Improving on Machine Reliability and Productivity Through Data Analysis

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Abstract

The objective of the manufacturing industry is to produce quality and quantity of goods to satisfy existing customer base, expand market sphare, remain competitive and profitable. However, achieving these ideals depend largely on the reliability of the machines in the production line. Therefore, it is necessary to explore the impact of machine reliability on production and profiability in a manufacturing industry by analysing and interpreting the operational information in the computerised maintenance management system (CMMS) database.This research adopted the principle of action research, involving a two-year longitudinal analysis of the operational information in the database of the machines in the production line of Adcock Ingram Critical Care (AICC) and benchmarking the same with that of Adcock Ingram Health Care (AIHC), a similar pharmaceutical industry. It focused on how AIHC used the factors of total breakdowns, total down time, mean time between failure (MTBF) and the mean time to repair (MTTR) to improve on the reliability of machines in their production network. The analysis was complemented with interviews of participants from inter-related units of the same industry. The findings revealed that in all the areas of measurement in 2017, the machines in the production line of AICC performed below the benchmark of AIHC. However, in 2018, there were appreciable improvements, due to the practice of preventive maintenance. Therefore, the introduction of appropriate CMMS in maintenance operations, including the detailed analysis of operational information and benchmarking, provides a useful learning curve to improve on the reliability of machines in the production line of manufacturing industries.

Keywords
Action research, Benchmark, Computerised maintenance management system, Machine reliability, Manufacturing industry, Production line.

1. Introduction

Machine reliability is a critical concept in the management of machines in the production network of any manufacturing industry. This is because the reliability of machines influences the rate at which the machines break down, the duration of down time and challenges of the maintenance unit to manage the mean time between failure (MTBF) and the mean time to repair (MTTR) of each failure. However, achieving machine reliability requires the 'optimum mix' of reactive, time-based, condition-based and proactive maintenance and the continuous analysis of information in the operational database of each machine in the production network of the industry (Lavy 2008; Adoghe et al., 2012; Vishnu and Regikumar, 2016). The periodic analysis of the operational information of each machine enables the maintenance unit to identify the areas requiring attention and to develop the necessary performance improvement strategies (Melnyk *et al*., 2014). The desire to improve on current performance should be driven further by comparing own performance with peers of similar characteristics, but are achieving better results. This concept in known as 'benchmarking'. It is "a process of comparing a product, service process - indeed, any activity or object - with other samples of a peer group, with a view to identifying 'best buy' or 'best practice' and targeting oneself to emulate it" (Wauters, 2005). The effective practice of the concept of benchmarking allows both organisations to grow as cheer givers and not being unhealthy competitors seeking to deprive each other of their market share.

The manufacturing industry used for this research is Adcock Ingram Critical Care (AICC), one of the three Adcock Ingram manufacturing sites. The company manufactures medical-grade plastic sheeting, a wide range of sterile medical-grade bags for intravenous (IV) solutions and renal dialysis solutions. Other products include the intravenous (IV) fluid and blood bags, pour bottles (PB) and form-fill-seal technology, used to produce small-volume parenterals (SVPs). The plant has a production capacity of 33 million units of large-volume parenterals (LVPs), 25 million units of SVPs, over 4 million units of PBs and one million units of blood collection bags per annum. The above level of production supports about 80% of all the IV fluids provided to government hospitals and 20% of that of private hospitals in South Africa. In order to ensure that the company controls its market share in the South African pharmaceutical supply chain, it was necessary to determine the level of the reliability of the machines in the production line and benchmark it with what is achieved by a sister company, the Adcock Ingram Health Care (AIHC) facility. To achieve these objectives, deliberate efforts were made to analyse the information in the computerised maintenance management system (CMMS) database for all the machines in the production line of AICC and comparing results with what is obtainale in AIHC in the following factors: total breakdowns, total down time, MTBF and MTTR. The CMMS data collected and analysed were for 24 months, between January 2017 and December 2018. The information in the database assisted in the computation of total breakdowns, total down time, MTBF, MTTR and plant reliability.

This paper is an excerpt from a larger research effort aimed at exploring the benefits of introducing CMMS into the maintenance operation of AICC. The focus of this paper is on comparing the outcome of the analysis of the the chosen factors from the CMMS database of the machines in the production network of AICC with that of AIHC, to determine the level of machine reliability in AICC. After this introduction, the paper progresses to the literature review, which focuses on reliability maintenance, the importance of CMMS in both record keeping and providing information on areas requiring improvements. The review culminates in the practice of performance improvements and benchmarking as well as relating reliability to productivity and profitability. The next section focuses on the research method adopted, namely the action research strategy, which provides detailed analysis of the operation of AICC and a comparison with an identical industry, AIHC. The section on findings and discussion provides information on the results obtained and the discussion of best practices. The final section provides the conclusion drawn from the research and suitable recommendations.

2. Literature review

The literature review provides broad based but structured information in the form of models and methodologies to guide subsequent researchers and can be adapted for new endeavours. The literature reviewed here provides general information on reliability centred maintenance, the importance of the different breakdown-related factors and ultimately the reliability of machines and their impact on productivity and profitability in manufacturing industries.

2.1 Reliability centred maintenance

Reliability centred maintenance (RCM) is the 'optimum mix' of reactive, time-based, condition-based and proactive maintenance. It is a preventive maintenance (PM) structure put in place for the management of complex systems and determines what must be done to ensure that a physical asset continues to do whatever it was designed to do (Vishnu and Regikumar, 2016). According to Adoghe et al. (2012), RCM is a process, which helps to outline essential activities to be carried out to ensure that any physical asset continues to perform to its optimum level in meeting the objectives of the end users. A complementary term commonly used when discussing RCM of machines in manufacturing industries, is the word ‘maintainability’. Maintainability reflects the ease of carrying out maintenance activities on the machines in the production line effectively, efficiently and safely (Gulati and Smith 2009). RCM and maintainability are therefore strategic tasks that are important throughout the life cycle of machines in a production line.

An effective RCM process includes, but is not limited to the following (Eti et al. 2006):

- Identifying the reasons that led to the failure of a component.
- Dealing effectively with each type of failure process with appropriate maintenance tactics.
- Developing a maintenance-oriented framework to meet all the challenges that could arise.
- Having a more proactive, planned approach tends to improve the maintenance productivity.
- Enjoying cooperation and active support from all personnel and departments to promote higher production levels, e.g. between the maintenance, operations, materials and technical functions.

There are many tools which can be employed for effective RCM to ensure the reliability of machines in any manufacturing industry. The following three are relatively simple and handy: root-cause analysis (RCA), failure mode and effect analysis (FMEA), and the optimizing maintenance function (OMF) (Campbell, 1999). Information from RCM should be used to populate the history of each machine in the production line through the effective management of the information in the CMMS database.

2.2 Computerised maintenance management system (CMMS) database analysis

The CMMS allows for the effective documentation of maintenance operations, communication of scheduled activities, and enhances the ability to develop and monitor the forward planning and execution of maintenance operations. It facilitates the tracking of progress in the execution of requests, resource management, effective development and dissemination of periodic reports and the analysis of operational history in the database of each facility (Lavy, 2008). Furthermore, the CMMS enables the automation of procedures (Gabriel, 2003). Effective CMMS tools require suitable human capacity to operate the structure, provide information on maintenance operational procedure to all relevant sections connected to the production line, facilitate the production and disseminate periodic and other relevant reports to all stakeholders in a user-friendly format (Carder, 1995; Gabriel, 2003; Farazmand, 2004). In this regard, periodic analysis of the information in the CMMS database is essential for the effective management of the plants in a manufacturing production network.

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 as well as the 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 to determine the functional state of the facility or its components (Lavy, 2008). Periodic analysis of facilities history enables maintenance units to effectively educate its stakeholders, especially senior management, on the state of the machines in the production line of the industry. The analysis provides the needed guide for effective maintenance management and the development of performance improvement strategies (Melnyk *et al*., 2014). In a typical manufacturing industry, the analysis of the CMMS database enables the maintenance unit to know the frequency of breakdowns and the duration of down time before repairs are carried out for the production process to be restored. The periodic analysis provides useful information for performance improvements.

2.3 Performance improvement through benchmarking

A benchmarking exercise is an effective management tool that enables a maintenance unit to continuously measure the performance of its operation against best practices of a similar organisation in the industry (Varcoe, 1996; Ho et al. 2000). The general use of the word, benchmark: … involves identifying a point of reference (a benchmark) which serves as a standard against which relative performance may be judged. The point of reference may be internal to an organisation or external in relation to competitors or ‘best practice’ (Loosemore and Hsin, 2001). According to Attiany (2014), benchmarking is the “continuous process of measuring one's products, services, and business practices against the toughest competitors or those companies recognized as industry leaders.” This suggests that any organisation that wants to compete globally or remain relevant, should benchmark their performance against other industries in the same sector. 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” (Attiany, 2014). Ho et al. (2000) simply describe benchmarking as a tool that serves both the purpose of helping companies to have an external focus and find industry best practices by constantly comparing their own performance against that of others. In a nutshell, benchmarking is identifying ‘best buy’ or ‘best practice’ and making deliberate efforts to emulate it, devoid of unhealthy practices (Wauters, 2005). The implications of benchmarking could be summarized as a process of constantly comparing own performance against superior performances within a peer group of best practice. 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, according to Ogbeifun (2016), requires:

- 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 is critical to the success of the exercise. The peer group must have identical features and the be 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 in order to succeed (Varcoe 1996). The potential factors that would affect the results include the level of competence, capacity and capabilities of the operating personnel, quality of data and commitment to their analysis (Ogbeifun 2016).

2.4 Reliability, productivity and profitability

In the manufacturing industry, profitability is directly proportional to the productivity of the machines in the production network. The availability of the machines for production is a function of the machine reliability, a demonstration of the quality of the maintenance management system in place. Machine reliability influences both equipment efficiency and the length of time the machines are available for production. This in turn plays a great role in the profitability of a manufacturing company. It impacts the production output, cycle times, costs of production, and return on investment in manufacturing capacity (Romanenko and Baybus, 2017). Research has shown that reliance on a traditional maintenance approach is no longer sufficient to guarantee machine reliability. Therefore, it is imperative to combine traditional maintenance strategies with other modern maintenance strategies, such as total productive maintenance (TPM) (Hooi and Leong, 2017), and RCM (Vishnu and Regikumar, 2016). Effective integration of traditional maintenance and TPM implementation initiatives enable proper planning, the adoption of correct maintenance procedures, the timely execution of maintenance activities and continuous improvement. These activities ultimately improve the manufacturing performance and lead to significant improvements in the productivity of the machines (Hooi and Leong, 2017). Thus, improved productivity leads to better business performance (Prakash et al. 2017). Typical manufacturing industries generate enormous volumes of data, but many have failed to make use of this mountain of potential intelligence. However, taking advantage of available CMMS software can facilitate easy data retrieval, computation, analysis and timely interpretation. The adequately processed data enable the maintenance operatives to learn by comparing their own operations with the machine models, operational sequence and the visual presentations in other platforms. In this regard, the maintenance operatives can uncover new ways to optimize their processes from the sourcing of raw materials to the sale of their finished products (Dilda et al. 2017). The adoption of an appropriate CMMS tool enables the maintenance operatives to harness other relevant supportive organisational functions and functionaries, such as resource allocation, decision-making structure, senior management support, employees’ involvement and effective instruction to achieve the effectiveness of total productive maintenance (Jamkhaneh *et al*., 2018). Productive maintenance enhances the prospects of reliability of machines, which in turn facilitates improved production. Productive machines enable the industry to meet its production target, customer satisfaction, improved sales, return on investments and profitability (Hooi and Leong, 2017; Prakash et al. 2017).

3. Research methodology

3.1 Introduction

An action research strategy was adopted because of its potential to foster a collaborative relationship between the different departments in the manufacturing industry which have interdependent relationships with the maintenance department. Action research is a broad-based research strategy that adopts different methods united by value, intention, process and general participation during execution (Titchen, 2015). Participation is regarded as one of the core features of action research (Dick, 2015). Action research is value driven. These values are dictated by the values of those involved in the exercise (Snoeren and Frost, 2011). The focus on value challenges the participants to form collaborative synergy for the success of the process, results and its application for the improvement of their practices. There are several definitions for action research, depending on the perspective and application. The proposal of McCormack (2009), focusing on practitioners, as participants in the research exercise, is considered suitable for this research. It states: “Practitioner action research is a formal and systematic attempt made by practitioners, either alone or in collaboration with others, to understand their work, with the intended purpose of making public new knowledge about the transformation of self, colleagues and work contexts” (McCormack, 2009). The importance of this definition is that practitioner action research involves all participants in the systematic process of identifying the problem and offering solutions for the problem under reference within the work context. The approach provides a collaborative relationship, where each participating department of a manufacturing industry sees themselves as stakeholders and an integrated unit along with the maintenance department (Hayward et al. 2004). The participants for this research were the strategic and tactical leaders drawn from the maintenance department, finance, purchasing and stores, sales and marketing, and human resources.

3.2 Data collection and analysis

The data for the research were collected over a longitudinal period of 24 months (January 2017 to December 2018). This involved retrieving and analysing the operational information in the CMMS database of AICC with the aim of identifying the areas of operational deficiency in the production network. Qualitative data were collected from representatives of inter-related departments, as identified in papragraph 3.1. The analysis of information from the CMMS database led to the detailed computation of the rate of breakdown, duration of down time, MTBF and MTTR against the benchmark set for each year’s operation. The graph of the results of each analysis provides the visual information for easy comprehension and communication with the relevant stakeholders. The influence of each result on the determination of the plant reliability was discussed with the relevant inter-related departments to identify how the performance of their functions influenced the preformance of the maintenance department. The details of the analysis, the results and their implication to effective planning of production, sales and maintaining customers’ satisfaction, are provided in the section for findings and discussion.

4. Findings and discussion

This section provides information on the results from the analysis of the information in the CMMS database for each year for machines in the production network of the AICC and compares the outcome with what the AIHC obtained.

4.1 Total breakdowns

The number of breakdowns per month in all the machines in the production line over the 24-month period is represented in Figure 1. The target number of 130 breakdowns was adopted as baseline for measuring the performance of the plants for 2017 and 120 was set as target for 2018. The results show that the average number of breakdowns in 2017 was 145, an increase of 15 breakdowns per month, above target. However, in 2018, the average number of breakdowns in the months of January, February, May and July exceeded the benchmark and the breakdowns in the other months were below the benchmark. Resulting in an annual average of about 120 breakdowns and within the benchmark for the year. The improvements made so far is because of the implementation of the maintenance management system. This system requires that all the machines in the production lines are stopped in a coordinated manner once a month and handed over to the maintenance department to service. Before this intervention, the maintenance department mostly did breakdown or reactive repairs, which accounted for about 60% of the annual repairs. However, best practice suggests that 85% of repairs should be executed through planned maintenance and 15% through breakdown repairs (Gulati, 2013). Furthermore, the research reveales that the maintenance department has improved on the effectivness of their communication to educate and inform other stakeholders of the needs of maintenace, constraints and progress. This resulted in achieving synergy with stores, and facilitating the provision of adequate spare parts for timely repairs. Similarly, effective communication of constraints and progress enables the finance and human resources departments to identify and support the aspirations of the maintenance department.

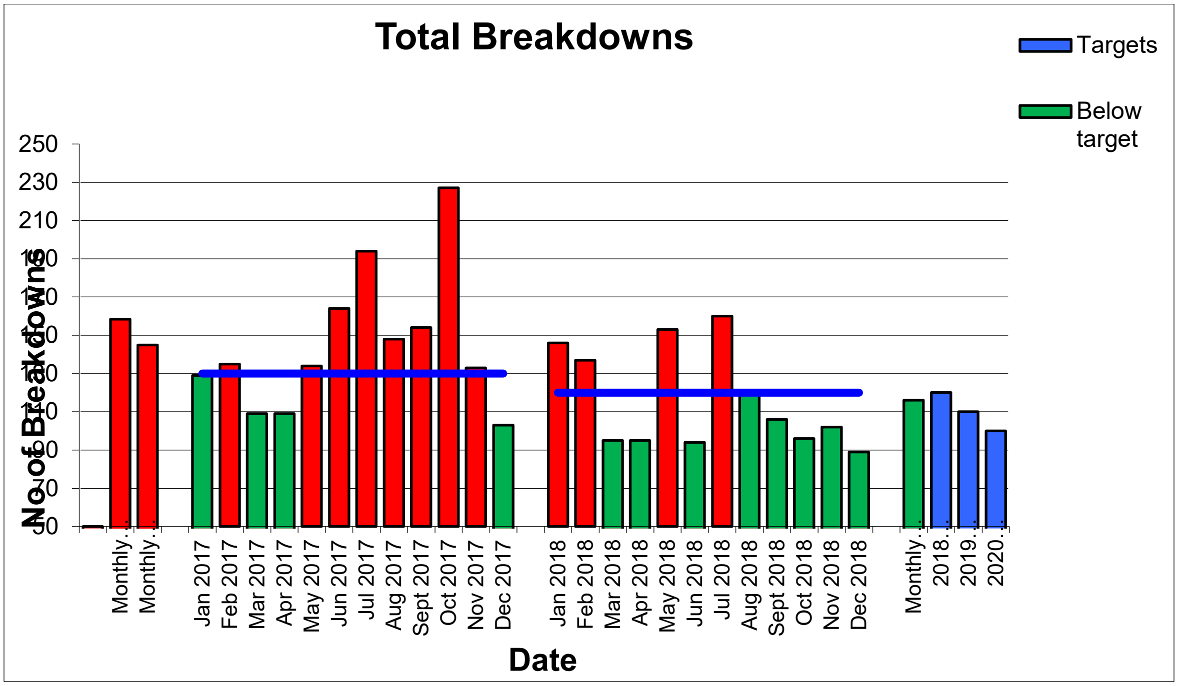

Figure 1. Total number of breakdowns

4.2 Total down time of the plant equipment

The graph in Figure 2 summarizes the duration of down time 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.

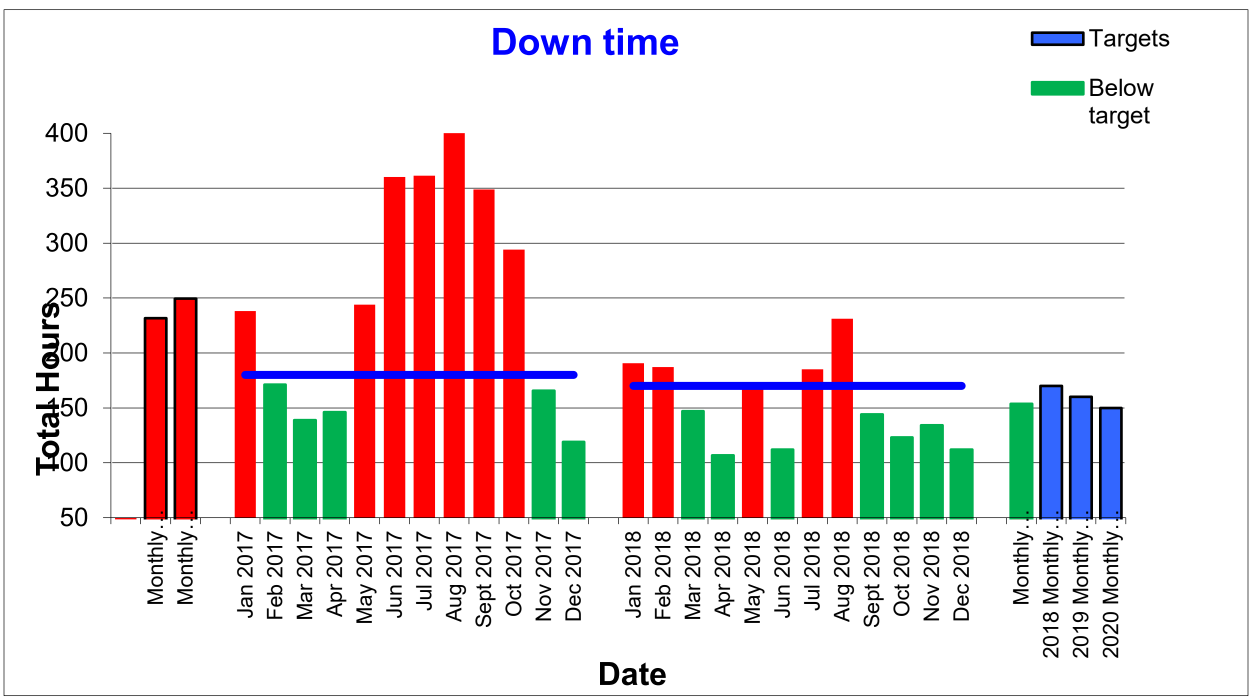

Figure 2. Total duration of down time of plant equipment

The analysis showed that the average duration of down time for 2017 was 250 hours per month which is considerably higher than the benchmark, representing 38.8% above target. This translates to 2.9 days production loss per month and an average of 34.8 days per year, resulting in revenue loss of the equivalent of one month per year. Interestingly, in 2018, the monthly average was about 170 hours, which is the benchmark set for the year. The improvements made in the year 2018 is as a result of the dynamic application of preventive maintenance (through forward planning), which involves periodic equipment lubrication, cleaning, parts replacement, tightening and adjustment (Hooi and Leong, 2017). This is the product of the collaborative relationship between the maintenance department and finance, purchasing, store and production departments.

During the interview, the representative of the finance department confirmed that "the timely receipt of the forward plan from maintenance department enables the department to make adequate funds available to the purchasing department for the purchase of relevant spare parts." In a similar sense, the production unit uses the forward plan from maintenace to manage their production activities to meet the requirements of the marketing department. Therefore, the reduction in the length of downtime has increased the machine reliability and improvements in production output, as corraborated in the research efforts of Prakash et al. (2017) and Romanenko and Baybus (2017).

4.3 Mean time between failure (MTBF)

The MTBF of a machine shows the average run time of equipment before the next failure. The longer the run time, the better the reliability of machines in the production network. It influences improvements in product output and reduces the duration between start-up and shutdown after each stoppage. The MTBF was calculated using equations 1 and 2.

λ = Number of failures/Total operating hours ……………………………………1

Therefore MTBF = 1/λ …………………………………………………………...2

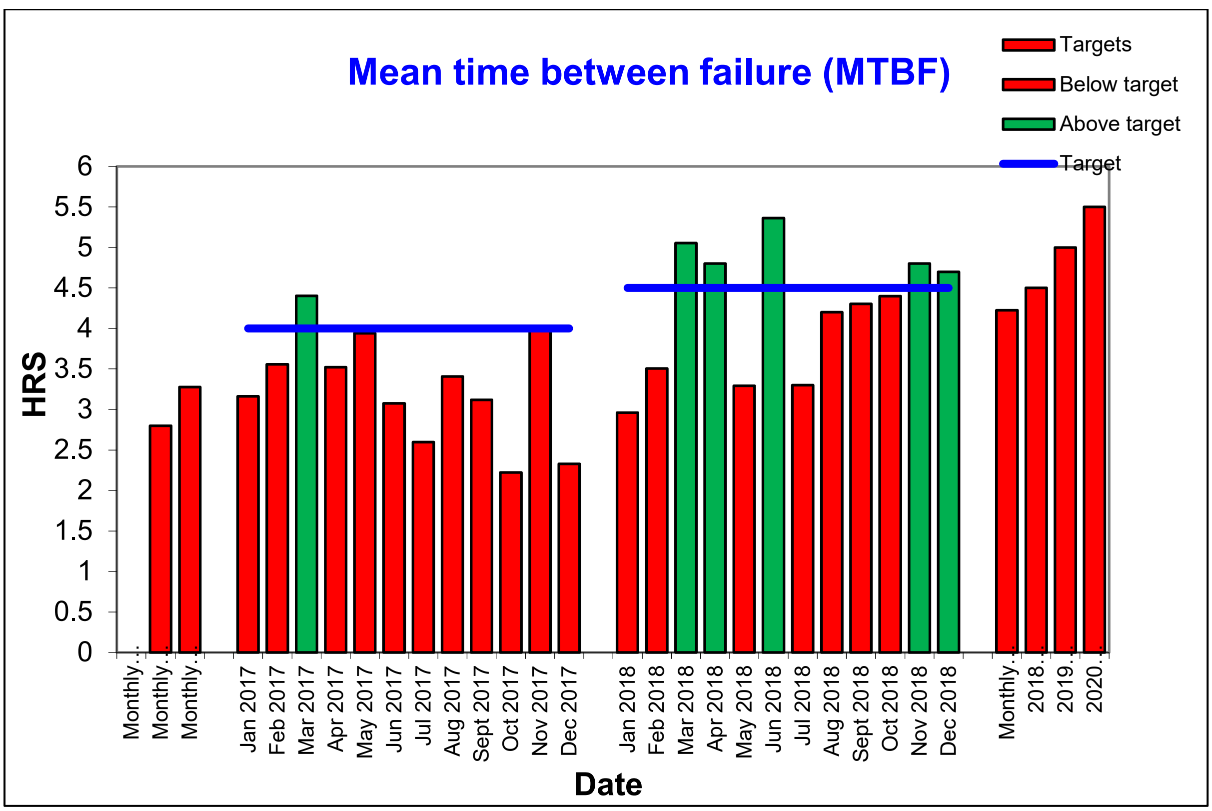

Figure 3. The mean time between failures (MTBF)

The MTBF benchmark set for 2017 was 4 hours operation time before failure, but achieved an annual average of 3.3 hours, which is below the benchmark, as shown in Figure 3. The benchmark for 2018 was 4.5 hours. There were remarkable performance improvements in March, April, June, November and December 2018 when the MTBF exceeded the benchmark. The performance of the machines, in the other seven months of the year was below the benchmark. Therefore, the monthly average is below the benchmark, but the annual average is approximately on par with the benchmark. This result was discussed with the human resources department, which confirmed the need for periodic and progressive training of the workforce in the maintenance crew of the maintenance department that will enable them to improve on their level of competency.

4.4 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 the MTTR, the better. This is because MTTR influences the duration of the down time of machines in the production line (Vishnu and Regikumar, 2016; Jamkhaneh *et al*., 2018). Similar to other factors, both the monthly and annual averages for the year 2017 exceeded the benchmark of 1.5 hours, Figure 4. Similarly, the 2018 annual average is marginally above the benchmark of 1.35 hours. However, the monthly performance in January and October are on par with the benchmark, the performance in the months of April, May, June, July and November were impressive and below the benchmark.

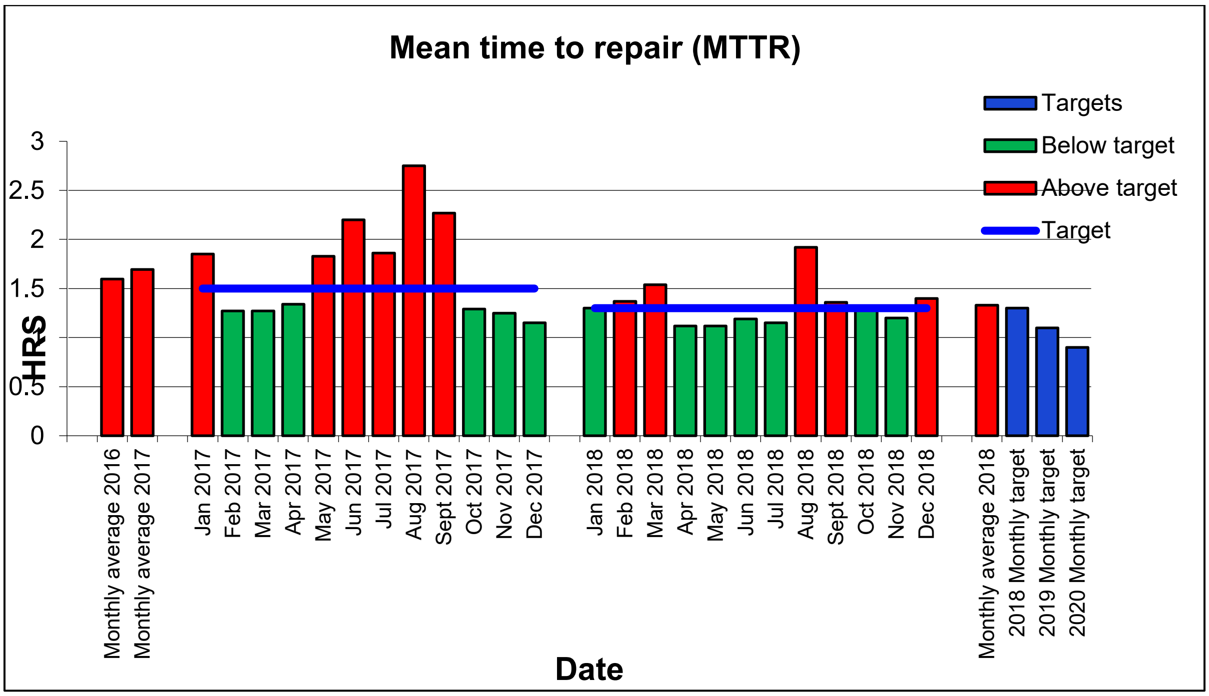

Figure 4. Mean time to repair (MTTR)

Success in MTTR is the product of appropriate maintenance planning, positive work ethics and a professional attitude of the workmen, coupled with effective coordination of all the team members required for the repairs (Dilda et al. 2017). Furthermore, success in MTTR requires the effective management of an adequate stock of spare parts. Inventory control of stock should not be limited to the purchasing department alone. It requires the active participation of the operatives responsible for maintenance planning, the purchasing department, store and finance departments. The research effort of Joachim (2013) shows that the manufacturing industry will receive value for money through the effective management of an adequate stock of spare parts, rather than purchasing on demand, which is more expensive. It was noted that the availability of spare parts reduces repair time and the incidence of the 'fire-fighting approach' when sourcing spare parts. Consequently, the maintenance department has delegated a tactical leader to extract the requirements in the forward plan, for every two weeks ahead, and liaise with all relevant stakeholders to ensure an adequate supply and execution of planned maintenance.

4.5 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. Improvements in the number of breakdowns and the duration of down time influences the reliability of the plants in the production line. Machine reliability is usually expressed in percentages. Positive improvements in MTTR translate into the reduced duration of down time and improvements in MTBF influence the number of breakdowns (Adoghe et al. 2012; Gulati 2013). Therefore, the practice of comprehensive maintenance management, which includes planned, preventive and proactive maintenance, will improve MTTR and MTBF. These in turn improve the duration of down time and the frequency of breakdowns, guaranteeing the reliability of machines in the production network of a manufacturing industry (Vishnu and Regikumar 2016).

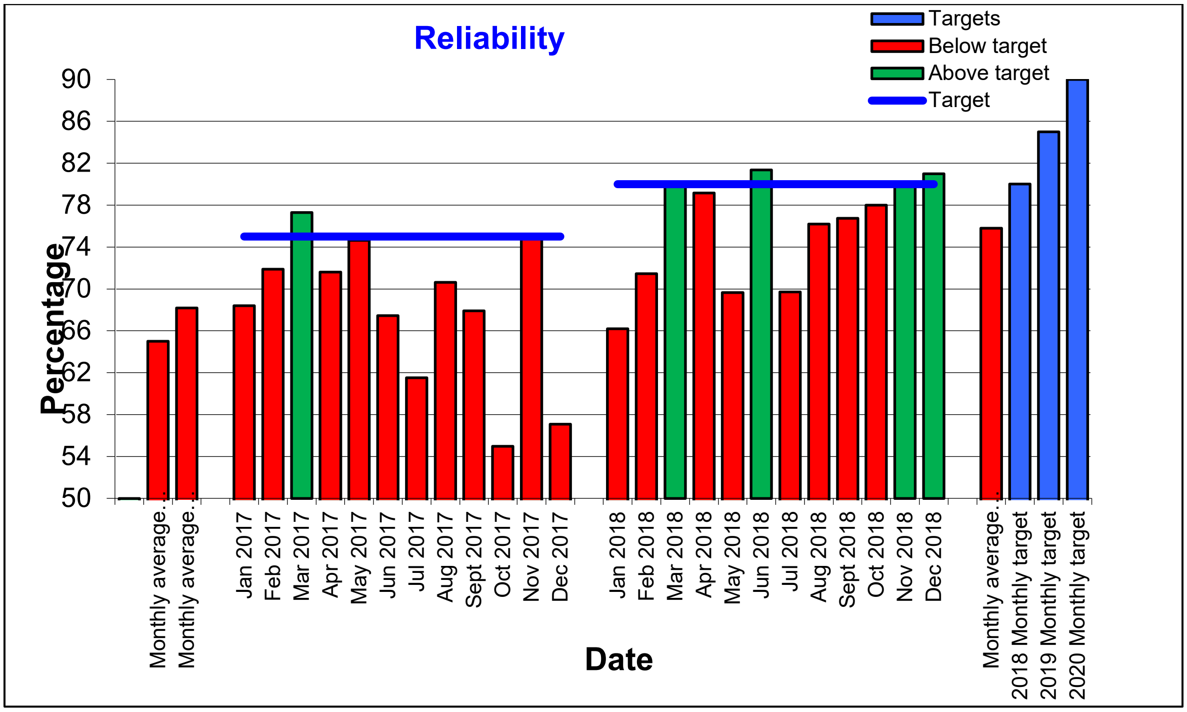

Figure 5. Plant reliability

In Figure 5, the plant reliability performance benchmark of 2017 for AIHC was 75% and AICC achieved an average of 68% for the same period. This is an indication that the plants of AICC performed below that of the sister industry, AIHC. Furthermore, in 2018, AIHC increased their machine reliability level to 80%. As shown in Figure 5, AICC achieved the 80% benchmark in March and November, and exceeded the benchmark (81%) in June and December 2018, respectively. In the remaining eight months of the year the plants in the production line of AICC performed below the benchmark, resulting in an annual average that is slightly below the benchmark. Although the immediate causes of this decline was not identified during this research, participants observed that there is a need for continuous improvements on MTBF and MTTR. The synthesis of information gathered from the participants and best practice from literature suggests that:

a. Improvements in MTBF require the sourcing of quality materials and improvements in the proficiency of maintenance operations (Prakash *et al*., 2017).
b. Improvements in MTTR requires the cultivation of the habit of 'just in time' (JIT) in responding to maintenance requests (Dilda *et al*., 2017).

Consequently, continuous improvements in MTBF and MTTR will have significant impacts on machine reliability and enable AICC to achieve and possibly exceed its periodic benchmarks. It is worth noting that plant reliability enhances production planning, sales and marketing projection, achieving customers' satisfaction and profitability.

4.6 Reliability, productivity and profitability

The production performance for the years 2017 and 2018 presented in Table 1 shows production improvement (more than projected production capacity) in item 1 (104.84% and 108.84%), for both 2017 and 2018. The production in item 3, was below (80.71%) projected production capacity in 2017, while the production output in 2018 exceeded (100.10%) the production capacity. Similarly, the production output in items 2 and 4 were significantly below their projected production capacities, in both years (67.08% and 63.37%) respectively.

Table 1. Production performance 2017 and 2018

S/No	Production capacity	Production output			
		2017	%	2018	%
1	The plant (AICC) has a production capacity of 33 million units of large volume parenteral (LVPs)	34 596 488	104.84	35 917 669	108.84
2	25 million units of SVP	20 177 744	80.71	20 327 496	81.31
3	4 million units of SVP	3 904 904	97.62	4 004 024	100.10
4	One million units of blood collection bags	670 824	67.08	633 661	63.37

The low production output can be traced to the inability to meet the benchmark in **MTBF, MTTR** and machine reliability. Ordinarily, it is easy to blame the maintenance department for poor perfomance. However, the analysis, presentation and interpretation of results allows the respective stakeholders to identify the implications of the performance in their roles on achieving the overall objectives of the industry. Through the collaborative relationship established during this research, the maintenance department had the opportunity to discuss their areas of concern, which include the timely purchase of relevant spare parts and the continuous training of maintenance personnel. The resulting synergy will enable the maintenance department to improve on the machine reliability in the production network, improved production and profitability.

5. Conclusions and recommendations

This research demonstrated that the analysis of past and current performance is an appropriate step to knowing where and what to improve to ensure machine reliability in the manufacturing industry (Table 2). The analysis amplified the critical roles of MTBF and MTTR in managing the duration of down time and the frequency of breakdowns of machines. As it is common with many maintenance units, a lot of energy is spent on breakdown maintenance, with very little thought going into forward planning, preventive and proactive maintenance. Although considerable effort and investment is made to provide modern technology to aid maintenance operations, the operational history lies dormant in their storage facilities.

Table 2. Summary of the results of data analysis

S/No	Description	2017		2018		Remarks
		Target (AIHC)	Achieved (AICC)	Target (AIHC)	Achieved (AICC)	
1	Total number of breakdowns	130 per month	145 per month	120 per month	128 per month	Fig. 1
2	Total length of down time	180 hours	250 hours	170 hours	Approximately 170 hours	Fig. 2
3	Mean time between failure (MTBF)	4 hours	3.3 hours	4.5 hours	Approximately 4.5 hours	Fig. 3
4	Mean time to repair (MTTR)	1.5 hours	.>1.5 hours	1.35 hours	Approximately 1.35 hours	Fig. 4
5	Plant reliability	75%	68%	80%	79%	Fig. 5

As shown in Table 2, the analysis of past performance amplified the poor performance of AICC in 2017, where it recorded 145 breakdowns per month, against the benchmark of 130 breakdowns per month. The increase in the number of breakdowns and the associated length of down time is equivalent to 2.92 days production loss every month. The resulting cumulative loss is 35.04 days per year, which means the revenue loss of more than one month in a year. This failure must have challenged the maintenance unit of AICC in 2018. In the same vein, the analysis of other factors showed marked improvements in 2018 (evidence of improved maintenance strategies) over what was achieved in 2017. Thus, continuous improvements in MTBF and MTTR resulted to reduction in the frequency of breakdowns, duration of down time and ultimately improved on the reliability of the machines in the production line.

Furthermore, the analysis, presentation and interpretation of result facilitates effective communication with all relevant stakeholders, elicite collaboration from other departments, provides information for timely decision making by senior management. The modest improvements achieved, through this exercise, provides encouragement to the maintenance unit to pursue the adoption of other maintenance best practices, including RCM.

It can be concluded that the analysis of operational information of machines in the production line in the database serves as a catalyst for identifying the influence of machine reliability on productivity and profitability of the manufacturing industries. This research recommends that AICC should have dedicated personnel, at the tactical level of leadership, to conduct quarterly analyses of the operational history for discussion within the maintenance unit, along with other stakeholders and communicated with senior management. Further research efforts should be dedicated to study the operations in AICC over a longer period to validate these findings or identify other additional factors suitable for the improvement of machine reliability in the production network.

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