Developing a framework for evaluation of a digital maintenance management system

Maleho M and Telukdarie Arnesh
Post Graduate School of Engineering Management
University of Johannesburg
Auckland Park, 2092, South Africa
Mmaleho75@gmail.com, arnesht@uj.ac.za

Abstract

The increasing demand for productivity, quality and availability is driving the need for the effective management of physical assets. The depletion of traditional cost cutting, the disadvantages associated with rapid growth and the management of change has caused companies to explore more effective and efficient options. Not only do organisations have to meet customer needs and improve the availability and performance of equipment, organisations also need to do so while also reducing operational costs. These factors have led to the increasing concentration on reliability within the business sector, specifically strategic maintenance management. Digital maintenance management systems are software-based systems used for managing and controlling plant and equipment maintenance in modern manufacturing and service industries. Many companies make use of such systems to ensure the effective management of physical assets, which plays an enormously important role in maintaining a profitable business. Historically, selecting a digital maintenance management system was simple and required minimal research, however, as markets become saturated with various types of maintenance software and technologies become more advanced, selecting digital maintenance management systems is becoming more complex. The main objective of this research is to develop of a framework for evaluating and selecting digital maintenance management systems. The research approach for this study applies a combination of various methods. Results analysis focuses on the current status of the maintenance management system, business needs and priorities. The results indicate that the toolset developed is effective in evaluating and selecting digital maintenance management systems that are of best practice and cater to the specific needs of the business.

Keywords
Digital maintenance management systems, evaluation toolset, best practice.

1. Background/Introduction

Maintenance is one of the most important functions of a business and forms an integral part of productivity improvement. Maintenance is the combination of all technical and associated administrative actions used to retain or restore an item to a state in which it can perform its required function (Muyengwa, 2015). Digital maintenance management systems are software-based systems used for managing maintenance tasks. A digital maintenance management system is an integral component of any efficient maintenance department (Ouellette, 2015). Digital maintenance management systems assist in reducing maintenance costs and minimizes emergency repairs and downtime.

1.1 Strategic asset management

In order to achieve an organisation's objectives, structured planning and execution is required. Strategic management involves planning and formulating an organisations objectives, analysing internal and global environments, implementing the set strategy, assessing the success of the strategy and adjusting the plan if need be (Wagner, 2010). Maintenance accounts for a significant fraction of operational costs, the effective management of maintenance management therefore requires maintenance to be viewed strategically from a business point of view (Murthy et al, 2002). Global competition has also led to maintenance being viewed in a strategic dimension (Turki, 2012). Production companies are now shifting focus from volume production to quick response, defect prevention and waste elimination associated with physical assets, such as equipment. These changes affect maintenance strategies. The advancement in

technology has brought new challenges that maintenance systems face (Turki, 2012). This then highlights the importance of developing maintenance plans at a strategic level in order to cope with these technologies.

1.2 Digital maintenance management systems

The need for efficient maintenance management is especially significant in production environments where there's a large number of critical equipment. Digital maintenance management systems are common in industries, they are increasingly being used to manage and control plant and equipment maintenance in modern manufacturing and service industries (Weir, 2015). A digital maintenance management system is defined as a management software that performs functions in support of management and tracking of operational and maintenance activities (Sullivan, 2002). In most organisations, digital maintenance management systems are often perceived to be means of scheduling maintenance work, however these systems are capable of much more than that (Weir, 2015). In fact, every aspect of maintenance can be managed by digital maintenance management systems. Digital maintenance management systems are supplied by vendors as complete packages. Purchasers then choose modules, which are most suitable for the required maintenance specifications. A digital maintenance management system provides information such as number of breakdowns and root cause analysis for a specific piece of equipment. Higgins et al (2008) defines a digital maintenance management system as an integrated software program that provides data on the functionality maintenance activities. In essence, digital maintenance management systems may be used for the following; compile and control the company's list of maintainable assets, schedule, control and document maintenance routines, planned or unplanned, budgeting, condition monitoring control, analysis of maintenance effectiveness and inventory control (Weir, 2015). The attributes and objectives of a digital maintenance management system in a generic view as listed by Duran (2011) are the ability to create equipment records, asset bills of material, inventory control, work order planning and so forth. The attributes will depend on the decision model used to select the system.

1.3 Industry 4.0

Over the years, there has been extraordinary growth in the development and adoption of information technology (Lee et al, 2013). Industry 4.0 describes this development. Manufacturing in the first industrial revolution involved the use of water and steam-powered mechanical systems, in the second industrial revolution these mechanical systems become electrical powered. The introduction of computers yielded the third industrial revolution while technologies such 3D printing, Internet of Things, Cloud computing, Mobile Devices and Big Data brought in the fourth industrial revolution (Sishi & Telukdarie, 2017). Industry 4.0 marks the end of traditional centralised applications for production control and envisions the start of systems consisting of decentralised intelligent and autonomous entities (Almada-Lobo, 2015). Manufacturing Execution Systems (MES) which are discussed in the following sections, are built to support these changes. Industry 4.0 has created unique opportunities for solutions that have the capability to support connected yet decentralized production and supply chain processes, it enables better planning methods, improved data analysis, remote monitoring, automation and predictive maintenance (Sishi & Telukdarie, 2017).

1.4 Best practice maintenance functions

There are a number of maintenance management software available in the market. Since the objective of this study is relative to best practice, the maintenance functionalities listed are derived from best practice software vendors. In order to determine which software vendors are considered best practice, a number of resources are reviewed. An article in Solutions review titled "Top 5 Best ERP Vendors to Watch in 2018" compiled a list of the top five Best ERP Vendors. Included in this list is SAP, Acumatica, DDI System, Rootstock Software and Epicor. Another article in Technology advice with the assistance of Niche, listed the following as top ERP Companies for enterprises: SAP, Oracle, Microsoft Dynamics, Infor and IFS Applications (Technology advice, 2018). An article in Software Connect listed the following as top MES software, SAP Business One, HYDRA, Epicor, Macola, Priority Software, SAP Manufacturing Execution, Rockwell and NetSuite (Software connect, 2018). As research suggests, SAP, which appeared in a significant majority of the lists of top ERP software is one of the global leaders in business software solutions. Founded in 1972, SAP is a German software company that offers an industry leading ERP solution, SAP S/4HANA. SAP S/4HANA is an ERP software for technologically advanced businesses. SAP S/4HANA has a number of benefits ranging from empowering business users with live information from across all operations to connecting workflows across every part of the enterprise (SAP, 2018). Software advice, an online software newsletter lists IBM Maximo as a world leading enterprise asset management software. When combined with the Internet of Things (IoT) and data from sensors and devices, Maximo provides warning signals from assets thus reducing unplanned downtime and increasing operational efficiency (IBM Maximo, 2018). These lists are compiled based on facts, figures and trends in the maintenance software landscape (Finances online, 2017). As derived from SAP and IBM Maximo, best practice maintenance management functional requirements include:

- Maintenance planning: involves, scheduling, inventory control and purchasing
- Maintenance execution: involves asset management and work order management
- Maintenance optimisation: involves maintenance performance measurement and data management
- Maintenance management: involves finances, legalities, safety and compliances.

2. Methodology

2.1Research design

The purpose of this study is to develop a framework for evaluation and/or selecting digital maintenance management systems. The framework is built from information provided by the study company on its business requirements and relevant references in previous works, best practices and successful case studies. The study uses a mixed method approach, this includes a qualitative and quantitative research approach. Data is extracted by means of a literature survey that outlines and defines strategic management, strategy formulation, executing the strategy and the importance of strategic management in the mining and metals sector. The literature survey also discusses strategic asset management, maintenance management systems, the evolution of Industry 4.0 and the gradual movement towards automated production systems. Also included in the literature survey are best practice digital maintenance management software and methods for evaluating and/or selecting digital maintenance management systems. The business requirements of the case company are outlined through a requirements analysis. An analysis of the results is then used to compile a set of attributes for digital maintenance management systems.

2.2 Evaluation toolset development

A business process model is used to develop an engagement toolset. The business process model is derived from various sources that consist of best industry practices. Asset management plays a significant role in the development and implementation of the maintenance strategy. According to El-Akruti and Dwight (2013) asset management is said to consist of two main aspects, the life cycle management of physical assets and the systems thinking control of the all assets. Life cycle management consists of the following asset related activities, technical support and development (Information Technology (IT)/Engineering), procurement, human resources and finance and accounting. These asset management activities together with business analysis, safety and environmental management form the first tier of the business process model. The focus of this study is maintenance as an engineering subcategory.
Murty et al (2002) lists the following as key elements of strategic maintenance management; business objectives, maintenance strategies, operating load and equipment state. Fernández and Márque (2012) define the following as maintenance management levels:

- Defined maintenance, this involves the process of planning maintenance. Maintenance plans should be aligned with company guidelines and should fulfil business requirements.
- Quantitative managed maintenance which focuses on the technical operational aspects
- Optimized maintenance which involves improving maintenance within a global environment. The development of technologies that assist with the distribution and generation of maintenance knowledge.

The defined maintenance level or maintenance strategy, maintenance planning, maintenance execution and optimize maintenance or maintenance optimization form the second tier of the business process model. Table 1 is the business process model developed.

Table 1. Business process model

	Tier 1	Tier 2
	L0	L1
Business Processes	Business Analysis	
	Finance	
	Human Resources	
	Safety	
	Environmental Management	

	Engineering	
	Maintenance Management	Maintenance strategy
		Maintenance planning
		Maintenance execution
		Maintenance optimization

When developing asset management strategies, key questions addressed include; what assets are needed to achieve strategic purpose and what goals are to be achieved through the strategic management of assets (Tranfield et al, 2004) while when developing maintenance management strategies, key factors to be addressed include the integration of technical and commercial issues and continuous improvement in maintenance management (Murthy et al, 2002). From the strategic maintenance plan, a maintenance strategy is chosen, this strategy must be related to organisational structure, maintenance methodologies and so forth. A system is then put in place to measure the performance of the chosen maintenance strategy. In the maintenance strategy category, questions such as, is the maintenance strategy defined? Are maintenance plans aligned with maintenance objectives and is there a system for measuring maintenance strategy performance are asked.

Maintenance planning involves the following sub-functions; Scheduling and Inventory Control. Scheduling plans out all work orders related to all maintenance activities. In best practice software solutions such as SAP and Maximo, work orders are scheduled in order of priority. The systems should scan all the assets in the asset register, be flexible, account for downtime scheduling, apply Multi-resource scheduling, and graphically schedule work orders. In terms of inventory control, the system should automatically allocate, balance and level resources. The inventory control sub-function should be used to monitor costs and budget adherence, record all parts and tools used, purchased and received.

Maintenance optimization is the process of ensuring that all maintenance activities are effective and efficient. Maintenance optimization consisting of the following sub-functions; Maintenance Performance Measurement and Data Management. Best practice software solutions are able to track and improve all maintenance activities using maintenance performance techniques from real time data. Best practice software solutions all have maintenance techniques in place that automatically generate Key Performance Indicators (KPIs) based on organisations objectives, custom reports, historical data, Original Equipment Manufacturer (OEM) and specifications. The software is also able to analyse trends, maintenance costs, Mean Time To Repair (MTTR), Mean Time Before Failure (MTBF) and equipment availability from reliable and accurate data collected from all integral parts of the overall business process models since all entities are interlinked. With this data, the user is also able to monitor the condition of equipment/items.

Maintenance execution is the actual carrying out of the maintenance activities and involves asset management and work order management. Asset management sub-function consists of an asset register composing of all the information on the assets. Information such asset name, serial & drawing number, location and metering information, all of which are arranged in hierarchies. The asset management sub-function should also consist of the asset bill of material, work order planning & history. Best practice software solutions have mobile app features that allows for maintenance task list tracking, failure trends amongst other features. With best practice software solutions, users can also view the subassemblies and parts of an asset, link maintenance costs to assets, automatically cost work orders, group and provide the status of all outstanding work orders, record service calls, facilitate labour scheduling and record any inventory change using real-time data.

Maintenance management is also linked to Finance, which relates all maintenance activities to cost and forms part of procurement/Supply Chain. Legal /Compliances are also taken into consideration, best practice software solutions also automatically generate ISO Certifications, Department of Mineral Resources (DMR) compliances, Safe Work procedures, Mine Health and Safety Act (MHSA) applicable, Original Equipment Manufacturer (OEM), Planned Task Observations (PTO) and Risk assessments. Table 2 is an expansion of the maintenance planning function and its subcomponents as derived from best practice maintenance software.

Table 2. Maintenance planning function

L1	L2	L3
Maintenance planning	Scheduling	Schedules work orders in priority
		Scans all the assets in the asset register
		Flexibility
		Automatically allocates, balances and levels resources
		Downtime scheduling
		Multi-resource Scheduling
		Historical data
		Alert Monitor feature
		Gantt tool to graphically schedule work orders
		Monitor costs and budget adherence.
	Inventory Control	Record all parts and tools used, purchased and received
		Item Master feature to keep track of stock items
		Automatically updates inventory by removing part used.
		Creates a reorder requisition to replenish inventory
		Automatically generate data on purchase requisitions and costs
		Automatically generates reliable electronic audit trails
		ABC Analysis feature

Another important aspect of selecting a software solution is the software quality and vendor criterion. In software quality function is divided into various subcomponents such as portability, personalisation and maintainability. The subcomponents all consider the capacity of the software, the hardware requirements and compatibility and the number of customizable fields and reports. The vendor criterion function is divided into training and documentation, maintenance and upgrades, vendor reputation and costs subcomponents. Most organisations select software solutions based on the vendor business skills, popularity, and experience.

2.3 Response indices

The main objective of the engagement toolset is to collect information on the state of the current system being employed and the importance or priority rating of certain functionalities, software quality and vendor information. The questions are rated on various Likert scales as follows:

- System required index has Yes or No options. Yes, weighs maximum 2 while No has a weighing of 1.
- System “as is” status is an indication of the state of the current system being used. A best practice is having a fully integrated system which weighs 4 while having no systems weighs 1
- Cost analysis scale ranges from 1 = No cost to 5 = Very high cost
- Capacity analysis scale ranges from 1 = No capacity to 4 = Large
- Priority analysis scale ranges from 1 = Not important to 3 = Very important. Priority is also calculated as the difference between weight and response.
- Software quality analysis scale ranges from 1 = Poor to 4 = Excellent

The response from each question is assigned a score based on the overall weight of the question and the weight of the response. Detailed in table 3 are the response indices.

Table 3. Response Indices

Descriptor	Feedback	Weight
System required	Yes	2
	No	1
System as-is status	No system	1

	Paper system	2
	Basic software-based system	3
	Full integrated system	4
Cost	No cost	1
	Low	2
	Medium	3
	High	4
	Very high	5
Capacity	No capacity	1
	Small	2
	Medium	3
	Large	4
Priority	Very important	3
	Moderately important	2
	Not important	1
Quality	Excellent	4
	Average	3
	Below average	2
	Poor	1

2.4 Test and deploy

The questions in the engagement tool are all derived from the list of best practice maintenance functionalities. Table 4 is an expansion of the maintenance planning function and its subcomponents as derived from best practice maintenance software into the engagement tool. The engagement tool is sent out to 10 employees for the purpose of testing the framework. Both management and operational representative are included in the test. The engagement tool also consists of a software quality and vendor criterion.

Table 4. Engagement tool

L1	L2	Questions
Maintenance planning	Scheduling	Does the system automatically schedule work orders in order of priority
		Does the system automatically scan the asset register for planned maintenance work orders
		How would you rate the importance of flexibility in the scheduling feature
		Is the demand for resources directly linked using a criterion
		Does the system account for downtime scheduling
		Does the system use multiresource scheduling
		Does the system automatically give alerts when maintenance is due
		What tool is used to schedule work orders
		Does the system link costs to scheduling
	Inventory Control	Does the systems inventory tool record all parts and tools used, purchased and received
		Does the system automatically update inventory by removing parts used
		Does the systems automatically create a reorder requisition to replenish inventory
		Does the system automatically generate reliable electronic audit trails

		Does the system analyse the financial benefits of having an item in stock

3. Result Analysis

The results serve as an indication of the state of the current system, business needs and priorities. The response from each question is assigned a score based on the overall weight of the question. The research results are presented as per the levels/categories described in the methodology.

3.1 Category specific analysis

The engagement tool consists of the following categories:

- Maintenance strategy
- Maintenance planning
- Maintenance execution
- Maintenance optimisation
- Maintenance Management
- Software quality
- Vendor criterion

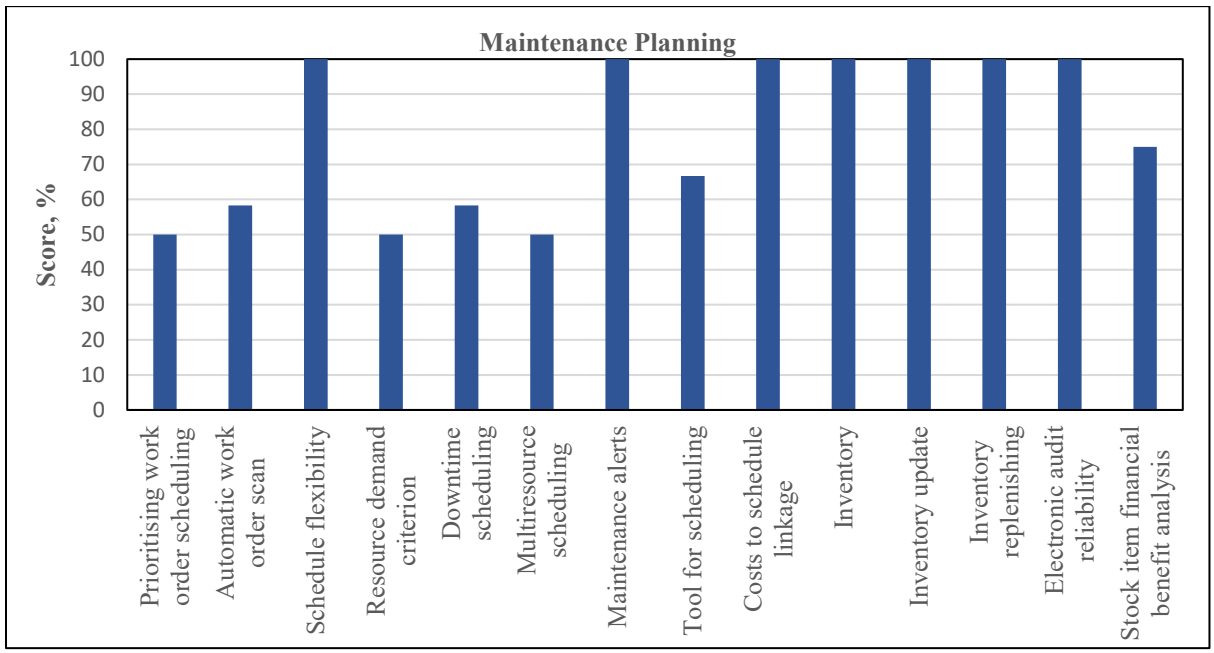

Figure 1. Maintenance planning analysis

In terms of maintenance planning, it is apparent in Figure 1 that questions relating to automatic work order scanning, schedule flexibility, downtime scheduling, maintenance alerts, costs to schedule linkage, inventory update and replenishing, electronic audit reliability and stock item financial benefit analysis all scored a 100%. This is an indication that a fully integrated system exists for these functions. The question relating to which tool is used for scheduling score 66%, indicating that only a basic system exists for this function. Questions relation to prioritizing work order scheduling, resource demand criterion and multiresource scheduling all score 0. This indicates that a fully integrated system does not exist for these functions.

It is apparent in Figure 2 that a fully integrated system does exist for asset registration, printing of lockout procedures when applicable, work order costing, work order grouping status, labour scheduling and the use of real time data. Literature suggest that the asset register needs to be built on hierarchies. This enables maintenance costs to be linked to a specific equipment/asset or location. Best practice maintenance management systems combine asset intelligence networks with enterprise asset management so there is no need to create or maintain hierarchical data manually. In the past, data accuracy and report timeliness have proved to be problematic, the use of real time data minimizes these

problems Best practice maintenance management systems create a platform for the accurate collection and analysis of data. Also apparent in Figure 2 is that the current system does not allow for the remote monitoring of active work orders. Over the years, there has been remarkable growth in the development and adoption of information technology. Industries are moving towards the use of advanced technologies that enables better and faster planning methods as well as improved data analysis. Remote monitoring is a trend of next generation production systems and should be of high priority if the business intends on competing globally.

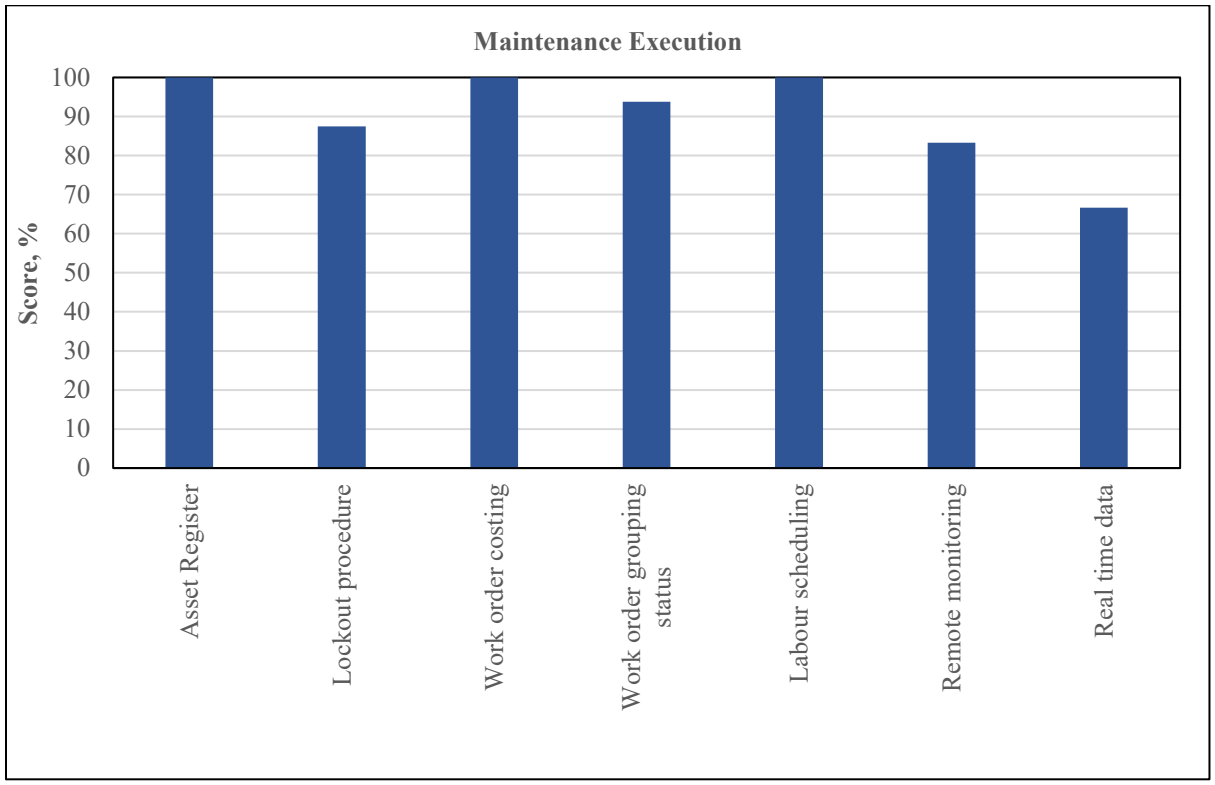

Figure 2. Maintenance Execution analysis

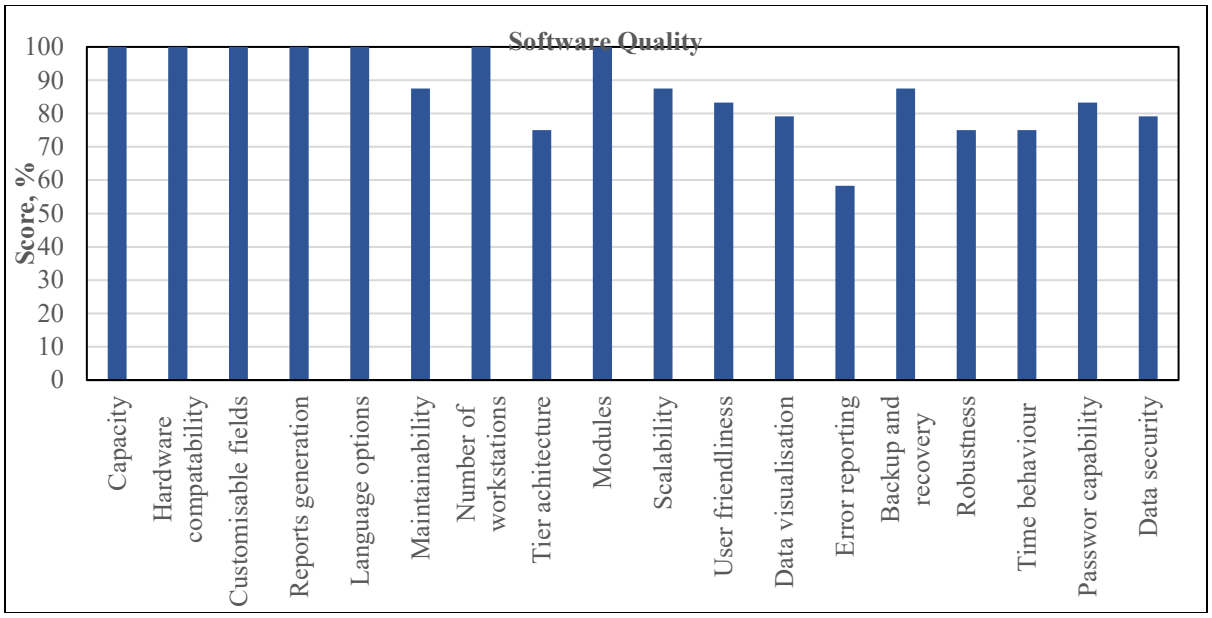

Figure 3. Software quality analysis

Figure 3 shows that in terms of capacity, hardware compatibility, customizable fields, reports generation, language options, maintainability, number of workstations, tier architecture, modules and scalability the current systems score 100%. This indicates that the capacity of the system is large and that there is a fully integrated system for customizable fields and reports generation. The systems excellent maintainability, scalability, allows for a large number of work stations to be connected at the same time and employs three-tier architecture. The system is offered in more than one language promoting diversity and minimising issues resulting from communication barriers.

3.2 Overall analysis

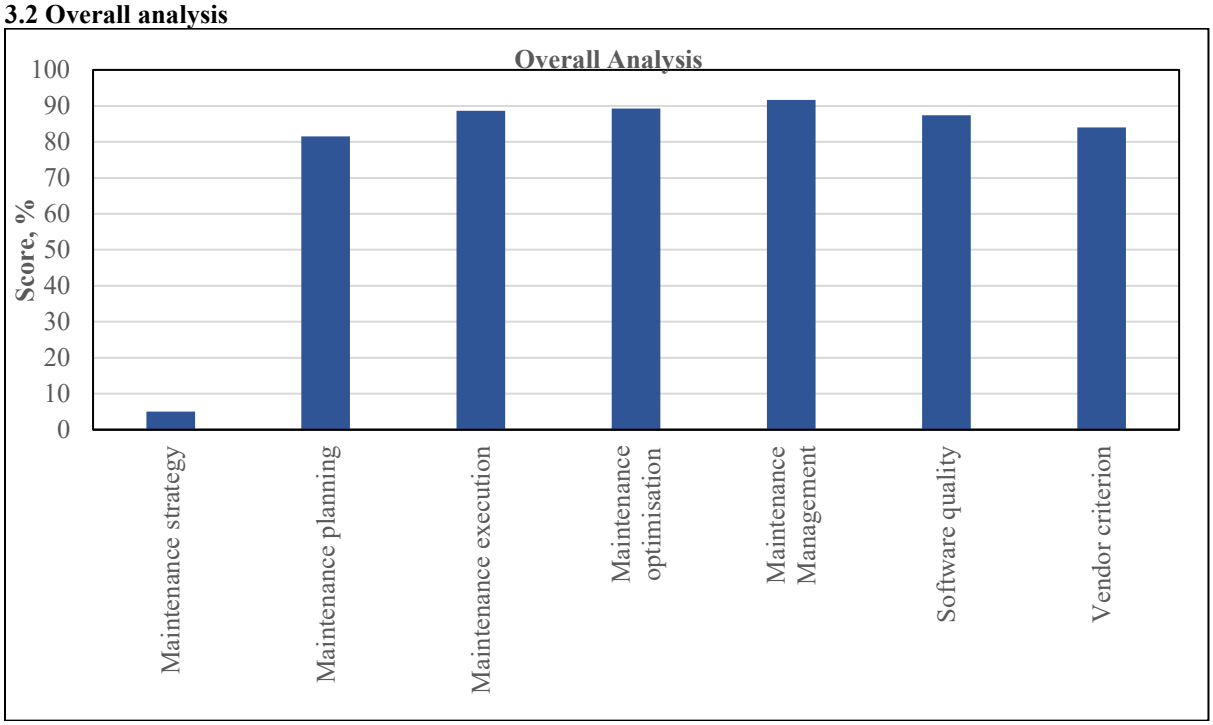

Figure 4. Overall analysis

It is apparent from Figure 4 that the business considers maintenance management (cost and budget reports and compliances (safety)) as the most important function. The second most important function is maintenance execution which consists of the asset register, lockout procedures, work order costing, work order grouping, labour scheduling and the use of real time data. Maintenance planning, maintenance optimisation, software quality and vendor criterion all have overall scores ranging from 84% to 89%. Maintenance strategy has the lowest overall score at only 5%. From the engagement tool, insufficient data is available on the maintenance strategy. However, literature suggests that maintenance strategies are of the outmost importance and form the backbone of the entire asset management plan as they contribute significantly to the overall efficiency of an organisation. The low score is as a result of insufficient data and does not indicate low priority.

From the results it is apparent that maintenance planning forms an important part of the overall maintenance management business process. It is also apparent that the current system does not apply multiresource scheduling and has a basic software system for real time data from trackers, alarms and sensors, although this is sufficient, in future, advances in technology will require a fully integrated system. The system also has a basic software system for generating KPIs for equipment. KPIs form an important part of preventative and predict maintenance, the application of KPIs ensures the monitoring of equipment and the reduction of downtime. The results also suggest that the demand for resources is not directly linked using a criterion. Having a criterion in place ensures that items are kept in stock in order of priority, again reduces downtime and the overall availability of equipment.

For the questions relating to maintenance execution a majority of the representatives in lower management levels suggest that the systems put in place are not effective. The move towards the use of trackers, alarms and sensors for real time data analysis and trends appears to be a slow one. Best practice software solutions make use of such devices when monitoring equipment and for reliable electronic audit trails.

Conclusion

The outcome of this research answers the following research questions; what is the international best practice in terms of maintenance management systems and what methods are used to evaluate and/or select maintenance management systems. For this study, data is extracted by means of a literature survey. In the literature survey, various methods for evaluating and/or select maintenance management systems are discussed and the standardized approach, which is the most common and simplest approach, mixed with other methods is used. This then answers the research question, what methods are used to evaluate and/or select maintenance management systems. The data gathered on best practice maintenance management systems, which answers the research question, what is the international best practice in terms of maintenance management systems, is used is develop an engagement toolset. This toolset/framework is then tested on a set of employees to establish its effectiveness in extracting data required for optimal selection or evaluation.

The results from the test indicates that a fully integrated system does exist for the majority of functionalities relative to best practice. There are some aspects however, that are not integrated and still function independently. This specific business should pay close attention to maintenance strategies, linking resource demand to criterions, effectiveness of the tools used for scheduling work orders, remote monitoring as well as KPI generation. From the result it is also apparent that the toolset developed is effective in evaluating and selecting digital maintenance management systems that are of best practice and cater to the specific needs of the business. This in evident in the amount relevant and useful data that was extracted from the test. Having such a system in place has the potential to contribute significantly to business profitability. A toolset such as this, aids in ensuring that the maintenance management system put in place, meets all the unique needs of the business and ensures the efficient management of physical assets thus reducing operational costs and improving the availability and performance of physical assets. This enables the business to secure a vantage point over competitors and puts the business in a better position to manage challenges associated with the increasing demand on productivity, quality, availability, advances in technology and competition.

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Biographies

Arnesh Telukdarie holds a Doctorate in Chemical Engineering from the Durban University of Technology, South Africa. Prof. Telukdarie is currently an associate professor in the School of Engineering Management at the University of Johannesburg and a Professional Consulting Engineer. Prof. Telukdarie has over 20 years of industrial experience, research interest includes Manufacturing and Corporate Systems.

Maleho M is a master's degree student at the postgraduate school of Engineering management, Johannesburg, South Africa.