performance measures, safety expectations, personnel competencies, supply of special tools and equipment, and draft maintenance schedules.

Regarding quality assurance/quality control, project and operations personnel should verify the information provided by vendors. This is to comply with content and quality standards specified in operations, maintenance, commissioning and training documentation/manuals. A MIM team (including Cataloguer and Materials Coordinator) should develop inventory procedures and materials workflow and integration processes, commence cataloguing of spares ordered (i.e., spares identification) and involve vendors in correcting inadequate cataloguing data.

There should be defined procedures and processes for planning and scheduling, execution, and closeout of maintenance tasks. Therefore, maintenance workflow and integration procedures should be developed. This should include the procedures for routine, and non-routine work, spares process flow, and interdepartmental roles and responsibilities in the overall maintenance development process. Besides, in the context of support services, for example, the plans and procedures for crane operations, lifting operations, and special tools management should be developed.

Moreover, it is important to identify the recruitment and training issues as early as possible for the operations/maintenance staff to develop appropriate learning and development plans and procedures. Training programs for employees should include the company’s MM philosophy and strategy, organisational structure, vendor specific equipment and operating principles, competency-based training
on critical procedures, training on regulatory standards, CMMS, and HSE requirements.

Prior to the commencement of operations, KPI’s together with the procedures on measurement, tracking of progress, and reporting requirements should be developed. The document management system should be in place so as to ensure that design data, information, experience, and engineering philosophies are effectively captured, documented, and transferred into the operations phase. This should be achieved by ensuring information requirements are delivered to dedicated documentation management personnel, and relevant information is stored electronically on the system.

5.3 The Pre-commissioning and Operation Phase
The activities of this phase involve the proper start-up, commissioning and operations of facilities that are based on the completion of the preceding phases. The formation of the multi-disciplinary team would play a crucial role in assessing the design for safety, maintainability, reliability and cost-effectiveness of the MMS. There are six core ECM areas, including 1) MM philosophy, 2) MM strategies, 3) organisational structure and staffing, 4) materials and inventory management, 5) computerised MM processes, and 6) effectiveness-centered improvements.

In line with these core areas, several secondary areas are identified. These include the EPCM process, HSE standards and requirements, budgeting and cost analysis; maintenance information systems management, documentation system, shutdown management, facilities development, and asset design acquisition and modification. These specific areas signify the underlying intent, expectation and requirements for maintenance operations.

The proceedings of this phase would rely significantly on: 1) the design and/or acquisition of assets for achieving optimal reliability, maintainability and cost effectiveness, 2) the design and implementation of the overall maintenance development processes, strategies and supports, 3) the recruitment and development of a competent and efficient workforce to execute the maintenance activities within operation, and 4) the compliance with HSE requirements and standards.

6. Discussions and Conclusion
The findings of this case study showed that the company had been experiencing difficulties and deficiencies in its MMS development. These were attributable largely to lacking appropriate guidelines for proper development and implementation of activities in various phases of the asset development. There were a lot of missing procedures required for inventory control, work planning and scheduling, and workflow integration of the CMMS and MIM. Since the MMS has been transitioned from the design to operational stage in the studied company, an independent audit of the system performance should be conducted. By doing so, this would identify other uncovered problems and deficiencies that might exist, propose timely corrective actions.

ECM is an integrated approach to maintaining various types of systems in organisations of varying business nature and sizes. The ECM model described in this paper contributes to the improvement of maintenance management practices at the studied company in Trinidad and Tobago. Based on the proposed model, improved maintenance guidelines could be developed along with the three respective ECM phases (i.e., from the Concept and Feasibility Phase via the Design and Execution Phase, to the final Operation Phase). These provide the effectiveness-centered base (with those core and secondary ECM areas) for the company to develop specific procedures and associated activities for eliminating potential deficiencies and improving its performance in maintenance operations.

The ECM approach focuses on system functions and asset performance, and has several features that are practical to enhance the performance of maintenance practices. People focus and process improvement is crucial in ECM process. The use of TPM and RCM methodology helps organisations to analyse the existing maintenance practice and suggest an appropriate technique and maintenance schedule. Moreover, organisations can develop company-specific KPIs to prioritise their problem areas and monitor their maintenance work progress. The results would help optimise management decisions (e.g. co-planning of operation with maintenance, overhaul/renewal of equipment and improvement of service performance), and ultimately determine the life cycle profits for overall effectiveness.

The ECM model could serve as a reference for setting targets and sustaining performance improvement. Further study can validate the efficacy of the ECM implementation and investigate the extent to which the employment of the approach can help organisations to achieve a competitive
advantage. Future studies into the development of mechanisms to track and measure ECM performance (e.g., in areas of equipment availability versus reliability, inventory costs versus maintenance costs, and personnel productivity) are recommended. Benchmarking should be considered as a method to track performance against industry standards for similar operations.

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Biographical Notes:

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