Chapter

Harnessing the Multiple Benefits of a Computerised Maintenance Management System

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Abstract

Those involved in maintenance operations are enjoying the benefits of information and communication technology in the planning and management of maintenance activities, resource management and planned production. In the digital space, the computer-based operating systems, commonly referred to as computerised maintenance management systems (CMMSs), enable quick and effective communication between stakeholders, facilitate improved planning, easy access to historical data, reporting and performance improvements of the maintenance function. However, success in the use of CMMSs depends on the human capacity of the users of the system. In practice, many organisations use the CMMS tool for planning, operations management and reporting, without the aid of detailed analysis of operational information in the CMMS database. They fail to harness all the possible benefits. Three case studies were used to illustrate the situation. Two of them refer to academic institutions and the third is a manufacturing company. In the academic institutions, the CMMS was used for maintenance planning, management and periodic reporting. The manufacturing company included analysis of the information in the operational database, which culminated in identifying the level of the reliability of machines in the production network through benchmarking. The conclusion is that the quality of the human capacity enables organisations to harness and make maximum use of the potentials inherent in typical CMMS software.

Keywords: analysis of operational information, benchmarking, computerised maintenance management systems, effective communication, reliability of machines, reporting

1. Introduction

Maintenance operations have over time continued to evolve and, in the digital age, are maximising the opportunities offered through the application of information and communication technology. 'Information systems that support maintenance functions are referred to as Computerised Maintenance Management Systems (CMMSs)' ([1], p. 269). Some of the objectives of a 'CMMS are effective maintenance of machines, rational asset management, and consequently higher productivity of a company' ([2], p. 277). The application of CMMSs in maintenance management allows the effective documentation of maintenance operations, planning and execution of maintenance operations, communication of periodic reports to stakeholders, analysis of operational history and the development of performance improvement strategies. Typical CMMS software contains different modules, which enable the maintenance operatives to execute different activities. Some of the operational modules include asset management, work order management, preventive maintenance management and inventory control and report management [1]. Others include service management, contract management, materials management and procurement management [2]. Any or multiple modules can be activated, depending on the quality of the human capacity of each organisation. They can be used for the planning and execution of scheduled operations and the development of functional periodic reports. It can also be used for the analysis of the operational history and for the development of performance improvement strategies. Therefore, the continuous explorative use of the content of a CMMS tool in maintenance operations enables the maintenance unit to achieve the 'just-in-time' (JIT) response to a maintenance request, address the problem and restore the facility or machine to functional use [3]. Achieving JIT facilitates a reduction in the cost of maintenance, a reduced duration in repair time and consequently the length of downtime, achieves improved customer satisfaction and improvements in production. Improvements in JIT require the deliberate action of collecting and analysing the data of maintenance operational history and the subsequent development of performance improvement strategies. This cycle of operations is in tandem with the requirements of smart maintenance [4].

The focus of this chapter is to explore the vast potential of typical CMMS software and to show that this vast potential can be harnessed in each module. The use of CMMSs in three maintenance units serves as an illustration of how the potential of CMMSs is being harnessed or neglected. The chapter covers the literature review in Section 2, which highlights the use and potential of a typical CMMS, and progresses to Section 3, which explores the place of the case study research strategy in qualitative research. Section 4 provides information on the research findings and their discussion, while Section 5 provides the synthesis of the content of the chapter in the form of conclusions and recommendations.

2. Literature review

A literature review provides the platform for researchers to explore and evaluate their efforts against previous research endeavours to harness existing information, models and methodologies. The literature reviewed here provides general information on CMMSs and its use in maintenance planning, operations, periodic reports, performance improvements and benchmarking.

2.1 Computerised maintenance management systems

The concept of maintenance has transformed over time. In the past, maintenance was the act of replacing a broken component in a process, machine, or facility [5]. However, maintenance is now considered as a vital component in the complex management process and is associated with several organisational processes like production, quality, environment, risk analysis and safety [6]. Considering that maintenance is an important function of organisations, maintenance management requires a multidisciplinary approach with a business perspective and the use of digital technology [7]. Adopting computer systems to support maintenance operations is commonly referred as Computerised Maintenance Management Systems (CMMSs) [1]. CMMSs allow the effective documentation of maintenance operations, communication of scheduled activities, enhance the ability to develop and monitor the forward planning and execution of maintenance operations. Typical CMMSs have assigned a set of functions and applications, including asset management, work order management, preventive maintenance management, inventory control and report management [1]. It also includes service management, contract management, materials management and procurement management [2]. Each of these functions is represented as specific modules in a typical CMMS software package and each module is activated according to the need and human capacity of the organisation. Many of the systems available in the market do not perfectly match the specific requirements of some organisations. Therefore, they prefer to develop their own software or buy commercial packages and activate the modules of interest [1].

The introduction of CMMSs in maintenance operations facilitates the tracking of progress in the execution of requests, the effective development and dissemination of periodic reports and the analysis of the operational history in the database of each facility [8]. The outcome of the analysis allows maintenance operatives to know the state of the facility, identify the causes of failure and develop suitable maintenance and performance improvement strategies. Furthermore, the CMMS enables the automation of maintenance procedures in terms of communicating with maintenance units, planning and executing maintenance operations and communicating (real time) with all relevant stakeholders [9]. The ease of use and usefulness of CMMSs are influenced by the level of training of the user before and during the implementation. The proposed training may end up with negative impacts if the focus of the training is on the technology itself and not on how the technology enhances personal satisfaction, facilitates and supports the user's method of executing relevant tasks [10].

The maintenance unit of any organisation spends considerable time in the development, operations and maintenance of the facilities that enable the performance of the core functions of the organisation. They do not pay adequate attention to documentation, reporting or providing extended information to the customer from the operational history for each facility in its portfolio. However, in the digital age, with adequate human capacity, the CMMS tools enable the maintenance unit to communicate easily with all relevant stakeholders in a user-friendly format and to include appropriate visual displays [11, 12]. Briefly, the CMMS documentation enables senior management to know the state of the facilities in the portfolio or production network. It helps to identify possible constraints to the effective performance of the core function of the organisation, resources and financial management. The details and structure of each report should reflect the hierarchy of the recipient. The executive summary of report is useful for leaders at the strategic level, but leaders at the tactical level require more details. The effective use of the CMMS tools facilitates the production and dissemination of periodic information to relevant stakeholders and the analysis of operational details, which guide senior management in taking objective decisions [9, 11, 13, 14].

2.2 Analysis of the content of a computerised maintenance management system (CMMS) database

The analysis of operational history is an extension of periodic reports over a long period with the objective of determining the functional state of the whole facility or its component parts. Unfortunately, the operational information about a facility, in many maintenance organisations, is stored in their computer or files for many years without objective analysis being done to determine the functional state of the facility or its components [8]. The periodic analysis of a facility's history enables maintenance units to effectively educate its stakeholders, especially senior management, on the state of the facilities or machines, in the case of production lines of manufacturing industries. The analysis provides the needed guidance for the effective maintenance management and the development of performance improvement strategies [15]. The progression in the analysis of a facility's history includes the identification of distress recorded against each facility; the classification of the distress recorded according to the constituent component sections; and determining the frequency of distress, the status of execution, outstanding requests not attended to and cost incurred [8, 16]. Each periodic report and the associated analysis should include explanatory notes to guide the customer and senior management in decision-making [11, 17]. Furthermore, the adequate archives of periodic reports, the analysis and accompanying notes form useful background information for data collection when developing long-term plans for maintenance, renovation, or rehabilitation exercises. Therefore, it enables senior management to decide whether to continue to maintain or to replace parts or the whole facility.

Detailed analysis of the CMMS database can save organisations from making costly mistakes when deciding on the change of use of a facility, upgrade, renovate or respond to legislative requirements. Research [15] cites the examples of two universities where detailed operational analysis and assessment guided the decision on change of use:

> *At a small urban university, officials wanted to add two stories to a historic building. An assessment determined that the existing structure could not support new floors; the work could be done, but it would require significant capital to do so. In another institution, officials needed to know if a 1960s science building could accommodate a program expansion. An assessment of the facility's operational history concluded that the best option was to build a new structure ([17], p. 311).*

The detailed analysis of a facility's history, which is disseminated to the relevant stakeholders, is a useful tool for effective communication, facilitates timely decision-making and enhances improved relationships between the customers and the maintenance unit. It also provides an objective assessment of the performance of a maintenance unit by their customers.

In a typical manufacturing industry, the analysis of the CMMS database enables the maintenance unit to know the frequency of breakdowns of a specific machine or machines in the production network and the delay before repairs are carried out and the duration of machine downtime in the production network of the industry and provides information for benchmarking [15]. The periodic analysis provides useful information on the productivity, the profitability of the industry and the development of performance improvement strategies.

2.3 Performance improvement

The continuous performance improvements in any endeavour, be it service or manufacturing industries, can be enhanced through the practice of the discipline of periodic analysis of operational records in the CMMS database. Such analysis helps to validate the performance measurement (PM) system in place, identify factors responsible for low performance and helps to develop performance improvement strategies. Performance assessment is the comparison of performance results (assessment) against the expectations of the measuring system in operation [18]. The assessments should be timely, accurate and relevant. The exercise should be undertaken in ways easily understood by the employees using the performance measuring system being evaluated [18]. PM or its tools are not an end in themselves but road maps for more effective management. It requires the effective analysis of results and honest attempts at improving performance [19]. The effective analysis of the content of the CMMS database and the coordinated feedback from stakeholders, facilitate the identification of the magnitude and source of variance, which require improvements. The differences in measurements are harnessed in coordinated feedback; this in turn is used to develop suitable strategies for improved performance. The indicators (in PM) are designed to achieve the goals of the organisation while the feedback from periodic observations (assessments) is used to improve the production or work process.

To achieve performance improvement, the outcome of the analysis of the CMMS database must be accompanied by action steps, according to reference [20]. These action steps are summarised as follows:

1. After analysis of PM, develop broad areas of performance targeted for improvement.

2. Continuously test the performance improvement strategies to confirm if they are working, and if not, why.

3. Establish the right structure which facilitates the effective use of PM results.

4. Use the PM results to bring about change in the organisation.

The developed performance improvement strategies challenge the relevant stakeholders to either confirm or change the current policy or ways of doing things to meet the goals of the organisation and to progressively refine and improve its operations [19].

The outcome of the analysis of operational history, which leads to the development of performance improvement strategies, provides intelligent information for decision-makers at all levels to assess the achievement of predetermined goals [19]. It facilitates the tracking of past progress, helps to learn about the future and challenges maintenance operatives to practise the art of continuous data collection, analysis and the interpretation of feedback information [21]. It enhances oversight and compliance activities, supports proposals for change and requests for additional resources [21, 22]. The practice of performance improvement is reinforced through contextual benchmarking.

2.4 Benchmarking and performance improvement

The general use of the word benchmark involves identifying a point of reference (a benchmark) that serves as a standard against which relative performance may be measured. The point of reference may be internal to an organisation or external in relation to competitors or 'best practice' [23]. Benchmarking has been referred to ([24], p. 42) as the 'continuous process of measuring one's products, services and business practices against the toughest competitors or those companies recognised as industry leaders'. Benchmarking promotes superior performance by providing an organised framework through which organisations learn how the 'best in class' do things. In essence, 'benchmarking is the process of borrowing ideas and adapting them to gain competitive advantage' ([24], p. 41). In a nutshell, benchmarking is identifying 'best buy' or 'best practice' and making deliberate efforts to emulate it, devoid of unhealthy practices [25]. The implications of benchmarking could be summarised as a process of constantly comparing own performance against superior performances within a peer group of best practice [26]. To achieve positive results from benchmarking requires commitment and investment from both senior management and operations personnel of the maintenance unit. The requirements of a successful benchmarking exercise include, but are not limited to the following ([26], p. 41):

- A clear understanding of organisational goals, knowing what needs improving and by how much.
- An authentic and dynamic database for computation, analysis and comparison with a peer group.
- A constant reminder that since 'the best does not stand still', improvement should be a continuous process.
- The selection of peer group members, which is critical to the success of the exercise. The peer group must have identical features and be the best in the chosen field from anywhere in the world.
- The selection of appropriate parameters for the benchmarking exercise.

It is worth noting that benchmarking is not a 'quick-fix' solution but an exercise that requires commitment to succeed [27]. The success is influenced by the level of competence, capacity and capabilities of the operating personnel, quality of the data and commitment to their analysis [26].

Specifically, in the manufacturing industry, the effective analysis of a CMMS database and benchmarking provide information for effective maintenance operatives. The information is used to monitor the impact of the frequency of machine breakdowns, the length of time between repairs and the duration of downtime on the availability and reliability of machines in the production network. This in turn enhances the productivity and profitability of the industry [28].

Literature is awash with the vast potential inherent in a typical CMMS tool. It can be used for asset management, work order management, preventive maintenance management, inventory control, report management, service management, contract management, materials management and procurement management. The benefits gained are influenced by the number of modules activated, the human capacity and training provided to the operators of the system.

3. The research method

The qualitative research method was adopted for the case studies discussed in this chapter. The case research strategy allows the detailed, in-depth and broad-based investigation of situations or phenomena in its context [29, 30]. The approach also enables the researcher to relate to the officials directly involved in the subject matter being investigated. The population and samples used for the research were 'purposively' selected [31] from the maintenance operatives and other relevant stakeholders associated with the operation of the maintenance units. The data were collected using a semi-structured questionnaire used as an interview guide and the detailed review (document analysis) of periodic reports emanating from the maintenance units of the institutions and manufacturing industry were used for the case study [30].

3.1 Interviews

In qualitative research, the interview (one-on-one or in groups as in the case of focus group sessions) is one of the methods of obtaining information from research respondents [30]. The one-on-one interview approach was adopted in this study, using a semi-structured (open-ended) questionnaire. A semi-structured questionnaire enables the researcher to ask follow-up questions, allowing respondents to provide additional information to emphasise or add to information provided to the lead questions. The transcribed information collected from each respondent was returned to them for confirmation of accuracy and interpretation [30]. The principle of content analysis was used for analysing the qualitative data, the synthesis of the ideas generated, as answers to the survey questions, lead to the development of suitable themes discussed in the section for the discussion of findings [32].

3.2 Document analysis

Document analysis allows researchers to examine operational records, reports, archival materials, or statutory information related to the subject of the research in hard or soft copies. These records provide authentic historical information about the research [33]. The documents analysed for this research were the periodic reports on maintenance operations of the academic institutions and the operational record in the CMMS database of the manufacturing company. The analysis of the periodic reports from the academic institutions shows that the reports contain generic information on maintenance operations, which do not serve as a tool of effective communication with their customers. However, the analysis of the operational history in the CMMS database of the manufacturing industry facilitated the identification of areas for improvement and the development of performance improvement strategies through benchmarking.

The findings revealed that, while the academic institutions limited their use of the CMMS to maintenance planning, operations and periodic reporting, the manufacturing industry went a step further. They included the detailed analysis of the operational history in the CMMS database. The analysis and benchmarking led to the improvements on the reliability and availability of the machines in its production network. The section on findings and discussion explains how the research strategy was executed and presents the resulting outcomes.

4. Findings, analysis and discussion

The three case studies used for the discussion on harnessing the potential of CMMSs in maintenance operations involve two academic institutions and a manufacturing industry. In the academic institutions, the CMMS is used for maintenance planning, operations and the development of periodic reports. The maintenance operations at Institution 1 are executed by service contractors, while Institution 2 adopts the combination of using in-house personnel and service contractors. Most of the maintenance operations in these institutions are executed through the breakdown maintenance approach. The customers register their maintenance requests through the call centre that assigns a unique code to the request according to the facility's fabric, component, or services. The maintenance request is sent to the trade supervisor, who raises a work order and assigns the request to the appropriate personnel or service contractor. When the request is addressed (or closed), the completed work order is signed off by the customer, returned to the supervisors and the call centre for record purposes. Similarly, the work requests that are not addressed (or open) are also documented. The maintenance units, from these institutions, produce their periodic reports from the information in the CMMS database and do nothing further.

In contrast, the maintenance unit in the manufacturing industry adopts the combined approach of a planned and breakdown maintenance system. In this regard, all machines in the production line are scheduled for maintenance at predetermined times. Any breakdown or other maintenance requests are sent to the maintenance unit for proper attention. Maintenance operations in this industry are executed through in-house personnel and in limited cases, through specialist service contractors. Many operational modules of the CMMS software are activated in this industry. These allow the maintenance unit to work in synergy with the stores department for inventory control of spare parts and the finance department for timely purchase of necessary materials and services. In addition to the periodic reports, the unit conducts detailed analyses of the information in the CMMS database and sets benchmarks for measuring performance. The evidence from the analyses brought to the fore the current performance, identified areas requiring improvement and developed suitable performance improvement strategies; thus, harnessing the vast potentials inherent in a CMMS, improving on the JIT principle and approaching the practice of smart maintenance.

In some maintenance organisations, the same personnel manage maintenance operations and the call centres, while they are separated in other organisations. The quality of the human capacity in both units influences how the potential of a typical CMMS can be harnessed.

Hereafter, this section presents, firstly, the use of the CMMS in the maintenance units of the academic institutions, and secondly, the use of the CMMS in the manufacturing industry followed by the discussion sub-section.

4.1 Operational report from institution 1

The development of periodic reports is the third component of the CMMS module activated by the operatives of the maintenance unit of this institution. The reports include the weekly report used for management meetings of the campus managers and a monthly report produced for the director. The typical weekly/monthly report contains the information about the work requests received in the period under review, the status of execution and the cost incurred. An excerpt of the format used for the development of these reports is shown in **Table 1**. The information provided includes the code for the request, reference number for the work order, description of the work request, date the customer made the request, the service contractor assigned to execute the request, date the work was completed and the cost incurred. The monthly reports are usually produced on the first Monday of the following month. The report of the work requests for March, examined for this research, was produced on 4 April 2010, and was made available in a 13-page document [34].

In **Table 2**, the analysis of the report shows that a total of 2995 requests were lodged with the maintenance unit during March 2010, and 813 or 27.20% were addressed by 4 April 2010. The report is silent about the over 70% of the work requests not yet addressed. The quality of this report can be improved by extrapolating the result of work done until 30 April. This shows that 2013 requests (67.21%) of the total work requests for March have been attended to, leaving an outstanding balance of 982 (32.79%). Furthermore, the analysis helps to present a fair representation of the performance of the maintenance unit.

Building code	Assigned work order	Work description	Date work requested	Service contractor's code	Date work completed	Total cost
127	70,792	Remove, investigate and quote on repair of leaking pump. Replace packing with mechanical seal	2010/03/01	PUMDATA	2010/05/10	R5462.88
127	70,794	Repair noisy pump motor fan	2010/03/01	MJL	2010/03/29	R53865
127	70,795	Professional service to HVAC. Supply and install 1 × 24,000 BTU York midwall unit in room GH525	2010/03/01	PERFECTAIR	2010/04/12	R10180.20
131	70,796	Supply and instal 1 × 18,000 BTU York midwall unit in room 236	2010/03/01	PERFECTAIR	2010/04/12	R9234.00
446	70,797	Repair/ replace broken toilet soap dispenser in room 2B34. Urgent	2010/03/01	SUPERCARE	2010/03/18	R0.00

Table 1.
Typical structure of monthly report.

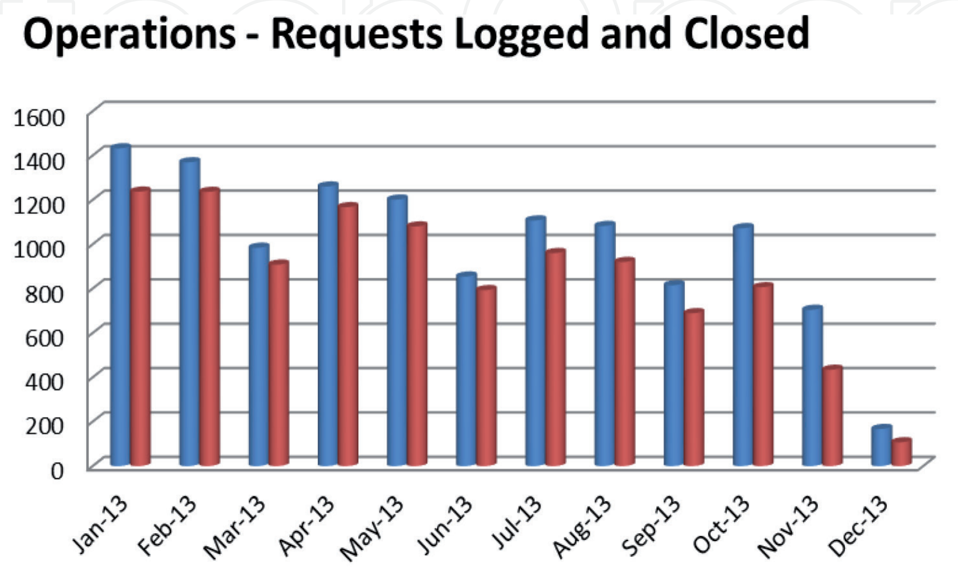
4.2 Periodic reports from institution 2

Like Institution 1, the periodic reports from this institution are in the form of monthly and annual reports on general maintenance operations. The reports are too technical, economical with details and are only understood by those who prepared them. The summary of the monthly report provides information on the quantity of requests lodged with the unit, the quantity resolved and the outstanding number. **Figure 1** presents the scorecard of the unit from all the campuses of the university for the year 2013, showing the number of requests received and the number addressed or closed.

Furthermore, the unit provides separate information on the number of unresolved requests; it is an indication that these outstanding issues are kept in perspective, as shown in **Figure 2**. However, this report is silent on what the unit is doing about these outstanding requests, the effect of deferred maintenance on the functional state of the facilities they represent and the financial implications of

2995	March				April				
Day ending	7	14	21	28	4	11	18	25	30
Quantity completed	9	85	286	463	813	1114	1621	1914	2013
% completed	0.30	2.84	9.55	15.46	27.15	37.20	54.12	63.91	67.21

Table 2.
Typical monthly report ([34], p. 117).



	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13
No of Requests	1432	1369	984	1260	1201	854	1107	1082	815	1072	704	167
Closed	1237	1236	908	1167	1080	793	960	920	689	806	434	107

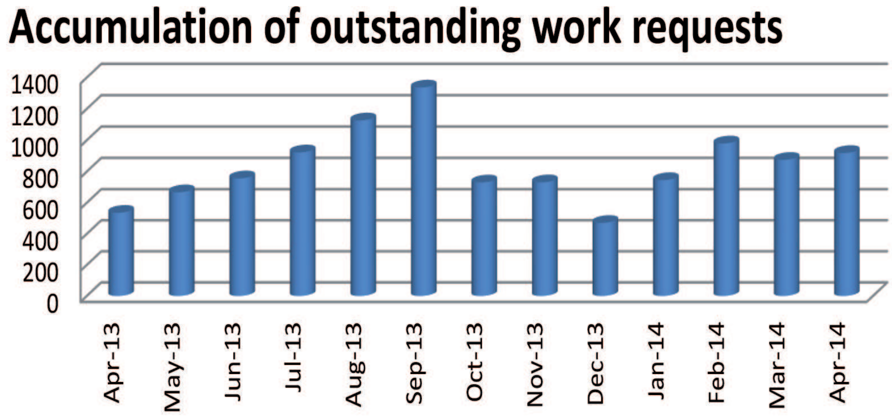
Figure 1.
Summary of performance on logged requests for the year 2013 ([35], p. 14).

addressing them. These reports provide generic information on maintenance operations without specifics or costs incurred.

The module of the CMMS tool activated by the maintenance units in these academic institutions is capable of managing maintenance planning (preventive, schedule and breakdown maintenance), work order, contract and procurement management, asset management, documentation of maintenance operations and analysis of historical records, report management and many more. However, **Table 3** provides a summary of the limited use and the latent potential of the CMMS tool, within the module being used by these institutions.

4.3 Discussion of findings

In a typical maintenance unit, there may be separate or integrated personnel for the call centre and maintenance operations. The quality and quantity of information developed from the CMMS database depends on the human capacity of the operatives in both units. This influences the ability to use the CMMS tool effectively [10]. Although maintenance operations have progressed from manual to digital systems, many maintenance units are underutilising the potentials available in a typical CMMS. The maintenance units in these academic institutions used the CMMS for work request management, maintenance operations and periodic reporting. **Table 3** provides the limited use of the CMMS tool. These components, currently being



	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13	Jan-14	Feb-14	Mar-14	Apr-14
Accumulative	535	667	756	922	1126	1336	730	731	470	745	979	874	918

Figure 2.
Summary of outstanding work requests.

Institution	Limited use of the CMMS tool	Remark: Latent potential not harnessed
Institution 1	*Recording of maintenance requests	*Developing planned maintenance *Effective maintenance budget and management of deferred or backlog maintenance *Producing customer friendly periodic report, accompanied by appropriate visuals *Detailed analysis of operational history, identifying the functional state of facilities, planning rehabilitation or disposal; educating customers on requests for change of use
	*Management of work requests	
	*Periodic reports on status of execution and cost incurred	
Institution 2	*Same as above, except that there are no records of cost incurred	
	*Record of work requests not attended to	

Table 3.
Summary of findings.

activated and used by these maintenance units, are insignificant fraction of the content of the maintenance management module and the inherent potentials of a typical CMMS software. The CMMS software has elastic capacity in different modules, which includes, but is not limited to asset management, work order management, preventive maintenance management, inventory control and report management [1]. Others include service management, contract management, materials management and procurement management [2]. Two major challenges were observed in the structure of the current periodic report. They are, firstly that the reports are not helpful in educating or communicating with the relevant stakeholders, because the customers cannot identify the component of the report that reflects the situation of the facilities in their portfolio or the status of execution of the work request emanating from their units. The second challenge is that the report is silent on the status of the work not completed at the time of reporting. Therefore, the units are not able to develop and monitor the forward planning, deferred maintenance, effective renovation, or rehabilitation scheme, provide suitable information for decisions on change of use or disposal of facilities. Consequently, they are not able to effectively communicate the performance of the maintenance units to their customers.

It is important to note that the maintenance and call centre operatives of these institutions should improve the quality of their periodic reports. Generally, a periodic report is the first step. Subjecting the set of reports to further analysis will enable maintenance operatives to manage the effectiveness of the loss of time before they respond to the work request of customers, the time taken to address the work request and to determine if they approximate the requirements of JIT [3]. Furthermore, detailed analysis of the CMMS database enables the maintenance unit to produce reports suitable for effective communication with their customers on the status of execution on their work requests and the functional state of the facilities in the customers' portfolio. To demonstrate this, the manager of the call centre of Institution 1, was requested to provide the comprehensive information on the requests lodged with the call centre from the School of Civil and Environmental Engineering for the period January to March 2010; arranging them in table format and providing a visual representation of the status of work and financial expenditure [34]. The eight-page report was reduced to a table as shown in **Table 4**. In a nutshell, **Table 4** provides the essential information contained in the eight-page report in a user-friendly format. **Figure 3** presents the status of the work requests for each month.

The visual presentation of the financial commitment, presented in **Figure 4**, shows that plumbing cost the most, while items under quotation cost the least.

The additional information, which is necessary, but was not available during the time of this research, includes explanatory notes on outstanding work requests, alternative suggestions on how to execute the outstanding work, the cost implications and the effect of the deferred maintenance on the functional state of the facilities of the customer. Despite these shortcomings, the Head, School of Civil and Environmental Engineering commented as follows: 'The layout is easy to determine the state of maintenance and it is easy to read. It also indicates that the maintenance unit is concerned about maintenance of the facilities in our School'. Furthermore, the Dean of the Faculty added: 'It is a good start. I would also like to see an age analyses (10 days, 30 days, 60 days, etc.) of addressing complaints or requests'.

Consequently, the vast potential inherent in a typical CMMS tool can be harnessed if the maintenance operatives could ask the right questions and the operatives in the call centre had the capacity, patience and commitment to answer the questions. This underlines the fact that the quality of the human capacity influences how much of the latent potential of a typical CMMS tool can be harnessed.

4.4 Analysis of maintenance database of a manufacturing company

The manufacturing industry used for this research is Adcock Ingrams Critical Care (AICC), a pharmaceutical manufacturing industry in South Africa. Maintenance requests are communicated directly to the unit as it doubles as call centre. In this industry, the maintenance unit uses the CMMS tool for scheduled and breakdown maintenance management. Furthermore, the unit conducts periodic detailed analyses

Problem type	Jan	Feb	Mar	Total issued	Total completed	Cost
Electrical	9	5	5	19	18	10,837.80
Plumbing	6	3	3	12	11	15,763.90
Quotation	1	1	2	4	1	136.80
Building		1	1	2	1	695.14
HVAC		1	3	4	3	2547.90

Table 4.
Summary of periodic report on work requests.

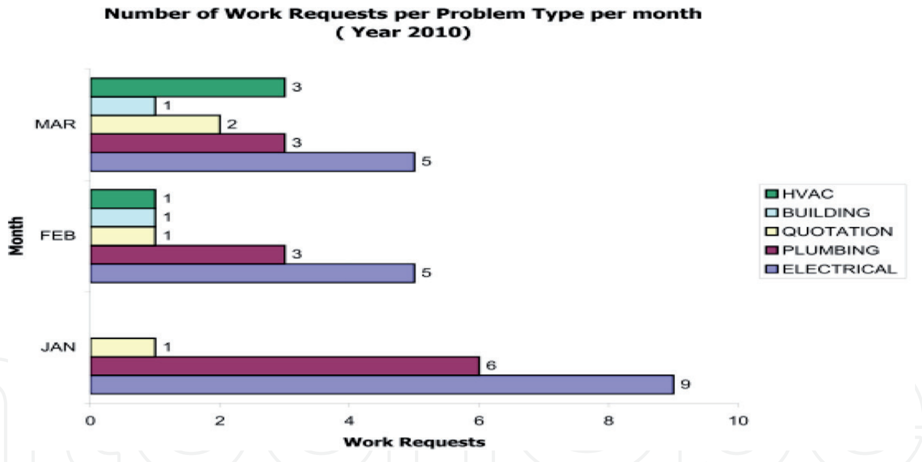


Figure 3.
Graphic presentation of the status of work requests.

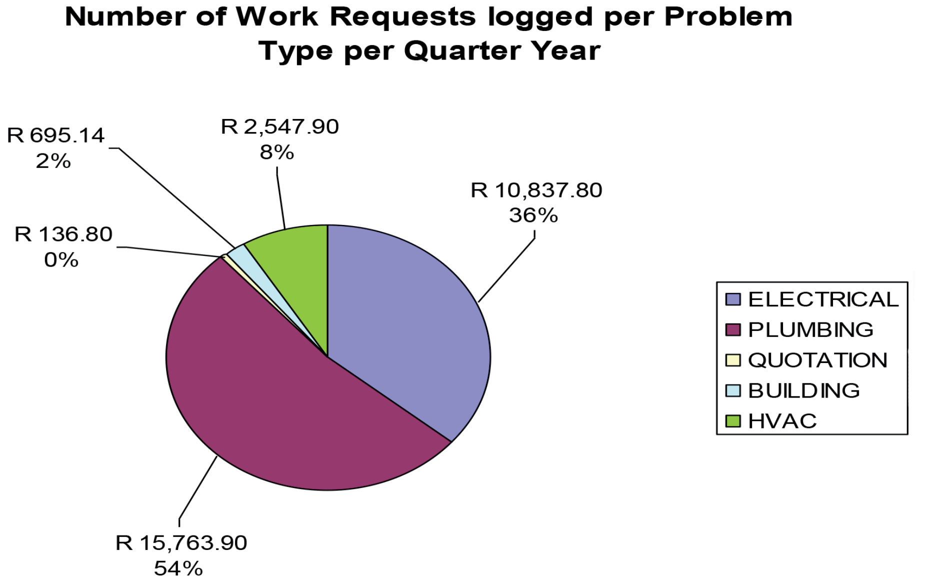


Figure 4.
Financial involvement of the work requests.

of the information in the operational database of the CMMS. The information in **Figures 5–8** present the findings of the analysis of the information in the CMMS database for all the machines in the production line of the company, for a period of 21 months between January 2017 and September 2018. The analysis identified the number of total breakdowns, mean time to repair (MTTR), total downtime and plant reliability. The reliability of the machines in the production line of the AICC was benchmarked with those in the operation of a sister company, Adcock Ingram Health Care (AIHC), to identify the level of performance improvements required.

4.4.1 Total breakdowns

The number of breakdowns per month in all the machines in the production line over the 21-month period is presented in **Figure 5**. The target number of 130 breakdowns, per month, was adopted as baseline for 2017 and 120 was set as target for 2018. The results from the analysis show that the average number of breakdowns in 2017 was 145, an increase of 15 breakdowns per month. Similarly, in September 2018, the average number of breakdowns was 128, showing an increase of 8 breakdowns above the benchmark of 120. However, in March, April, June and September 2018, the number of breakdowns was lower than the benchmark of 120, and in August, the number

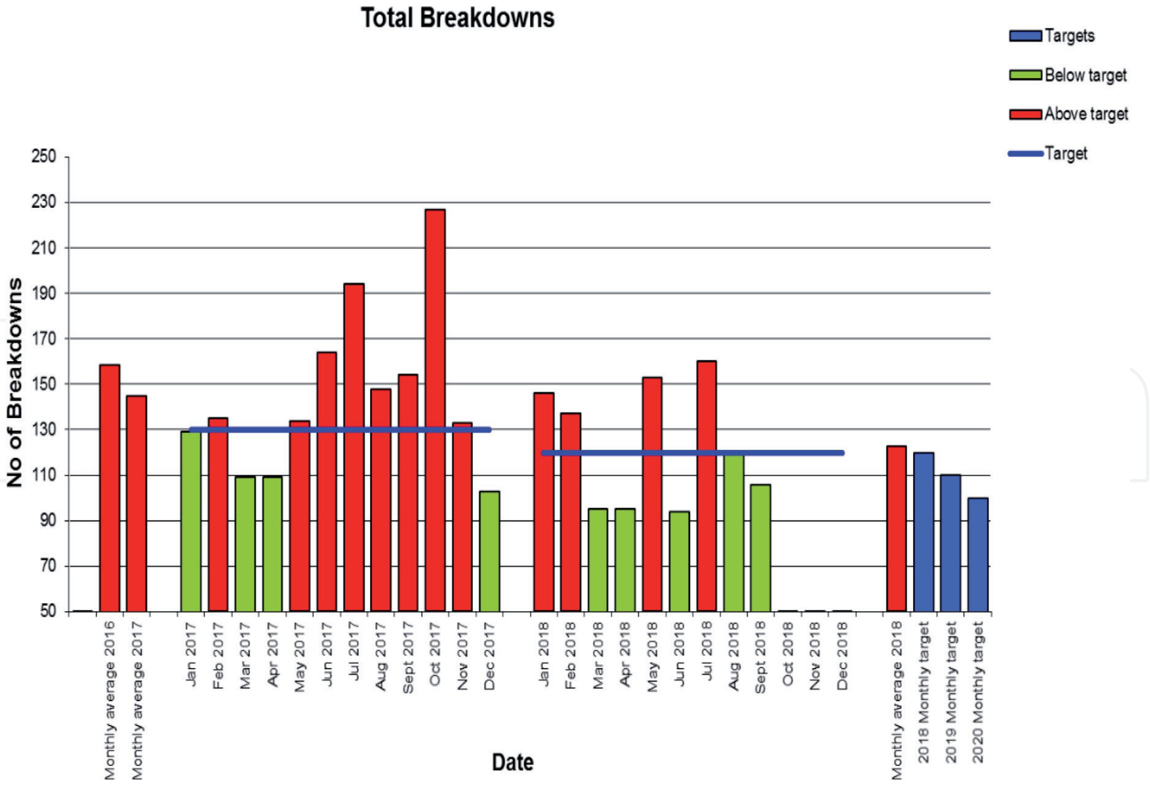


Figure 5.
Total number of breakdowns.

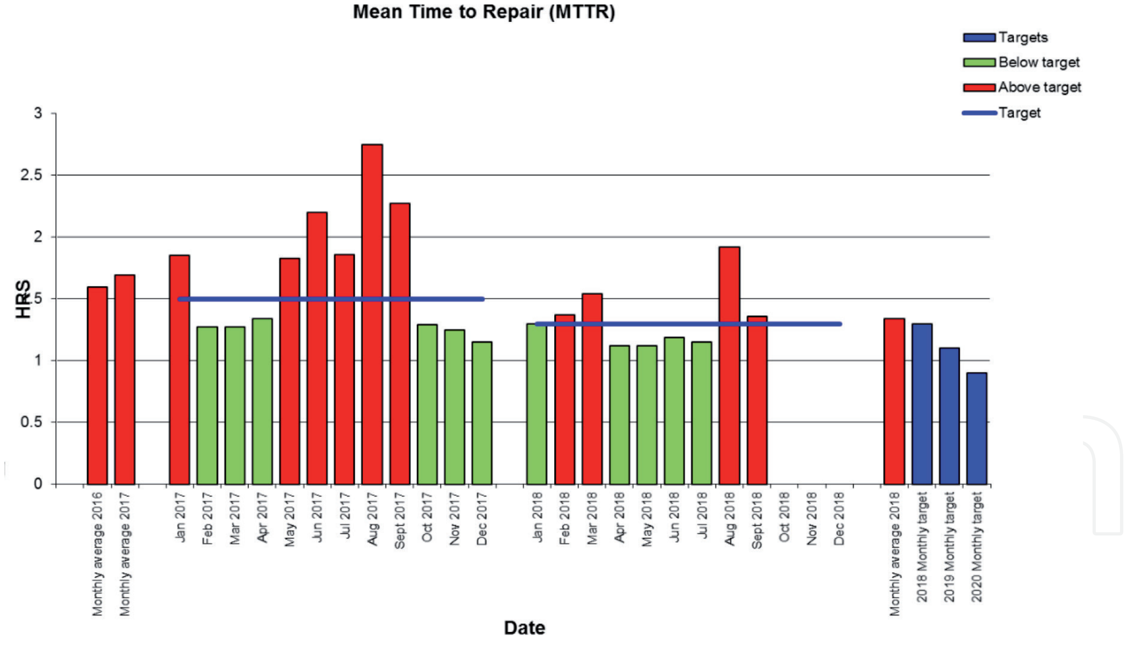


Figure 6.
Mean time to repair (MTTR).

of breakdowns was the same as the benchmark set for 2018. It was hoped that in the remaining months of 2018, the plants would record a lower number of breakdowns. Another concern was the length of time it takes to conclude repairs or known as MTTR.

4.4.2 Mean time to repair (MTTR)

The MTTR is the average time taken to complete the repair of each breakdown, restore the plant(s) to functional use and resume production. The shoter

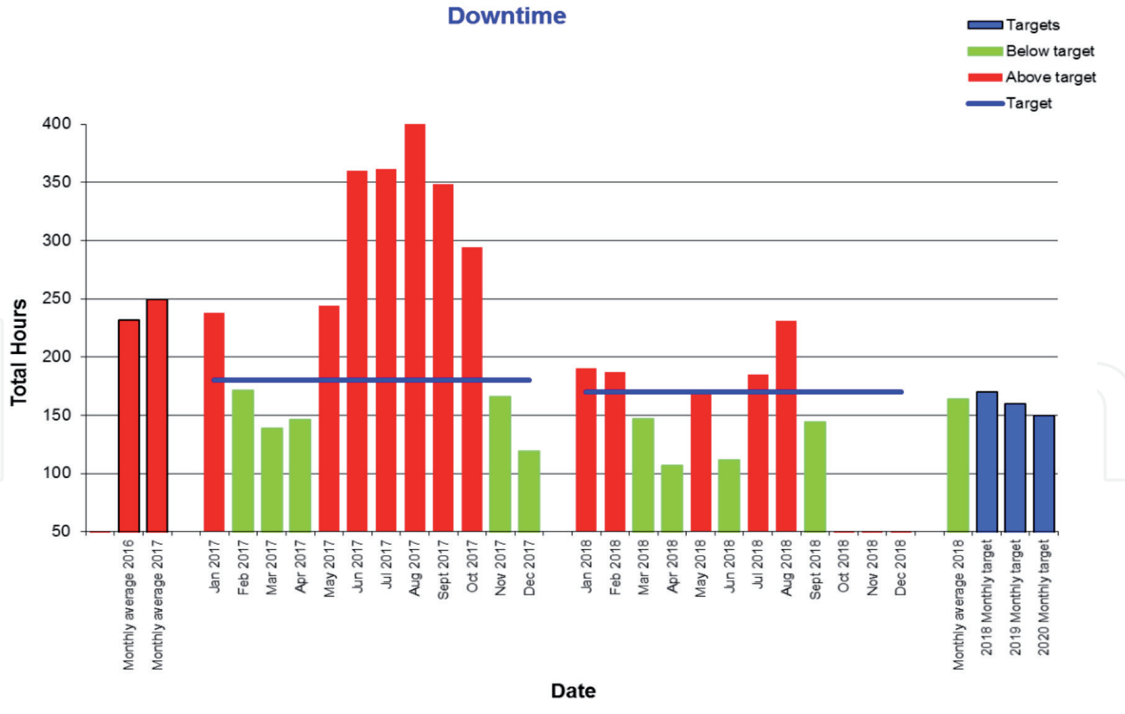


Figure 7.
Total duration of downtime of plant equipment.

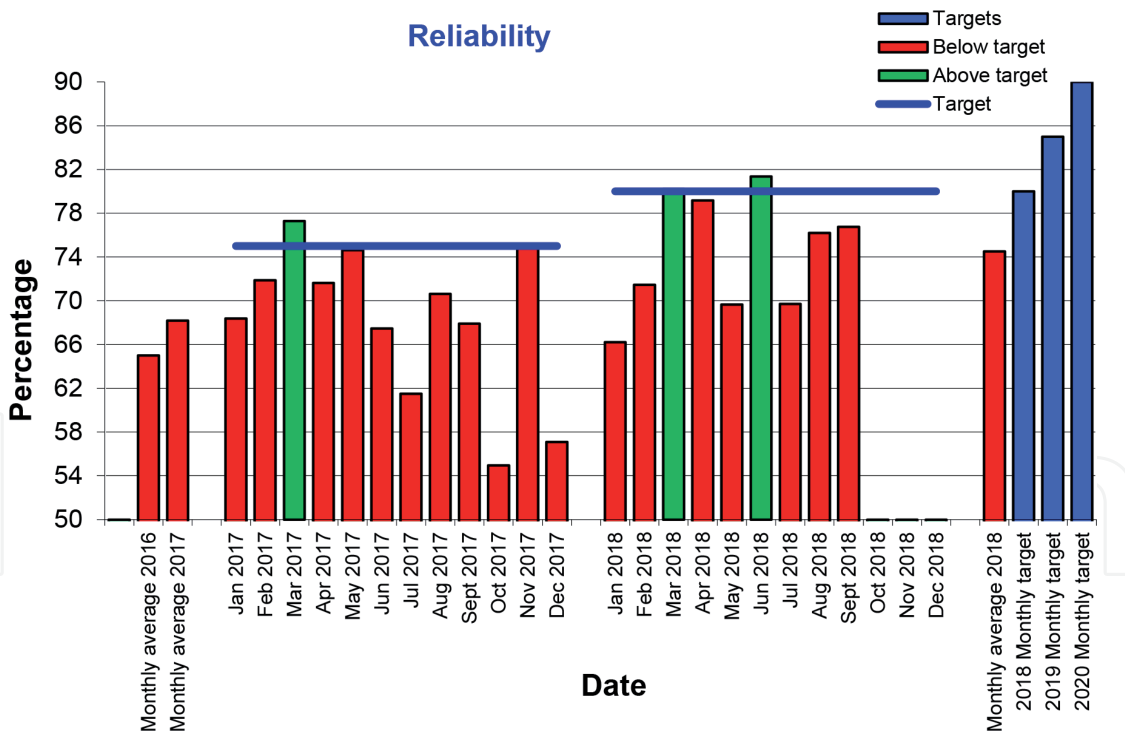


Figure 8.
Plant reliability.

the MTTR, the better. This is because the MTTR influences the duration of the downtime of machines in the production line. Similar to other factors, the monthly and annual averages for 2017 exceeded the benchmark of 1.5 hours, as is evident from **Figure 6**. Similarly, in 2018 the average in September is marginally above the benchmark of 1.35 hours. However, the monthly performance in January, April, May, June and July was impressive. It was hoped that, in the last quarter of the year, the performance would improve.

4.4.3 Total downtime

The graph in **Figure 7** summarises the duration of downtime when any or a combination of the plant or equipment in the production network breaks down. The target of 180 and 170 hours per month was adopted for 2017 and 2018, respectively. The analysis of the information in the operational database showed that the monthly average duration of downtime for 2017 was 250 hours per month, which represents 38.8% above target. This translates into 2.9 days' production lost per month and an average of 34.8 days per year, resulting in a revenue loss equivalent to 1 month per year. However, in September 2018, the monthly average was about 170 hours, which is the benchmark set for the year. If this trend continued, there would be marked improvements in the duration of downtime in the plants on the company's production network, ensuring increased machine reliability and improvements in production output.

4.4.4 Plant reliability

Plant reliability can be described as the probability that the plant(s) in the production network will be available for effective production in a manufacturing industry. Plant reliability is influenced by the number of breakdowns, the length of time before repairs are concluded and the duration of downtime. Machine reliability is usually expressed in percentages. Positive improvements in the MTTR (like JIT) translate in the reduced duration of downtime as well as a reduction in the number of breakdowns. The plant reliability performance of the AICC was benchmarked against the performance of a sister industry, the AIHC.

As shown in **Figure 8**, the plant reliability benchmark of the AIHC (the blue horizontal line) for 2017 was 75%. In comparison, the AICC achieved a monthly average of 68% (second red vertical bar from origin of the graph in **Figure 8**) for the same period. This is an indication that the plants of the AICC performed below that of the sister company, the AIHC. Although, the AICC, in September 2018, attained a reliability of 75%, (the red vertical bar, to the right, next to 2018 yearly average), this is still below the new benchmark of 80% set by the AIHC for 2018. However, if there were consistent improvements in the MTTR in the last quarter of the year, it may be possible to meet the benchmark set by the AIHC.

Industry	Current use of CMMS tool	Potential harnessed
Adcock Ingrams Critical Care (AICC)	*Development of maintenance management, preventive and breakdown maintenance	*Making maximum use of the maintenance management module *The synergy being created can facilitate the activation of the automation module *Progressing towards the practice of smart maintenance
	*Periodic analysis of operational details in CMMS database	
	*Benchmarking and identification of areas requiring performance improvements	
	*Improvements on MTTR (or JIT) and effects on machine reliability	
	*Develop synergy with finance, purchasing and store departments to ensure timely resourcing of spare parts for maintenance operations	

Table 5.
Summary of findings.

4.4.5 Summary of findings

Table 5 provides a summary of the functional use of the CMMS tool by AICC industry. Currently, the maintenance unit have activated and effectively using the different components of the maintenance management modules, as well as create synergy with other divisions of the industry. This will facilitate automation of operation and help in achieving the objectives of smart maintenance.

4.5 Discussion

The manufacturing company demonstrated a higher level of harnessing the potential inherent in a typical CMMS through the practice of comprehensive maintenance management, which includes planned, preventive, proactive and breakdown maintenance. The practice includes the analysis of the information in the operational database of the CMMS. These analyses enabled the maintenance unit to know the impact of the frequency of breakdowns, the length of time before repairs are completed and the effect of the duration of downtime of machines on the reliability and availability of machines in the production line. The analysis exposed the impact of the length of downtime on the productivity of the company. This could be described in the following understandable terms.

> *The average duration of downtime for 2017 was 250 hours per month, which is considerably higher than the benchmark, representing a level of 38.8% above target. This translates into 2.9 days' production lost per month and an average of 34.8 days per year, resulting in a revenue loss equivalent to 1 month per year.*

This realisation challenged the maintenance unit to improve on the MTTR. Success in the MTTR or JIT [3] is the product of appropriate maintenance planning, positive work ethics and the professional attitude of the workforce. This includes effective coordination between the maintenance unit, purchasing department, finance department and stores, the inventory control of stock and the timely availability of spare parts. It is important to note that the industry will have value for money through the effective management of an adequate stock of spare parts rather than purchasing on demand, which is more expensive [36]. Spares that are available reduce repair time and reduce the incidence of the 'fire-fighting approach' when sourcing spare parts. This enables the maintenance unit to strive towards achieving best practice, which suggests that 85% of repairs should be executed through planned maintenance and 15% through breakdown repairs [37]. These efforts culminate in the benchmarking of plant reliability with their sister industry. It is worth noting that plant reliability facilitates production planning, sales and marketing projection, achieving customers' satisfaction and profitability [37, 38].

The detailed analysis of the information in the operational database of plants in the production network enables maintenance units to identify area(s) requiring critical attention around which performance improvement strategies should be developed [39]. It provides intelligent information relating current performance against predetermined goals to decision-makers at all levels [19, 21]. This exercise challenges maintenance units to practise the art of continuous data collection, analysis and the interpretation of information to facilitate the development of appropriate improvement strategies [15]. Furthermore, it supports compliance activities, proposals for changes or requests for additional resources as it illuminates the link between strategies, performance and expected outcomes. It also achieves the objectives of smart maintenance [4, 19, 20].

5. Conclusions and recommendations

Although maintenance management and operations have significantly evolved from the use of manual to digital facilities, many of the operations of the maintenance units using CMMS tools are still operating at rudimentary levels. Generally, a typical CMMS tool has the capacity for planning and managing maintenance activities, resource management, analysis and interpretation, the contextual use of information in operational databases, the development of periodic reports, effective communication with stakeholders, performance and production improvements. However, the quality and quantity of the human capacity of the users of the system influences the potential of the CMMS tool that can be harnessed and put to productive use. Three case studies were used in this chapter to illustrate the potential capacity of a CMMS tool accessed by the maintenance units. Two of them refer to maintenance units in academic institutions and the third to a manufacturing company. In the academic institutions, the CMMS module activated was underutilised, as is evident from the poorly structured periodic reports. The reports were too technical, economical in details, best understood by those who prepared the reports and not suitable for effective communication with customers. The reports were silent about what the units were doing with work requests not completed at the time of reporting or the plans for addressing backlogs or deferred maintenance. The CMMS tool was being used for reactive maintenance instead of harnessing the vast potential of the CMMS tool for proactive maintenance, which is the backbone of smart maintenance.

In contrast, the manufacturing company uses the CMMS tool for planned and breakdown maintenance operations. It included the analysis of the information in the operational database, which enabled the unit to know the impact of the MTTR on the length of downtime, machine reliability and availability in the production network. This has challenged the maintenance unit to create synergy with the finance, purchasing and store departments, to facilitate the availability of spare parts and motivate the maintenance crew to timely identify and execute repairs. The activation and contextual use of the inter-related modules of the CMMS has enabled the maintenance unit to continuously improve on the MTTR, aiming at executing maintenance activities through planned maintenance rather than through a breakdown approach. It therefore improves on the practice of JIT, which is necessary for smart maintenance.

Although considerable effort is put in and investments are made to provide modern technology to aid maintenance operations, the potential uses of this tool are not adequately harnessed by many of the maintenance operatives. The maintenance units in the manufacturing company, in contrast to those in the academic institutions, through the analysis of the operational information in the CMMS database, have taken up some of the latent and rich potential inherent in a typical CMMS tool. Furthermore, they demonstrated the relationship of the 'work order management' tool with the 'assets management, preventive maintenance management, inventory control, report management and procurement management' tools. By doing so, they highlighted the collaborative relationships between the maintenance unit and other stakeholders, such as the finance, purchasing and store departments, in inventory control of stock and the timely availability of spare parts. Consequently, improvements in the MTTR translate into improved machine reliability, which facilitates production planning, sales and market projection, achieving customer satisfaction and profitability.

It is safe to conclude that the quality of the human capacity available to operate a typical CMMS tool influences the ability to harness the inherent potential of a CMMS. Therefore, this research recommends adequate resourcing and continuous development of the human capacity for the effective operation of the CMMS.

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