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# The Effects of Maintenance Strategy on Equipment Performance in Heavy Industry Operations in South Africa

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# The Effects of Maintenance Strategy on Equipment Performance in Heavy Industry Operations in South Africa

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**A research article submitted to the Faculty of Commerce, Law and Management, University of the Witwatersrand, in fulfilment of the requirements for the degree of Master of Business Administration.**

**Johannesburg, 2023**

**Protocol Number:** WBS/2512764/953

# DECLARATION

I, *Bongani Fanelabongwe Bhengu*, declare that this research article is my own work except as indicated in the references and acknowledgements. I am hereby submitting it in partial fulfilment of the requirements for the degree of Master of Business Administration in the Graduate School of Business, at the University of Witwatersrand, Johannesburg. I have not submitted this report before, for any other degree, or examination to any other institution.

X

Bongani Fanelabongwe Bhengu
Signed in Johannesburg, 27 February 2023

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# SUPPLEMENTARY INFORMATION

| | |
|---|---|
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| Supplementary files: | Qualtrics online targeted survey, and the analysis will be performed through SPPS statistical analysis tool. |
| Supervisor | Dr. Ufuo Oro. |

# ABSTRACT

**Key words**: Maintenance Management, Maintenance Strategy.

Existing literature in maintenance strategy selection does not quantify the relative benefit of each applied maintenance strategy, neither does it indicate the perceived benefit to maintenance practitioners.

The existing literature does not enable inference to be made to the South African context of Pulp, Paper and Packaging Sector. Therefore, for South African maintenance practitioners, who want to know which strategy within South Africa (SA), is associated with a consequential world class equipment performance, there is no literature that provides adequate quantitative information. Therefore, this research article seeks to close the abovementioned research gap.

Two research questions needed to be investigated quantitatively, the first question is “what maintenance strategy in the target industry achieves competitive equipment availability?”, the research results showed that PdM strategies are perceived to be the strategies that achieve the most competitive availability.

The second research question is “What strategy is widely used in SA’s Heavy Industries, particularly Pulp, Paper and Packaging sector?”. The finding on this research question, is that combined, or hybrid strategies are applied by 67.9% of the sample, 21.4% applies PM strategies, 7.1% PdM strategies. This finding should trigger managerial practical questions, such as “why a such small portion of PdM strategies are in practice?”, if they are perceived to provide consequently competitive equipment performance.

The third part of this research, focused on deriving and testing a mathematical model of availability as a function of maintenance strategy applied. The model derived was found to be reasonably reliable, and valid, as the independent variables utilized explained 84.3% of the model, which is acceptable.

The key findings, and success of this research article, is that a mathematical model that was postulated, explains the consequential equipment performance as a function of maintenance strategy applied. Therefore, inference could be cautiously made, that this model possessed a reasonable degree of internal and external validity and could therefore be employed by the target population to fine tune and achieve the desired equipment availability.

# Table of Contents

**DECLARATION** ..... ii

**ACKNOWLEDGEMENTS** ..... iii

**SUPPLEMENTARY INFORMATION** ..... iv

**ABSTRACT** ..... v

**Table of Contents** ..... vii

**List of Figures** ..... ix

**List of Tables** ..... x

**Nomenclature** ..... xi

**1. Introduction** ..... 1

1.1. Background and Context ..... 1

1.2. Research Rationale ..... 2

1.3. Research Conceptualisation ..... 3

1.3.1. Problem Statement ..... 3

1.3.2. Research Knowledge-Gap Demonstration ..... 3

1.3.3. Research Purpose Statement ..... 5

1.3.4. Research Question and Hypothesis ..... 5

1.3.5. Delimitations and Assumptions of Research Study ..... 5

1.3.6. Significance of the Research ..... 6

**2. Literature Review** ..... 7

2.1. Maintenance Strategies ..... 7

2.1.1. Reactive Maintenance Strategy ..... 8

2.1.2. Preventative Maintenance Strategy ..... 8

2.1.3. Predictive Maintenance Strategy ..... 9

2.2. Maintenance Management Performance Indicators ..... 10

**3. Research Methodology** ..... 12

3.1. Proposed Research Strategy ..... 12

3.1.1 Target Companies ..... 13

3.1.2. The Model of Postulated Conjecture ..... 14

**4. Presentation of Results and Interpretation** ..... 16

4.1. Sample Descriptive Statistics ..... 16

4.2. Proposition Evaluation Results ..... 21
4.2.1. Evaluation of Proposition #1 ..... 21
4.2.2. Evaluation of Proposition #2 ..... 22
4.2.3. Evaluation of $Ax$ and $MTBFx$ Conjecture ..... 23
4.3. Summary of Proposition Evaluations ..... 25

**5. Research Results Discussion ..... 26**
5.1. Descriptive Statistics Discussion ..... 26
5.1.1. External Validity Discussion ..... 26
5.1.2. Raw Data Cleaning Discussion ..... 27
5.2. Discussion of Proposal #1 ..... 28
5.3. Discussion of Proposal #2 ..... 30
5.4. Discussion of Conjecture Models ..... 31
5.4.1. Discussion of $Ax$ Conjecture ..... 31
5.4.2. Discussion of $MTBFx$ Conjecture ..... 33
5.5. Conclusion of the Discussion ..... 33

**6. Conclusions and Future Recommendations ..... 35**
6.1. Conclusion of Research Question #1 ..... 35
6.2. Conclusion on Research Question #2 ..... 36
6.3. Conclusion of Postulated Mathematical Conjecture ..... 37
6.4. Theoretical Implications ..... 37
6.5. Research Limitations ..... 38
6.6. Managerial Implications and Recommendations ..... 38
6.7. Recommendations on Future Research ..... 39

**7. References ..... 40**

**8. Appendices ..... 44**
8.1. Appendix A – Participant Information Sheet ..... 44
8.2. Appendix B – Participant Agreement Form ..... 45
8.3. Appendix C – Research Instrument ..... 46
8.4. Appendix D – Ethics Approval ..... 47
8.5. Appendix E – Data Analysis Outputs ..... 48
8.5.1. Research Question 1 – Proposal Results ..... 48
8.5.2. Appendix E – Statistical Results for Availability Conjecture ..... 49

# List of Figures

Figure 1: Descriptive Statistics ..... 17
Figure 2: Frequencies Statistics ..... 17
Figure 3: Engineering Availability ..... 18
Figure 4: Benefits and Draw Backs of CM Strategies ..... 18
Figure 5: Benefits or Draw Backs of PM ..... 18
Figure 6: Benefits or Draw Backs of PdM ..... 19
Figure 7: Sample Demographics Companies ..... 19
Figure 8: Effective Capacity ..... 19
Figure 9: Reliance on Reactive Maintenance Strategy ..... 20
Figure 10: Reliance of Proactive Strategies ..... 20
Figure 11: Benefits or Draw Backs of PdM ..... 21
Figure 12: Maintenance Strategies ..... 22
Figure 13: Planned Capacity Utilization ..... 23
Figure 14: Data Summary ..... 24
Figure 15: Conjecture Model Cronbach Alpha ..... 24
Figure 16: Conjecture Model R Square ..... 25
Figure 17: Participant Consent Form ..... 44
Figure 18: Participant Agreement Form ..... 45
Figure 19: Ethics Approval ..... 47
Figure 20: Item Statistics Availability Conjecture Reliability Assessment ..... 49
Figure 21: Summary of Statistic for Availability Conjecture Reliability Test ..... 49
Figure 22: Availability Conjecture Items Statistics ..... 49
Figure 23: Pearson Correlations and Sig. (2 -tailed) ..... 50

# List of Tables

Table 1: Nomenclature Table ..... xi
Table 2: Research Questions and Hypothesis ..... 5
Table 4: Research Question and Proposition ..... 21
Table 5: Analysis of Relative Availability Benefit from Maintenance Strategies ..... 29
Table 6: Draft Research Questions ..... 46

# Nomenclature

**Table 1: Nomenclature Table**

| Nomenclature Table | |
|---|---|
| OEE | Overall Equipment Effectiveness |
| SMART | Specific Measurable Achievable Realistic and Time-bound |
| MTBF | Mean Time Between Failure |
| CAPEX | Capital Expenditure |
| FMCG | Fast Moving Consumer Goods |
| CONMON | Condition Monitoring |
| SA | South Africa |
| UKZN | University of KwaZulu-Natal |
| CM | Corrective Maintenance |
| PM | Preventative Maintenance |
| PdM | Predictive Maintenance |
| JSE | Johannesburg Stock Exchange |
| Sig. (2-tailed) | P - Value |
| DV | Dependant Variable |
| IV | Independent Variable |
| $\boldsymbol{A(x)}$ | Computed Availability of Correlated Variable |
| $\boldsymbol{MTBF(x)}$ | Computed MTBF |
| MTTR | Mean Time to Repair |
| CBM | Condition Based Maintenance |

# 1. Introduction

The introduction of this research article covers the background, context, the “why?” of conducting this study, and conceptualisation.

## 1.1. Background and Context

With an ever-increasing product performance requirement by customers (aesthetics, improved reliability, high demand for green products etc.), and the demand for attractive segment price points. Manufacturing Plants need to produce cutting edge products, be abreast with the consumer trends, whilst keeping the cost of production at the minimum (for cost competitiveness). They also need to continually invest to improve towards state-of-the-art manufacturing excellence, to compete sustainably in the market.

Manufacturing Plants in Heavy Industry Operations, such as Petrochemical, Steel, Pulp Paper and Packaging, Mining, FMCG, Sugar, and Power Utilities, have significant financial investments in fixed production assets. These fixed manufacturing assets are maintenance intensive, and maintenance spending accounts for a significant portion of the capital employed in operations (Rommert, 1996, as cited by Tsang, 1999).

Maintenance has been historically viewed as a necessary evil (Cooke, 2003), that is required to keep the fixed assets reliably operational, throughout their design service life. The primary reason for asset maintenance to be perceived as nonvalue adding, is that it contributes largely to the indirect costs of production. However, for manufacturing equipment to remain reliably productive, a proportionally high maintenance performance is required.

If equipment performance is low, production capacity is proportionally reduced, this is due to low equipment availability. The alternate solution to low equipment productivity for an organization, is to access additional production capacity through, either a horizontal-acquisition or plant expansion, both of which are CAPEX intensive. The above statement justifies the need for high equipment performance, as it ensures economical access to production capacity.

Therefore, it is imperative to gain further insights, to the effect of maintenance strategies that can be utilised to enhance equipment performance, particularly of Heavy Industry Operations in the South African context. With a particular focus on how selected strategies impact equipment performance indicators such as availability and mean time between failures (MTBF), which are also called lagging indicators.

Various combinations of asset maintenance strategies are employed to extend the useful economic life of fixed assets for example pumps, compressors, hydraulic equipment, digesters, boilers, smelters, paper machines etc. The intention of performing equipment maintenance is to extend the useful life of these capital-intensive manufacturing assets, in a manner that contains life-cycle costs (lower fixed cost of maintenance) and maximises production (profitability). The above statement explains the “why?” maintain manufacturing operations’ fixed assets.

Maintenance strategy selection is the sole responsibility of maintenance practitioners, Patil et al. (2021) says that due to the ever-increasing competitiveness of industrial manufacturing, the task of selecting maintenance strategies has become a difficult and complex, largely due to an extensive number of qualitative and quantitative variables (Patil, Soni, Prakash, & Karwasra, 2021). This proposed study, will contribute insight into the strategies that result in increased productivity in the selected sample of SA’s Heavy Industrial Operations, by evaluating correlations between maintenance strategies employed and equipment performance indicators (availability and MTBF).

## 1.2. Research Rationale

Due to the high cost of fixed asset replacement, and the cost of acquiring additional production capacity. Maintenance as an activity, is therefore justified. The researcher’s rationale for this research article, is that, if the tactical capacity of maintenance focuses on value adding maintenance strategies, the subsequent positive maintenance performance can contribute the overall organizations competitiveness. Furthermore, production capacity utilization in large enterprises is a variable of significance to the SA’s economic performance measurement (Stats-SA, 2022).

Therefore, an evaluation of the effect of strategies to the equipment performance in heavy industrial operation in SA would be adding valuable insight to state of fixed asset

performance in SA, and clearly identifying which selected strategies, are perceived to yield improved equipment performance, and which in turn should contribute positively to profitability.

This research article contributes to the body on knowledge and adds valuable further insight in the field of maintenance strategy, particularly the consequential effect on equipment availability, and MTBF, which are a function maintenance activity.

## 1.3. Research Conceptualisation

### *1.3.1. Problem Statement*

The problem that this research article seeks to answer is “what asset maintenance strategies will enable the target South African population of heavy industrial operations, in Pulp, Paper and Packaging to achieve world-class equipment availability”.

The existing literature failed to provide studies that enable inference to be made with regards to “which strategies are widely used in SA’s context of Pulp, Paper and Packaging, and which achieve the most competitive equipment performance, and why that strategy achieves the best performance in this context?”. The inability to access this information, is a detrimental problem. As it leaves room for Maintenance Practitioners in SA’s Pulp, Paper and Packaging Sector to make decisions that not based on empirical evidence, and quantitatively proven strategies.

### *1.3.2. Research Knowledge-Gap Demonstration*

Research of existing literature shows a significant gap, with regards to availability of direct, credible, and clear evidence, as a solution to this research problem. Effort to identify research from which, conclusions can be inferred is also not available. To demonstrate this knowledge-gap, the studies that investigate the field of maintenance strategy, particularly with an interest in gaining insight to benefits leveraged from the application of maintenance strategies are discussed below. The sole intention of the discussion below is to demonstrate exhaustively, that the existing literature does not answer the problem in question, that this research article seeks to evaluate empirically.

Cooke studied plant maintenance strategies used by four British Manufacturing Plants (Cooke, 2003), this study shares similarities to the research article in question, in that

the object is to assess the strategies employed, reliance on a particular strategy, and the relative perceived consequential value derived for each strategy. However, the study was conducted with a sample of only four manufacturing plants (1- Utility Plant, 2-Manufacturing Plants, and 1 – News Paper and Printing Company), all these plants have limited inherent similarities in their operations or industry sectors, and these plants are only British Manufacturing Plants. Furthermore, the research conducted by Cooke, has a qualitative conclusion, which leaves a gap in terms of conclusively quantifying the relative benefit attributable to specific strategic maintenance. The proposed research on the other hand, will fill the gap by providing quantified benefits in terms of equipment availability, which can in-turn be compared to world-class benchmark availability of 90%. Nayak et al. (2013) supports the claim world class equipment availability is 90% (Nayak, Kumar, Naidu, & Shankar , 2013).

Further review of literature, led to an identification of a publication by Swanson (2001), this published paper sought to understand the link between strategies and performance. Swanson does not clarify in detail what aspect of Plant Performance is measured and referred on this study, which leaves room for significant misinterpretation and uncertainty.

Swanson sought to examine empirically, the qualitative implications on plant performance, relative to the strategy that the operation is reliant on (Swanson, 2001). The research gap identified in Swanson's paper, is common with that of Cooke, in that the research has qualitative results, which also cannot be inferred to the context the target population, due to the demographic of the sample. Furthermore, Swanson's definition of "Plant Performance", is not conclusively defined as equivalent to that of interest in this proposal, which is equipment performance indicator – called "availability and MTBF".

This research intends to close the demonstrated existing knowledge gap, by conducting an empirical study, with an aim of acquiring quantitative implications for reliance on maintenance strategy. Furthermore, contextualising the study to the target sample, will enable reliable inference to be made about the overall population within South Africa. This inference will allow a degree of benchmarking of SA's target

population relative to other countries in terms of equipment performance (availability and MTBF), and relative to world-class availability target of 90%. This abovementioned inference will contrast the strategic position of SA's industrial assets in the target sector.

### *1.3.3. Research Purpose Statement*

The aim of this research study is to evaluate the effects of strategic maintenance, in selected Heavy Industrial Operations of SA, with particular focus on shedding light to the widely used strategies, and the "Why?", as well strategies that are perceived by relevant industry maintenance practitioners as most effective in achieving organization maintenance objectives.

The objective was to test the overall target industry sector equipment reliance on Reactive versus Proactive maintenance strategies, through assessment of perceived effect of strategies on availability, MTBF, both which are lagging-indicators.

### *1.3.4. Research Question and Hypothesis*

**Table 2: Research Questions and Hypothesis**

| Question | Hypothesis |
|---|---|
| **Question 1**<br>What maintenance strategy in the selected Heavy Industrial Operations of South Africa achieves competitive equipment availability? | **Hypothesis**<br>PdM strategies achieves relatively higher equipment MTBF and availability therefore high reliability. |
| **Question 2 –**<br>Which strategy is widely in-practice in the selected Heavy Industrial Operations in South Africa? | **Hypothesis**<br>PM strategies consume more tactical capacity utilization. |

### *1.3.5. Delimitations and Assumptions of Research Study*

The target sample is comprised of relevant industry maintenance practitioners, as respondents of a quantitative survey. The limitation here, is that the target sample may be biased in their responses (self-protection), there are also expected errors in inputs and interpretation.

The abovementioned bias and errors will be reduced through data cleaning, before running descriptive statistics analysis, and by eliminating responses with

inconsistencies with existing literature through use of Likert Scales, and structured selective responses.

### *1.3.6. Significance of the Research*

List of Key Benefits:

1. Significant insight will be gained on Maintenance Strategies applied in Heavy Industrial Operations of the target companies, and therefore an inference can be reached with regards to condition of fixed industrial assets, in the target manufacturing sector, as well the expected future performance (sustainability).
2. The expected conclusions are crucial to the Heavy Industry of SA in question, and may trigger further Maintenance Policy questions, as the quantifiable equipment performance indicators can be compared to world-class benchmarks.
3. Insight will be gained on which strategies employed by the target sample, are contributing positively to measured equipment performance of fixed assets, and enhance production maximization, and in-turn profitability.
4. The study will further reveal strategic positioning of the target sector's fixed assets.

This research article report has six sections, the first section is (Section-1 Introduction) which introduces the field of study, the relevant technical jargon, the research problem, the rationale of this research, the research questions, and propositions.

The second section (Section-2 Literature Review) is of the existing Literature Review, which covers the theoretical basis for research field in question, the state of the art, as well as the research gap. The third section is (Section-3 Research Methodology) covers the Research Methodology, research strategy, and approach of the research.

The fourth section (Section-4 Presentation of Results and Interpretation) presents and describes the results from the statistical analysis, The fifth section is research article discussion of results from the statistical analysis (Section-5 Research Results Discussion). The sixth and final section is the conclusion, and reflection on future recommended research gaps (Section-6 Conclusion and Future Recommendations).

# 2. Literature Review

The literature review of this research article gives a summary of existing literature on maintenance strategies, and how maintenance performance is measured, and which measurement definition is targeted by this article. Furthermore, the literature review intends to comprehensively demonstrate the knowledge gap, for which this research will contribute.

## 2.1. Maintenance Strategies

What is maintenance?, for purposes of this article, the definition that is to be used is adapted from BSI, which is British Standards Institution EN 13306:2010, where maintenance is defined as “a combination of all technical, administrative and management actions during the lifecycle of an item, intended to retain it in, or restore to, state in which it can perform the required function” (EN13306, 2014). The definition is consistent with maintenance practice in Heavy Industry Operations, where maintenance is a practice that entails variety of activities (management, and tactical functions) performed with an intent to maintain equipment functionality.

What is a maintenance strategy? According to the BSI EN13306, it’s a methodical approach utilised to achieve a maintenance objective (EN13306, 2014).

Existing literature broadly categorises maintenance strategies, but the categorization adopted in this article is consistent with that of Swanson, the two categories are Reactive and Proactive Strategies (Swanson, 2001). Patil et al. (2021) further supports Swanson’s view by reinforcing this categorization and expressing that maintenance strategies are divided into unplanned(reactive) and planned (proactive) maintenance (Patil, Soni, Prakash, & Karwasra, 2021). Where, proactive strategies include, Predictive (PdM) and Preventative (PM). The reactive strategies are referred to as corrective strategies.

It is noteworthy that, manufacturing operations use a combination of maintenance strategies. However, it is expected that that significant tactical maintenance capacity utilization will be on the dominant strategy.

### *2.1.1. Reactive Maintenance Strategy*

A reactive strategy is a strategy where maintenance function takes a form of restoration or improvement once the equipment has lost functionality (broken down). This strategy is widely referred to as fire-fighting strategy (Patil, Soni, Prakash, & Karwasra, 2021), or as a corrective maintenance strategy (CM), which is consistent with Swanson's view (Swanson, 2001).

This strategy is reactive in a sense that, it is a "only repair once broken down", according to Cooke it was common in the during the first world war (Cooke, 2003). This strategy is perceived as the most uneconomical, as it will result in unplanned equipment loss of functionality, and may lead to extensive equipment damage, subsequently leading to higher cost of maintenance. Salonen and Bengtsson's view is consistent with the abovementioned observations, as it concluded that researchers identified consistencies with higher cost of maintenance where CM strategies are adopted, when compared to PM (Salonen & Bengtsson, 2011).

The researcher contests, that the CM strategy though it has its disadvantages, it can be justified by maintenance practitioners, and can applied economically in less critical equipment's. The main benefit of this strategy is that it is labour efficient. This statement is supported by Patil et al. (2021), where he adds that this strategy is suitable where, performance of equipment that does not have ramifications on the production operation as a whole (Patil, Soni, Prakash, & Karwasra, 2021).

### *2.1.2. Preventative Maintenance Strategy*

Preventive strategies are referred to time-based strategies, where maintenance function is proactively performed periodically to prevent failure. Ahuja and Khamba are of an agreeing view that the PM strategy comprise of activities performed to prevent equipment breakdown (Ahuja & Khamba, 2008). The strategies are applicable where equipment's reliable design life and performance are known, where maintenance interventions are scheduled to restore resistance to failure at frequencies that are predetermined, the frequency of restorations is of such a nature that is adjusted or iterated with ageing, and as per need basis, throughout the lifecycle of the equipment, the intention ensure optimal economy in maintenance interventions.

This strategy leads to a sustainable production, to more efficient capacity utilization, it enables maintenance to be planned and scheduled. This strategy enables an organization to reliably forecast accessible production capacity.

The downside of this strategy is that, for maintenance activity to be carried out, the equipment must be taken out of service, even if the equipment has shown no signs of deterioration in reliability, it will be taken out of operation for restoration, which means that there is always a case of over-maintenance, which is costly.

### *2.1.3. Predictive Maintenance Strategy*

Predictive strategies are referred to Condition-Based Strategies (Pintelon, Pinjala, & Vereecke, 2006), predictive strategies continually or at determined frequency monitor equipment performance, the equipment is monitored for early signs of failure resistance deterioration, which enables maintenance interventions to be scheduled as per need basis to avoid a catastrophic equipment failure. This strategy does result in CM, but a planned form of CM (equipment brought to controlled stop) where production loss in minimised.

Typical condition-based monitoring (CBM) activities are oil-sample analysis for metal fillings, water ingress and other contaminants checks on lubrication. For rotating equipment's, vibration monitoring is common, where baseline vibration data acquisition is necessary, and this data acquisition continues throughout the life cycle of the equipment, a trained analyst monitors trends for any deviation from the baseline readings, and can accurately and timeously identify reliability deterioration, and then plan a necessary maintenance intervention to restore resistance to failure.

Predictive strategies have an advantage over preventative strategies, as they rely on real-time data collected, depending on the application it can be on-line equipment performance monitoring, which allows equipment to utilised exhaustively, to a point where it has shown evidence of deteriorated reliability. This strategy ensures maximised access to production capacity and extends useful life and is more economical. Whereas preventative strategies, rely on time-of-use, with a combination

preventive action (oil level-refilling etc.), but the equipment is still restored even if there are no signs of defects (risk averse strategy).

## 2.2. Maintenance Management Performance Indicators

Why is it crucial for management to measure maintenance performance? the justification is that the cost of poor maintenance can erode the organizations profit margins. Wireman asserts that 33% of maintenance costs are said to be wasted without measurable benefit (Wireman, 1990, as cited in Salonen, 2011), therefore it is important to measure and manage maintenance performance, to keep the cost of maintenance at minimum. Bevilacqua and Braglia said that maintenance cost can be between 15% to 70% of the total cost of production (Bevilacqua and Braglia, 2000 as cited in Salonen, 2011). The above citations on cost impact of maintenance, highlight the need to manage maintenance performance, and justify viewing maintenance as of strategic competitive advantage, if perfected.

Optimizing maintenance performance, particularly of equipment performance, is of strategic importance. Kumar et al. (2013) expresses that, achieving high equipment reliability enables the organizations to access higher production capacity (Kumar, Glar, Parida, Stenstrom, & Berges, 2013), the logic is that low maintenance performance limits the production capability of an installed capacity. Where, high maintenance performance enables organizations to leverage added value (profitability), hence measurement and management of maintenance performance is paramount importance to maximised profitability.

There are three common categories of measurement of maintenance performance, as highlighted by Campbell, which are equipment, cost, and process performance (Campbell, 1995, as cited in Tsang, 1998).

1. Equipment Performance Indicators (availability, MTBF etc.)
2. Maintenance Cost Performance (overtime cost, indirect costs, spares costs, renewal etc.)
3. Maintenance Process Indicators (planning accuracy, back-log ratio, schedule compliance etc.)

For purposes of this research proposal, the focus is on measurement of equipment performance (availability, and MTBF), with this abovementioned focus, a link between equipment performance and applied maintenance strategies, shall be evaluated quantitatively.

# 3. Research Methodology

The research methodology provides the much-needed clarity on the proposed approach, strategy, expected results, as well as the probable methods of reaching reliable and credible conclusions.

The methodology further gives an overview of pertinent specifics, underpinning the research design. It also covers the “what will be the valuable theoretical contributions to the body of knowledge” in question, and the managerial implications particularly for SA Heavy Industry Operations, also highlights the limitations inherent in this study.

## 3.1. Proposed Research Strategy

The research method used is quantitative, through Qualtrics a survey was administered, structured quantitative information was collected from a targeted sample of maintenance practitioners in target sector. The sample of practitioners were respondents such as Maintenance Engineers and Technicians, Engineering Managers, Maintenance Managers, Reliability Engineers, Industrial Engineers etc.

The respondents are the primary source of data, the data collected will be from respondents with first-hand field exposure, and maintenance expertise. The data was then quantitatively analysed on SPSS for descriptive statistics, Pearson’s correlations (relationships), and their significance, as well assessing reliability through Cronbach Alpha.

How were the respondents reached? A Qualtrics questionnaire was sent to the already established connections on LinkedIn, to Wits Business School and University of KwaZulu-Natal (UKZN) alumni networks.

The target respondents were randomly selected, amongst the target population of maintenance practitioners of the JSE Listed Pulp, Paper, and Packaging Companies. The responses were also intentionally designed to protect personal information, privacy, and dignity of the respondents. A statistically significant sample size yields statistical confidence level of 95%, which acceptable in management studies (Taherdoost, 2017). Since the population size is unknown, the proposed sample size

60 responses. This target sample size is higher than the sample recommended by Creswell (Creswell, 2009). The pre-condition set by Creswell are that the sample must have an alpha of 0.05, the power of 0.08 and effect of 0.05 (Creswell, 2009, p. 147). Cross reading the required sample size specification on Cohens tables yields a minimum required sample size of 20 reliable responses. The sample size has been kept small, due to the nature of the research, the resources available and time allocated to conclude the study, however measures have been taken to ensure that the sample is sufficiently representative to the target population.

### *3.1.1 Target Companies*

To make an accurate inference about equipment performance of an overall sector of industry, the researcher has further narrowed down the respondents to be from the Pulp, Paper, and Packaging sector, and focused only the JSE listed corporations. The reason for focusing JSE companies, is that the performance of these companies is of public interest, and it is assumed by the researcher that there will no restrictions placed upon the practitioners from sharing the sought-after raw data.

The large enterprises in the abovementioned sector, that are targeted within SA are:

1. Mpact
2. Sappi Limited
3. Mondi Group
4. Nampak

The benefit of narrowing the target sample to the JSE listed Pulp, Paper, and Packaging sector corporations, and particularly to the selected proposed list of companies, is that it will make the study conclusive on the sector's state of asset health, this is because these companies share significant similarities, in terms of:

- The raw-materials used, such as wood-fibre (virgin or recovered fibre).
- The scale of operation, and equipment's utilised.
- They are all large enterprises, with significant fixed assets that require strategic maintenance.
- They compete for market share, for example Sappi's office paper product "Typek", competes with Mondi's "Rotatrim".

The inherent similarities as mentioned above, are expected to yield statistically significant correlations, with regards to the maintenance strategies employed.

### *3.1.2. The Model of Postulated Conjecture*

The researcher has postulated a mathematical conjecture that defines equipment performance of an organization (availability, and MTBF), as a function of the maintenance strategy employed.

$$A(x) = \sum_{n=1}^{\infty} PM(x_n) - \sum_{n=1}^{\infty} CM(x_n) + \sum_{n=1}^{\infty} PdM(x_n) + e$$

$$MTBF(x) = \sum_{n=1}^{\infty} PM(x_n) - \sum_{n=1}^{\infty} CM(x_n) + \sum_{n=1}^{\infty} PdM(x_n) + e$$

Were.

- $A(x)$ is availability, which is a function of proportion of maintenance strategy that an organization is reliant on.
- $MTBF(x)$ is MTBF, which is a function of proportion of maintenance strategy that an organization is reliant on.
- $\sum_{n=1}^{\infty} CM(x_n)$ is a function that defines the reliance on CM strategy, it is a sum of all CM maintenance activity contributions.
- $\sum_{n=1}^{\infty} PM(x_n)$ is a function that defines the reliance on PM strategy, it is a sum of all PM maintenance activity contributions.
- $\sum_{n=1}^{\infty} PdM(x_n)$ is a function that defines the reliance on PdM strategy, it is a sum of all PdM maintenance activity contributions.
- $e$ is an error that is inherent in study.

The conjecture is postulated based on the understanding that, significant reliance on CM strategy would result in low equipment performance, hence its negative contribution. An organization with higher reliance for PM and PdM strategies would consequently have higher equipment performance.

The error component of the conjecture is representative of inherent error in the study in question, one of the identifiable errors is that “CM strategy will negatively affect availability”. The abovementioned statement is not always true, if the CM strategy is employed on an equipment with built-in redundancy, or where equipment failure will not hinder production, then CM will not have a negative effect on availability.

# 4. Presentation of Results and Interpretation

This section of the applied research project article, presents, describes, highlights and contrast key statistical results, that were received from the target sample of respondents. The results that are presented in this section are intended to answer, or are in response to the research questions, purpose, and problem. The main research problem, is to use the statistical information received to gain insight on maintenance strategies in application in SA, within the Pulp, Paper, and Packaging sector.

The main subtopics of this section are:

1. Descriptive Statistics,
2. Proposition Evaluation Results and,
3. Summary of Proposition Evaluations.

## 4.1. Sample Descriptive Statistics

There was total of 39 responses received from target companies which are Mondi PLC, Sappi Limited, and Mpact. No responses were received from Nampak, in time for the analysis.

Figure 1: Descriptive Statistics below shows descriptive statistics information from SPSS, with a total usable sample of 28 responses. Figure 1: Descriptive Statistics sample shows a higher degree of reliance to Proactive Maintenance Strategies rather than the Reactive Strategies.

**Descriptive Statistics**

| | N | Range | Minimum | Maximum | Mean | | Std. Deviation | Skewness | | Kurtosis | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Statistic | Statistic | Statistic | Statistic | Statistic | Std. Error | Statistic | Statistic | Std. Error | Statistic | Std. Error |
| Are you responsible for asset maintenance in SA? | 28 | 1 | 1 | 2 | 1.07 | .050 | .262 | 3.520 | .441 | 11.183 | .858 |
| Which of the companies do you work for? | 28 | 2 | 1 | 3 | 2.14 | .112 | .591 | -.024 | .441 | .014 | .858 |
| Are your maintenance objectives aligned to the Organizations objectives? - Scale | 28 | 40.00 | 60.00 | 100.00 | 90.1071 | 2.07807 | 10.99609 | -1.026 | .441 | .457 | .858 |
| What is the degree of reliance to Proactive vs. Reactive Maintenance Strategies in you plant? - Reactive Strategy | 28 | 100.00 | .00 | 100.00 | 51.0000 | 5.48085 | 29.00192 | .010 | .441 | -1.349 | .858 |
| What is the degree of reliance to Proactive vs. Reactive Maintenance Strategies in you plant? - Proactive Strategies | 28 | 80.00 | 20.00 | 100.00 | 72.1429 | 3.99229 | 21.12523 | -.933 | .441 | .176 | .858 |
| What is the equipment or engineering availability percentage in your plant. | 28 | 2 | 8 | 10 | 9.57 | .130 | .690 | -1.367 | .441 | .629 | .858 |
| What maintenance strategy is widely applied in your plant? | 28 | 3 | 1 | 4 | 3.39 | .181 | .956 | -1.177 | .441 | -.153 | .858 |
| What are benefits or draw-backs from applying Corrective Maintenance Strategies in your plant? | 28 | 1 | 1 | 2 | 1.64 | .092 | .488 | -.631 | .441 | -1.732 | .858 |
| What are benefits or draw-backs from applying Planned Maintenance Strategies in your plant? | 28 | 1 | 1 | 2 | 1.11 | .060 | .315 | 2.686 | .441 | 5.614 | .858 |
| What are benefits or draw-backs from applying Predictive Maintenance Strategies in your plant? | 26 | 1 | 1 | 2 | 1.12 | .064 | .326 | 2.558 | .456 | 4.915 | .887 |
| Unplanned Capacity Utilization | 28 | 47 | 5 | 52 | 26.04 | 2.639 | 13.964 | .193 | .441 | -.947 | .858 |
| Planned Capacity Utilization | 28 | 47 | 48 | 95 | 73.96 | 2.639 | 13.964 | -.193 | .441 | -.947 | .858 |
| Is your backlog increasing or decreasing? | 28 | 2 | 1 | 3 | 2.18 | .137 | .723 | -.287 | .441 | -.956 | .858 |
| Computed Availability Correlated Variable | 28 | 171.00 | -71.00 | 100.00 | 21.1429 | 8.21660 | 43.47815 | -.406 | .441 | -.185 | .858 |
| Valid N (listwise) | 26 | | | | | | | | | | |

**Figure 1: Descriptive Statistics**

Figure 2: Frequencies Statistics below shows the frequency statistics information from the sample. It is noteworthy that the sample size is N = 28 responses. Other pertinent descriptive information about the sample is presented on Figure 2: Frequencies Statistics below.

**Statistics**

| | | What maintenance strategy is widely applied in your plant? | What is the equipment or engineering availability percentage in your plant. | What are benefits or draw-backs from applying Corrective Maintenance Strategies in your plant? | What are benefits or draw-backs from applying Planned Maintenance Strategies in your plant? | What are benefits or draw-backs from applying Predictive Maintenance Strategies in your plant? | Are you responsible for asset maintenance in SA? | Which of the companies do you work for? | Are your maintenance objectives aligned to the Organizations objectives? - Scale | What is the degree of reliance to Proactive vs. Reactive Maintenance Strategies in you plant? - Reactive Strategy | What is the degree of reliance to Proactive vs. Reactive Maintenance Strategies in you plant? - Proactive Strategies | Is your backlog increasing or decreasing? | Unplanned Capacity Utilization | Computed Availability Correlated Variable | Planned Capacity Utilization |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N | Valid | 28 | 28 | 28 | 28 | 26 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 |
| | Missing | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mean | | 3.39 | 9.57 | 1.64 | 1.11 | 1.12 | 1.07 | 2.14 | 90.1071 | 51.0000 | 72.1429 | 2.18 | 26.04 | 21.1429 | 73.96 |
| Std. Error of Mean | | .181 | .130 | .092 | .060 | .064 | .050 | .112 | 2.07807 | 5.48085 | 3.99229 | .137 | 2.639 | 8.21660 | 2.639 |
| Median | | 4.00 | 10.00 | 2.00 | 1.00 | 1.00 | 1.00 | 2.00 | 91.0000 | 50.0000 | 80.0000 | 2.00 | 28.00 | 19.5000 | 72.00 |
| Std. Deviation | | .956 | .690 | .488 | .315 | .326 | .262 | .591 | 10.99609 | 29.00192 | 21.12523 | .723 | 13.964 | 43.47815 | 13.964 |
| Variance | | .914 | .476 | .238 | .099 | .106 | .069 | .349 | 120.914 | 841.111 | 446.275 | .522 | 194.999 | 1890.349 | 194.999 |
| Skewness | | -1.177 | -1.367 | -.631 | 2.686 | 2.558 | 3.520 | -.024 | -1.026 | .010 | -.933 | -.287 | .193 | -.406 | -.193 |
| Std. Error of Skewness | | .441 | .441 | .441 | .441 | .456 | .441 | .441 | .441 | .441 | .441 | .441 | .441 | .441 | .441 |
| Range | | 3 | 2 | 1 | 1 | 1 | 1 | 2 | 40.00 | 100.00 | 80.00 | 2 | 47 | 171.00 | 47 |
| Minimum | | 1 | 8 | 1 | 1 | 1 | 1 | 1 | 60.00 | .00 | 20.00 | 1 | 5 | -71.00 | 48 |
| Maximum | | 4 | 10 | 2 | 2 | 2 | 2 | 3 | 100.00 | 100.00 | 100.00 | 3 | 52 | 100.00 | 95 |
| Percentiles | 25 | 2.25 | 9.00 | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 83.5000 | 21.2500 | 60.0000 | 2.00 | 10.50 | -2.5000 | 65.00 |
| | 50 | 4.00 | 10.00 | 2.00 | 1.00 | 1.00 | 1.00 | 2.00 | 91.0000 | 50.0000 | 80.0000 | 2.00 | 28.00 | 19.5000 | 72.00 |
| | 75 | 4.00 | 10.00 | 2.00 | 1.00 | 1.00 | 1.00 | 2.75 | 100.0000 | 77.7500 | 88.0000 | 3.00 | 35.00 | 59.7500 | 89.50 |

**Figure 2: Frequencies Statistics**

According to Figure 3: Engineering Availability below, 67.9% of the sample has an engineering availability of 91-100%, which is well above world class of 90%. It is noteworthy, that none of the sample operations had availability below the 71-80%.

**What is the equipment or engineering availability percentage in your plant.**

| | N | % |
|---|---|---|
| 71-80% | 3 | 10.7% |
| 81-90% | 6 | 21.4% |
| 91-100% | 19 | 67.9% |

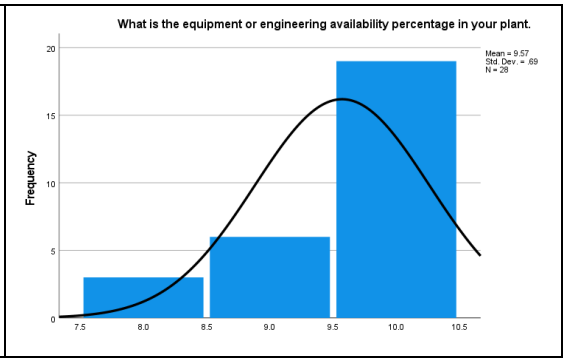



**Figure 3: Engineering Availability**

Figure 4: Benefits and Draw Backs of CM Strategies below, further shows that 64.3% of the sample population, claim that there is a drawback of "reduction in availability and MTBF" associated with reliance on CM strategies.

**What are benefits or draw-backs from applying Corrective Maintenance Strategies in your plant?**

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | Increase in availability and MTBF | 10 | 35.7 | 35.7 | 35.7 |
| | Reduction in availability and MTBF | 18 | 64.3 | 64.3 | 100.0 |
| | Total | 28 | 100.0 | 100.0 | |

**Figure 4: Benefits and Draw Backs of CM Strategies**

Figure 5: Benefits or Draw Backs of PM below shows that the sample associated reliance PM Strategies to a benefit in availability and MTBF. Within the sample 89.3% of the respondents supported that PM strategies are beneficial, whereas 10.7% supported the vice versa, which would be a drawback and reduction in availability and increase in MTBF.

**What are benefits or draw-backs from applying Planned Maintenance Strategies in your plant?**

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | Increase in availability and MTBF | 25 | 89.3 | 89.3 | 89.3 |
| | Reduction in availability and MTBF | 3 | 10.7 | 10.7 | 100.0 |
| | Total | 28 | 100.0 | 100.0 | |

**Figure 5: Benefits or Draw Backs of PM**

The sample tested, shows that 82.1% of the respondents associate an PdM strategies to a benefit if increased availability, see Figure 6: Benefits or Draw Backs of PdM above. There were two responses that are missing as inputs.

**What are benefits or draw-backs from applying Predictive Maintenance Strategies in your plant?**

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | Increase in availability and MTBF | 23 | 82.1 | 88.5 | 88.5 |
| | Reduction in availability and MTBF | 3 | 10.7 | 11.5 | 100.0 |
| | Total | 26 | 92.9 | 100.0 | |
| Missing | System | 2 | 7.1 | | |
| Total | | 28 | 100.0 | | |

**Figure 6: Benefits or Draw Backs of PdM**

On the final statistically usable sample, 64.3% of responses which are a larger proportion of respondents were from Sappi Limited, whilst Mpact contributed 25%, and 10.7% from Mondi. Nampak respondents did not to participate in the survey.

**Which of the companies do you work for?**

| | N | % |
|---|---|---|
| Mondi | 3 | 10.7% |
| Sappi | 18 | 64.3% |
| Mpact | 7 | 25.0% |

**Figure 7: Sample Demographics Companies**

The sample responses seen on Figure 8: Effective Capacity, these responses indicate that for 46.4% of the sample, the backlog of maintenance activities is decreasing, whilst 35.7% of the respondents reported a net-net of a constant backlog of equipment operational risks. A smaller portion of 17.9% the sample indicated an increasing backlog. The increase in backlog, proportionally increases the frequency equipment loss of functionality.

**Is your backlog increasing or decreasing?**

| | N | % |
|---|---|---|
| Increasing | 5 | 17.9% |
| Decreasing | 13 | 46.4% |
| Constant | 10 | 35.7% |

**Figure 8: Effective Capacity**

The degree of reliance on reactive strategies (i.e., CM) is seen on Figure 9: Reliance on Reactive Maintenance Strategy above, the shape of this curve skewed towards the left, with the highest concentration at 20-40% of maintenance activities being CM or reactive in nature. The mean of the sample is 51% reliance on CM strategies for the sample.

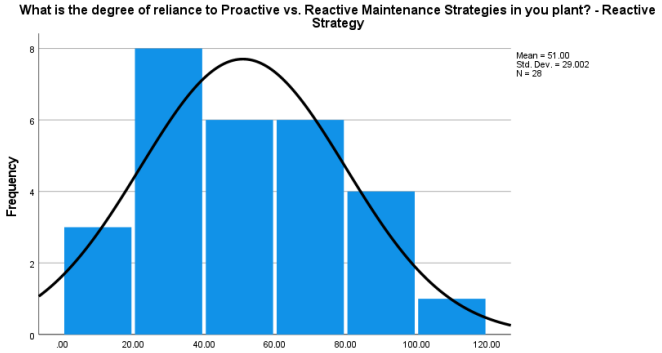



**Figure 9: Reliance on Reactive Maintenance Strategy**

On Figure 10: Reliance of Proactive Strategies the sample showed that there is a higher degree of reliance on proactive strategies, with the highest concentration of above 80-90%. The average reliance to proactive strategies is 72%, for the sample in question.

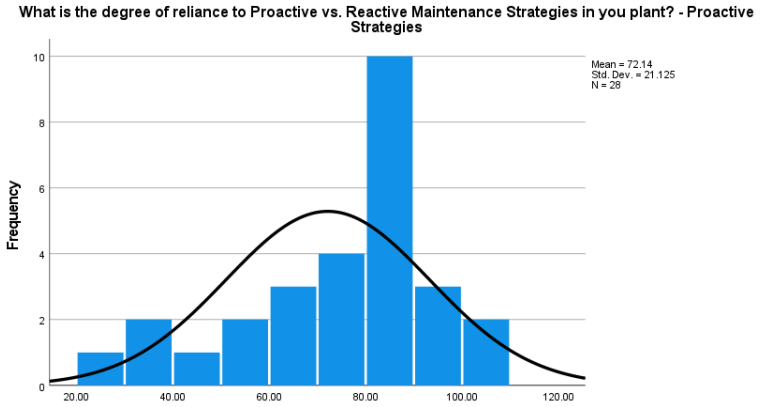



**Figure 10: Reliance of Proactive Strategies**

## 4.2. Proposition Evaluation Results

The research has two primary questions that need to be answered, which are as per Table 3: Research Question and Proposition below, this section of the research report is intended to present and discuss statistical results related to the propositions.

**Table 3: Research Question and Proposition**

| Research Question | Proposition |
|---|---|
| ***Question 1***<br>What maintenance strategy in the selected Heavy Industrial Operations of South Africa achieves competitive equipment availability? | ***Proposition 1***<br>PdM strategies achieves relatively higher equipment MTBF and availability therefore high reliability. |
| ***Question 2***<br>Which strategy is widely in-practice in the selected Heavy Industrial Operations in South Africa? | ***Proposition 2***<br>PM strategies consume more tactical capacity utilization. |

Furthermore, the propositions will be tested for validity and reliability, and if the result have consistencies with existing literature. If the results are found reliable, a discussion will be extended towards concluding on generalizability, and if a reliable inference to the population can be reached with said results.

The mathematical models derived to predict equipment performance as a function of maintenance strategy applied, will also be discussed, the results from SPSS are presented on this section. The results are described briefly, highlighting key findings.

### *4.2.1. Evaluation of Proposition #1*

The sample tested, shows that 82.1% of the respondents associate PdM strategies to a benefit of increased availability, see Figure 11: Benefits or Draw Backs of PdM below. There were two responses that are missing as input.

**What are benefits or draw-backs from applying Predictive Maintenance Strategies in your plant?**

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | Increase in availability and MTBF | 23 | 82.1 | 88.5 | 88.5 |
| | Reduction in availability and MTBF | 3 | 10.7 | 11.5 | 100.0 |
| | Total | 26 | 92.9 | 100.0 | |
| Missing | System | 2 | 7.1 | | |
| Total | | 28 | 100.0 | | |

**Figure 11: Benefits or Draw Backs of PdM**

Figure 23: Pearson Correlations and Sig. (2 -tailed). shows a Pearson correlation of +0.814, between an increase in availability of equipment and the application of PdM strategies. This statistic is significant, with a P value of less than 0.001, which is a confidence interval of 99%.

The statistical information does not explain the relative degree of how much higher PdM strategies' availability compares to the PM and CM. Therefore, the proposition is not adequately explained by the above results.

### *4.2.2. Evaluation of Proposition #2*

Figure 12: Maintenance Strategies shows that only 21.4% of the sample relies on a Proactive Maintenance Strategy, predominantly Preventative or Planned Maintenance (PM). Overall, a higher percentage of 67.9% is attributable to a combination of Proactive and Reactive Strategies (i.e., PM + PdM ± CM).

**What maintenance strategy is widely applied in your plant?**

| | N | % |
|---|---|---|
| Corrective Maintenance Strategy | 1 | 3.6% |
| Planned Maintenance Strategy | 6 | 21.4% |
| Predictive Maintenance Strategy | 2 | 7.1% |
| A combination of the above strategies | 19 | 67.9% |

**Figure 12: Maintenance Strategies**

It is also evident that within this target sample, that corrective maintenance is the least relied upon, as only a single response, which makes up 3.6% of sample, claims reliance on corrective maintenance strategies.

Figure 13: Planned Capacity Utilization below shows, that overall, there is a significant portion of the responses indicating higher degree of reliance on employing capacity on PM strategies.

Planned Capacity Utilization

| | N | % |
|---|---|---|
| 48 | 1 | 3.6% |
| 50 | 2 | 7.1% |
| 60 | 3 | 10.7% |
| 65 | 2 | 7.1% |
| 67 | 2 | 7.1% |
| 70 | 4 | 14.3% |
| 74 | 2 | 7.1% |
| 80 | 3 | 10.7% |
| 84 | 1 | 3.6% |
| 88 | 1 | 3.6% |
| 90 | 5 | 17.9% |
| 94 | 1 | 3.6% |
| 95 | 1 | 3.6% |

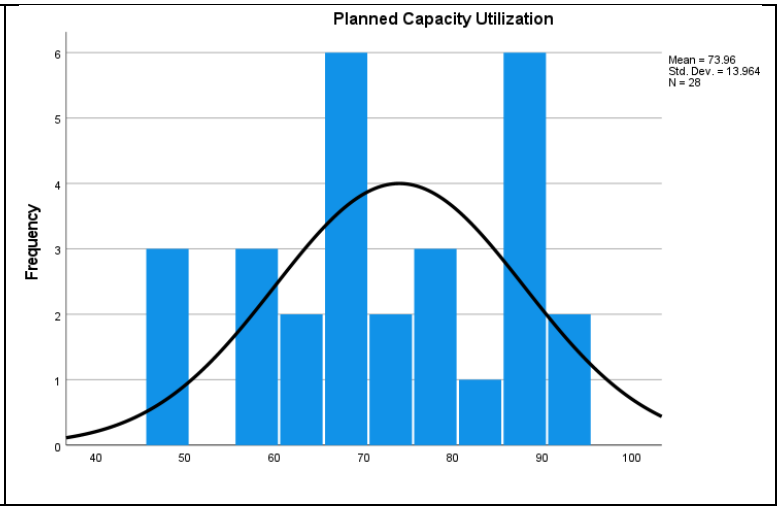



**Figure 13: Planned Capacity Utilization**

The planned capacity utilization as seen on Figure 13: Planned Capacity Utilization for the sample, is bimodally distributed. Kaki et al. (2013) supports this shape conclusion as bimodal (Kaki, Salo, & Talluri, 2013). The sample has a high concentration of 17.9% of the sample', employed capacity utilised to complete PM strategy activities (90% of their capacity employed in planned maintenance tactics).

### *4.2.3. Evaluation of $A(x)$ and $MTBF(x)$ Conjecture*

The below results were obtained during the evaluation of the conjecture $A(x)$, that has been postulated using conclusions from existing literature, the postulated conjecture is defined by the following formular:

$$A(x) = \sum_{n=1}^{\infty} PM(x_n) - \sum_{n=1}^{\infty} CM(x_n) + \sum_{n=1}^{\infty} PdM(x_n) + e$$

$A(x)$ is a function that was computed on SPSS, this dependant variable (DV) was named "Computed Availability Correlated", the results the below subsections represent the results from correlation analysis, reliability tests, as well as regression performed.

#### *4.2.3.1. Correlations and Significance Results*

Figure 23: Pearson Correlations show the correlation between variables of the model. It is immediately evident that Pearson Correlation between the $A(x)$ and reactive maintenance strategy (CM), is strong, negative -0.986, with a P value less than 0.001. This result from the statistical test, is consistent with the mathematical conjecture presented above.

Furthermore, it is noteworthy, that the Pearson Correlation between the $A(x)$ and proactive maintenance strategy (PdM + PM), is strong, and positive Pearson Correlation coefficient of 0.814, with a P value less than 0.001, which means that this statistic is significant at a confidence level of 99%. From this correlation, it was concluded that the mathematical conjecture presented above, explains the behaviour of availability as a function of maintenance strategy.

#### *4.2.3.2. Reliability and Validity Test Results*

The results from the validity test conducted are as shown below, Figure 14: Data Summary, shows the sample size that was used to compute the reliability of the model.

**Case Processing Summary**

| | | N | % |
|---|---|---|---|
| Cases | Valid | 28 | 100.0 |
| | Excluded[a] | 0 | .0 |
| | Total | 28 | 100.0 |

a. Listwise deletion based on all variables in the procedure.

**Figure 14: Data Summary**

Figure 15: Conjecture Model Cronbach Alpha below, shows that the Cronbach alpha for the $A(x)$ model is 0.569, which is quite reliable, but a Cronbach Alpha that is below 0.7 should always be viewed with caution. This enhanced Cronbach Alpha is computed using N = 5 independent variables of the computed availability model.

**Reliability Statistics**

| Cronbach's Alpha | Cronbach's Alpha Based on Standardized Items | N of Items |
|---|---|---|
| .569 | .632 | 5 |

**Figure 15: Conjecture Model Cronbach Alpha**

Figure 16: Conjecture Model R Square shows the results from the statistic reliability test, the results show that the linear regression of the dependant variable (i.e., calculated availability using conjecture formular), is explained by 84.8% of sample.

**Model Summary[b]**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate | Change Statistics | | | | Durbin-Watson |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | R Square Change | F Change | df1 | df2 | Sig. F Change | |
| 1 | .921[a] | .848 | .747 | 21.15971 | .848 | 8.371 | 10 | 15 | <.001 | 1.454 |

a. Predictors: (Constant), Unplanned Capacity Utilization , Are your maintenance objectives aligned to the Organizations objectives? - Scale, Are you responsible for asset maintenance in SA?, What are benefits or draw-backs from applying Corrective Maintenance Strategies in your plant?, What are benefits or draw-backs from applying Planned Maintenance Strategies in your plant?, What is the degree of reliance to Proactive vs. Reactive Maintenance Strategies in you plant? - Proactive Strategies, What are benefits or draw-backs from applying Predictive Maintenance Strategies in your plant?, What is the equipment or engineering availability percentage in your plant., What maintenance strategy is widely applied in your plant?, Which of the companies do you work for?

b. Dependent Variable: Computed Availability Correlated Variable

**Figure 16: Conjecture Model R Square**

## 4.3. Summary of Proposition Evaluations

The research questions, and propositions relevant results from the statistical analysis are exhaustively presented above. Furthermore, the conjecture models that were mathematically postulated are also presented with the relevant statistical tests that we performed to test for correlations, significance of the statistic, and reliability.

It is noteworthy, that the conjecture for $MTBF(x)$, could not be evaluated, as the participants responses had missing inputs, inputs of high variations, inputs with multiple unrelated units of measure, and some were in form wording. Therefore, the information gathered through the survey to explain $MTBF(x)$, was rendered unusable for a statistical analysis.

# 5. Research Results Discussion

This section of the research report discusses the statistical analysis results and compares it with existing literature review. The intent of reflecting and contrasting results, is to assess the significance of the results to the existing body of knowledge, verify whether the research objectives are achieved through these results. The final and the most important part of this section of the report, is the emphasis on what has been learnt from this research effort, versus what existing literature claims.

The section of the research report has the following subtopics, which are.

1. Descriptive Statistics Discussion.
2. Discussion on Proposition #1.
3. Discussion on Proposition # 2.
4. Discussion of the Conjecture Models.
5. Conclusion of the Discussion.

## 5.1. Descriptive Statistics Discussion

The raw data collection questionnaire was designed in such a way that it protects the identity of participants, as per Figure 17: Participant Consent Form. The sample also had to be representative of the general population's characteristics, this was done to enhance the generalizability of the results.

This subsection of discussion has two further subtopics, which are External Validity, and Raw-Data Cleaning Discussions. The descriptive statistics section is largely concerned with explaining the sample demographics, its suitability for this study, which validity enhancement efforts were employed, as well the samples' ability to achieve the research objective.

### *5.1.1. External Validity Discussion*

The demographic of the sample had specificity built into it, to ensure enhanced external and internal validity of the study. Findley et al. (2021) explains external validity as the degree to which inferences can be made from the research study to the broader population (Findley, Kikuta, & Denly, 2021).The measures that were built into the questionnaire to ensure external validity, are that the sample was to ensure that the participants are:

1. Skilled maintenance practitioners (i.e., Foreman, Engineer, Maintenance Managers, Engineering Managers etc.).
2. Practice in the Pulp, Paper, and Packaging Sector of Public Companies, which are JSE Listed (i.e., Sappi Limited, Mondi PLC, Nampak and Mpact). It is noted on the responses, that a significant portion of the responses were from Sappi Limited, which may have distorted external validity of the results.
3. The target companies have similarities in their installed fixed assets, in terms of scale, products produced etc.
4. Geographically, the target Manufacturing Plants are from South Africa.
5. The minimum sample size of 20 was also exceeded, as the final sample used had 28 usable responses. Larger sample sizes increase both internal and external validity of the study. Taherdoost supports the above argument, that validity data require large sample sizes for representative data (Taherdoost', 2016).

### *5.1.2. Raw Data Cleaning Discussion*

The initial sample size comprised of 39 responses, the cleaning process of data yielded 28 usable responses for the statistical analysis, the initially proposed sample size was of 20 responses on the research methodology section, which was justified as sufficient to make credible statistical conclusion.

The notable data cleaning efforts are summarised below:

- Two respondents from Mpact did not consent for their responses to be used for this study. Their responses were subsequently removed and excluded from the statistical analysis.
- The second screening question was “whether the respondent is a maintenance practitioner in the Pulp, Paper and Packaging Heaver Industrial Operation?”. The responses that indicated that the participant was not a maintenance practitioner were also removed from the sample, two of such responses were excluded further.

- Further analysis identified missing inputs on descriptive data analysis, a total of 9 respondents' inputs were found to be incomplete, and not usable, these inputs were also removed from final sample.
- A transform function on SPSS was used to create a new variable "Computed Availability Correlated Variable". This variable represents $A(x)$, for the postulated mathematical conjecture.
- The raw data that was collected, with an intension of measuring $MTBF(x)$ on the target companies was found to be inconsistent, as the respondents did not insert values in scale of hours. These erroneous inputs could have been prevented through research design. The data collected on this question could not be cleaned, it was subsequently removed.

## 5.2. Discussion of Proposal #1

The first proposition is in response the research question "What maintenance strategy In SA's Heavy Industrial Operations of Pulp, Paper and Packaging, achieves a competitive equipment availability?", the proposition that was made is that PdM strategies achieves relatively higher equipment availability. This proposition is supported by literature in maintenance strategies, such Velmurugan and Dhingra by saying that PdM strategies achieve breakthrough increases in equipment performance (Velmurugan & Dhingra, 2014).

Figure 11: Benefits or Draw Backs of PdM, shows the results that were from an assessment of this research question, and the finding is that 82.1% of the sample is evidently reliant on the PdM strategies, where the observed benefits by the sample respondents is increased availability and MTBF. The benefits are consistent with Velmurugan and Dhingra (2014).

Reliance on PdM strategies will translate to equipment being operationally available for longer than PM strategies, or achieve relatively higher availability, as the equipment only needs to be taken down for restoration when clear signs of deterioration are evident (Tsarouhas, 2019). Tsarouhas proceeds to claim that PdM strategies are superior to PM, which supports the Proposition that that PdM, will yield higher reliability and availability of equipment. Another researcher He et al. (2017) quantifies the relative cost saving benefit attributable to PdM to between 20.54% and 26.02%, over

other strategies, including PM (He, Gu, Chen, & Han, 2017). This abovementioned benefit warrants the need to further expand this abovementioned empirical assessment on the SA's Industrial Sector.

Furthermore, the statistical results show that PdM strategies have a strong, positive Pearson's correlation of 0.814 to availability and MTBF as represented Figure 23: Pearson Correlations and Sig. (2 -tailed). This correlation is statistically significant with a P value that is less than 0.001, which translates to a confidence at level of 99%.

It is therefore concluded that an increasing reliance on PdM will yield an increasing availability of equipment. Which proves that the proposition made to the Research Question 1 is valid, for the sample tested. The validity is also backed up by existing literature, such as Velmurugan and Dhingra (2014).

A further test of the strength of the relationship between the two variables of "computed availability" and PdM strategies yields an R Square value of 0.663, which means that 66.3% of PdM strategic tactics explain the dependant behaviour of availability. To prove that the PdM strategies yield a relatively higher equipment performance or availability and MTBF. The β coefficient value, which are the gradients of a regression line, which represents relationship of each of the strategies to availability are needed.

The results of this test are condensed on Table 4: Analysis of Relative Availability Benefit from Maintenance Strategies below. The results were inconclusive, as the β coefficient values do not definitively explain the effect, the R Square values are 0.025 and below, which is insignificant, which means that the DV (availability is not explained by the sample), the Sig. value also highlights that the statistic is not within 95% confidents interval.

**Table 4: Analysis of Relative Availability Benefit from Maintenance Strategies**

| Maintenance Strategy | Y = $\beta_0 + \beta_1 x_1 +$ | R Square | Sig. |
|---|---|---|---|
| **PdM Strategy** | 43.957-20.478$x_1$ | 0.025 | 0.439 |
| **PM** | 9.867-1.653$x_1$ | 0.000 | 0.952 |

| | | | |
|---|---|---|---|
| **CM** | 26.911-3.511$x_1$ | 0.002 | 0.842 |

Therefore, Proposition #1 is not fully explained by the results obtained. Only the relative benefit of PdM to other strategies could not be definitely be quantified. However, the strategy that is percieved to be most benefitial by the sample is PdM, and this statement is supported by various researchers including Rastegari, where is asserts that this CBM (i.e. CBM = PdM) strategies are the most efficient strategies (Rastegari, 2015). Therefore, proposition #1 partly answers research question #1.

It is of paramount importance that this quantified relative benefit be understood and be defined, as the current body of knowledge, and current state of the art of maintenance does not provide this critical information. This information would be “novel” in nature, and be of great benefit to maintenance practitioners, as it would declutter the process of maintenance strategy selection. Strategy selection remains a sophisticated challenge (Velmurugan & Dhingra, 2014), Bevilacqua and Braglia (2000) further supports this argument that the selection of the applied strategies is particularly difficult.

## 5.3. Discussion of Proposal #2

The research question for proposal #2, specifically targets insight about which strategy that is widely used in SA Heavy Industry, that of Pulp, Paper, and Packaging. The proposition is that in industry the PM strategies are widely in practice, this proposition was informed by literature review, as it is supported by Swanson by saying that there is an increasing number of companies moving toward PM strategies for competitive equipment performance (Swanson, 2001). Cooke also conducted a study, that supported the fact that PM strategies are largely applied (Cooke, 2003).

The proposition #2 in question, assumes that production plant establishes their competitive advantage through higher equipment performance. The follow-up question of the research objective is, why? “Why is such a strategy used widely?”.

The results from the statistical analysis can be seen above on Figure 12: Maintenance Strategies, which shows that a significant proportion of 67.9% of the sample relies on a combination of strategies (i.e., Proactive + Reactive Strategies), which is not

consistent with the proposition to the research question. Whereas PM strategies account for only 21.4% of the statistic, which is second highest widely applied strategy.

The data from Figure 12: Maintenance Strategies makes a sound and compelling revelation that PM strategies are not applied blindly across all assets within the industry, as PM strategies also have their drawbacks, particularly on fixed cost. PM strategies are not cost efficient, as there is likelihood of equipment over-maintenance. Velmurugan and Dhingra (2014) attests that the cost of maintenance has been increasing for decades. On the other hand, the reliance on a combination of strategies, means a strategy application is on a case-by-case bases, to ensure optimum cost economy, by utilizing the equipment until its very end of functional lifecycle.

To respond to the proposition #2, claiming that PM strategy consumes more tactical maintenance capacity, Figure 13: Planned Capacity Utilization shows a mean value of 73.96%, with a curve skewed towards right. This means that the sample attests to that 73.96% of their staff's time at work is consumed by performing Planned Maintenance tasks or tactics. This proposition #2 holds true for research question #2, as on the above-mentioned discussion, PM strategy tactics consume a significantly larger proportion of hired capacity. However, the strategy that is widely in practice in Heavy Industrial Operations of SA's Pulp Paper and Packaging is a combined strategy.

## 5.4. Discussion of Conjecture Models

There were two mathematical conjectures models that were proposed to explain the equipment performance, as a function of maintenance strategy employed. On this section of the discussion, these conjectures are analysed further for consistencies or inconsistencies with existing literature.

### *5.4.1. Discussion of $A(x)$ Conjecture*

The postulated equation for availability is a function of applied maintenance strategy as shown below, the equation shows that the applied strategies are a combination, which is consistent with the finding on Research Question #2.

During the analysis and coding on SPSS transformation, this variable of availability $A(x)$ was named “Computed Availability Correlated Variable”.

$$A(x) = \sum_{n=1}^{\infty} PM(x_n) - \sum_{n=1}^{\infty} CM(x_n) + \sum_{n=1}^{\infty} PdM(x_n) + e$$

The analysis of the $A(x)$ shows that this dependant variable (DV) is negatively and strongly correlated to the application of CM strategies, which is consistent with the postulation, hence the subtraction on the formular. The negative on the formular is because CM maintenance is associated with lower equipment performance, which means an increased reliance on CM will yield lower equipment performance, and high production loss. This rationalization is supported by Arena et al. (2022) by saying that this type of maintenance intervention takes place after a catastrophic failure (Arena, Florian, Zennaro, Orru, & Sgarbossa, 2022).

Therefore, the influence of $CM(x_n)$ on the $A(x)$ above, was expected to not enhance availability (i.e., be negative). The results showed Pearson correlation of -0.986 which is negative and strong. This correlation has P value less than 0.001, which makes this statistical relationship significant at confidence of 99%.

The correlation of the $A(x)$ to proactive strategies, which is made of a sum of PM and PdM strategies (i.e., $\sum_{n=1}^{\infty} PM(x_n)$ + $\sum_{n=1}^{\infty} PdM(x_n)$), is positively and strongly correlated to the DV of the postulation. The Pearson correlation was found to be 0.814, the P value of this correlation was found to be less than 0.001, which means that this correlation is significant at 99% confidence level.

The conjecture model was subjected to reliability tests, after it had been checked as per the above for validity. The reliability test that was performed to check for internal consistency is Cronbach Alpha, the outcome of the results from SPPS is Cronbach Alpha of 0.569, which according to Hinto is “moderately reliable” (Hinto et al. 2004 as cited by Taherdoost’ 2016). The R Square value for the model was found to be 0.848, which means that $A(x)$ is explained by 84.8% of the IV on the sample.

In conclusion, the mathematical conjecture of $A(x)$ as a function of maintenance strategy application is valid and can be used cautiously to make reasonable inference

to the target population. The reason for the caution, is that CM strategy is not always going to be a negative variable, George et. al. (2022) explains that CM can be used successfully in non-critical assets (George, Loo, & Jie, 2022).

The CM variable becomes negative if the maintenance practitioner is over-reliant on this strategy. It is noteworthy, to repeat that CM strategy is labour efficient, however due to the nature of catastrophic failures on equipment, it becomes a very costly tactic.

### *5.4.2. Discussion of $MTBF(x)$ Conjecture*

The conjecture that was postulated for $MTBF(x)$ could not be tested due to the shortcoming on the research design. This question was intended to gather information with regards to the MTBF perceived by the target sample. However, erroneous responses were received. Hence, the information received could not be used for analysis.

However, further research revealed that $A(x)$ and $MTBF(x)$, can be related with the below formular derived below. Dos Santos et al. (2016) explained that $A(x) = \frac{MTBF}{MTBF+MTTR}$ (dos Santos Silva, Garcia Viana, & Aquino Queiroz, 2016), rearranging the formular shows that $MTBF(x) = \frac{MTTR}{1-\frac{A(x)}{100}}$. It is noted from the above formular, that an increase in $A(x)$ results in a proportional increase in $MTBF(x)$. The $MTBF(x)$ conjecture could not be tested or validated due to lack of statistically usable data.

## 5.5. Conclusion of the Discussion

The conclusion that can be drawn from the discussion sections is that the Research Question #1, is partly answered by descriptive information from Figure 12: Maintenance Strategies, which proves adequately that the sample is reliant on PdM strategies. The portion of the proposition that is not adequately answered, is whether PdM strategies achieve relatively higher equipment performance. Therefore, the first research question lacks further information to be fully explained.

The second research question seeks to gain insight about which maintenance strategy is widely used in SA heavy industry of Pulp, Paper and Packaging, the proposition was

that PM strategies are widely used. The conclusion was that the PM strategies come second to the Combined Strategies.

This is a plausible and exciting result, as the combined strategies have been found in the literature review to have positive cost benefits. Considering that the cost maintenance can be between 15% to 70% of the total cost of production (Bevilacqua and Braglia, 2000 as cited in Salonen, 2011). The application of combined strategies will allow for cheaper tactics (i.e., CM) to applied where they fit the need.

In short, the research question #2 objective is achieved, as the sought-after insight with regards to “which strategy is widely in application in the target population”, is gained, the “strategy widely applied is a combination”. Though the initial proposition is not necessarily the correct strategy that was expected to be in abundant use.

With regards to the Mathematical Conjecture for $A(x)$, that was formulated to predict the model was to explain availability adequately, the model was also found to be reliable. The $MTBF(x)$ conjecture could not be analysed due to research design shortcomings.

# 6. Conclusions and Future Recommendations

This last section of the research report expands on the discussion of research objectives, by clarifying whether the insights that we sought were indeed obtained. This section revisits the research problem to recommend further efforts that can be taken to enhance conclusiveness of the research propositions. Furthermore, the conclusions on this section impart recommendations for future research, they highlight managerial implications brought to the fore by the results of this research, as well as theoretical implications that may need to be expanded upon, and that may trigger new studies and change in relevant industry maintenance policies of companies in question.

This section has the following subsections:

1. Conclusion on Objective #1
2. Conclusion on Objective #2
3. Theoretical Implications
4. Research Limitations
5. Managerial Implications
6. Recommendations on Future Research

## 6.1. Conclusion of Research Question #1

The most notable conclusion of the abovementioned research question is that we do find that PdM strategies are perceived to be beneficial in terms of achieving increased availability. But the remaining question is how much more beneficial it is relative to other strategies, including a combined strategy. The question of relative degree of equipment performance improvement could not be adequately supported through the analysis, which means that this research question could not be answered fully.

Furthermore, the research problem of main concern on this study, is “which strategy will enable SA’s Pulp, Paper and Packaging fixed assets to achieve world class equipment performance, such as availability of 90%?”. It is noteworthy, that 67% of the sample attested that their facilities equipment performance was already above world class. Which is of strategic competitive advantage position for SA’s Pulp, Paper and Packaging Sector.

It is recommended that research design be reconsidered, for a range of questions that will test quantitatively the relative benefit of each of the maintenance strategy. The gradient of the regression line between DV which is availability, and IV maintenance strategy in question, will define this relative benefit. It would be interesting to see, for maintenance practitioners, to know the abovementioned relationship from an empirical study. This above recommendation will provide significant quantitative backing, to the qualitative literature that already exist, and close the research gap, at least for the Pulp, Paper and Packaging Sector in SA.

## 6.2. Conclusion on Research Question #2

The second research question was strategically setup to unveil the strategies that are currently applied in the SA's Pulp, Paper and Packaging Sector. Whilst the first research question intended to understand "what is the perceived as best strategy that would yield relatively higher availability?". The first and second research question results uncover a gap between the perceived as best strategy, and what the industry is currently using. Which should trigger maintenance policy questions for those respondents who are not achieving world class equipment performance.

The exciting outcome from this research question is that it was answered satisfactorily. The outcome of the widely used strategy in SA's Pulp, Paper and Packaging Industry is the combined strategy (i.e., a combination of all the strategies presented Proactive and Reactive). The proposition had been that PM strategies are the ones widely used, which is not necessarily true.

Therefore, for maintenance practitioners concerned, it is of great importance, that in the future an understanding is reached, on whether the respondents that had equipment availability exceeding 91-100% are reliant largely on combined strategy. This as a further study, would be instrumental and would cement the claim of a strategy, that if applied diligently, would yield equipment performance exceeding that of world class. The above recommendation should be of management's top priority, as this revelation will enable management to understand the relative contribution of each variable of strategic tactic.

## 6.3. Conclusion of Postulated Mathematical Conjecture

The conjecture was tested for reliability and proved valid and significant. The DV which is availability that was computed, which was subsequently found to be explained sufficiently by the IV that were sampled. The only component for conjecture that was not computed was the amount of error built into the equation. The take away is that, If the conjecture holds true, therefore the qualitative existing literature used to formulate the conjecture is also true. Which is also true for the target population.

On the other hand, The mathematical conjecture for $MTBF(x)$ was incorrectly assessed through the questionnaire, the research design lacked critical variable called mean time to repair (MTTR). Though $MTBF(x)$ is function of availability, the study failed to test the sample for MTTR, which is a critical variable that could not be assumed for the sample.

## 6.4. Theoretical Implications

If maintenance cost accounts for such a high proportion of cost towards production in industry in general, it is therefore of management interest to have quantified relative benefits of each strategy. Tsang et. al. (1999) supports this statement by saying that, accurately measuring maintenance performance should be management's top priority (Tsang, Kolodny, & Jardine , 1999).

Reflecting on the above statement contrasts the main theoretical implication of this research to the body of knowledge. As it provides further insight to the effected strategies in the SA's Pulp, Paper and Packaging Sector. It has brought clarity that a combined strategy is most perceived as imperative to achieving high equipment performance, this selection is cost efficient enough to be practical in the real world. The most important theoretical contribution from this study, is the insight gained with regards to the fact that PM strategies consume most of the planned capacity, this is a positive indication and enables inference to be made for SA companies within this sample, that they compete for the future.

## 6.5. Research Limitations

The study focuses only on the Heavy Industry Operations, and targets maintenance practitioners' perceptions of maintenance strategy performance, the end-user's perception is not factored in to eliminate the bias, towards self-protection. This study's findings have appreciable external validity, and are transferable, but only to the Pulp, Paper and Packaging Sector.

The additional limitation is that maintenance performance measurement is not standardised across the studied sector of industry. Therefore, the data collected for this study has an inherent error, which may question credibility of the conclusions. The definitions, calculations, perceptions may be different across the target companies in question, resulting dissimilar variables being compared on the study. In the case of Sappi Limited, there is Engineering Availability and OEE availability, these are different availability numbers. Therefore, it is noted that future studies, there is a need to be more specific with regards to which definition of variables are targeted, for increased internal validity.

Furthermore, most variable measurements can be in form month-to-date, year-to-date, and instantaneous. The research design, failed to be specific with regards to which measurement average is sought.

One of the most notable limitations of this study, is that the population size is not known, which makes the sample sizing exercise have a degree of error. The reason for the sample size to be small is fact that the study, focuses on a particular group of expert practitioners of maintenance, all of which would be considered specialised. Which further makes this sample small.

## 6.6. Managerial Implications and Recommendations

Maintenance practitioners in SA, through this research gain invaluable insight, with regards to which strategies are widely employed, and they gain benchmarking insight of the major industry players in SA's Sector of the Pulp, Paper and Packaging.

The results will also trigger re-evaluation of employed maintenance strategies in sampled operations, and other relevant manufactures. The sample showed a relatively high number of the respondents, whose equipment performance in their operation is higher than that considered world class. Which is excellent, as this means that SA's health of the fixed assets in the Pulp, Paper and Packaging, is competitive.

The understanding that 67.9% of Heavy Industrial Fixed assets in the Pulp, Paper and Packaging Sector perform at 91-100% plant availability. Enables this research to provide baseline data for benchmarking the sector, against the World Class of 90%, SA's average availability is higher. Velmurugan et. al. (2014) supports the above statement, by saying that benchmarking is adapting best practices from the high performer (Velmurugan & Dhingra, 2014, p. 12).

## 6.7. Recommendations on Future Research

It is recommended that in the future, that the quantitative relative benefit of each of the maintenance strategies is defined. It is also recommended that the future research design, should be considered carefully, as well the sample size to be increased as much as possible. For validity and reliability tests, it is recommended that real equipment performance secondary raw data be accessed for each of the target organizations, to be able to compare with the responses from a quantitative survey.

The future research would need to build into the research design methodology, a strategy to attract more participation, from wider range of companies in this sector. This will increase the reliability of the results, as well as the generalizability to the entire population of the companies that operate in the Pulp, Paper and Packaging Sector.

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# 8. Appendices

## 8.1. Appendix A – Participant Information Sheet

Dear Participant,

My name is Bongani Bhengu, and I am a Masters student in Business Administration at the University of the Witwatersrand, Johannesburg. As part of my studies, I must undertake a research project, and I am investigating "Effects of Maintenance Strategies on Equipment Performance in the Heavy Industrial Sector in South Africa", under the supervision of Dr. Ufuo Oro.

The aim of this research study is to evaluate the effects of strategic maintenance, in selected Heavy Industrial Operations of SA, with particular focus on shedding light to the widely used strategies, and the "Why?", as well strategies that are perceived as most effective in achieving equipment performance competitive advantage.

The questionnaire will take an estimated 5-10 minutes for you to complete. Your responses will be protected, and confidentiality of your participation will be ensured. The raw-data collected will be stored in a password-controlled device and only the researcher will have access to this raw-data. The data set will be deleted after 5 years.

If you have any questions during or afterwards about this research, feel free to contact me on the details listed below. This study will be written up as a research report which will be available online through the university library website. If you wish to receive a summary of this report, I will be happy to send it to you.

If you have any concerns or complaints regarding the ethical procedures of this study, you are welcome to contact the University Human Research Ethics Committee (Non-Medical).

Yours sincerely,

Researcher: Bongani Bhengu (+27 60 494 7784)

Supervisor: Dr. Ufuo Oro. (+234 810 995 7665)

**Figure 17: Participant Consent Form**

## 8.2. Appendix B – Participant Agreement Form

# Consent Form

**Title of project: Effects of Maintenance Strategy on Equipment Performance in Heavy Industrial Operations in South Africa**

**Name of researcher: Bongani Bhengu**
**Student number: 2512764**

I, ....., agree to participate in this research project. The research has objective has been explained to me and I understand what my participation will involve. I agree to the following:

| | | |
|---|---|---|
| I agree that my participation will remain anonymous. | YES | NO |
| I agree that the raw-data I provide may be used in an anonymized format only. | YES | NO |
| I agree that the raw-data I provide may be stored safely by the researcher in a password protected personal computer, for a period not exceeding 5 years. | YES | NO |

..... (signature)
..... (name of participant)
..... (date)

**Figure 18: Participant Agreement Form**

## 8.3. Appendix C – Research Instrument

**Table 5: Draft Research Questions**

| Question | Response Options | Type of Question |
|---|---|---|
| Are you responsible for asset maintenance in SA? | Yes/No | Select one response |
| Which of the companies do you work for? | Mondi, Sappi, Nampak, Mpact | Select one response |
| Are your maintenance objective aligned to the Organizations objectives? | Strongly disagree, disagree, neutral, agree, strongly agree. | Likert |
| What is the degree of reliance on strategy? | Proactive strategy | 0-100% |
| What is the degree of reliance on strategy? | Reactive Strategy | 0-100% |
| What is your facilities equipment availability? | 0-100% | Likert Scale |
| What are your facilities MTBF? | Insert value | Numerical value in hours |
| What strategies are widely used in your operation? | CM or PM or PdM or Combination | Selection of sum to 100% |
| Benefits from each CM | Increased Availability, and MTBF | One selection |
| Benefit from each PM | Increased Availability, and MTBF | One selection |
| Benefit from each PdM | Increased Availability, and MTBF | One selection |
| What is your ratio of following | Unplanned vs. unplanned maintenance activity | Scale 0-100% |
| What is your ratio of following | Back-log to new-work completed | Scale 0-100% |

## 8.4. Appendix D – Ethics Approval

Graduate School of Business Administration
University of the Witwatersrand, Johannesburg

Wits Business School Ethics Committee
Constituted under the University Human Research Ethics Committee (Non-Medical)

### Ethics Clearance Certificate

**Ethics protocol number:** WBS/BA2512764/953
*This certificate is only valid with a legitimate ethics protocol number and signed by the Researcher (below)*

| | |
|---|---|
| **Project title** | Maintenance strategy and equipment performance in the heavy industrial sector in South Africa |
| **Investigator / Researcher** | Mr Bongani Bhengu |
| **Nature of Project** | MBA (Research Article) |
| **Decision of the Committee** | Approved, provided stakeholders and participants are guaranteed anonymity and confidentiality. |
| **Issue Date of Certificate** | 25 09 2022 |
| **Expiry date** | Date of submission of the project / research report |
| **Chairperson** | Prof Anthony Stacey<br>☎ +27 11 717 3587<br>+27 82 880 4531<br>anthony.stacey@wits.ac.za |

**Declaration by Researcher**

*One copy must be signed by the Researcher and returned to the Chairperson of the Wits Business School Ethics Committee.*

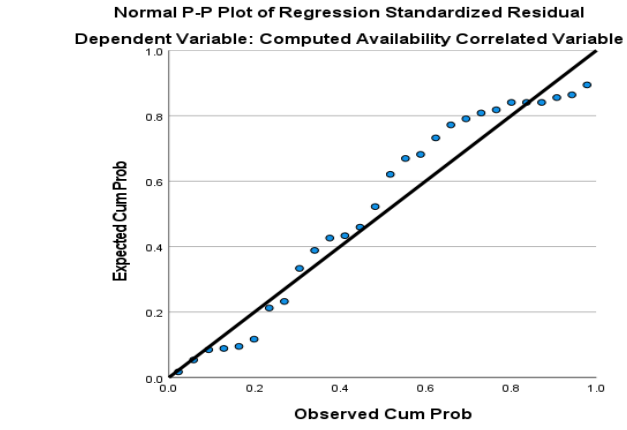
I fully understand the conditions under which I am authorized to carry out the abovementioned research and I guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I undertake to resubmit the protocol to the Committee.

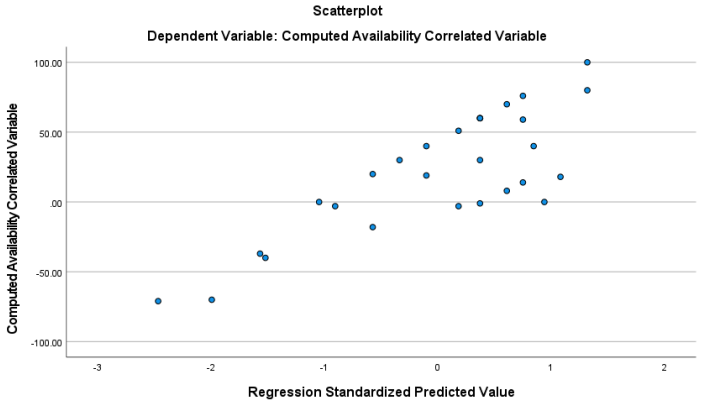
Signature _____ Date: 26/09/2022

**Figure 19: Ethics Approval**

## 8.5. Appendix E – Data Analysis Outputs

### *8.5.1. Research Question 1 – Proposal Results*



### 8.5.2. Appendix E – Statistical Results for Availability Conjecture

**Item Statistics**

| | Mean | Std. Deviation | N |
|---|---|---|---|
| What is the equipment or engineering availability percentage in your plant. | 9.5714 | .69007 | 28 |
| Computed Availability Correlated Variable | 21.1429 | 43.47815 | 28 |
| What is the degree of reliance to Proactive vs. Reactive Maintenance Strategies in you plant? - Proactive Strategies | 72.1429 | 21.12523 | 28 |
| Planned Capacity Utilization | 73.9643 | 13.96419 | 28 |
| What maintenance strategy is widely applied in your plant? | 3.3929 | .95604 | 28 |

Figure 20: Item Statistics Availability Conjecture Reliability Assessment

**Summary Item Statistics**

| | Mean | Minimum | Maximum | Range | Maximum / Minimum | Variance | N of Items |
|---|---|---|---|---|---|---|---|
| Item Means | 36.043 | 3.393 | 73.964 | 70.571 | 21.800 | 1182.503 | 5 |
| Item Variances | 506.603 | .476 | 1890.349 | 1889.873 | 3969.733 | 631843.990 | 5 |
| Inter-Item Covariances | 105.843 | -1.122 | 747.757 | 748.878 | -666.632 | 52506.322 | 5 |
| Inter-Item Correlations | .256 | -.077 | .814 | .891 | -10.580 | .089 | 5 |

Figure 21: Summary of Statistic for Availability Conjecture Reliability Test

**Item-Total Statistics**

| | Scale Mean if Item Deleted | Scale Variance if Item Deleted | Corrected Item-Total Correlation | Squared Multiple Correlation | Cronbach's Alpha if Item Deleted |
|---|---|---|---|---|---|
| What is the equipment or engineering availability percentage in your plant. | 170.6429 | 4643.720 | .060 | .110 | .606 |
| Computed Availability Correlated Variable | 159.0714 | 774.143 | .821 | .791 | .226 |
| What is the degree of reliance to Proactive vs. Reactive Maintenance Strategies in you plant? - Proactive Strategies | 108.0714 | 2580.884 | .756 | .688 | .255 |
| Planned Capacity Utilization | 106.2500 | 3901.972 | .317 | .322 | .534 |
| What maintenance strategy is widely applied in your plant? | 176.8214 | 4581.930 | .518 | .449 | .596 |

Figure 22: Availability Conjecture Items Statistics

**Correlations**

| | | Are you responsible for asset maintenance in SA? | Which of the companies do you work for? | Are your maintenance objectives aligned to the Organizations objectives? - Scale | What is the degree of reliance to Proactive vs. Reactive Maintenance Strategies in you plant? - Reactive Strategy | What is the degree of reliance to Proactive vs. Reactive Maintenance Strategies in you plant? - Proactive Strategies | What is the equipment or engineering availability percentage in your plant. | Computed Availability Correlated Variable | What maintenance strategy is widely applied in your plant? | What are benefits or draw-backs from applying Corrective Maintenance Strategies in your plant? | What are benefits or draw-backs from applying Planned Maintenance Strategies in your plant? | What are benefits or draw-backs from applying Predictive Maintenance Strategies in your plant? | Unplanned Capacity Utilization | Planned Capacity Utilization |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Are you responsible for asset maintenance in SA? | Pearson Correlation | 1 | .410* | .010 | .049 | .319 | .175 | .122 | -.116 | .207 | -.096 | -.072 | -.061 | .061 |
| | Sig. (2-tailed) | | .030 | .959 | .806 | .098 | .372 | .535 | .556 | .291 | .627 | .726 | .756 | .756 |
| | N | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 26 | 28 | 28 |
| Which of the companies do you work for? | Pearson Correlation | .410* | 1 | .334 | .240 | -.260 | .519** | -.286 | -.431* | .312 | -.284 | -.490* | -.041 | .041 |
| | Sig. (2-tailed) | .030 | | .083 | .219 | .182 | .005 | .140 | .022 | .106 | .143 | .011 | .836 | .836 |
| | N | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 26 | 28 | 28 |
| Are your maintenance objectives aligned to the Organizations objectives? - Scale | Pearson Correlation | .010 | .334 | 1 | -.264 | .100 | .436* | .225 | .327 | -.124 | .050 | -.341 | -.023 | .023 |
| | Sig. (2-tailed) | .959 | .083 | | .174 | .611 | .020 | .249 | .089 | .530 | .800 | .088 | .906 | .906 |
| | N | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 26 | 28 | 28 |
| What is the degree of reliance to Proactive vs. Reactive Maintenance Strategies in you plant? - Reactive Strategy | Pearson Correlation | .049 | .240 | -.264 | 1 | -.492** | -.115 | -.906** | -.560** | .113 | -.089 | .221 | .404* | -.404* |
| | Sig. (2-tailed) | .806 | .219 | .174 | | .008 | .561 | <.001 | .002 | .569 | .652 | .278 | .033 | .033 |
| | N | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 26 | 28 | 28 |
| What is the degree of reliance to Proactive vs. Reactive Maintenance Strategies in you plant? - Proactive Strategies | Pearson Correlation | .319 | -.260 | .100 | -.492** | 1 | -.077 | .814** | .463* | .073 | -.147 | -.012 | -.188 | .188 |
| | Sig. (2-tailed) | .098 | .182 | .611 | .008 | | .697 | <.001 | .013 | .710 | .455 | .952 | .339 | .339 |
| | N | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 26 | 28 | 28 |
| What is the equipment or engineering availability percentage in your plant. | Pearson Correlation | .175 | .519** | .436* | -.115 | -.077 | 1 | .039 | -.072 | .079 | -.122 | -.128 | -.294 | .294 |
| | Sig. (2-tailed) | .372 | .005 | .020 | .561 | .697 | | .843 | .715 | .691 | .537 | .534 | .128 | .128 |
| | N | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 26 | 28 | 28 |
| Computed Availability Correlated Variable | Pearson Correlation | .122 | -.286 | .225 | -.906** | .814** | .039 | 1 | .598** | -.039 | -.012 | -.159 | -.361 | .361 |
| | Sig. (2-tailed) | .535 | .140 | .249 | <.001 | <.001 | .843 | | <.001 | .842 | .952 | .439 | .059 | .059 |
| | N | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 26 | 28 | 28 |
| What maintenance strategy is widely applied in your plant? | Pearson Correlation | -.116 | -.431* | .327 | -.560** | .463* | -.072 | .598** | 1 | -.164 | .101 | .225 | .049 | -.049 |
| | Sig. (2-tailed) | .556 | .022 | .089 | .002 | .013 | .715 | <.001 | | .403 | .609 | .270 | .805 | .805 |
| | N | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 26 | 28 | 28 |
| What are benefits or draw-backs from applying Corrective Maintenance Strategies in your plant? | Pearson Correlation | .207 | .312 | -.124 | .113 | .073 | .079 | -.039 | -.164 | 1 | .017 | .038 | -.129 | .129 |
| | Sig. (2-tailed) | .291 | .106 | .530 | .569 | .710 | .691 | .842 | .403 | | .931 | .854 | .515 | .515 |
| | N | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 26 | 28 | 28 |
| What are benefits or draw-backs from applying Planned Maintenance Strategies in your plant? | Pearson Correlation | -.096 | -.284 | .050 | -.089 | -.147 | -.122 | -.012 | .101 | .017 | 1 | .246 | -.237 | .237 |
| | Sig. (2-tailed) | .627 | .143 | .800 | .652 | .455 | .537 | .952 | .609 | .931 | | .225 | .225 | .225 |
| | N | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 26 | 28 | 28 |
| What are benefits or draw-backs from applying Predictive Maintenance Strategies in your plant? | Pearson Correlation | -.072 | -.490* | -.341 | .221 | -.012 | -.128 | -.159 | .225 | .038 | .246 | 1 | .101 | -.101 |
| | Sig. (2-tailed) | .726 | .011 | .088 | .278 | .952 | .534 | .439 | .270 | .854 | .225 | | .625 | .625 |
| | N | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 |
| Unplanned Capacity Utilization | Pearson Correlation | -.061 | -.041 | -.023 | .404* | -.188 | -.294 | -.361 | .049 | -.129 | -.237 | .101 | 1 | -1.000** |
| | Sig. (2-tailed) | .756 | .836 | .906 | .033 | .339 | .128 | .059 | .805 | .515 | .225 | .625 | | .000 |
| | N | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 26 | 28 | 28 |
| Planned Capacity Utilization | Pearson Correlation | .061 | .041 | .023 | -.404* | .188 | .294 | .361 | -.049 | .129 | .237 | -.101 | -1.000** | 1 |
| | Sig. (2-tailed) | .756 | .836 | .906 | .033 | .339 | .128 | .059 | .805 | .515 | .225 | .625 | .000 | |
| | N | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 26 | 28 | 28 |

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

**Figure 23: Pearson Correlations and Sig. (2 -tailed).**