Is forecasting the solution to operations management difficulties in the South African energy sector?

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FLOWCAST

PROCESS FORECASTING

ABSTRACT

The global growing demand for increased operational availability and safety, system productivity, quality of products and customer satisfaction has all raised the importance of successful operations management. Considering this statement, power stations are still operated with limited knowledge regarding future operational performance. When power generation load output losses or hardware failures occur on a power station as a result of system constraints, employees are forced to respond in a re-active manner instead of having the benefit of pro-actively preventing operational problems from occurring.

The primary objective of the study was to establish if Process Variable Forecasting (PVF) can improve Operations Management at a power station. To this end, implementation of Process Variable Forecasting took place in the form of Flowcast®, which is a practical implementation of thermo-hydraulic analysis results from the modelling of coal fired power stations in order to predict its future operational outputs. Flowcast® was developed based on the skills the researcher obtained as part of the NWU SBG MBA course, combining Financial, Operational and Strategic Management courses in order to provide industrial entities with operational performance forecasts. Exhibits are presented of practical results where process variable forecasting was used to alleviate operations management difficulties at Alpha, Kilo and Tango coal fired power stations. Examples include engineering resources applied to other operational constraints subsequent to PVF being used to identify inherent operational constraints. Along with this seasonal capital expenditure of hardware components could be diverted to cover operational costs incurred on other operating units. Maintenance crews which had to do repetitive inspections on previously constrained systems were freed up to be re-allocated to other balance of plant systems to perform preventative maintenance. The total generating output of these stations was also increased, enabling more power to be produced and increasing the revenue of the stations.

Secondary objectives were also established in order to support the primary objective of the study. These objectives were shaped after prudent consideration given to literature which outlines critical influencing factors which promote efficiency and effectiveness in any operational environment. The secondary objectives included amongst others, establishing if employees perceive that PVF will positively influence their working environment and duties; if improved learning experiences and knowledge transfer can be stimulated when using PVF; and if PVF will be helpful for operational and routine maintenance planning. A total of 102 respondents from the Charlie, Mike and Tango coal fired power stations took part in an empirical study by way of answering questions via a questionnaire in order to support the primary and secondary objectives of the study.

Cronbach's alpha was used in order to determine the reliability of five constructs within the questionnaire namely *Working Environment*, *Quality of Work*, *Effectiveness of Work*, *Learning* and lastly *Forecasting*. The Cronbach's alpha of *Effectiveness of Work*, *Learning* and *Forecasting* all showed acceptable reliability of the constructs.

A very high percentage (46%) of respondents indicated that they feel over worked in their current working environment, while 92% agreed that PVF can have a positive change on their working environment. This is an indication that PVF can possibly reduce the overburdened sentiment which the respondents experience within their operational working environment. Execution of proper routine maintenance is one of the most important aspects within an operational environment since it provides the platform for operational reliability. More than 95% of respondents agreed that PVF will enable better routine maintenance to be done along with 92% who supported the improvement of effectiveness of operational tasks carried out by virtue of PVF.

Amongst others, operations management focus on sustainably preventing defects and minimizing operational constraints as far as possible. Proper management of these constraints and defects are essential since they directly correlate with operational stability, throughput and operations cost. Respondents agreed that PVF enables better management of the effect of defects and system bottlenecks (97%) and more than 96% of respondents agreed that PVF can improve operation management difficulties.

Keywords: South African Energy Sector, Forecasting, Operations Management, Flowcast

In Memory of Mr. Dhiraj Maharaj my mentor and dear friend who tragically passed away a week before the completion of this mini-dissertation. Your wisdom and vision gave birth to the concept of harnessing process variable forecasting to help make the South African Energy Sector a better place.

We are taking photos of Pluto and sending people to the moon, yet the way in which we approach our industry problems have not changed for the last 30 years.

Dhiraj Maharaj (Kriel Power Station Technical Plant Manager)

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Making the decision to do an MBA is a gradual process. At first you start to read about it, paging through financial blogs and magazines, considering the process of intellectual enrichment and making new friends in different business sectors of South Africa. The romantic idea then shakes hands with reality when you wake up one morning with uncombed hair and unbrushed teeth, looking yourself in the mirror and saying out loud… I am going to do this!

My MBA experience was one of the most rewarding and stimulating endeavours I have had the fortune of completing. Exposure to subjects like Operations Management, Financial Management, Strategic Management, Entrepreneurship and many more provided me with practical tools to approach the business sector afresh and with new creative ideas. As a result, the MBA enabled me to develop an operational forecasting service called Flowcast® which has subsequently been implemented at several operational entities in South Africa and already enable clients to save millions of Rands due to its unique approach to analyse and solve operational constraints. Thank you to the lecturing and support staff of the NWU SBG for making this a reality.

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ABB	ASEA Brown Boveri
ACU	Air cooling unit
CFD	Computational fluid dynamics
dP	Differential Pressure
GPS	Global Positioning System
i.e.	id est
ID	Induced Draft
ISO	International Organisation for Standardisation
kPa	kilo pascal
KPI	Key Performance Indicator
MBA	Master of Business Administration
MOC	Maatla Otlhe Consulting
MTBF	Mean Time Between Failure
MW	Megawatt
NERSA	National energy regulator of South Africa
NWP	Numerical Weather Prediction
NWU	North-West University
OEM	Original Equipment Manufacturer
PA	Primary Air
POS	Point of Sale
PVF	Process variable forecasting
SA	Secondary Air

SOW	Scope of Work

CHAPTER 1: NATURE AND SCOPE OF THE STUDY

1.1 INTRODUCTION

Flowcast® was developed based on subjects presented at the North-West University (NWU) School of Business and Governance. Subjects including the likes of Operations Management, Financial Management, Strategic Management and Entrepreneurship all provided a platform of practically identifying challenges experienced within an organisation and how to analyse and create innovative solutions to address such shortcomings. Working within the energy generation sector for the last 10 years, the tools acquired within the MBA programme enabled the researcher to identify specific operational challenges at five different power stations, study the shortcomings, implement solutions and evaluate the results.

The Flowcast® service, which was developed by the researcher along with engineers of Maatla Otlhe Consulting (MOC), makes use of the thermo-hydraulic software package Flownex and applies the operations management principle of forecasting while utilizing process variable analysis results. The integration of these value adding services enabled the birth of the concept of **Process Variable Forecasting** (PVF), which will be discussed in detail in this mini-dissertation.

This study presents an analysis of specific operational challenges at five coal fired power stations. The use of forecasting in the form of PVF was used to show improved performance under different operational scenarios and supported by station personnel from different departments who completed detailed questionnaires which analysed their experience and exposure to the forecasting approach.

The strategic goal of employing process variable forecasting is to ensure a common harmony exists between the departments of an industrial plant by offering a holistic solution to its employees by leveraging all of the organisations' different strengths in the form of its best practices and processes and unlocking the potential of all of its employees. The focus therefore is to create an empowering environment between employees, their plant and its processes. Therefore, the focus of this research study will be on all three of the above-mentioned aspects, since a synergy needs to be created between them for PVF to be implemented successfully. The ultimate objective of PVF is therefore not only operations improvement translating into financial gains, but also the well-being of the employees working at these power stations.

By employing this strategic approach, PVF can be used by an organisation to reduce its operation management difficulties by managing its employees as its greatest asset and not necessarily its hardware or systems. The reasoning behind this is that although many coal fired power stations have systems and processes which are revolutionary and unique, the challenge of constant change in its operational businesses, its market and its clients is a reality. Given the daily constant of change in its operations entities, creating a stable and reliable platform from which change can be managed is important. It is proposed that this stable and reliable platform vests within an organisation's employees. To achieve this, PVF underlines the importance that industrial organisations need to invest in the wellbeing of its workforce, who will ultimately be the driver behind the execution of forecasting solutions.

Chapter 1 describes the problem statement and establish the primary and secondary research objectives of this study. The research methodology used in this research study will also be discussed and a short overview of each chapter will also be provided

1.2 PROBLEM STATEMENT

Despite 21st century technology improvements in the power generation industry, power stations are still operated with limited knowledge regarding future performance. When power generation load output losses or hardware failures occur on a power station as a result of system constraints, employees are forced to respond in a re-active manner instead of having the benefit of pro-actively preventing problems from occurring.

Eskom, South Africa's power generation utility, has been heavily criticised in the media for its role in the country's poor economic standing and future growth outlook (Business Day Live, 2015). Many economists believe that the tariff rate hikes in the price of electricity awarded by the National Energy Regulator of South Africa (NERSA) to Eskom, is to blame for a slowdown in private sector growth and a downturn of foreign investment in the country. President Jacob Zuma said the extent of load-shedding and uncertainty of supply was the "biggest challenge" facing the country (Finweek, 2015). Eskom on the other hand has voiced their frustration and highlighted the fact that most of its fleet of power stations are older than 45 years and require regular outage maintenance. These maintenance interventions are required because of equipment breakdowns. To this end, energy experts have voiced their concern on what they believe is poor operations management which led to equipment breakdowns, and ultimately compounds to a rise in operating costs. The Duvha Unit 3 incident in 2014 is highlighted as an example of poor operations management, when a boiler tube leak alarm was ignored and sufficient boiler clinker management was not applied (a clinker is ash which melted and hardened over time). This lead to extensive damage and rendered the unit out of service with more than R4.5 Billion damage (Moneyweb, 2015).

Heizer and Render (2014:40) describe operations management as a set of undertakings which create value in the form of services or goods by converting inputs into outputs. In the instance of a coal fired power station, this entails the pulverizing of coal (input) which is burned in a boiler to change water (input) to steam, eventually used to drive a turbine connected to a generator, which produces electricity (output). Jacobs *et al*. (2010:6) explain that operations management can also be described as the design, operation and improvement of those systems which generate the organisation's main products or services. The improvement of systems is an important aspect underlined by Jacobs *et al*. (2010:6) since only designing and operating a system will eventually translate to operation management difficulties. To this end, the improvement of systems is synonymous with operational efficiency, a critical part in modern day operations management.

In order for a power station to function successfully it relies on the three pillars of its operations management, namely engineering, maintenance and plant operating. Integration between these three disciplines is vital. The integration ensures these three departments are aligned with the common objective of operating a power station to generate as much electricity as possible. The second objective is to promote a better understanding of each department's role in ensuring a common goal is achieved. Heizer and Render (2014: 693-697) confirm this by underlining the correlation of operator, artisan and machine with that of successful operation, maintenance and reliability. The integration of these three operation management departments still face individual challenges which can sometimes result in delayed employee reaction to an operational risk. If forecasts can predict which hardware or systems will become constrained in the future it may provide employees more time to prepare themselves for when it occurs. This can contribute toward employees being better prepared and in all likelihood improve the operations management performance when faced with a potential operational risk.

Survey data from Lindberg (1990:94) shows that variances in the length of plan horizons for work organisations and control systems create substantial problems in manufacturing, especially with personnel and quality issues. The phenomenon is to a large extent attributed to a lack of integration between systems/departments. It is proposed that the integration (which is achieved with a greater plan horizon) is vital for all proactive endeavours. The data also shows that successful operations are underpinned by effective implementation of quality control, integration of different departments, successful maintenance management and involvement of relevant employees in operations (Lindberg, 1990:94).

Flowcast® is a future system performance forecast service which provides detailed process variable forecasts (PVF). Projections can be made between three to five days in advance. The Flowcast® methodology uses advanced thermal fluid modelling and historical data to evaluate the operating condition of the power plant. The future process-health, i.e. turbine condenser pressure and the individual component-health, i.e. mill dP, essentially indicating how effective the mill works, can also be determined by PVF. Actual plant conditions are used to characterise thermodynamic models in relation to the plant conditions in order to establish accurate and reliable forecast results. These results are intended to enable power station personnel to pro-actively prepare for system constraints in a hope to better manage the effect of defects and system bottlenecks.

The main objective of this research study will be to determine whether this upfront indication of system and hardware challenges, which allows more time to react and prepare better, can stimulate better integration between the various departments and as a result improve overall operations management.

1.3 OBJECTIVES OF THE STUDY

The objective of this study is to ensure that both the primary and secondary objectives of the study is supported by the literature review and the empirical study:

1.3.1 Primary objective

The primary objective of this study is to establish if Process Variable Forecasting (PVF) can improve Operations Management at a power station.

1.3.2 Secondary objectives

In order to support the primary objective, secondary objectives were also created:

1. Analyse the sentiment which employees hold towards their working environment and work responsibilities.
2. Establish if employees perceive that PVF will positively influence their current work activities and environment.
3. Analyse the sentiment which employees hold towards the quality of work performed and how external factors can influence it.
4. Confirm if PVF will be helpful for operational and routine maintenance planning.
5. Discover if improved learning experiences and knowledge transfer can be stimulated when using PVF.
6. Determine if better management of the effect of defects and system constraints can be achieved when employees have upfront knowledge of emerging operational problems.

1.3.3 Literature review objectives

The literature review objective is firstly to determine if suitable literature is available which will be applicable to Process Variable Forecasting in the coal fired power generation industry. Depending on the suitability of the literature available, this information will be used in order to support the development of Process Variable Forecasting mechanisms and processes which can be used for operations management at a coal fired power station.

1.4 SCOPE OF THE STUDY

The scope of this study is presented by discussing the field of study as well as the research setting.

1.4.1 Field of study

The field of study can be classified as Operations Management – although there is a strong engineering element present in the description of the benefits of PVF within Operations Management. Long lead times, operational bottlenecks and equipment breakdowns are all examples of operations management difficulties experienced at coal fired power stations. When employees respond reactively to these operations management difficulties, it further contributes towards the problem. When breakdowns and system constraints occur, it exposes weaknesses in the stations' operations management. One example is the inter-departmental integration between engineering, operating and maintenance at the power station. These three departments are viewed as the three pillars of operations management at power stations. Sufficient preparedness to deal with plant defects and quick turnaround times to properly react to an operational problem appears to be a challenge at most stations at times. If this can be improved it can drastically enhance the efficiency of power station operations management. If PVF can be used to project when systems or hardware problems will occur in three to five days' time, it will ease out operations difficulties. However, PVF will not be able to ensure that operations management will be done better. It is very important to remember the following concepts:

- When a unit at a power station is offline, it cannot generate electricity and therefore its revenue collection for that period stops.
- To get the unit back online to generate electricity is costly in itself, along with the fact that these costs grow with every hour the unit is off-line.
- Reactive response time by employees is one of the contributors which can lead to a unit to go offline.
- PVF will be able to project when a unit becomes more constrained from a generating output perspective three to five days before it happens.
- By knowing in advance which systems or hardware will provide problems, it will make the general operations management easier and make it more effective.

With the Flowcast® PVF service (3-5 days warning in advance) instructions for preventative maintenance actions and operational readiness can be provided in advance to resolve problems which have not yet manifested in the plant. This study investigates whether this extra time and specific identification where the problem will be, can allow operations management to be proactive to challenges associated with reactive behaviour towards operational problems.

1.4.2 Research setting

The entities which will form part of the research study is situated at five different coal fired power stations, that being Alpha, Charlie, Kilo, Mike and Tango Power Station (pseudonyms), all in the province of Mpumalanga. The researcher has been working at power stations for more than ten years and can identify and relate to the operational management challenges of power station personnel. The selection of these coal fired power stations, with their maintenance, engineering, operating and production departments provide a unique and comprehensive blend of operational challenges which can be experienced in a modern day South African industrial plant.

Due to the fact that the researcher works at these power stations, access to the station personnel occurs on a daily basis. The information obtained from the research participants will be presented to the power station management. This research study can be used by research participants to further unlock ground-breaking answers to research questions in the field of Operations Management in the energy sector of South Africa. This can also support further research endeavours in this field of study. Figure 1 shows where the five power stations are situated in Mpumalanga.

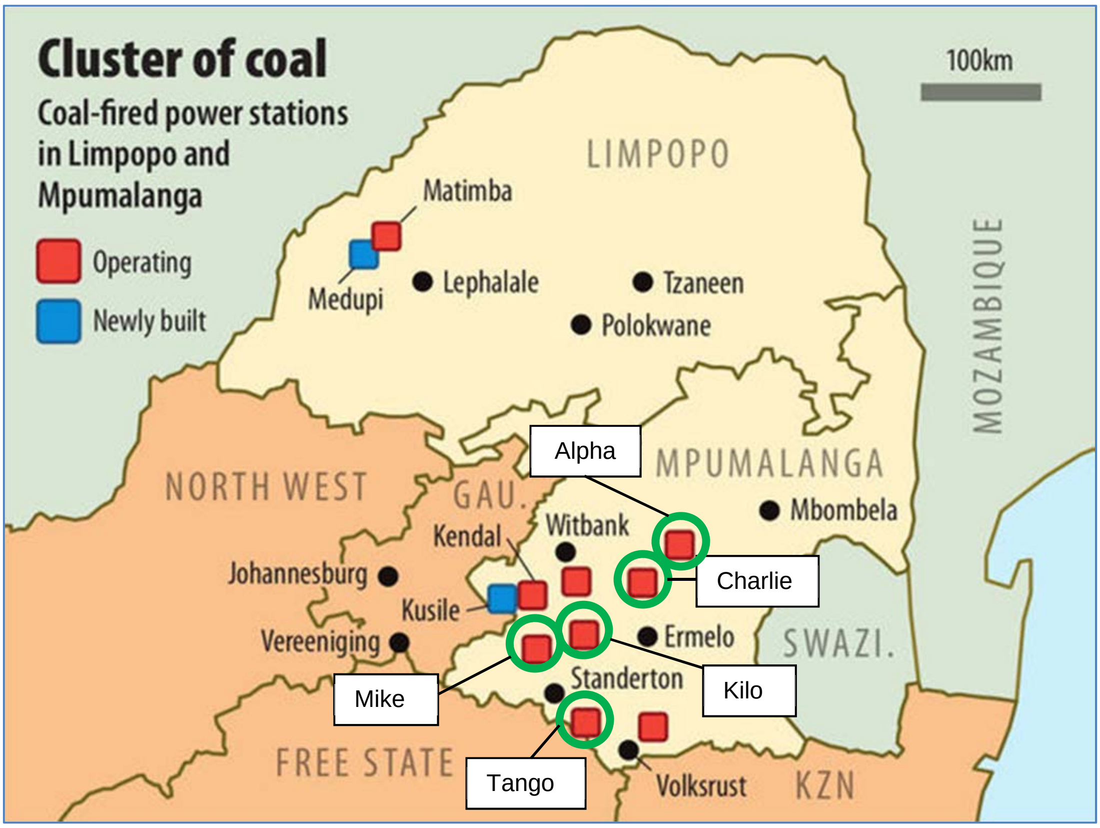


Figure 1: Coal fired power station in Mpumalanga and Limpopo

(Source: Mail and Guardian, 2014)

1.5 RESEARCH METHODOLOGY

The research follows a positivist philosophy, operationalised through a quantitative approach.

1.5.1 Literature review

PVF as employed by the Flowcast® approach is a novel concept. As a result, the researcher made use of academic literature in fields where similarities can be drawn to that of the Flowcast® forecasting approach. One such field is that of early warning hardware failure software systems as well as certain hardware condition monitoring systems. Despite the focus of these approaches looking at hardware performance in isolation and not on the overall holistic performance of an entire power station as with Flowcast®, similarities can be drawn nonetheless. Academic articles which consider the influence of condition monitoring on Operations management were consulted, as well as the role of forecasting within the solar and wind energy generation sector. Databases which were consulted include ScienceDirect and EBSCOhost, as well as industry leaders such as Schneider Electrical, Siemens and ASEA Brown Boveri (ABB) who developed software to improve power plant performance. These companies have also participated in academic research to quantify the impact their software has on improved plant performance, but mostly from an in-situ measurement and control perspective. Despite their alternative focus on plant performance, literature from these organisations was consulted in order to establish or make use of findings relevant to this research topic.

The following sources were used to compile the literature review:

1. Academic articles
2. Academic dissertations
3. Academic journals
4. Newspaper articles
5. National surveys conducted on coal-fired power providers in South Africa

1.5.2 Empirical study

The empirical study made use of a highly structured hard copy questionnaire handed to the respondents by hand for completion. The researcher sought written consent from every individual who was willing to be a respondent in this research undertaking.

Due to the fact that the individuals involved in the study work in an operations environment, the researcher was keenly aware of the fact that the respondents might not always be available to partake in the research despite prior confirmation of engagement times to complete the questionnaire. As a result, the researcher budgeted sufficient time to change questionnaire sessions with groups or individuals at short notice and reschedule for alternative dates. Depending on the nature of the work of the individual, the questionnaire engagements were on occasion interrupted by plant emergencies which required the respondent's involvement. It was therefore necessary to cater for questionnaire sessions to be continued at an alternative time and date. A final point of consideration was that the researcher was wary of individuals who were physically exhausted due to high plant work engagements and the strenuous nature of boiler operations and related temperature exposures. When the researcher felt the respondent was tired and that the response might have been compromised due to the respondent who tries to speed up questionnaire answering process, the researcher proposed an alternative engagement which might elicit more accurate answers from a refreshed respondent.

1.5.2.1 Questionnaire layout

The researcher made use of a structured questionnaire which was handed out at the power stations. A 4-point Likert scale was used providing four answer options namely: Strongly disagree, Disagree, Agree or Strongly agree). In order to ensure that the questionnaire contained meaningful and relevant questions, the researcher conducted a pilot study before proceeding to the full scale empirical field study.

A total of 25 questions were posed in the questionnaire in order to determine whether PVF reduced Operation Management difficulties at a power station. In order to answer the main research objective of this research study, frequency tables were used. This allowed the researcher to determine if the respondents agree or disagree that PVF can reduce operation management difficulties at power stations.

The questionnaire contained eight sections:

Section 1 focussed on the demographics of the respondents and personal information pertaining to their education and tenure. It also enquired at which station the respondent works, within which department, their job description, years working within that specific department and the number of hours required to complete the tasks handed to them.

Section 2 posed the research question of the study which determined if coal fired power station employees believed that process variable forecasting can improve Operations management difficulties at a power station. This question made use of a dichotomous (Yes/No) answer type.

Section 3 focussed on the respondents' working environment. The aim was to understand whether the respondents enjoyed their working environment and their work responsibilities. The section then continues to pose questions more relevant to forecasting within the work environment.

Section 4 focussed on the quality of work within the respondents' work environment. Questions posed in the section included determining if PVF can help with routine maintenance, managing unplanned activities and positively influence the quality of work executed.

Section 5 focussed on determining respondents' effectiveness of work. This section asked questions associated with adding value and being more productive within the workplace.

Section 6 focussed on learning possibilities PVF might unlock. Questions posed to the respondents focussed on PVF's ability to enhance learning experiences of work activities carried out which in turn could potentially support better quality work and enable respondents to complete their work on time.

Section 7 focussed on whether PVF can assist respondents to make better operational decisions, operate the power station more safely and enable better management of defects and bottlenecks.

Section 8 posed the same research question as in Section 2, which determined if coal fired power station employees believed that process variable forecasting can improve operations management difficulties at a power station. This question was asked again (using a Likert scale as opposed to a yes or no answer) to the respondents.

The two most important factors considered in designing the questionnaire was relevancy and accuracy, since this supported the researcher in acquiring accurate results (Zikmund *et al.*, 2013:362). To achieve relevancy and accuracy, the questionnaires provided to the respondents were self-developed by the researcher and provided to the respondents at a specific time interval. The questionnaires investigated the respondents after their exposure to PVF in the operational environment of the power station.

1.5.2.2 Study population

The elements which comprise the sample population, or the study population, used in research projects are defined by Welman, Kruger and Mitchell (2005:53) as a unit of analysis. The unit of analysis can also be referred to as the research participants – the individuals who decide to partake in this research venture. To place this definition into context, the research participants of the study, which can also be viewed as the study population, comprise not only the performance output of individuals but also of the collective of their department or institution as a whole.

The research study at hand was carried out at five coal fired power stations, that being Alpha, Charlie, Kilo, Mike and Tango power stations (pseudonyms). All are located in the province of Mpumalanga, South Africa. The power stations comprise several departments with minor differences between the departmental structures. To this end, there are seven primary departments:

1. Maintenance department
2. Operating department
3. Engineering department
4. Production department
5. Finance department
6. Risk & Assurance department
7. Human Resource department

This study only focussed on the engineers, operators, artisans and managers of three departments, that being the Maintenance, Operating and Engineering departments. Within the Maintenance and Engineering Departments, a further level of distinction can be made:

1. The Maintenance Department comprises:
    a) Mechanical or Heavy Maintenance department

   b) Electrical Maintenance Department
   c) Control & Instrumentation Department

2. The Engineering Department comprises:
   a) Process Engineering department
   b) Boiler Engineering department
   c) Turbine Engineering department
   d) Electrical Engineering department
   e) Control & Instrumentation Engineering department
   f) Auxiliary Engineering department

Along with the Operating department, these nine departments constituting the Maintenance and Engineering departments provide a total of 10 entities which were assessed and analysed as part of this research undertaking. To better describe the research participants, a better understanding of the various departments must be undertaken. The Maintenance departments of Kilo, Mike, Charlie and Tango power stations are concerned with activities such as the following:

1. Planning of work activities and scheduling of relevant plant maintenance.
2. Execution of corrective maintenance for unplanned defects or failures.
3. Execution of preventative maintenance making use of planned activities to prevent defects or failures.
4. Quantifying spares consumption and planning for additional spares acquisition.
5. Providing the Engineering department with a history of work performed in order for Engineering to perform plant and system performance analysis.
6. Provides input to Engineering department for the generation of maintenance procedures.
7. General safety adherence of all maintenance activities to the Occupational Health and Safety Act 85 of 1994 (SA, 1994).

The Kilo, Mike, Charlie and Tango Engineering departments are accountable for the medium to long term asset care management of the stations. The Engineering department is concerned with activities including the following:

1. Root cause analysis when hardware or systems fail or underperform in the station.
2. Improving the technical or financial performance of the power station.
3. Developing and improving maintenance procedures.
4. Motivating and managing system or hardware modifications.
5. Generating technical design documentation for use by maintenance or operating departments.

The Kilo, Mike, Charlie and Tango Operating departments are responsible for operating the power plant, for water cleaning and management as well as chemical services. The primary tasks of this department include:

1. Continuous operation of the power plant.
2. Carries out plant inspections and performs minor maintenance activities.
3. Tracks the daily performance of the plant.
4. Recording all plant incidents.
5. Issues and manages permits to work for all departments performing work on plant equipment in the plant.

By understanding the function of each of these departments, a better understanding of the research participants is also achieved. The explanation above provides a clearer understanding of the integration of the various departments at a power station. This will also assist in highlighting the responsibilities and performance outputs of each individual within a department. Lastly, it can assist in determining how the different departments can influence operations management success at power stations.

The study population of the empirical study focused on the Charlie, Mike and Tango power stations' 10 departments. In total, 150 questionnaires were handed out at the power stations. A total of 102 questionnaires were returned, indicating a 68% return rate. Exhibits of the practical implementation of PVF by means of Flowcast® were carried out at Alpha, Kilo and Tango power stations.

1.5.2.3 Data collection

The research design is a cross-sectional survey with a quantitative research method approach. Questionnaires were handed out to power station employees and completed at the power stations during the same week. The quantitative questionnaire was developed by the researcher to be completed by the respondents. A 4-point Likert scale were used to measure respondents' feedback and to force respondents to make a decision without the option of choosing a neutral answer (as would be the case with a 5-point Likert scale). Before the respondents were handed the questionnaires, they were exposed to the benefits of the Flowcast® forecasting approach (providing them with 3-5 days upfront warning of plant or system constraints before it manifests in the plant). Engineers, operators and artisans were requested to complete the questionnaire. The respondents were asked to indicate their level of agreement or disagreement with aspects pertaining to successful operations management. The questionnaire also tested whether the additional time benefit which forecasting provided them enabled them to prepare better (proactive response is created instead of reactive) for system bottlenecks or defects and that interdepartmental integration is improved.

1.5.2.4 Statistical analysis

Statistical analysis was employed in the research study and various factor analysis tools were utilised. The Cronbach's alpha (α) was used in order to determine the reliability of constructs posed in the questionnaire. The Spearman's correlation coefficient was used to determine the linear relationship between the variables. This will enable the researcher to observe the data and see which correlations have the biggest influence on certain operations processes at the power stations. In order to determine whether the statement of the primary research question is true and is present among the respondents, frequency tables were used to determine if respondents agree or disagree that PVF does improve Operation Management difficulties at a power station.

The nature of this research study is exploratory and therefore it was essential to have a quantitative research approach. The validation of operational management improvement as a result of PVF must be supported by both the respondent feedback, as well as the actual system performance improvement in the power plant itself. By using this approach, the primary research question could be answered without any ambiguity.

The sampling strategy followed in the selection of the various individuals to participate in the study was a probability sampling method of employees who have had exposure to process variable forecasting by means of Flowcast®. The justification for the selection of this sampling method is that the samples are collected by means of a method which allows all individuals in a population an equal opportunity of being selected (Welman *et al*., 2005:56). In order to achieve probability sampling, utilisation of randomisation must occur. The researcher did this by making use of MS Excel's random number generator to select 150 random individuals (with numbers assigned to every individual's name) from the population identified. By following this approach, the intention was to eliminate systematic and sampling bias in order to provide a sample which is representative of the whole population. In order to make sure that the original research intent was achieved, employees from all levels of management and skills level in the departments qualified for selection. As an example, this means that managers like the Engineering and Operating manager, right down to the Plant Operator working in the plant or a Boiler Plant Engineer working in the Boiler Engineering department, all qualified for selection. Due to the fact that operational value for coal fired power stations can only be unlocked when individuals from management right down to floor personnel work together as a unit, the sample selection must cater for all individuals. The aim therefore was to achieve a sample selection which is representative of all skill levels from the population and focus on how PVF can assist them to improve operations management difficulties.

1.6 LAYOUT OF THE STUDY

The chapters in this study are presented as follows:

Chapter 1: Introduction

This chapter explained why the specific research topic was chosen. The problem statement for the research was discussed along with the research goals and methods.

Chapter 2: Literature review

Despite the fact that process variable forecasting (PVF) has not been used on a commercial scale for coal fired power stations before, as will be done by the Flowcast® approach, early indication of hardware failure approaches is commercially available. The aim of this chapter is therefore to evaluate related concepts to that of forecasting within the domain of operations management. A breakdown of different types of forecasts along with the time horizons associated with each one is done. The role of forecasting within the solar and wind energy generation sector was done along with the general use of forecasting as it is currently employed at power stations in South Africa.

Chapter 3: Power stations implementing Flowcast®

This chapter focus on the implementation of the process forecasting service Flowcast® at coal fired power stations and its role in forecasting key system variables and future system performance at power stations. It also highlight the relationship between process variable data produced by the Flowcast® service and its application in operations management.

Chapter 4: Empirical research

This chapter gives an account of the empirical questionnaire development as well as the results obtained from a pilot study which was used to make final adjustments to the final questionnaire handed to respondents on the power stations. It also provides background information on each of the questions contained within the questionnaire.

Chapter 5: Research findings and recommendations

In Chapter 5 the research results are deliberated and the findings are discussed. Conclusions and recommendations are made regarding the benefit process variable forecasting has on improving operations management. Lastly, suggestions are provided for future research which can be conducted in this research field.

The five chapters are visually illustrated in Figure 2 below:

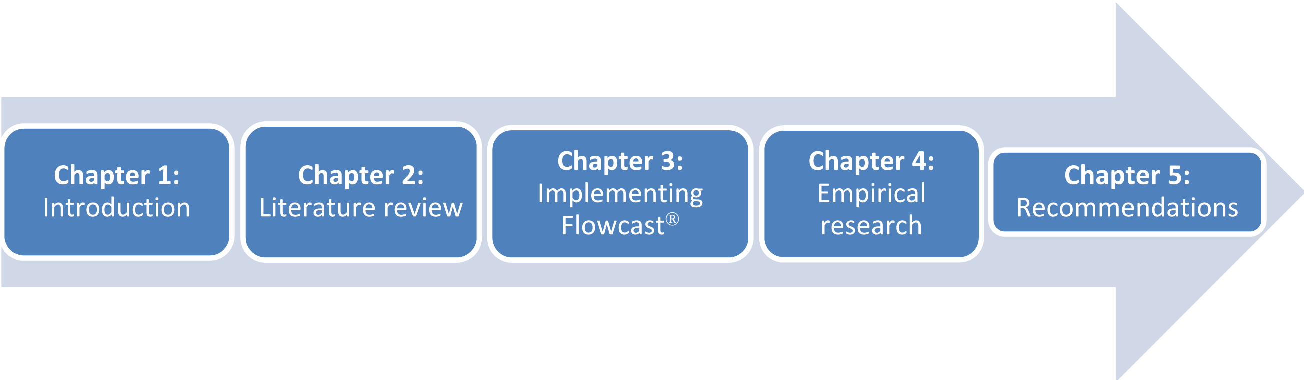


Figure 2: Layout of the study

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

The objective of the literature review is to give an account of relevant academic material which can support the successful empirical and practical research required to determine whether forecasting is a solution for operations management difficulties in the energy sector of South Africa.

The literature review starts off by defining operations management as well as the concept of forecasting within the domain of operations management. This is followed by a breakdown of different types of forecasts along with the time horizons associated with each one. A review of different measurement techniques used as part of condition monitoring and intelligent maintenance in order to facilitate measures of forecasting was also done. The role of forecasting within the solar and wind energy generation sector was reviewed along with the general use of forecasting as it is currently employed at power stations in South Africa.

The integrated role which **people**, **plant** and **process** play within successful operations management is vital. To this end the literature review considers each of these elements along with the role they play in operations management. Consideration should be given to these aspects to clearly define the role which forecasting will play and how it can support these three elements of operations management.

Due to the novel nature and concept of employing process variable forecasting to predict operational output in the coal-fired energy sector, literature relevant to the **process** and **plant** elements within operations management had to be considered carefully. The researcher made use of academic literature in fields where similarities can be drawn to that of the process variable forecasting (PVF) approach. One such field is that of early warning hardware failure software systems as well as certain hardware condition monitoring systems. Despite the focus of these approaches when considering hardware performance in isolation and not on the overall holistic performance of an entire power station as with PVF, similarities can be drawn nonetheless. Regardless of the alternative focus on hardware performance, literature from academic and industrial sources was consulted in order to establish or make use of findings relevant to this research topic.

2.2 DEFINING OPERATIONS MANAGEMENT

Operations management can be defined as a set of undertakings which create value in the form of services or goods by converting inputs into outputs (Heizer and Render, 2014:40). The operations management of a coal fired power station can also be summarised in terms of its value creation when converting its inputs into outputs. This entails the pulverizing of coal (input) which is burned in a boiler to change water (input) to steam, eventually used to drive a turbine connected to a generator, which produces electricity (output). As part of this high-level definition of a production system, the process of converting the inputs into outputs are also supported by raw materials, machines, personnel, buildings, technology, information, cash and additional resources.

Throughout the study the words *operations* and *operational* will be used. With the exception when used within the context of hardware, *operational* will refer to the level of management while *operations* refers to the value creation process.

2.3 THE IMPORTANCE OF SUCCESSFUL OPERATIONS MANAGEMENT

The global growing demand for increased operational availability and safety, system productivity, quality of products and customer satisfaction has all raised the importance of successful maintenance and operations management (Crespo Marquez *et al*., 2006:326). The expectation for improvements in the above-mentioned factors is frequently constrained by decreased profit margins, further underlying the significance of sound operations management (Al-Najjar *et al*., 2003:86).

Pinjal (2006:228) and others make specific reference to the critical function of operations and maintenance management in order to support an organisation to be competitive on the basis of cost, quality and delivery performance by synchronising maintenance with production requirements.

2.4 CRITICAL INFLUENCING FACTORS ON OPERATIONS MANAGEMENT

In order to achieve efficiency and effectiveness in any operational environment, three critical factors need to be present (Gaither and Frazier, 2001:660):

1. Employee engagement and productivity
2. Maintenance management
3. Quality control

2.4.1 Employee engagement and productivity

Various studies have shown the positive contribution which high employee engagement has on organisational productivity. Jalal (2016:63) highlights that an organisation which maintains an engaged workforce encourages more productive operations which in turn stimulates improved financial performance. This sentiment is also shared by Osborne (2017:29) who states that engaged employees generally leads to decreased operational costs, improved finances and increased productivity. The positive correlation between employee engagement and benefits to operations is also highlighted by Chase *et al.* which attribute the success of productive maintenance endeavours to that of employee engagement and information sharing. From an operational perspective the benefit is not only to keep the operational systems in a sound condition and prevent production interruptions, but to also keep operational costs low and maintain a safe operating environment.

2.5 DEFINING FORECASTING

Heizer and Render (2014:140) define forecasting as the art and science of predicting future events. Forecasting can take different forms:

- Using historical data such as past sales and projecting those sales into the future by making use of a mathematical model.
- It may be an intuitive prediction or a subjective one, where a person might for instance state that "this new product is great and will sell 20% more than the old one".
- Customer plans to purchase is an example of demand-driven data. This data can be used to project sales into the future and create a sales forecast.
- Forecasts can also involve a combination of the above-mentioned aspects, where a manager could for instance make use of his own experienced judgement and enter it into a mathematical model in order to get a forecast of expected sales.

In general, there is no one forecasting technique superior to any other (Heizer and Render, 2014:140). There are, however, many factors which can influence forecasts. A product's position in its life cycle for instance, can have a substantial effect. Sales may be in an introduction, growth, maturity or decline stage which could influence the forecast. Some services or products may be influenced by the demand of another product. As an example, the sale of Global Positioning System (GPS) navigation equipment may follow the general sale of new cars (Heizer and Render, 2014:142). It is therefore evident that forecasts also have limits in terms of the success with which they can predict future events. To this end, error measures are used to provide a band within which forecasted scenarios can be expected. This removes the focus from an absolute value of a future scenario to that of a "range" of probable expected scenarios taking place. This is a very important aspect to take into consideration – especially within the energy sector and at power stations.

2.6 DEFINING FORECASTING TIME HORIZONS

When a forecast of an event or scenario is done, it can be categorised in accordance with the future time horizon that it covers. There are three categories within which time horizons of forecasts fall (Heizer and Render, 2014:140):

2.6.1 Short-range forecasts

In general, this type of forecast has a maximum time span of one year, but mostly the applicable time span of this forecast is less than three months. The domain within which this forecast is used is for activities such as purchasing planning, workforce levels, production levels, job scheduling and job assignments (Heizer and Render, 2014:140).

2.6.2 Medium-range forecasts

An intermediate forecast or a medium-range forecast normally spans for a period from three months to three years. This type of forecast is used for activities such as sales planning, cash budgeting, production planning and analysis of different operating plans (Heizer and Render, 2014:140).

2.6.3 Long-range forecasts

This type of forecast is used for extended time spans, generally three years or more. Long-range forecasts are employed for activities or endeavours such as the planning of new products, facility location or expansion, capital expenditures and research and development undertakings (Heizer and Render, 2014:140).

Short-range forecasts can be distinguished from medium and long-range forecasts by three key features (Heizer and Render, 2014:141):

- Gravitas of issues:

  Medium and long-range forecasts tend to deal with more comprehensive issues than short-range forecasts. Endeavours that are supported by medium and long-range forecasts include providing platforms to management to make decisions pertaining to planning and products, processes and plants. The implementation of such decisions can take several years, as in the case of the construction of the Medupi and Kusile power stations that took several years from the inception to completion of their first generating units.

- Different methodologies are employed:

Short-range forecasts usually employ different methodologies to that of the long-range forecasts. The use of mathematical modelling such as exponential smoothing, moving averages and trend extrapolation are more present in shorter term forecasts. Long-range forecasts make use of broader, less quantitative methods for predicting future scenarios.

- More accurate:

Short-range forecasts are generally more accurate than long-range forecasts. Factors which influence the outcome of a scenario change on a daily basis. As a result, an increase in the time horizon usually tends to minimise the accuracy of the forecast. This underlines the importance of regular forecasts in order to maintain the integrity of expected future scenarios or results.

2.7 TYPES OF FORECASTING

For the planning of future operations, organisations use three key types of forecasts (Heizer and Render, 2014:141):

2.7.1 Economic forecasts

These forecasts are primarily used in the business cycle of organisations by predicting aspects such as inflation rates and money supplies.

2.7.2 Technological forecasts

These forecasts are focused on the tempo of technological advancements made in the industry. Forecasts of the creation of new novel products which might require new equipment or new plants for the production, is made with these forecasts.

2.7.3 Demand forecasts

A company's products or services have a certain demand associated with it. The demand for these services is contained within a demand forecast which is a projection of the future demand for these products or services. Due to the fact that forecasts drive the decisions which managers make, the importance of immediate and accurate information is essential in order to establish real demand. Various sources can serve as the input for demand driven forecasts which could include current point of sale (POS) data along with customer preference reports from retailers in order to forecast with the most current and reliable data possible. A company's production, scheduling systems and capacity are driven by demand forecasts which in its turn serve as the input for personnel, marketing and financial planning. Additionally, benefits are elicited which could include less overstocking of inventory and preventing further acquisition of hardware or products which might be obsolete.

The concept of the above-mentioned types of forecasting can also be implemented within the energy sector at power stations by focusing on the most important operational process variables, stock levels and many more.

2.8 GENERAL STEPS IN THE FORECASTING PROCESS

The general steps in a forecasting process can be outlined as follows (Gor, 2009:146):

1. Identification of the general need of the forecast.
2. Select the period or the time horizon required for the forecast.
3. Choose an applicable forecast model pending:
    a. Knowledge of different forecasting models.
    b. Relevance of forecasting models for specific situations.
    c. Reliability of different models.
    d. Data requirements for each model are understood.
4. Data collection from various appropriate sources. This is influenced by the selected model chosen in the above-mentioned step. During this process, it is important to ensure that a prudent history of data is selected in order to meet the requirements of the model chosen.
5. Prepare the forecast: Using the data collected, apply the model and determine the forecast results.
6. Evaluation of forecast: Upon completion of the forecast the results, the forecast should first be evaluated in terms of a confidence interval or a similar tool to put the forecast into perspective. Proper forecast models usually have techniques of calculating upper and lower values. The forecast projected should then remain within these parameters.

With the general time horizons of forecasts discussed in Section 2.6 and the most common type of forecasts prevalent in the industry discussed in Section 2.7, the most common forecasting techniques used is presented in Figure 3:

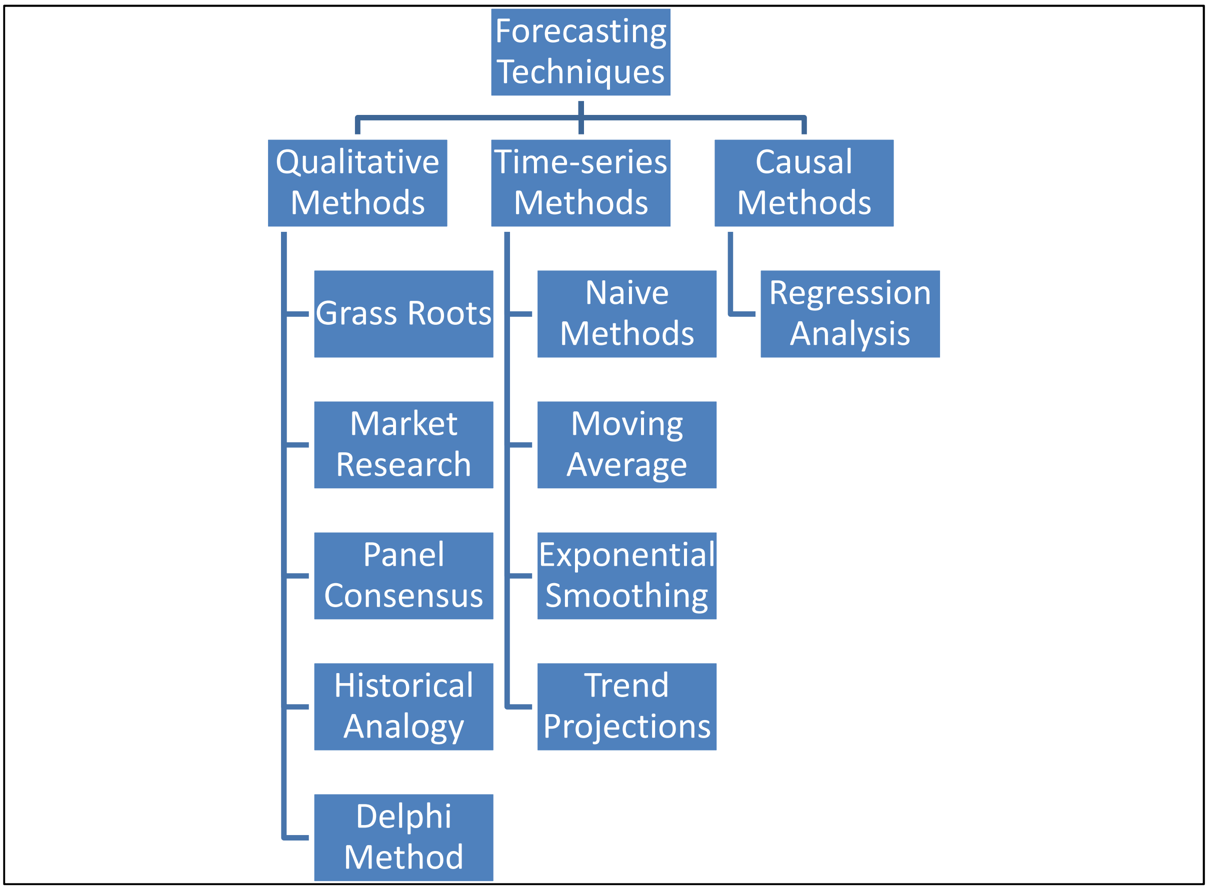


Figure 3: Different forecasting methods

Source (Gor, 2009:146)

2.8.1 Qualitative Methods

Qualitative forecasting methods are subjective in nature and are based on people's personal experiences, judgements, intuition, opinions or emotions. It is important to note that these forecasting methods do not rely on any rigorous mathematical computations. A list of qualitative forecasting methods is discussed below.

2.8.1.1 Grass Roots

The Grass Roots forecasting approach is based on building from the bottom up with relevant information pertaining to the forecast. The entity which is the closest to the end use or terminating point will understand its need and future the best (Gor, 2009:146). The forecasts at this bottom level are summed and escalated to a higher level up to a point where all inputs are received in order to make a consolidated forecast. This approach is usually used in the manufacturing sector where the procedure repeats itself until an input value is created at the top level and becomes and input to the production process.

2.8.1.2 Market research

According to Gor (2009:147) organisations often hire companies to conduct this type of forecasting. Most of the time these companies specialise in market research. An organisation might want to develop a new product and get a feel of consumer's likes and dislikes. This data can be obtained by customers taking part in market research ventures. In most cases, the data is collected by means of conducting interviews or completing a questionnaire.

2.8.1.3 Panel consensus

Panel consensus are used when a variety of individuals part take in a brainstorming session in order to have various opinions about a certain topic. This will provide an organisation the ability to develop a more reliable forecast. The more people involved in the brainstorming session, the bigger the chances are that the possible outcome was identified by an individual and it was discussed. However, Gor (2009:147) warns against the possibility that lower level employees might feel intimidated by higher level employees and then choose not to contribute towards the discussion. Gor (2009:147) suggests that the management team, who wishes to implement this panel consensus, make use of the Delphi technique. This technique will be discussed later on.

2.8.1.4 Historical analogy

This method is used to forecast the demand for a product or service, by paying no attention to past demand data (Gor, 2009:147). This technique can be used by organisations who want to develop a new product. In some instances, organisations may have in the past, marketed previous products which now have similar features than a new product. This new product is then developed, marketed and introduced to the specific industry and then the marketing team makes use of the historical analogy and derive the demand for the new developed product. This can be accomplished by making use of the earlier product's historical data.

2.8.1.5 The Delphi technique

In order to ensure that lower level employees feel comfortable enough to share their opinions with higher level employees, the Delphi technique allow employees to anonymously participate in a research study. This can be done by handing out questionnaires to be completed by employees. Once the questionnaires have been completed, the responses are summarised and given back to the employees, together with a new set of questions to be answered. According to Gor (2009:147) this technique usually achieves satisfactory results from the employees – whether from lower level or higher level employees.

2.8.1.6 Time-series methods

A statistical analysis can be performed on past data to develop a forecast and predict how many sales a product will have or how high the demand for a specific service will be. This is an example of what time-series methods can do – it can develop forecasts for the future, but only if the past relationship will continue to be the same in the future (Gor, 2009:148). When making use of time-series methods, it is important to remember that the values of variables are measured at specific time intervals.

2.8.1.7 Naïve methods

The naïve methods are used when all prior observations before a specific time-series, will not be considered. The two most used methods include the “free-hand projection method” and the “semi-average projection method” (Gor, 2009:151). The first method can be conducted by plotting the data on a graph and drawing a free-hand curve through it. The second method is conducted by dividing the time-series into two equal halves, calculate the averages for both and draw a line to connect the two semi averages. Forecasts are then developed based on this line that was drawn.

2.8.1.8 Moving average

A moving average can be used when the demand for a product or service, which does not have seasonal attributes, are not growing, but also not declining. With this method, random fluctuations are removed from the average when the forecasting is determined (Gor, 2009:152).

2.8.1.9 Exponential smoothing

When using this method, each increment of the past is decreased by (1-α). The weights of past data automatically decreases exponentially with time (Gor, 2009:156).

2.8.1.10 Smoothing constant

With this technique, the α-value can be between 0 and 1. When the forecast becomes more sensitive to current conditions, the higher the value of α becomes. When the forecast becomes more stable to current conditions, the closer the α-value gets to 0 (Gor, 2009:157).

2.8.1.11 Trend projections

Medium to long-range forecasts can be projected by drawing a line into the future by fitting a trend line to a series of historical data points (Gor, 2009:164). There are various mathematical trend equations which can be used to develop trend projections. In most cases, linear trends are used and secular trends can assist in determining the long-term direction of a time-series. There are three reasons why the study of trend projections is important:

- Can assist in determining a historical pattern;
- Assist in projecting past patterns into the future; and
- Assist in eliminating the trend component from the series.

2.8.1.12 Causal models

This model uses associations to try and project forecasts. The variable which is being forecasted is related to other variables within the environment. This model can be used when projections with regards to future demand wants to be determined. This can be achieved by making use of linear regression (Gor, 2009:146).

2.8.1.13 Regression analysis

The functional relationship between two or more correlated variables is referred to as a regression. Observed data is used to develop the functional relationship between the variables. The data should be plotted in order to determine if the data appears to be linear (Gor, 2009:164). If that is the case, linear regression can take place since the relationship between the variables forms a straight line.

2.9 APPROACHES TO FORECAST OPERATIONAL CHALLENGES

Maintenance of hardware and equipment plays a critical role in operations management in order to ensure interruptions of the production processes is minimised as far as possible (Jagtap and Bewoor, 2017:690). The cost implication which unplanned breakdowns have on production revenue losses as well as equipment replacement costs can quickly turn successful operations into ones running on the verge of break-even (due to increased global competition and a depression in local South African client demand). With the purpose of making power plants more economical, maintenance activities should be improved level-headedly and due diligence should form part of the selection and planning of maintenance philosophies and approaches which will satisfy the maintenance requirements of the plant in the most cost-effective fashion. Jagtap and Bewoor (2017:690) underline the importance of successful identification and confirmation of equipment defects and faults as an important building block for maintenance strategies and operational decision making. Condition monitoring techniques are used to fulfil this need by making use of instruments which measure the plant/process variables of the different systems and their equipment. When a significant change in measured process variables starts to develop, this could be an early indication of a developing fault. This information is then used by operational management personnel to make decisions regarding the required steps to be taken in order to mitigate the developing risk or problem.

A substantial growth of techniques used to predict and monitor plant equipment and assist with diagnosis of operational challenges, has taken place in recent years. Piyushsinh (2014:65) describes these as:

1. Vibration analysis
2. Acoustic Emission monitoring
3. Wear Debris Analysis
4. Temperature Analysis
5. Ultrasonic monitoring
6. Thermography
7. Non-destructive testing
8. Visual inspection
9. Motor condition monitoring
10. Motor current signature analysis

These performance related parameters of equipment such as vibrations, wear debris in the oil and temperature are all valuable indicators of the condition of the hardware. To this end, Jagtap (2017:695) developed a condition monitoring algorithm which can be employed to detect faults before breakdowns of equipment or systems potentially take place. In Figure 4 an example of the algorithmic steps is provided to monitor a system or specific equipment.

1. As a first step ISO standards or Original Equipment Manufacturer (OEM) manuals are used to compile the operational limits.
2. The equipment relevant for improvement or monitoring is selected (on instruction from the operations management or relevant entity).
3. Criticality analysis is performed for equipment selected at the power station.
4. Condition monitoring data relevant to the equipment is selected to measure variables such as temperature, vibrations, wear debris in oil and more.
5. The trends applicable to these parameters are analysed.
6. The first stage of diagnosis starts with a comparison of measured variables against limit standards. If the limit threshold is exceeded due to worsening of the measured variable value, then the second stage of diagnosis continues.
7. The parameters extracted from the equipment are analysed in detail in order to identify the changes in the particular parameter.

8. Confirmation of the fault takes place by using a combination of multiple condition monitoring techniques. These include vibration analysis techniques, wear debris analysis, sound measurement and ultrasonic measurement techniques.
9. The next step is to make a decision whether the equipment will be replaced or repaired. Once this decision has been made, operational management can start with schedule planning of the maintenance and operations activities.
10. Finally, an assessment of the performance of the equipment is done to determine the success with which work was done. This assessment can only take place after the intervention of repair or replacement was completed.

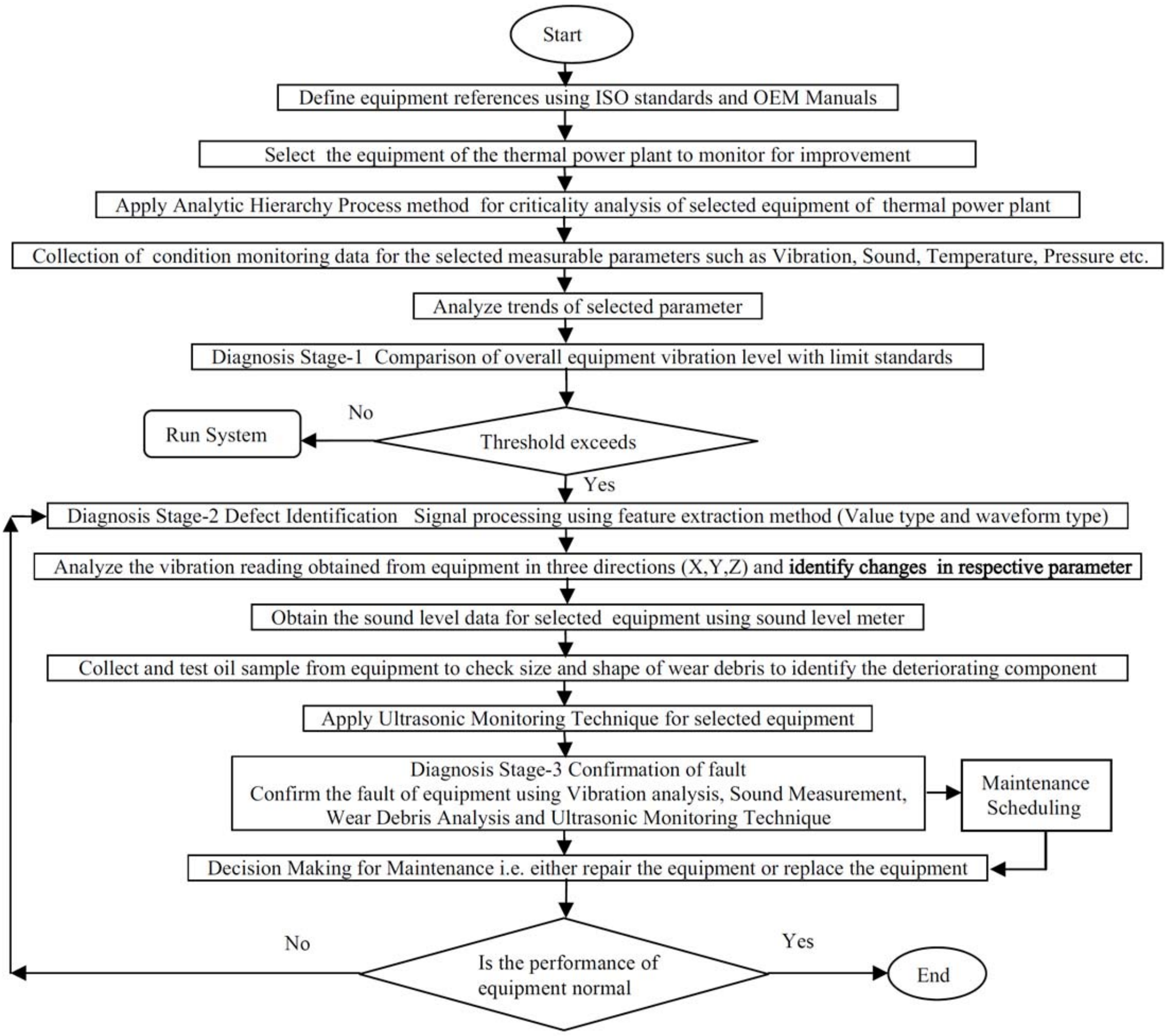


Figure 4: Intercepting operational faults by using a condition monitoring algorithm

(Jagtap, 2017:695)

By following this algorithmic approach, Jagtap provides a platform to potentially intercept faults before they lead to breakdowns. When this approach is repeated frequently for a specific system or its equipment, the results can serve as quantitative, naïve time-series forecasts.

Alternatively, if the results are used as an input by operations management or associated experts, a qualitative Delphi forecast can be made. The algorithmic approach outlined by Jagtap (2017:695) can however be very time-consuming and also costly. Dynamic changes in the operational environment can also negate the validity of the results in a very short space of time. Despite this, invasive condition monitoring will always remain a valuable tool in terms of identifying potential hardware failures but it can be concluded that its forecasting value to operations management is rather limited to individual hardware sets.

Contemplating the advent of "Big Data" and the manner in which statistical analyses is employed to produce holistic results of the entire operational health of the plant, it could render the algorithmic condition monitoring approach to be invasive and perhaps even rudimentary.

2.10 FORECASTING USED IN THE SOLAR AND WIND ENERGY SECTOR

The use of forecasting within the intermittent energy sector of solar and wind energy has seen a significant rise in the modern renewable energy era (Widen *et al*., 2015:366). Due to the fact that the power generated from these renewable entities vary constantly as a result of the role which weather play on them, the use of forecasting to predict their power output has become critical. Many commercial entities need to be aware of how the power output will change in order to inform and negotiate power delivery to their respective national electricity grids. The integration of their delivered power into the grid is therefore vital.

2.10.1 Forecasting for solar energy plants

Forecasting used at solar energy plants focus on predicting the error of power output of the plant, usually expressed in Megawatt (MW). Kleissl *et al*. (2013:2) provides the main aspects which require forecasting:

1. Estimation of the photo-voltaic power output of the plant using a solar variability model based on measurements using an irradiance sensor along with a numerical weather prediction model to determine cloud speeds.
2. Estimation of the power plant ramp rates (i.e. how quickly can the power plant produce more or less power) using a cloud speed sensor.
3. Estimation of intra-hour solar forecasting using algorithms and an advanced sky imaging system.
4. Estimation of marine layer clouds a day ahead using a numerical weather prediction tool.

All of these aspects however focus on the element of variability and how it ultimately affects power output. The impact which power producing variables like cloud cover and solar irradiance have on the plant is therefore not considered for the influence they have on the general operations issues of the power station.

2.10.2 Forecasting for wind farms

The stochastic and inherently variable nature of wind has a substantial impact on the generation of wind power and as a result differs quite substantially from the orthodox thermal generation of power. Forecasting of wind power therefore plays a key role in order to manage the associated challenges of matching the supply and demand of the electricity network due to the uncertainty associated with the power output from wind farms. In order to integrate wind power into the electricity grid and minimize the quantity of balancing energy required, accurate wind power forecasting is required (Foley *et al*., 2011:1). With the use of forecasting, the financial and technical risk of uncertainty of wind power production is reduced.

Short-term forecasts which range from 1 hour up to 72 hours are used for power system planning in order to commit and dispatch electric power generated. Medium-term forecasts which range from 3 days to 7 days are used to plan for maintenance activities at the wind farms, power dispatching as well as the maintenance outages required for the thermal generators which provide balancing power to the wind farm. As the time horizon increases, so does the forecasting error.

Wind power forecasting can be divided into two groups (Foley *et al*., 2011:2):

1. Historical time-series of wind for a specific area is used and analysed.
2. Numerical weather prediction models are used to produce forecasted values which serve as inputs for analysis.

Physical methods are generally used to describe wind power forecasting by making use of statistical methods (this is the case with the first group mentioned). More recently artificial intelligence or learning approach methods have started to lead the way (this is the case with the second group mentioned). A statistical approach is used in the models of the first group to forecast electric power production as well as to forecast the hourly mean wind speed. Explanatory variables which mainly include hourly mean wind speed and direction are derived from meteorological models of wind dynamics in order to predict current and future wind power (Landberg *et al*., 2007:237).

Wind power forecasting can be broken down into three steps:

1. Determination of wind speed from a model is executed.
2. Calculation of wind power output follows.

3. Regional forecasting (with up or down scaling) for different time horizons are then completed.

The concept of up and down scaling as part of regional forecasting is employed since the prediction of wind power output from each wind farm can become extremely time-consuming. To prevent such a situation, up-scaling is used where the wind power output from several wind farms are used to produce reference data. The benefit of up-scaling is that it reduces the error of forecasts due to the error being averaged across the whole region of the forecast (Focken *et al*., 2002:237). The concept of downscaling makes use of physical and statistical models by means of Numerical Weather Prediction (NWP) outputs to produce detailed spatial information (Lange *et al*., 2005).

By making use of these forecasting approaches, wind farms are able to manage and plan their operations tasks better, given the stochastic nature of its primary energy source, that being wind.

2.11 FORECASTING DONE AT COAL FIRED POWER STATIONS

Forecasting at power stations in South Africa is done in the traditional sense of the term. Anticipated coal consumption is used to make sure coal stockpiles are maintained. Fuel oil tank levels are maintained in line with anticipated light-ups of power generation units, with additional truckloads ordered if tank levels drop below the normal operating level. Other outputs like the removal of fly ash from the station by cement companies are also managed to ensure a healthy take-off. Certain consumable spares are also planned for by engineering, maintenance and outage departments in order to ensure critical spares are always on hand when required.

The examples provided above are commonplace forecasting which take place in most industries in South Africa and around the world. The aspect of PVF however has a direct impact on the main outputs of a power station. Any constraint within the value chain of producing electricity therefore upsets the final output. The forecasting of peripheral aspects which supports electricity production in general, are present. Enough coal and fuel oil are available (daily, weekly and monthly forecasts are done) to generate power, as well as the spares required for breakdowns (forecasts done after maintenance interventions). But the concept of forecasting takes a turn if one considers that most power stations are operated with limited knowledge regarding future performance. The concept of PVF tries to address this limited view of future operations performance by making use of recent variable performance to predict future performance.

In contrast to PVF, the concept of Meant Time Between Failures (MTBF) is a very basic reliability measure which is used as a guideline for expected hardware failures of repairable hardware products. The MTBF provides reliability, expected service life and failure rate of equipment based on in-situ statistical analysis (Pan *et al*., 2016:1).

It is important to state that the assumption in some cases is that power stations do not implement medium and long-term forecasts. This can lead to long-term challenges and problems for the power station. Inadequate forecasting can also lead to possible problems in the long run. This aspect does not form part of this research study since PVF is an example of short-term forecasting. This short-term forecasting approach can however assist the operational management team to prevent long-term challenges and problems in advance.

2.12 TRANSFORMATIONAL LEADERSHIP IN THE WORKPLACE

In the modern day South African organisational climate, research focussing on different leadership styles, plays a vital role in enhancing job satisfaction, motivating employees and decrease employees' turnover intentions (Eustace and Martins, 2014:2). Increasing workforce diversity, globalisation and emerging employment relationships, are some of the major obstacles organisations are currently facing (McShane and Von Glinow, 2010:20 – 22). Therefore, it is crucial for managers within the operational environment of South Africa's energy sector to have the capabilities to manage their employees through difficult times. Applying the incorrect leadership style or the absence of leadership can lead to devastating consequences for power supply utilities from an operations management perspective.

According to McShane and Von Glinow (2010:360), leadership can be defined as motivating, enabling and influencing individuals to contribute toward the success and effectiveness of an organisation. In the last thirty years, various research undertakings were conducted focusing on transactional leadership and transformational leadership. This include research conducted by Conger and Kanungo, 1987; House, 1977; Podsakoff *et al.,* 1990; Tichy and Devanna, 1986; Trice and Beyer 1986 and Yukl, 1989; Bass and Avolio, 1993).

McShane and Von Glinow (2010:375) explain that transformational leadership illustrated remarkable results in various organisations in the workplace. Since transformational leadership is the most recently researched leadership style, the literature review, will only focus on transformational leadership, while reference will be made to transactional leadership as comparison. In order for transformational leadership to emerge within an organisation, the leader should cooperate within an interdependent relationship where motivation, enabling and influencing of employees can be implemented successfully over time (McShane and Von Glinow, 2010:4).

2.12.1 Character traits of transformational leadership

There are four characteristics of transformational leadership which distinguish this leadership style from other leadership styles (Bass and Avolio, 1993:112):

2.12.1.1 Idealised influence

Influence can be defined as how effectively an influential individual can influence the attitudes and behaviours of less influential individuals (Atuahene-Gima and Li, 2000:454). According to Muenjohn and Armstrong (2008:4), a transformation leader wants to be a role-model for other individuals who strive to encourage colleagues to share the goals and visions of an organisation by providing a clear vision and purpose.

2.12.1.2 Inspirational motivation

McShane and Von Glinow (2010:134), explains that a leader's ability to identify and engage the needs and drives of employees is very important in an organisation, when creating organisational citizenship behaviour. This can be obtained when the transformational leader provides employees with challenging and meaningful work which are aligned with the company's vision and mission (Muenjohn and Armstrong, 2008:4).

2.12.1.3 Intellectual stimulation

The Schwartz' Value Circumplex model, indicated that individuals' creativity enhances when self-direction and high stimulation are present in an organisation (McShane and Von Glinow, 2010:48). Muenjohn and Armstrong (2008:4) also highlighted the fact that transformational leaders challenge employees' values and ideas when problem solving occur.

2.12.1.4 Individualised consideration

A transformational leader has the capabilities to determine when a situation requires a people-orientated leadership style or when a task-orientated leadership style should be used. It is important for any leader in an organisation to know that each employee and scenario is different and leadership styles should be adapted accordingly (McShane and Von Glinow, 2010:364).

Based on the above-mentioned characteristics of transformational leadership, the following traits should therefore be displayed by operations management personnel in order to enhance employee job satisfaction and motivate high levels of performance:

1. **Idealised Influence** – Operations management personnel should be role-models who encourage colleagues to share the goals and visions of an organisation by providing a clear vision and purpose (McShane and Von Glinow, 2010:364). An example relevant to

this study is that operations management can set a goal of 0% ashing on the ground. Ashing refers to the process where ash is rejected from the boiler and automatically transported to ash dams. In some cases the automatic process can be interrupted which require unwanted ashing on the ground next to the boiler. Operations management personnel can set the example by walking the plant early in the morning to ensure this bad practice does not occur and if it happens show visual support and presence in the plant to rectify and mitigate the situation. This will show visible felt leadership.

2. **Inspirational Motivation** – Stimulate organisational citizenship by providing employees with stimulating work. By providing stimulating work aligned with the organisational vision and mission employees are leveraged at their highest level which improves job satisfaction and work engagement (McShane and Von Glinow, 2010:364). These aspects will also be researched as part of a questionnaire which will investigate the opinion of respondents from three different power stations. An example of how operations management personnel can show organisational citizenship and create stimulating work is by promoting an inherent understanding of deviations from optimum operational performance. By providing inspirational motivation, employees will buy into goals of management easier. An example of how this can be achieved is that operations management can say that "we" will become the cleanest operating plant in Mpumalanga in order to keep "our" air clean and prevent pollution related illnesses in local communities close to the power station. When management prioritises defects on the precipitators or fabric filter plant (used to minimise dust emissions), and personally partake to oversee repair or maintenance interventions can serve as inspirational motivation. The notion which is created is: "If the operations manager personally come and provides support, then surely us as personnel can also pull our weight to ensure thorough work is performed."
3. **Intellectual stimulation** – Questions like *"Why did the unit produce less power today but consume more coal?"* can be used to stimulate thinking. When operations management are involved in kicking off these types of investigations and giving their own ideas and supporting creative solutions from employees, it will stimulate work engagement (McShane and Von Glinow, 2010:364).
4. **Individualised consideration** – Recognising that employee X works very well within a group and employee Y appreciates to focus independently on a task can be harnessed to leverage operational performance (McShane and Von Glinow, 2010:364). Employee X can form part of the group which inspects the gas pass ducting (a substantial system requiring group work) while employee Y is responsible for verifying and interpreting the in-situ results obtained by employee X and the rest of the group.

2.13 JOB SATISFACTION AND WORK ENGAGEMENT

Though there are various factors like motivation, turnover intent, trust and employees' need for relatedness where transformational leadership can play a vital role within an organisation, this study primarily focuses on PVF's impact on operations management. To prevent a situation where the possible contribution of PVF on operations management is viewed in isolation, it is important to understand other latent contributory factors which can influence operations management. To this end, the concept of job satisfaction and work engagement is defined. These two aspects are also highlighted since two sections in the quantitative questionnaire (Chapter 4) specifically focuses on employees' job satisfaction and work engagement at three different power stations.

2.13.1 Job satisfaction

According to Lumley *et al.* (2011:101) the term job satisfaction can be defined as an employee's general feeling about their work responsibilities and the way the employee approaches their work responsibilities. The level of job satisfaction an employee experience can influence the quality of the employee's work, the employee's relationship with management and fellow colleagues and their opinion about the organisation.

Mokgolo *et al.* (2012:4) stated that job satisfaction is a holistically integrated part of any organisation. The working structure, the remuneration, the working environment and the leadership styles implemented in an organisation are all examples of organisational variables which can influence an employee's job satisfaction.

2.13.2 Work engagement

Research conducted by Shuck (2011:307), determines there are four character traits to determine the state of employee engagement:

- Need-satisfying approach (Kahn, 1990)
- Burnout-antithesis approach (Maslach *et al*., 2001)
- Satisfaction-engagement approach (Harter *et al*., 2002)
- Multidimensional approach (Saks, 2006)

Other definitions explain that work engagement can be the behavioural, cognitive and emotional state of an employee directed towards certain organisational outcomes (Shuck and Wollard, 2010:103).

2.14 LITERATURE REVIEW SUMMARY

Analysis tools like condition monitoring are used in industry to serve as predictive measures to highlight emerging risks in an operations environment. These emerging risks which can include changes in temperatures, vibrations or wear debris in oil are used by operations personnel to predict how the future performance of equipment might change. This prediction can be viewed as qualitative forecasting approaches where input variables of current operations performance is used along with the experience of the operational personnel or management (a gut feeling) in order to predict future performance. The premise of this approach however is that a deviation in plant performance need to occur first (it must take place) before instrumentation can relay the information and present it as a developing issue which require operational intervention. This is a significant difference from process variable forecasting which makes use of current operational conditions and process variables to predict future variable performance based on thermal-hydraulic analysis. A breakdown of different types of forecasts along with the time horizons associated with each one was also done. The role of forecasting within the solar and wind energy generation sector was also provided along with the general use of forecasting as it is currently employed at power stations in South Africa. The four characteristics of transformational leadership were discussed at the hand of examples relevant to operations management. Lastly, the concept of job satisfaction and work engagement were reviewed in order to understand how it can influence operations management.

CHAPTER 3: POWER UTILITY IMPLEMENTING FLOWCAST®

3.1 INTRODUCTION

Chapter 3 provides an account of three practical examples of how forecasting was used to improve operations management at power stations in South Africa. The main purpose of this chapter is to orientate the reader and to put the study into perspective. To this end, tangible technical examples are provided to highlight the success with which Flowcast and Process Variable Forecasting is used to improve operations management within the coal fired power generation industry in South Africa.

The forecast in Figure 5 provides operations management with a 7-day forecast of operations constraints at their power station. The operations constraint manifests in the total generating output of the power station, measured in megawatt (MW). Without constraints, the operating unit should be able to achieve 100% load. In the case below, this is 500MW. On Monday the 2nd of November 2015, the forecast was made that the greatest constraint in generating output would occur on Thursday the 5th of November 2015, along with the most significant operations management difficulties in order to mobilise resources to address operations shortcomings.

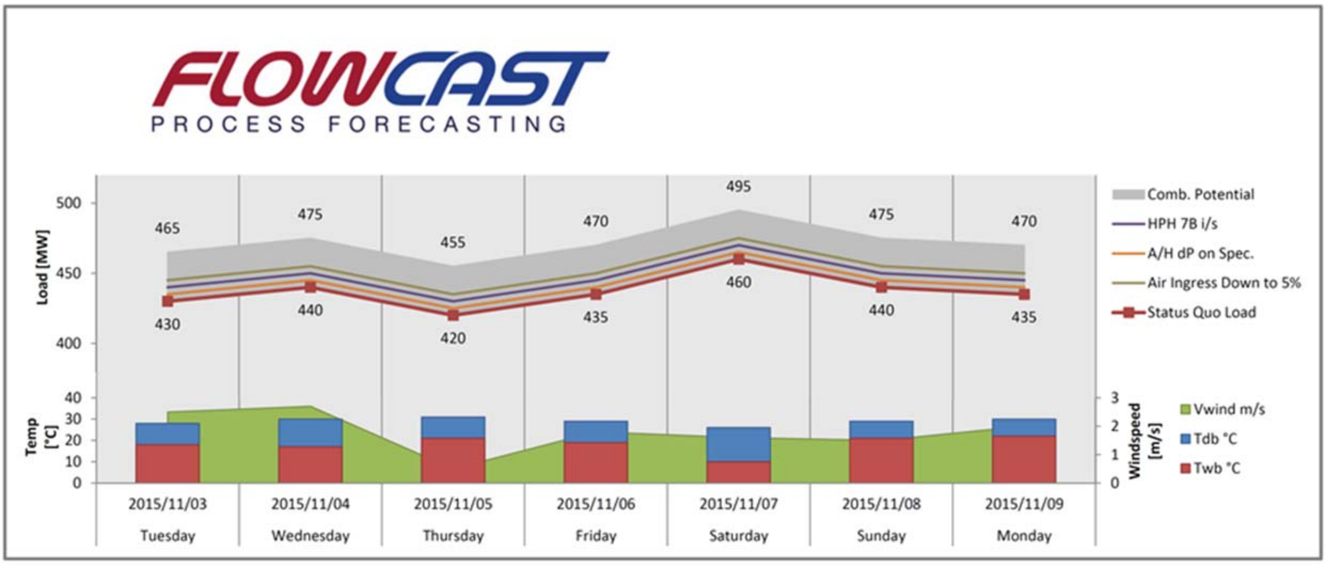


Figure 5: Seven day forecast of Operational Constraints for Power Station Management

By providing an upfront warning of operations management difficulties with enough time to plan, act and execute remedial actions, forecasting can be used as a successful operations management tool to minimise and mitigate operations and production losses. In the case of Thursday 5 November 2015, management was informed on Monday 2 November how big their output losses would be, on which system the constraint would lie, and what work could be done on which operations systems in order to minimise losses. Three practical case studies will follow to highlight how forecasting can minimise operations management difficulties.

3.2 POWER STATION ALPHA

The management team of power station Alpha was experiencing a constant operations output constraint on one of their generating units. This was as a result of the unit's Induced Draft (ID) fans running out of operational capacity (i.e. it was at its highest operational duty) although the production capacity was not at full duty point (i.e. it did not produce its full generation capability). The constraint on the ID fans therefore limited production capacity.

3.2.1 Operation challenges

The management team of power station Alpha faced the following **operations difficulties**:

- Operations resources were required to walk the boiler multiple occasions without success to find possible open inspection doors which could lead to unwanted air ingress into the boiler and on its turn result in the ID fans maxing out. No open inspection doors were found and resources were encumbered to perform a very physical task with no success. Despite not finding open inspection doors, repetitive requests for similar inspections were requested without success and negatively impacting on job satisfaction and work engagement of employees.
- When the generating unit was off-load external contractors were called in at significant cost to inspect the air heater for possible defects in a hope of finding the elusive problem contributing to ID fans running out of operational capacity. No substantial defects were found.
- The integrity of the ID fans themselves were questioned. Once again capital was allocated to verify the performance of the fans only to confirm their operations conformity to performance guarantees.
- Throughout the process boiler engineers were involved to identify a problem without a clear indication of the root cause of the problem. Other boiler plant problems had to be managed on an "as and when required" approach and sometimes put on the back burner.
- Losses in revenue due to the operations constraint were incurred.

3.2.2 Forecasting solution for Operations challenges

Process variable forecasting (PVF) was used in order to match the ID fan constraints in the plant. The objective was to identify where the source of the operations constraint was and to re-divert operations resources to the constraint. The **constraints** identified were:

- PVF highlighted that possible holes in the gas pass ducting could be present and could potentially be responsible for ingress air between the air heater outlet and fabric filter plant outlet.

Due to the fact that isolation material is used to cover the gas pass ducting, visual confirmation of the forecasting was not possible, except if the isolation material was removed when the unit was off. Such a step is extremely costly since it usually requires for new isolation to be installed when it is removed from the gas pass walls. To simply remove the isolation material without any substance or proof is therefore not acceptable. PVF postulated holes in the gas pass but the only way in which confirmation could be achieved was to shut the unit down, open the gas pass and remove the isolation material to inspect the ducting.

Table 1: PVF forecast of potential benefit for power station Alpha

System	Gain
1. Ingress between AH outlet and FFP outlet (-73kg/s)	25.1 MW
2. CW flow increase (+1000 kg/s)	3.0 MW
3. Terminal Temperature Difference (TTD) decrease (-2°C)	3.0 MW
Total:	31.1 MW

Estimated total hole size of 2.45 m^2

A hole the size of 2.45m^2 were postulated as the root cause for the operations constraint of the ID fans for power station Alpha.

3.2.3 Operations Management benefit due to forecasting

Based on the PVF recommendation, operations management personnel decided to proceed with the recommendation and shut the unit down. Isolation material was removed and internal inspection of the gas pass ducting was performed. The photos taken inside the gas pass is presented in Figure 6 and Figure 7, showing a significant number of holes.

Figure 6: Power station Alpha gas pass ducting internal inspection

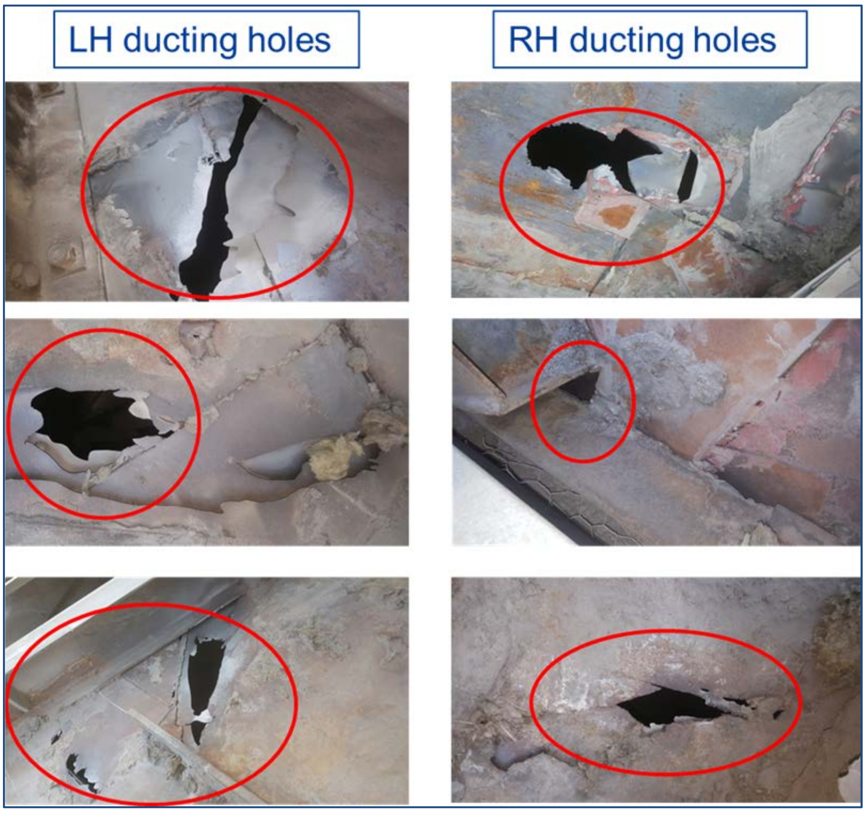


Figure 7: Power station Alpha Left Hand and Right Hand ducting holes visible after isolation removed

The **benefit** of this successful forecast had the following positive impact on operations at power station Alpha:

1. Without the requirement for expensive removal of isolating material which covers the gas pass and makes visual confirmation of holes in the ducting impossible, PVF correctly predicted substantial holes in the ducting.
2. The magnitude of the hardware defects and the impact which it had on operations output could be confirmed by forecasting the effect of the defects on plant performance.
3. By providing an upfront account of the estimated hole size, better planning for better scope of work could be completed in order to minimize repair time.

3.3 POWER STATION TANGO

The management team of power station Tango faced a significant seasonal operations constraint on the Primary Air (PA) fans at their power station. During winter months their operations difficulties on this system decreased substantially, only for it to resurface again in summer months.

3.3.1 Operation challenges

The management team of power station Tango faced the following **operations difficulties**:

- The first challenge of the management team was the application of valuable engineering resources to investigate the intermittent PA fan problem which would grow in summer and subside in winter. This meant encumbering skilled resources on a very specific area of the plant while other operations challenges enjoyed less attention.
- The second operations challenge of the management team was seasonal investments of expensive capital resources by way of hardware replacements. Maintenance crews also needed to open up, inspect and interrogate the mechanical parts of the PA fans. The repetitive investment of capital on this plant area also meant constraining other operations systems from necessary funding and maintenance.

3.3.2 Forecasting solution for Operations challenges

With Summer 2017/2018 approaching, forecasting was done during winter 2017 to understand the operations challenges faced by the management team of power station Tango. Two specific **future constraints** were identified:

- PVF highlighted that PA fans on the plant would become a constraint during summer 2017/2018.
- The performance of some of the main turbine condensers would necessitate specific intervention in order to intercept high back-pressures during very warm ambient conditions.

For the purpose of this study, the focus will be limited to the PA fan operations constraints. With the constrained identified as a real operations risk for power station Tango, the process of addressing the operations challenge starts.

After providing a platform for all relevant role-players at power station Tango to make suggestions, several solutions were investigated. One specific suggestion was to investigate the impact of removing a deflector plate from the Secondary Air (SA) duct from which the PA fan takes suction. An illustration of the arrangement is shown in Figure 8.

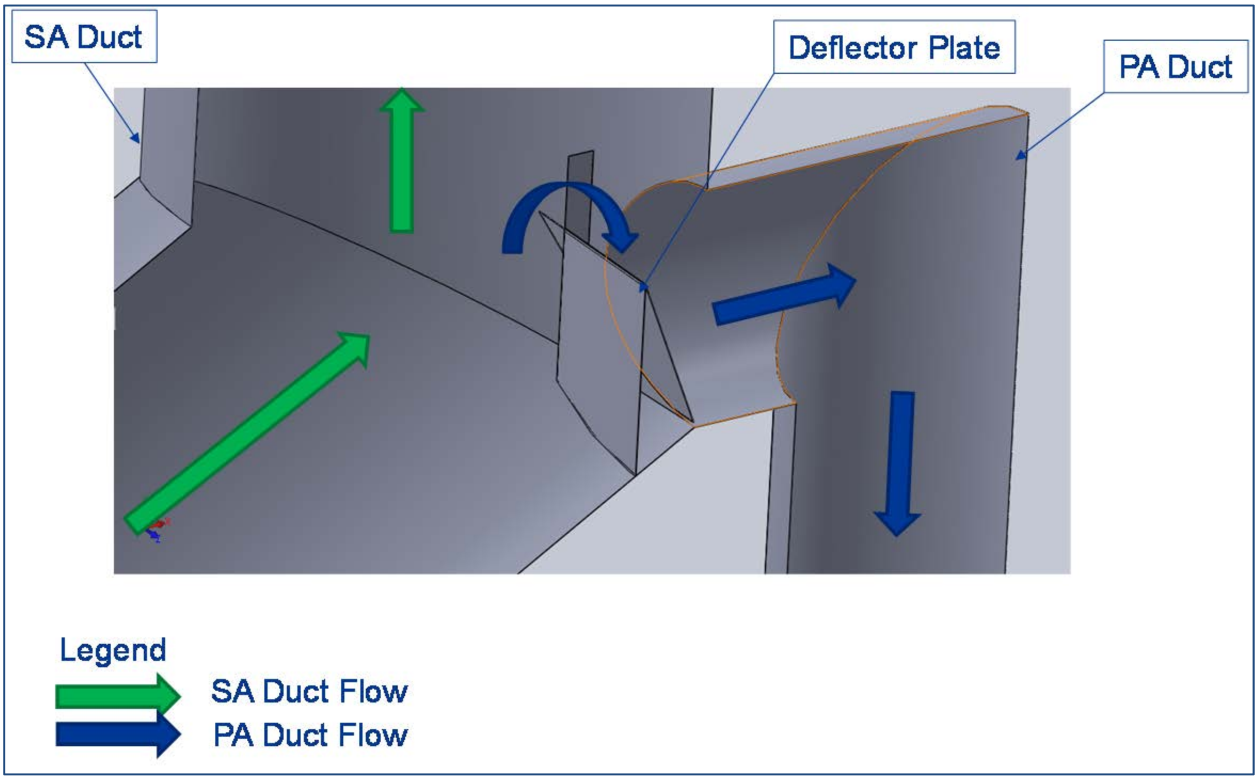


Figure 8: PA fan deflector plate arrangement drawing

With the forecast completed and indicating operations constraints on the PA fan system for summer 2017/2018, the same forecast was repeated for a scenario where the PA fan deflector plate was removed from the SA duct. The result is presented in Figure 9.

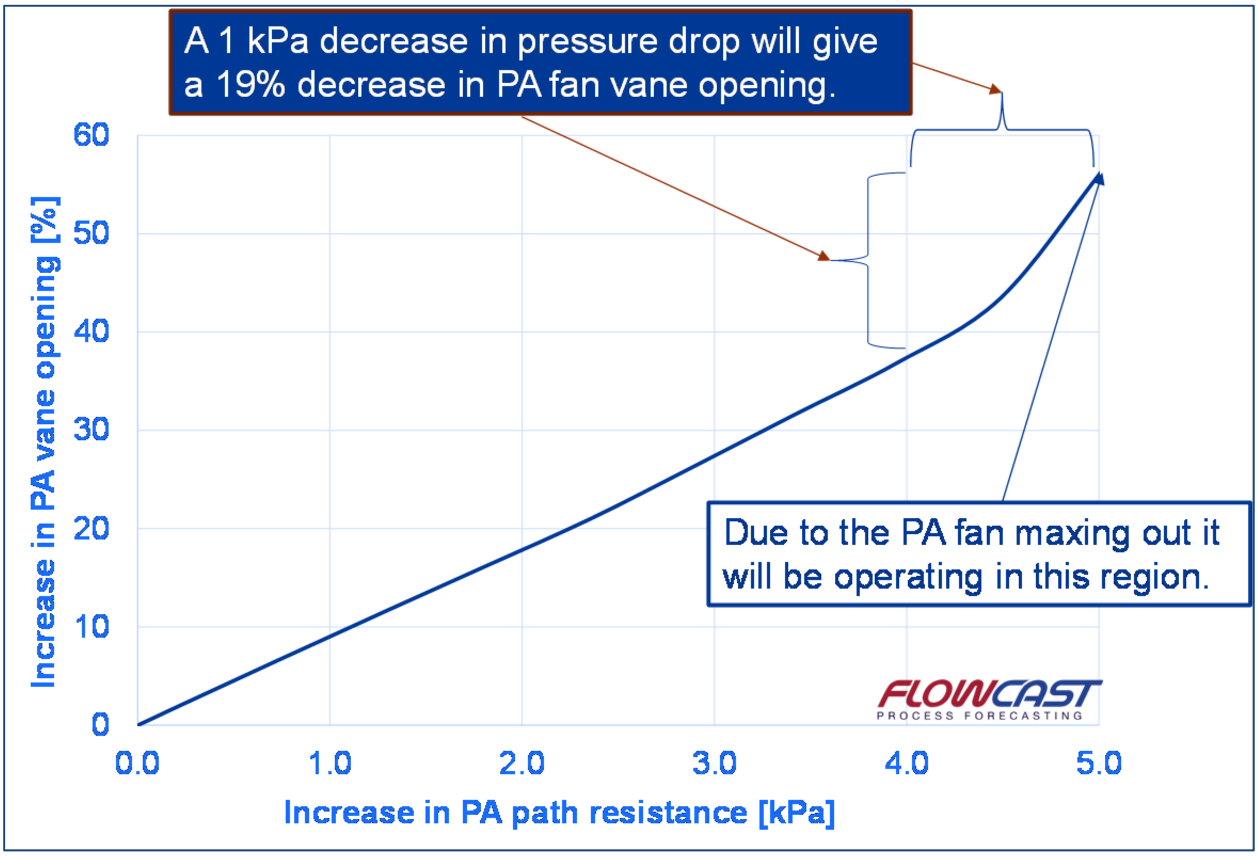


Figure 9: PA fan vane opening as a function of path resistance (kPa)

The result shows that should the PA fan deflector plate be removed, a 19% lowering in PA fan vane would be achieved. This would lower the vane opening from the 100% constrained position to 81% and enable greater generating output for power station Tango. The operations improvement to be realised from this intervention was shared with power station management. As a result, the power station management approved the operations intervention to remove the PA fan deflector plate. A photo of the deflector plate before removal is illustrated in Figure 10.

Figure 10: PA fan ducting with deflector plate

A photo of the deflector plate after removal is illustrated in Figure 11.

Figure 11: PA fan ducting after removal of deflector plate

Upon completion of the removal of the deflector plate, the constraint on the PA fan system was immediately lifted. A comparison of the “unconstrained performance” of the PA fan in winter (20 July 2017) is made to that of the “improved performance” of the fan in summer (28 September 2017) in Figure 12. During the winter period of the year the operations challenges at Power Generation Utility 3 on the PA fan system is less because of improved cycle efficiencies due to colder cooling water to the turbine system. Historically, during summer these operations challenges would increase due to warmer cooling water to the turbine system. However, the exacerbated performance during summer still did not justify the constraint on the PA fan system. Figure 12 highlights the extent of the successful forecast which was done and the effect it had on the PA fan system. With summer usually having the greatest constraint, the removal of the plate during spring 2017 enabled the performance of the fan during summer 2017/2018 to be even better than the historic winter performances. Figure 12 and Figure 13 also show that the PA fan differential pressure was reduced by 0.934 kPa, in line with the 19% improvement in PA fan vane opening % which was forecasted and provided to the power station management.

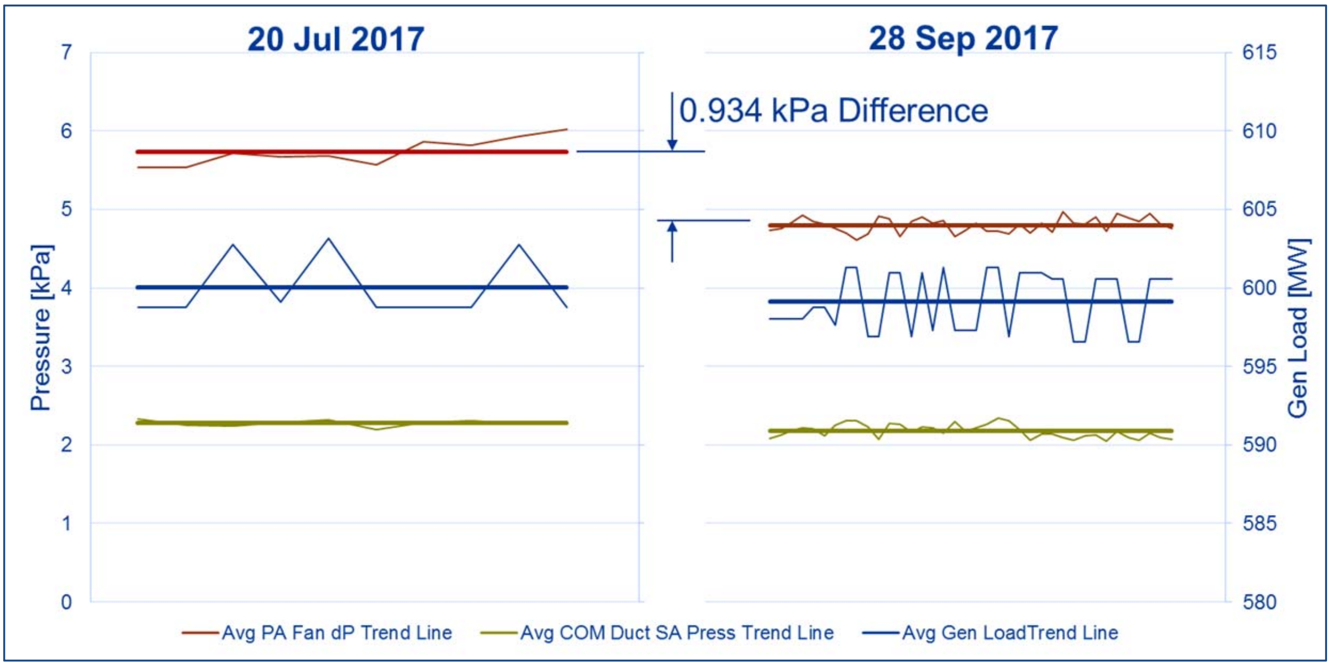


Figure 12: PA fan performance before and after deflector plate removal

	Before removal	After removal	Difference
Load [MW]	600	599	1
PA Fan dP [kPa]	5.73	4.8	0.934
SA Com Duct Press [kPa]	2.3	2.2	0.1
PA Flow [m^3/s]	120.3	121.1	-0.8

Figure 13: PA fan performance metrics before and after deflector plate removal

The **benefit** of this successful forecast had the following positive impact on operations at power station Tango:

- Engineering resources could be applied to other operations constraints, in this particular case the poor performance of the cooling towers at power station Tango.
- The seasonal capital expenditure of hardware components on the PA fan which was not required anymore could be diverted to cover some of the costs incurred as a result of fire damage on one of the operating units.

- Maintenance crew which had to do repetitive inspections on the PA fans were freed up to be re-allocated to other plant areas to perform preventative maintenance.
- The total generating output of power station Tango increased, enabling more power to be produced and increasing the revenue of the power station.

3.4 POWER STATION KILO

The operational management team of power station Kilo had the benefit of a power generating unit running very close to maximum performance. This performance however changed dramatically with an upset in the process which could not be quantified. PVF was deployed in order to predict how long it would be until the constraint escalated to such a level that it would lead to the unit tripping. A unit trip refers to the operations shutdown of all hardware to a safe state in order to protect the plant equipment. PVF was also used to identify which system process variable required intervention in order to create a positive impact on the overall process and change the outcome of the current scenario forecast of the unit possibly tripping. This allowed for the specific direction of operations resources to the root of the constraint in order to mitigate the problem.

3.4.1 Operation challenge

As with any industrial process, the presence of anomalies is common. A problem occurs and requires intervention. Depending on how the problem is addressed (including such aspects as speed and quality of work) the problem is either completely solved, managed within a specific non-optimal band or the problem leads to further plant challenges at an escalated level.

The management team of power station Kilo were faced with a very unique **operations difficulty**. After a long period of very sound operations performance, one specific process variable started to trend in an adverse direction. The main turbine condenser pressure started to increase ever so slightly over time and instead of plateauing off and trending down again, kept on increasing. Upon increasing even more, the Panel control operator [Employee # 1] informed his Operating shift manager [Employee # 2] of a potentially serious problem.

The management of operations resources now became critical. With no obvious problem standing out, the Operating shift manager had no other choice than to dispatch a team to search for the problem. This led to the following allocation of resources:

- Operating shift manager oversees recovery of challenge.
    - Net result – one additional resource allocated to the control room of the problematic unit.

- A Panel control operator [Employee # 3] from another unit joined the Panel control operator [Employee # 1] of the unit experiencing the problem, which enabled him to focus exclusively on the problem at hand while the other operator [Employee # 3] monitored the rest of the plant for developing risks or challenges.
  - Net result – one additional resource allocated to the control system of the problematic unit at the expense of his unit now not being actively monitored (in this case Employee # 3 will only react to his unit if audible alarms sound which require his intervention).
- Two senior plant operators are dispatched to the plant to look for the problem.
  - Net result – two additional resources are directed to the plant.
- Turbine engineering called out to assist with fault finding and sends two engineers.
  - Net result – two additional resources are availed, one to the control room and one to the plant.
- Process engineering called out to assist with fault finding and sends one engineer.
  - Net result – one additional resource is availed to the control room.
- Control and Instrumentation engineering called out to assist with fault finding and send one engineer and two technicians.
  - Net result – three additional resources are availed, one to the control room and two to the plant.

After the allocation of all the resources mentioned and two hours of investigation, the problem kept on escalating. The net result is ten resources allocated for 2 hours without successful intervention.

This necessitated the Operating shift manager to escalate the response to the problem. This led to the following allocation of resources:

- One more Panel control operator
- Turbine engineering sends three more engineers
- Turbine engineering manager called out
- Engineering manager called out
- Operating manager called out

Then more resources were sent:

- Production manager was called out
- Plant technical manager was called out

With several resources involved and investigating several possible shortcomings, the problem kept on escalating.

3.4.2 Forecasting solution for Operations challenges

The main turbine condenser pressure for the generating unit kept on increasing to critical levels. With a full complement of operations staff already involved for an entire operating shift (8 hours), no plausible solution or remedy to mitigate the situation was available. The following **constraints** already transpired:

1. The operations output of the generating unit was lowered substantially to try and reduce the tempo with which the turbine condenser pressure decayed. By doing this, the primary output of the entity, that being electricity, dropped sharply.
    - This translates to less MW/h being sold.
2. The efficiency with which the generating unit was producing its electricity became substantially less.
    - This translates to a higher operations cost per MW/h produced.
3. Due to a radical drop in plant efficiency, the balance of the plant hardware had to work harder in order to carry the burden of an inefficient operations system.
    - This translates to a greater risk of equipment failure due to the plant hardware operating beyond its optimal design envelop.
4. Encumbering of several resources from several departments to focus on the problem.
    - This translates to the execution of less productive work at the facility by the resources.

With all avenues exhausted, PVF was used to assess the general status of the problem:

1. The forecast underlined that given the current operations approach of lower output in order to minimize the tempo of the worsening state of the generating unit, only four hours of operations would remain before the generating unit would trip because of various alarm levels being breached. The four hour time frame provided a platform for proper operations planning of resources and to define a scope on how to interrogate the problem given the time cut-off after which the generating unit would trip.
2. PVF showed that further operations performance deterioration in the form of higher condenser pressure would occur, unless the seal water system (Figure 14) pressure is not raised.

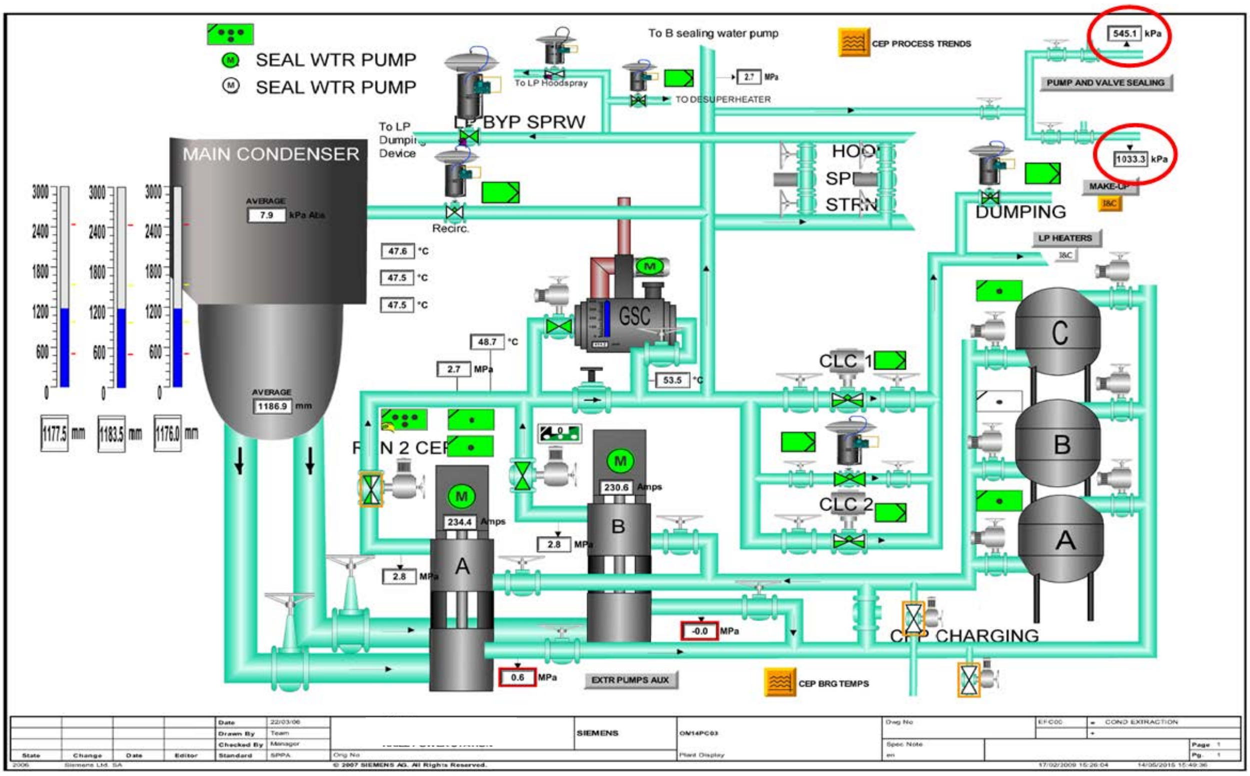


Figure 14: System layout drawing of turbine condenser and seal water system

With PVF showing that four hours of operations time remained before the generating unit would in all likelihood trip, corrective intervention became paramount. Sharing the results of PVF with the relevant role-players along with the area where the problem was emanating, operations personnel immediately established a significant discrepancy in the gland sealing water pressure and the pump sealing water pressure. For some unexplained reason, the gland sealing water pressure was at 50.2 kPa (instead of above 500 kPa) and the pump sealing water pressure was at 59.5 kPa (instead of above 1000 kPa) and is displayed in Figure 15.

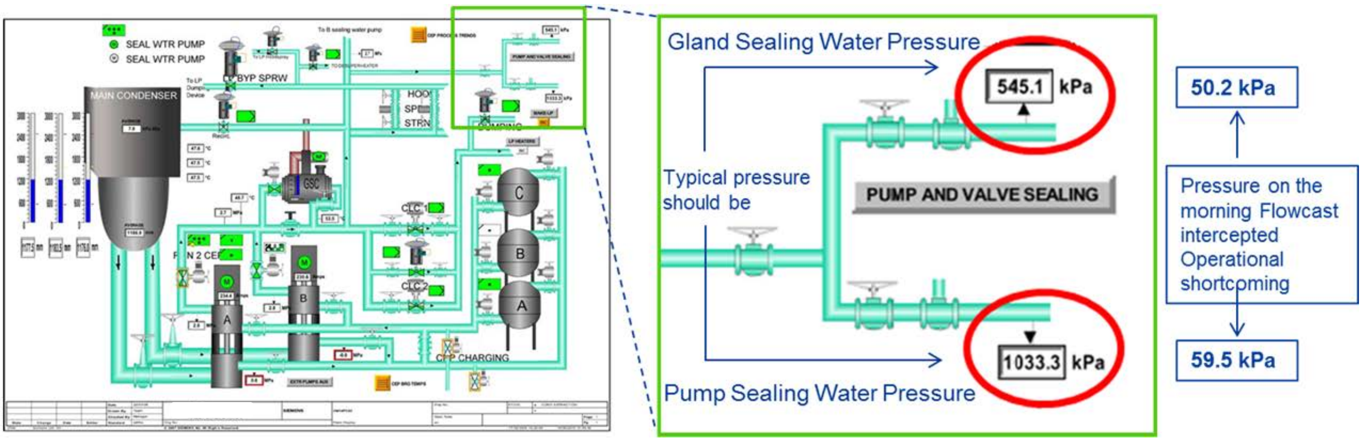


Figure 15: Blown-up view of seal water system pressure deviations from acceptable operations pressure

With the specific problem identified, operations personnel were dispatched to the sealing water system and found that the isolating valve was closed. Immediate intervention took place and the valve was opened by the plant operator (Figure 16).

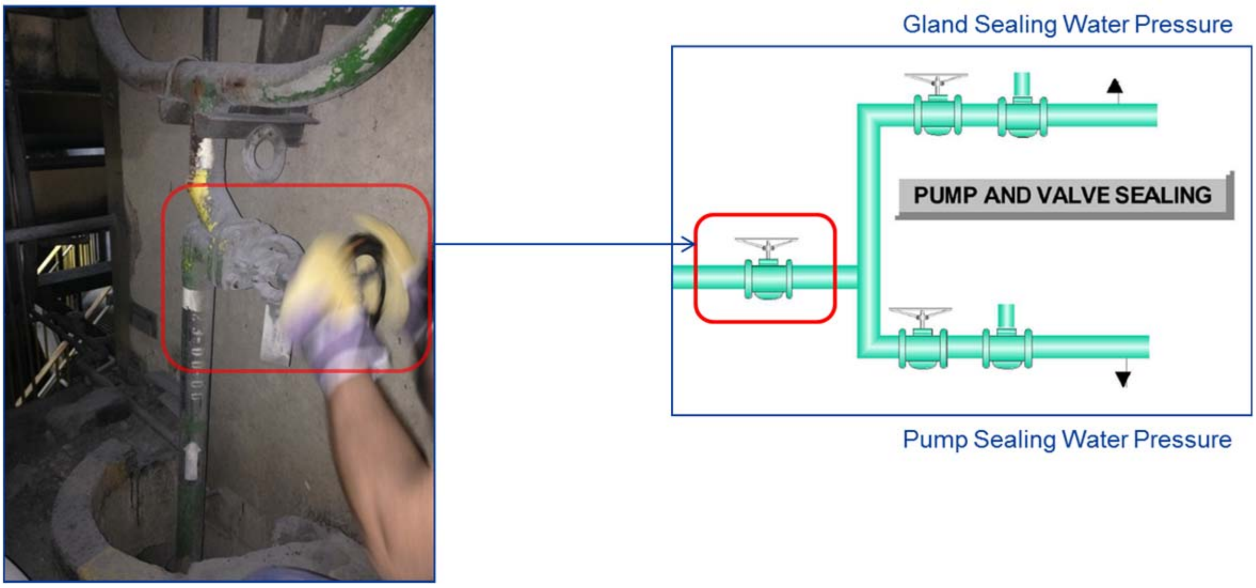


Figure 16: The valve which was opened by the plant operator

After the isolation valve was opened the imminent threat of a generating unit trip was mitigated. The benefit started to show immediately with a dramatic reduction in turbine condenser pressure and normal operation established soon after (Figure 17).

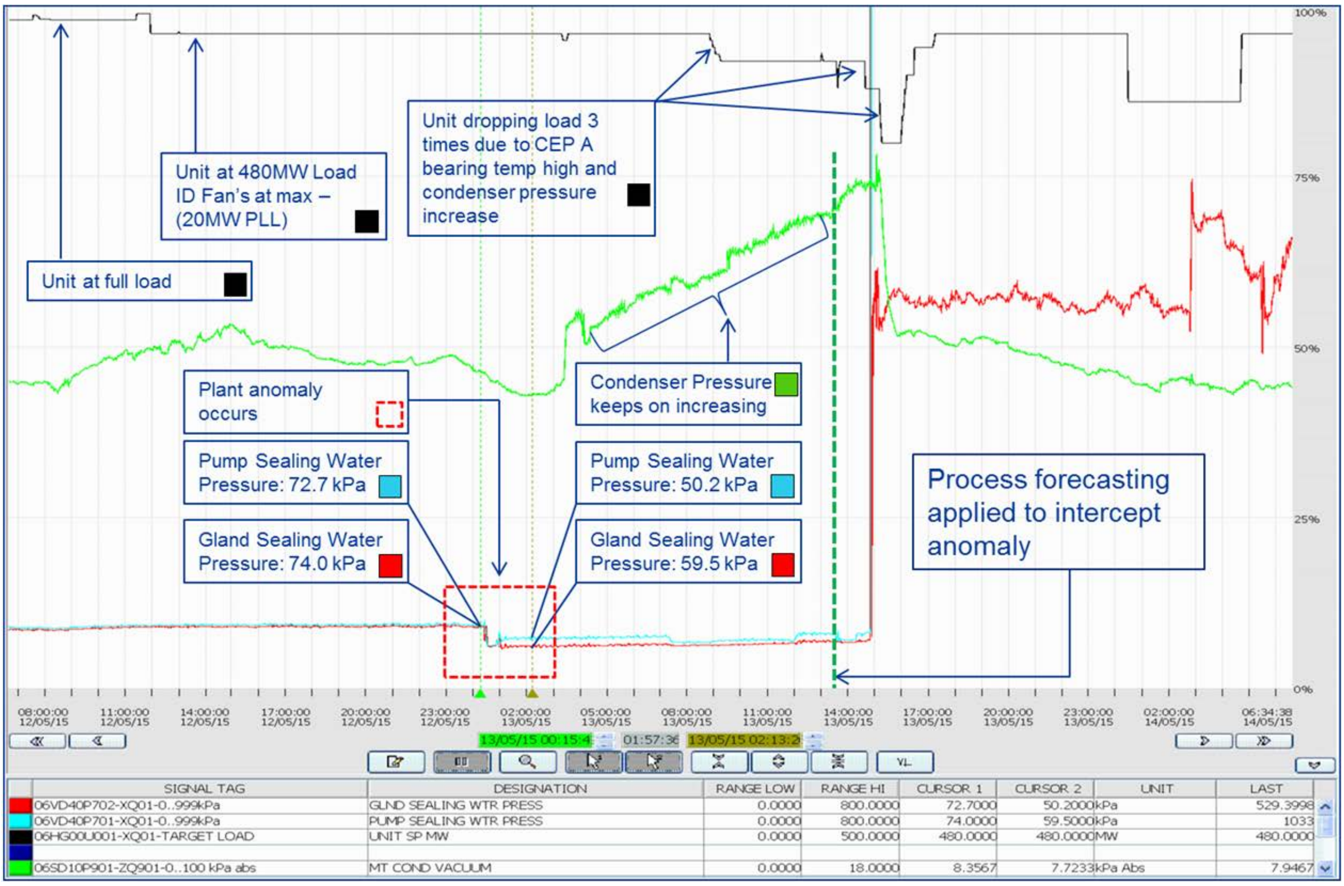


Figure 17: PVF applied to intercept anomaly on turbine condenser pressure operations constraint

The **benefit** of this successful forecast had the following positive impact on operations at power station Kilo:

1. A generating unit trip was averted which appeared to be inevitable up until the point when PVF was deployed. As a result of mitigating this risk, no upset in production took place.
2. Depending if a hot or cold start would have been used to return the unit to operations, the light-up cost could be between R400 000 and R800 000. These costs were all saved and could be used on alternative operations expenses.
3. Identification of an operations shortcoming which was not considered by employees.
4. Empowering employees to understand the operations environment better.

3.5 CHAPTER SUMMARY

The benefit of PVF by means of Flowcast was shown in this chapter. Case studies from three power stations were presented where PVF was implemented and made a tangible difference in order to improve operations management.

CHAPTER 4: EMPIRICAL RESEARCH

4.1 INTRODUCTION

In order to lay the foundations for this study and quantify the potential benefit of PVF to reduce operations management difficulties, the literature review in Chapter 2 focussed on two primary aspects:

- The first set of aspects that was studied focused on factors which are critical for the successful and effective management of operations activities at power stations. These included factors such as:
    - Quality
    - Employee engagement
    - Productivity
    - Maintenance
    - Integration

Studying these factors were relevant to understand the role they play in successful operations management as opposed to the potential benefit of PVF at power stations to improve operations management.

- The second aspect which formed part of the literature review was the general role of forecasting in operations management. These included factors such as:
    - Types of forecasting
    - Forecasting time-horizons
    - Forecasting within the solar and wind energy sector
    - The current, limited use of forecasting at coal fired power stations

Studying these aspects of forecasting were relevant to understand the general role of forecasting in industry and to outline the difference between forecasting currently employed at power stations and the difference to that of PVF.

Various literature sources underline the importance of the role of employees in relation to operational successes. Gaither and Frazier (2001:661), Heizer and Render (2014:55) and Nicholas (2016:255) all highlight the critical role of people in successful operations. Employees have the ability to affect the general morale of an organisation, its costs, its productivity and quality. Employee empowerment and respect for employees are also successfully used in industry in order to support successful operations. A relevant example of this strategic approach to operations management has successfully been used by Toyota for many years (Nicholas, 2016:259). The importance of employee empowerment to support successful operations management and reduce potential management difficulties is acknowledged.

4.2 DATA COLLECTION

The most advisable current day approach to data collection in terms of ease and post data analysis is using electronic questionnaires conducted via emails or dedicated web applications. Despite the advantages offered to the researcher by making use of these approaches, most of the respondents involved in the quantitative facet of this research study do not have access to email addresses or computer services. The researcher made use of a random stratified sampling approach from employees who had exposure to PVF by means of the Flowcast® service. A hard copy questionnaire was provided to each respondent. A pre-agreed date and time for completion of the questionnaire was confirmed with the respondents upon which time the researcher collected the questionnaires from the respondents. The results data was manually transferred by the researcher from the hard copy questionnaires into Excel in order to analyse the results with the statistical analysis tool SPSS version 22.

4.3 DATA ANALYSIS

In terms of data analysis, instruments and data reliability, the questionnaire developed for completion by the respondents were highly structured. The questionnaire made use of a 4-point Likert scale in order to measure the perceptions and attitudes of the respondents towards the 25 questions. The Likert scale was employed in this research study since it is the most extensively used and accepted psychometric scale for quantitative questionnaires (Li, 2013:1609).

As part of the questionnaire, a standard set of demographic factors were measured, including age and qualification, both being factors which can influence the answers provided by the respondent. The researcher made use of the services of the NWU Statistical Consultation Services in order to ensure oversight of correct statistical analysis of the data was undertaken by the researcher.

The software programs used in order to provide participants with PVF of plant conditions included the Siemens TA3000 plant control package and the Flownex Simulation Environment thermodynamic package, through which plant data were collected and further processed.

The researcher also decided to make use of Cronbach's alpha in order to determine the degree to which the Likert scale used, produced consistent results. Malhotra *et al.* (2006:214) recommends that Cronbach's alpha coefficients of over 0.7 are considered to be acceptable (Field, 2009:675)

4.4 THE PILOT STUDY

A pilot study was undertaken with five respondents for their input and comments on the questionnaire.

Gorman and Clayton (2005:98) define a pilot study as the process during which a draft research plan is created and applied in an unbiased location. This data will not be used in the real field of intended study.

The intent of the pilot study was to select a representative sample of typical candidates who would form part of the complete empirical study, and to discuss the questions contained in the questionnaire with them in an interview setting. The above-mentioned sampling method is an example of purposive stratified sampling. In the case of the pilot study, five respondents were selected from three different power stations. The breakdown of respondents was as follows:

- Senior manager at power station Alpha
- Engineer at power station Kilo
- Maintenance Technician at power station Tango
- Plant Operator (Control Room) at power station Alpha
- Production planner at power station Kilo

The most relevant remarks from the interview will be discussed.

4.4.1 Results from pilot study

- Question 1.2 pertained to the gender of the respondent. The pilot questionnaire catered for:
    - Male
    - Female

The senior manager at power station Alpha made the comment that they do have an employee who had undergone a gender transition. In light of the question posed, should the employee form part of the study, the question with regards to gender might not be accommodating to the individual. In light of this remark, the question for the empirical study was supplemented with an additional option of:

- Prefer not to disclose

- Question 1.3 pertained to the ethnicity of the respondent. Three of the respondents questioned this question in retrospect, when they completed the questionnaire. The comments from them were that they did not understand why the question should be relevant given the technical setting of operations management and forecasting. As a result of this comment the researcher decided to remove this question from the questionnaire.

- Question 1.4 pertains to the highest level of education of the respondent. The pilot questionnaire catered for:
    - No schooling
    - Matric
    - Diploma
    - Degree
    - Honours Degree
    - Master's Degree
    - PhD

Comments which came from the respondents were that many of their colleagues or subordinates did not necessarily have a matric qualification but all of them had some form of schooling, as opposed to no schooling. In light of these remarks, the question for the empirical study was changed to:

- Some form of schooling

- Question 1.10 pertains to the number of hours the respondent has to work per week in order to complete the tasks handed to them. The question posed:
    - How many hours do you work per week?

All of the respondents had many comments and recommendations on this question. The senior manager at power station Alpha mentioned that managers on their level of appointment do not get paid for working overtime. They do however work on a rotational schedule where they are always on call for a specific week and weekend. Should it happen that a unit must be returned to service during a particular week or weekend, and depending on the complexity or risk involved, the manager can be called out at any particular time. This would make it difficult to give an accurate answer to the question since some weeks could entail a normal 40 hour work week and others could mean more than 60 hours.

The engineer at power station Kilo had a different response. The engineer's response was that he works mostly between 40-60 hours per week, but that he often only gets remunerated for a maximum amount of 45 hours per week. The reason for this was that an embargo was placed on personnel recruitment and that he subsequently has to carry the burden of other systems as well. This means he has to work on other systems (vacant positions) during the day and only gets time for his personal work (the system he is responsible for) in the evenings. Officially he has 40 hours per week within which he is able to complete his work but unofficially a second set of hours based on additional tasks handed to him. This means that his working hours increased with almost 50%.

The maintenance technician explained that he works long hours in the summer and more normal hours in the winter. Prompted for a more detailed explanation, he highlighted that in winter the performance of the systems was better because the system efficiency was better. This was ascribed to the driven thermodynamically, because of an improved water and steam cycle efficiency due to colder cooling water temperatures in winter. In winter, most of the operating units are operational to generate as much power as possible. In summer, some of the units are taken down to perform maintenance on them. This maintenance is performed by the outage department, and not by the general maintenance department. This means the SOW theoretically gets less in summer. However, the operating units have to work much harder (the physical plant hardware) in summer due to lower efficiencies (as opposed to winter, clarified above). Although the SOW in winter is more since more operational units produce power, the plant hardware does not work as hard as in summer. The end result is that maintenance personnel therefore tend to work longer hours in summer than in winter. The seasonal difference in weekly hours was not a sentiment shared by the other respondents.

The plant operator, working in the control room, at power station Alpha had a similar answer to that of the engineer at power station Kilo. His response was that his weekly working hours change every week. When colleagues take leave, the remaining personnel has to work extended shift hours due to the personnel recruitment embargo and the lack of resources able to stand in for them.

The intent of the question is to get specific estimates of the weekly hours worked by the respondents. By providing a sample range for the respondents as potential answers, there is no statistical approach which can be followed to narrow down the weekly hours worked. An example was that if one option was between 40-45 hours and most employees do work between 40-45 hours, this answer set will be selected by all respondents. If some worked 40 hours and some 45 hours, the statistical difference could now be correlated with other constructs contained in the questionnaire. For this reason, it was decided to still ask for a specific number of hours worked by the respondents per week, but also take cognisance of the comment from the engineer at power station Kilo by changing the question to:

- How many hours do you work per week in order to complete the tasks handed to you?

This would then include the official allocated hours per week as stipulated in the service contract of each individual as well as the additional work which has to be done by the respondent in the evenings in order to carry the load of staff shortages.

- A general finding from the pilot study was that on a couple of occasions the respondents opted to choose the neutral answer from the questionnaire. When pressed for an explanation on why the respondent chose the neutral option, the answer was that they were not really sure how they felt. They did not fully agree nor did they fully disagree and therefore the reason for choosing the neutral option. This was particularly the case with question 3.1 which focussed on whether the respondent enjoys their working environment. Hesitant to say no, they would rather select the neutral option which is politically correct, rather than lying and saying they do enjoy their working environment. It became evident that the presence of a neutral answer provided a platform for an easy way out when the respondent was faced with making a difficult decision. From a statistical perspective neutral answers also make it more difficult to really assess the opinion and perceptions of respondents. After careful consideration it was decided to remove the neutral option from all the questions of the questionnaire so that the respondents have to make a clear-cut choice regarding their perception or opinion of a particular matter at their operations facilities.

- The researcher also gave the respondents an opportunity to provide their inputs on any additional questions which can be posed in the questionnaire on possible improvements which could aid operations management at the power stations. Two respondents made mention of the issue of racism in the work place and how it hampers creative solutions to improve operational practices in some instances. One respondent made specific reference to inter-racial discrimination as a tangible problem in the organisation while the other respondent felt gender-based discrimination prevented women to grow into managerial positions. Further dialogue with the latter respondent led to specific examples provided where females within the operations environment was not always afforded the opportunity to take leadership roles and where their suggestions of improved operations approaches were discarded. This situation led many female workers to feel desponded which could potentially have an impact on their contributions within their operational environment. To this end the researcher took note of this and decided to list discrimination within an operations environment as a suggestion for future research studies.

- One respondent gave quite elaborate feedback regarding leadership within their department and the impact it had on the way employees approached their duties and tasks. The pilot study conversation carried on further while the respondent elaborated on how some managers were very successful with their departmental endeavours and how some struggled a bit more. To this end it was also decided to include the aspect of transformational leadership in the literature review and how it can influence operations management within organisations.

4.5 SAMPLE SELECTION

A total of 102 respondents voluntarily took part in the research study, spread across three different power stations. Within this group of respondents, the employees' surveyed came from a combination of the following departments:

- Engineering department
- Maintenance department
- Operations department

All the respondents were selected at random from the employee list of the power stations' departments mentioned above.

Table 2: Summary of respondent demographic data

Category	Attribute	Frequency	Percentage (%)
Total Employees	-	102	100
Gender	Male	79	77.5
	Female	20	19.5
Age Distribution	18-24	8	8
	25-34	49	48
	35-44	30	29
	45-54	7	7
	55+	8	8
Education	Some form of schooling	0	0
	Matric	14	14
	Diploma	39	39
	Degree	27	27
	Honours Degree	14	14
	Master's Degree	6	6
	PhD	0	0
Years of work experience	1-5	27	27
	6-10	36	36
	11-15	18	18
	16-20	5	5
	21-25	4	4
	25+	10	10

4.6 MEASURING INSTRUMENT

The selection of the measuring instrument was based on three previous studies which all focussed on interventions at industrial facilities in order to achieve operations improvements. These included the work of Mutloane (2009), Van Blerk (2012) and Viljoen (2014). In all three instances the approach of using a summated attitude scale was used. With this approach a collection of statements pertaining to the attitudinal object is examined, with the respondents then indicating to which extent they agree or disagree (Welman *et al.,* 2005:157). To this end, a 4-point Likert scale was used to measure the respondents' opinion towards operations related aspects in the workplace. For this study the questionnaire which was developed by the researcher for completion by the respondents were highly structured and made use of a 4-point Likert scale in order to measure the perceptions and attitudes of the respondents towards 25 questions. In contrast with the previous studies where neutral answers were accommodated, this questionnaire did not accommodate neutral answers in order to elicit a definitive answer from the respondents.

Because of repeated measures taken as part of this study, it was decided to make use of Cronbach's alpha in order to determine the degree to which the Likert scales which were used, produced consistent results. Malhotra *et al.* (2006:214) prescribe that Cronbach's alpha coefficients of over 0.7 are considered to be acceptable (Field, 2009:675). The 25 questions in the questionnaire were grouped into 8 primary question sections, with 5 distinct variable sets or constructs:

- Section 1 focused on the respondent's working environment
- Section 2 focused on the quality of work within the working environment
- Section 3 focused on the effectiveness of work executed
- Section 4 focused on the role of learning within the working environment
- Section 5 focused on forecasting in the workplace

The 4-point Likert scale was utilised to assess employee perception and attitude towards several aspects of forecasting by giving a score of: Strongly Disagree (1), Disagree (2), Agree (3) and Strongly Agree (4).

4.7 LAYOUT OF THE QUESTIONNAIRE

4.7.1 Section 1 – Demographics

Section 1 focussed on the demographics of the respondents and personal information pertaining to their education and years of working experience. It also enquires at which power station these respondents work, within which department, their job description, tenure in the specific department and the number of hours required to complete the tasks handed to them.

4.7.2 Section 2 – Research question

Section 2 poses the research question of the study:

Do you believe that process variable forecasting can improve Operations Management difficulties at a power station?

4.7.3 Section 3 – Working environment

Section 3 focussed on the respondents working environment. The aim was to understand whether the respondents enjoyed their working environment and their work responsibilities. The section then continues to pose questions more relevant to forecasting within the work environment.

Question 3.3, "Can process variable forecasting improve the working relations (team spirit) between the maintenance, operating and production departments?" tries to establish whether forecasting can improve the working relations or team spirit between the various operational departments at the power station. The question is posed in light of historic difficulties in trying to establish healthy working relationships between operations departments at power stations. The primary reason for the tension between departments can be laid at the feet of operations failures – if something went wrong from an operations perspective, blame shifting takes place between the operations, maintenance and engineering departments. This leads to animosity between the departments and influences the willingness of future inter-departmental cooperation and working relationships.

Question 3.4, "When workers are informed earlier of unplanned work to be done, will it enable them to make better arrangements with their families for call-out work to be done?" focuses on unplanned work within the working environment. Due to the operations nature of a power station, unplanned work will always form part of an employee's working environment. The challenge from an operations management perspective is to try and manage operations in such a way so as to curb unplanned work as much as possible. When unplanned work needs to be done the prerogative is to attempt to intercept the possibility of it having to be done as quickly as possible. Every additional hour gained of upfront knowledge regarding an emerging problem which could potentially lead to unplanned work, is worth its weight in gold within an operations environment. This information provides a platform for better planning in order to carry out effective, unplanned work. The latent effect of unplanned work is working longer hours and spending less time with families. This knock-on effect potentially has a detrimental effect on the well-being of the employee. However, as previously stated, the nature of the operational environment lends itself to unplanned work. This question, therefore seeks to understand if workers are informed earlier of unplanned work, whether it will enable them to make better arrangements with their families. The underlying concept which is studied comes down to whether families will be more accommodating when they know in advance unplanned work will intrude on their family time, or whether it will make no difference at all. If the question is answered in a positive light, this could potentially improve the working environment of the employee - if it can be proven that forecasting can provide upfront warnings of potential emerging operations constraints or challenges. Questions on this aspect are posed in Section 7 of the questionnaire.

Question 3.5, “Do you feel over worked in your current working environment?” and Question 3.6, “Do you believe that process variable forecasting can have a positive change on your working environment?” are aligned with each other. The former asks whether the respondents feel overworked in their working environment and the latter whether forecasting can have a positive change on their working environment.

4.7.4 Section 4 – Quality of work

Question 4.1, “Working under pressure of deadliness influence the quality of work executed?” tries to establish whether the pressure of deadlines influence the quality of work performed by the respondents. The time afforded for operations personnel to execute work is often constrained due to delayed permit issuing and the request of expedited execution to meet deadlines set by management. This means deadlines are moved forward in order to achieve production KPI’s (Key Performance Indicator). The result is that valuable time is lost at the beginning of the work activity and quicker turnaround times are expected from management in order to return the system to service quicker than expected.

Question 4.2, “When afforded more time to do work activities, workers have more confidence to ask for guidance on work activities from supervisors or managers?” focuses on the confidence employees have to ask for guidance on work activities from supervisors or managers. Root cause analysis investigations have often found that critical errors are made by employees in the operations environment if they do not have the confidence to ask questions pertaining to the work they do. For this reason, it is critical that an environment is created where employees can ask for direction if they are unsure about the execution of a task or have to resort to pose their question if they experience operations challenges during the execution of their duties.

Question 4.3, “Will proses variable forecasting enable better routine maintenance to be done?” poses a very direct question to the respondents by asking whether PVF will enable better routine maintenance to be done. With most respondents having had a certain measure of exposure to forecasting in the workplace (by means of Flowcast®), it was felt that a direct question regarding forecasting is suitable.

Question 4.4, “Knowing in advance which equipment will break or require specific maintenance, enables better maintenance scope of work to be planned?” focuses on the quality of SOW created and planned for if the respondents know in advance what maintenance will be required for a specific system. The quality and detail contained in the SOW directly influences the quality of work. A greater outline of detail with very specific guidance on execution of activities empowers the employee executing the SOW to be more successful with the execution of the tasks. By affording more time to the employee who has to create the SOW, more detail can be accommodated in the SOW to ensure the executer of the SOW is empowered.

Question 4.5, “Your work responsibilities are more manageable when unplanned activities are minimal?” seeks the opinions of the respondents regarding unplanned work activities and the impact it has on making work responsibilities less manageable. Unplanned work activities have a tendency to disrupt normal work practices and duties and should therefore be kept to a minimum as far as possible.

4.7.5 Section 5 – Effectiveness of work

Question 5.1, “Will process variable forecasting improve (add value) to the effectiveness with which you carry out your tasks?” tries to establish whether respondents feel that PVF can assist them to carry out their work more effectively. This is an important question since the focus is not on the influence PVF has on the quality of the work executed, but rather in this instance the effectiveness with which the work is done. If work can therefore be executed more effectively, this enables cost savings by quicker returning the plant to full production capacity.

Question 5.2, “Will process variable forecasting allow for better planning of work activities in your department?” seeks to understand whether PVF allows for better planning of work activities within the department where the respondents work. The planning of work activities often involves several individuals to reach consensus on the execution approach to follow, as well as inter-departmental consultation to schedule an activity and avail specific resources. This also entails consultation with stores departments to establish stock levels and book out the relevant spares equipment required for maintenance activities.

Question 5.3, “Will process variable forecasting allow for better planning of work activities when different departments are required to work together?” focuses on the contribution of PVF to support for better planning of work activities when different departments are required to work together. In general, execution of work activities within departments is completed without excessive challenges. When two or more departments are required to work towards a common goal, planning plays a critical role to ensure successful execution of work activities. Challenges which usually upset the work which must be done together as an inter-departmental team is the allocation of personnel resources, with aligned diaries. Sometimes specific individuals from a department are only available in the morning while the individuals from the other department are only available in the afternoon. Execution however requires both parties to be present. Eventually diaries do g*et al*igned but at a costly time delay. This question therefore seeks to determine if PVF can support better inter-departmental planning of work activities (due to the upfront indication of operational constraints before they manifest in the plant, by making use of PVF).

Question 5.4, “Are you more productive when you have more time to plan for a work activity?” poses a simple question by asking the respondents whether they are more productive when they have more time to plan for a specific work activity.

Question 5.5, “Enjoying your work responsibilities enhances your productivity?” concludes Section 5 by asking the respondents whether enjoying their work responsibilities assist them to be more productive. This question is important in light of the fact that Question 3.2 specifically tries to establish whether the respondents enjoy their work responsibilities. If respondents answer negatively to Question 3.2 (i.e., they do not like their work responsibilities) but answers positive to Question 5.5 (i.e they are more productive when they enjoy their work responsibilities) it could assist with drawing correlations on how PVF can improve operation management difficulties in the energy sector.

4.7.6 Section 6 – Learning

Question 6.1, “Will process variable forecasting provide workers with more confidence to do work?” attempts to establish whether respondents will have more confidence to do their work if PVF provides them with upfront predictions of system performance. To this end, the term confidence is also clarified in the question by explaining that confidence to do work is based on experience and understanding of the problem, and achieved by means of training or through guidance.

Question 6.2, “Does process variable forecasting enhance the learning experience of work activities carried out?” seeks to understand whether PVF enhances the learning experience of work activities carried out. Quite often, work activities within the energy sector are carried out by individuals without having the opportunity to understand how their work fits in and influences the greater performance of the plant. Work is carried out in silos with an extremely localised view of the operations activity or maintenance which has to be done. The intention of PVF is to provide the worker with an upfront indication of work which will have to be carried out in the near or imminent future without the plant or system having expressed that need yet. The intention of the question is therefore to establish whether this platform of upfront PVF will enhance the learning experience of work activities carried out by understanding the problem before proceeding to resolve it.

Question 6.3, “Enhancement of learning activities in the work place enables better quality work to be done?” is a follow-up question carrying on from the question posed by Question 6.2, whereby the respondents are asked whether enhancement of learning activities in the workplace enables better quality work to be done.

Question 6.4, “Enhancement of learning activities in the work place enables work to be done on time?” ends off the questions of Section 6 by asking the respondents whether the enhancement of learning activities in the workplace enables work to be done on time.

Questions 6.3 and 6.4 therefore both focus on the benefit of learning activities and how it can improve the quality of work and effectiveness with which tasks are carried out within the operations environment.

4.7.7 Section 7 – Forecasting

Question 7.1, “Knowing in advance which equipment will break or require specific maintenance, enables the plant to be operated more safely?” tries to establish whether the respondents perceive that knowing in advance which equipment will break or require specific maintenance, will enable the plant to be operated more safely. Safety in the workplace is extremely important. Employees must be able to work within an environment which is safe and healthy and have the confidence to perform their tasks without fear of getting injured. Legal compliance to safety is also non-negotiable. Any process which can therefore easily facilitate a safer working environment should be considered. This question therefore tries to understand whether respondents agree that forecasting can provide them with this benefit.

Question 7.2, “Knowing in advance which equipment will break or require specific maintenance, enables management to make better operational decisions?” seeks to understand whether forecasting will enable management to make better operational decisions given that they will know in advance which equipment will break or require specific maintenance. A situation which often unfolds at power stations are the execution of certain maintenance tasks with a specific operations outcome expected at the completion of the maintenance task. The desired outcome is unfortunately not always achieved, with the expected maintenance benefit falling far short from expectations and other plant areas coming to the fore with substantial operations challenges and shortcomings. If management had a platform whereby they could make better informed decisions on the operations management of their plant, would it enable them to make better decisions? This question tries to understand whether such an opportunity will in fact support better operational decisions.

Question 7.3, “Knowing in advance which equipment will break or require specific maintenance, enables workers to plan better for after hour call-outs?” seeks to understand whether forecasting will enable employees to plan better for potential after hour call-outs. It is sometimes required that more than one individual form part of a team which plan around an operations or maintenance activity which needs to be done. When after hour call-outs are made (which also has a cost impact), only staff that are on call are involved. This often leads to limited work done after hours because critical resources are only available during office hours. Operations interruptions can therefore happen as a result of this shortcoming.

Question 7.4, “Knowing in advance which equipment will break or require specific maintenance, tries to establish if forecasting supports better management of the effect of the defect and constraints. The premise which is made is that if forecasting highlights specific risks to components or equipment, will it enable management to manage the symptoms better? An example is that Flowcast® could highlight that the Compressed Air system will become severely constrained, which could afford management to hire in diesel compressors to supplement the constrained station air compressors. If the problem however creeps up unexpectedly, the opportunity to hire in diesel compressors are still available but will take time, most likely leading to operations output losses till the compressors arrive on site.

Question 8 is the final question in the questionnaire and asks respondents whether they believe PVF can improve operations management at a power station.

4.8 CHAPTER SUMMARY

The data collection process followed along with the data analysis which was carried out was discussed. A pilot study was carried out in order to serve as a forerunner for the empirical research which was done. The sample selection is described along with the measuring instrument which was selected. The layout of the questionnaire along with the questions posed to the respondents is presented along with the reasoning behind each individual question contained in the questionnaire.

CHAPTER 5: RESEARCH FINDINGS AND RECOMMENDATIONS

5.1 INTRODUCTION

Successful operations management is arguably one of the single most important endeavours for any manager in an organisation. By genuinely understanding the true principles and concepts this field offers, remarkable improvements in overall product, process and service quality can be realised by management while also acknowledging all of the relevant support systems and individuals which play a part in rendering this success.

In Chapter 3, several exhibits were presented where the concept of PVF was employed in order to test the effect it has on improving operations management on an industrial scale.

Chapter 4 served as an extension of Chapter 3 but with a specific focus on the opinion of respondents who had the opportunity of forming part of these exhibits where PVF was used in their day to day tasks and duties. A pilot study which was undertaken to test and formulate questions for the questionnaire was presented along with the most important feedback elicited from the respondents. These answers and feedback was used in order to rephrase and reformulate some of the questions before the final questionnaire was used in the field.

Chapter 5 will present these results and discuss the findings obtained. A conclusion will also be drawn on the contribution which PVF makes to the three pillars of operations management namely: people, plant and process.

5.2 ANALYSING AND DESCRIBING THE RESULTS WITH FREQUENCY TABLES

The frequency table results are presented in Table 2 and provide a better understanding of the opinion of respondents who participated in the research questionnaire. The mean and standard deviation enables the researcher to quantify the amount of respondents who agree to a specific statement in the questionnaire. Field (2009:38) states that a smaller standard deviation compared to the mean of the results are indicative of less variation in the answering of the questions.

Table 3: Frequency table results

Descriptive Statistics			
	Mean	Answer	Std. Deviation
3.1. Respondents enjoy their current working environment	2.79	Agree	0.706
3.2. Respondents enjoy their work responsibilities	2.96	Agree	0.644
3.3. PVF can improve the working relations (team spirit) between the Maintenance, Operating and Engineering departments	3.19	Agree	0.565
3.4. When workers are informed earlier of unplanned work to be done, it enables them to make better arrangements with their families for call-out work to be done	3.30	Agree	0.598
3.5. Respondents feel over worked in their current working environment	2.49	**Disagree**	0.843
3.6. Respondents believe that PVF can have a positive change on their work environment	3.08	Agree	0.514
4.1. Working under the pressure of deadlines influence the quality of work executed	3.06	Agree	0.679
4.2. When afforded more time to do work activities, workers have more confidence to ask for guidance on work activities from supervisors or managers	3.16	Agree	0.631
4.3. PVF enables better routine maintenance to be done	3.23	Agree	0.510
4.4. Knowing in advance which equipment will break or require specific maintenance, enables better maintenance scope of work to be planned	3.46	Agree	0.521
4.5. Work responsibilities are more manageable when unplanned activities are minimal	3.31	Agree	0.581
5.1. PVF improves (add value) to the effectiveness with which respondents carry out their tasks	3.09	Agree	0.473
5.2. PVF allows for better planning of work activities in respondents' department	3.18	Agree	0.500
5.3. PVF allows for better planning of work activities when different departments are required to work together	3.17	Agree	0.493
5.4. Respondents are more productive when they have more time to plan for a work activity	3.42	Agree	0.535
5.5. Enjoying your work responsibilities enhances your productivity	3.50	**Strongly Agree**	0.522
6.1. PVF provides workers with more confidence to do work (Confidence to do work is based on experience and understanding of the problem, achieved by means of training or through guidance.)	3.22	Agree	0.561
6.2. PVF enhances the learning experience of work activities carried out	3.12	Agree	0.498
6.3. Enhancement of learning activities in the work place enables better quality work to be done	3.30	Agree	0.461
6.4. Enhancement of learning activities in the work place enables work to be done on time	3.24	Agree	0.515
7.1. Knowing in advance which equipment will break or require specific maintenance, enables the plant to be operated more safely	3.41	Agree	0.514
7.2. Knowing in advance which equipment will break or require specific maintenance, enables management to make better operational decisions?	3.44	Agree	0.519
7.3. Knowing in advance which equipment will break or require specific maintenance, enables workers to make better planning for after hour call-outs	3.31	Agree	0.545
7.4. Knowing in advance which equipment will break or require specific maintenance, enables better management of the effect of defects and system bottlenecks	3.25	Agree	0.500

Key		
The mean of answers in green notes interesting results		
The mean of answers in orange are highlighted because of their high or low agreement values		

5.3 CALCULATING THE RELIABILITY OF THE CONSTRUCTS IN THE QUESTIONNAIRE

As mentioned in the Statistical Analysis Section 1.5.2.4 pertaining to the Research Methodology used, it was decided to make use of Cronbach's alpha in order to determine the degree to which the Likert scales which were used, produced consistent results. It was also noted that Cronbach's alpha coefficients of over 0.7 were considered to be acceptable, while coefficients of greater than 0.8 were considered to be good. With Cronbach alpha's greater than 0.7 it can be assumed that the statements of the constructs measure the same underlying theme and that internal consistency is present. In this study, the 25 questions which were measured in the survey had Cronbach's alphas of:

1. Working Environment: $\alpha = 0.606$
2. Quality of Work: $\alpha = 0.658$
3. Effectiveness of Work: $\alpha = 0.718$
4. Learning: $\alpha = 0.794$
5. Forecasting: $\alpha = 0.874$

The analysis of the results of the 25 questions, grouped into the five distinct constructs, is presented in detail in the following tables below:

Table 4: Reliability Statistics and Inter-Item Correlation Matrix for "Working Environment"

Reliability Statistics		
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.606	0.606	5

Inter-Item Correlation Matrix (Working Environment)					
	Do you enjoy your current working environment?	Do you enjoy your work responsibilities?	Can PVF improve the working relations (team spirit) between the Maintenance, Operating and Production departments?	When workers are informed earlier of unplanned work to be done, will it enable them to make better arrangements with their families for call-out work to be done?	Do you believe that PVF can have a positive change on your work environment?
Do you enjoy your current working environment?	1.000	0.833	0.115	-0.009	0.109
Do you enjoy your work responsibilities?	0.833	1.000	0.157	-0.083	0.149
Can PVF improve the working relations (team spirit) between the Maintenance, Operating and Production departments?	0.115	0.157	1.000	0.236	0.494
When workers are informed earlier of unplanned work to be done, will it enable them to make better arrangements with their families for call-out work to be done?	-0.009	-0.083	0.236	1.000	0.351
Do you believe that PVF can have a positive change on your work environment?	0.109	0.149	0.494	0.351	1.000

Quality of content: In order to collect the data necessary to determine the "Working Environment" effect, a 4-item Likert scale was used consisting the following options: Strongly disagree, Disagree, Agree or Strongly agree. The inter-item correlation matrix above was used to group relevant questions together in order to calculate the Cronbach Alpha (α) for each variable. Originally an α = 0.577 was achieved, but after removal of Question 3.5 the α = 0.606 improved slightly. In order to produce consistent and reliable results it is recommended that future research might be required to repeat this part of the study in order to achieve values above 0.7

Table 5: Reliability Statistics and Inter-Item Correlation Matrix for "Quality of Work"

Reliability Statistics		
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.658	0.664	5

Inter-Item Correlation Matrix (Quality of Work)					
	Working under the pressure of deadlines influence the quality of work executed?	When afforded more time to do work activities, workers have more confidence to ask for guidance on work activities from supervisors or managers?	Will PVF enable better routine maintenance to be done?	Knowing in advance which equipment will break or require specific maintenance, enables better maintenance scope of work to be planned?	Your work responsibilities are more manageable when unplanned activities are minimal?
Working under the pressure of deadlines influence the quality of work executed?	1.000	0.402	0.135	0.407	0.209
When afforded more time to do work activities, workers have more confidence to ask for guidance on work activities from supervisors or managers?	0.402	1.000	0.198	0.419	0.111
Will PVF enable better routine maintenance to be done?	0.135	0.198	1.000	0.397	0.132
Knowing in advance which equipment will break or require specific maintenance, enables better maintenance scope of work to be planned?	0.407	0.419	0.397	1.000	0.426
Your work responsibilities are more manageable when unplanned activities are minimal?	0.209	0.111	0.132	0.426	1.000

Quality of content: In order to collect the data necessary to determine the "Quality of Work" effect, a 4-item Likert scale was used consisting the following options: Strongly disagree, Disagree, Agree or Strongly agree. The inter-item correlation matrix above was used to group relevant questions together in order to calculate the Cronbach Alpha (α) for each variable. An α = 0.658 was achieved. In order to produce consistent and reliable results it is recommended that future research might be required to repeat this part of the study in order to achieve values above 0.7

Table 6: Reliability Statistics and Inter-Item Correlation Matrix for "Effectiveness of Work"

Reliability Statistics		
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.718	0.722	5

Inter-Item Correlation Matrix (Effectiveness of Work)					
	Will PVF improve (add value) to the effectiveness with which you carry out your tasks?	Will PVF allow for better planning of work activities in your department?	Will PVF allow for better planning of work activities when different departments are required to work together?	Are you more productive when you have more time to plan for a work activity?	Enjoying your work responsibilities enhances your productivity?
Will PVF improve (add value) to the effectiveness with which you carry out your tasks?	1.000	0.613	0.496	0.208	0.225
Will PVF allow for better planning of work activities in your department?	0.613	1.000	0.489	0.243	0.193
Will PVF allow for better planning of work activities when different departments are required to work together?	0.496	0.489	1.000	0.224	0.255
Are you more productive when you have more time to plan for a work activity?	0.208	0.243	0.224	1.000	0.470
Enjoying your work responsibilities enhances your productivity?	0.225	0.193	0.255	0.470	1.000

Quality of content: In order to collect the data necessary to determine the "Effectiveness of Work" effect, a 4-item Likert scale was used consisting the following options: Strongly disagree, disagree, Agree or Strongly agree. The inter-item correlation matrix above was used to group relevant questions together in order to calculate the Cronbach Alpha (α) for each variable. An α = 0.718 was achieved, highlighting that the Likert scale employed produced very consistent and reliable results over repeated measurements taken.

Table 7: Reliability Statistics and Inter-Item Correlation Matrix for "Learning"

Reliability Statistics		
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.794	0.796	4

Inter-Item Correlation Matrix (Learning)				
	Will PVF provide workers with more confidence to do work? (Confidence to do work is based on experience and understanding of the problem, achieved by means of training or through guidance.)	Does PVF enhance the learning experience of work activities carried out?	Enhancement of learning activities in the work place enables better quality work to be done?	Enhancement of learning activities in the work place enables work to be done on time?
Will PVF provide workers with more confidence to do work? (Confidence to do work is based on experience and understanding of the problem, achieved by means of training or through guidance.)	1.000	0.555	0.485	0.445
Does PVF enhance the learning experience of work activities carried out?	0.555	1.000	0.370	0.477
Enhancement of learning activities in the work place enables better quality work to be done?	0.485	0.370	1.000	0.630
Enhancement of learning activities in the work place enables work to be done on time?	0.445	0.477	0.630	1.000

Quality of content: In order to collect the data necessary to determine the "Learning" effect, a 4-item Likert scale was used consisting the following options: Strongly disagree, disagree, Agree or Strongly agree. The inter-item correlation matrix above was used to group relevant questions together in order to calculate the Cronbach Alpha (α) for each variable. An α = 0.794 was achieved, highlighting that the Likert scale employed for this construct produced consistent and reliable results over repeated measurements taken.

Table 8: Reliability Statistics and Inter-Item Correlation Matrix for “Forecasting”

Reliability Statistics		
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.874	0.874	4

Inter-Item Correlation Matrix (Forecasting)				
	Knowing in advance which equipment will break or require specific maintenance, enables the plant to be operated more safely?	Knowing in advance which equipment will break or require specific maintenance, enables management to make better operational decisions?	Knowing in advance which equipment will break or require specific maintenance, enables workers to make better planning for after hour call-outs?	Knowing in advance which equipment will break or require specific maintenance, enables better management of the effect of defects and system bottlenecks?
Knowing in advance which equipment will break or require specific maintenance, enables the plant to be operated more safely?	1.000	0.756	0.659	0.579
Knowing in advance which equipment will break or require specific maintenance, enables management to make better operational decisions?	0.756	1.000	0.585	0.545
Knowing in advance which equipment will break or require specific maintenance, enables workers to make better planning for after hour call-outs?	0.659	0.585	1.000	0.677
Knowing in advance which equipment will break or require specific maintenance, enables better management of the effect of defects and system bottlenecks?	0.579	0.545	0.677	1.000

Quality of content: In order to collect the data necessary to determine the “Forecasting” effect, a 4-item Likert scale was used consisting the following options: Strongly disagree, Disagree, Agree or Strongly agree. The inter-item correlation matrix above was used to group relevant questions together in order to calculate the Cronbach Alpha (α) for each variable. An α = 0.874 was achieved, highlighting that the Likert scale employed produced very consistent and reliable results over repeated measurements taken.

Table 9: T-test for respondents 34 years and younger and respondents 35 years and older

Construct	Respondent Age	N	Mean	Std. Deviation	Sig. (2-tailed)	Effect Size
Working Enviroment	34 years and younger	57	3.0959	0.31898	0.587	0.09
	35 years and older	45	3.0533	0.46788	0.603	
Quality of Work	34 years and younger	57	3.2906	0.34015	0.235	0.21
	35 years and older	45	3.2000	0.42640	0.248	
Effectiveness of Work	34 years and younger	57	3.2561	0.32183	0.505	0.12
	35 years and older	45	3.3022	0.37325	0.513	
Learning	34 years and younger	57	3.1959	0.38107	0.457	0.14
	35 years and older	45	3.2556	0.42470	0.463	
Forecasting	34 years and younger	57	3.3465	0.41392	0.918	0.02
	35 years and older	45	3.3556	0.47521	0.920	

A T-test was conducted to compare the opinion of respondents 34 years and younger and respondents 35 years and older. This data will assist in determining if there is a practical significant difference as to how these two age groups answered the different constructs. Based on the data obtained from the respondents, there is no practical significant difference as to how the different age groups answered the constructs focussing on the working environment, quality of work, effectiveness of work, learning and forecasting.

Table 10: T-test for male and female respondents

Construct	Respondent Gender	N	Mean	Std. Deviation	Sig. (2-tailed)	Effect Size
Working Enviroment	Male	79	3.0675	0.37126	0.678	0.10
	Female	20	3.1067	0.39494	0.692	
Quality of Work	Male	79	3.2646	0.39485	0.462	0.18
	Female	20	3.1933	0.34465	0.429	
Effectiveness of Work	Male	79	3.2899	0.34515	0.603	0.13
	Female	20	3.2450	0.33791	0.601	
Learning	Male	79	3.2078	0.39582	0.433	0.18
	Female	20	3.2875	0.43886	0.466	
Forecasting	Male	79	3.3734	0.44012	0.321	0.24
	Female	20	3.2625	0.46222	0.341	

A T-test was conducted to compare the opinion of male and female respondents. This data will assist in determining if there is a practical significant difference as to how these two gender groups, answered the different constructs. Based on the data obtained from the respondents, there is no practical significant difference as to how the different gender groups answered the constructs.

Table 11: T-test for respondents with different years of work experience

Construct	Respondent Work Experience (Years)	N	Mean	Std. Deviation	Sig. (2-tailed)	Effect Size
Working Enviroment	0 - 10 years	64	3.0583	0.36195	0.646	0.09
	11 + years	37	3.0955	0.43505	0.662	
Quality of Work	0 - 10 years	64	3.2484	0.34778	0.980	0.00
	11 + years	37	3.2505	0.44233	0.981	
Effectiveness of Work	0 - 10 years	64	3.2422	0.32602	0.208	0.24
	11 + years	37	3.3324	0.37569	0.227	
Learning	0 - 10 years	64	3.1940	0.38777	0.319	0.20
	11 + years	37	3.2770	0.42403	0.332	
Forecasting	0 - 10 years	64	3.3438	0.42375	0.761	0.06
	11 + years	37	3.3716	0.47369	0.768	

A T-test was conducted on respondents with less than ten years working experience and respondents with more than ten years working experience. This data will assist in determining if there is a practical significant difference as to how these two groups answered the different constructs. Based on the data obtained from the respondents, there is no practical significant difference as to how the two groups answered the constructs focussing on the working environment, quality of work, effectiveness of work, learning and forecasting.

Table 12: Testing for the statistical significant difference between respondent level of education

Construct	Respondent Highest Level of Education	Sum of Squares	df	Mean Square	F	Sig.
Working Enviroment	Between Groups	0.288	3	0.096	0.656	0.581
	Within Groups	13.189	90	0.147		
	Total	13.477	93			
Quality of Work	Between Groups	0.778	3	0.259	1.837	0.146
	Within Groups	12.711	90	0.141		
	Total	13.489	93			
Effectiveness of Work	Between Groups	0.061	3	0.020	0.162	0.921
	Within Groups	11.244	90	0.125		
	Total	11.305	93			
Learning	Between Groups	0.211	3	0.070	0.420	0.739
	Within Groups	15.024	90	0.167		
	Total	15.235	93			
Forecasting	Between Groups	0.453	3	0.151	0.744	0.529
	Within Groups	18.265	90	0.203		
	Total	18.718	93			

There is no statistical significant difference as to how the various groups answered the different constructs.

Table 13: ANOVA analysis of respondent qualification level against five operational constructs

Construct	Respondent highest level of Education	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum	Matric	Diploma	Degree
						Lower Bound	Upper Bound					
Working Enviroment	Matric	14	3.2000	0.24807	0.06630	3.0568	3.3432	2.80	3.60			
	Diploma	39	3.0855	0.44088	0.07060	2.9426	3.2284	1.60	4.00	0.26		
	Degree	27	3.0494	0.28858	0.05554	2.9352	3.1635	2.40	3.60	0.52	0.08	
	Honours Degree	14	3.0143	0.46716	0.12485	2.7446	3.2840	2.20	4.00	0.40	0.15	0.08
	Total	94	3.0816	0.38067	0.03926	3.0036	3.1595	1.60	4.00			
Quality of Work	Matric	14	3.3143	0.41298	0.11037	3.0758	3.5527	2.80	4.00			
	Diploma	39	3.2222	0.40127	0.06425	3.0921	3.3523	2.40	4.00	0.22		
	Degree	27	3.2111	0.32384	0.06232	3.0830	3.3392	2.40	3.80	0.25	0.03	
	Honours Degree	14	3.4714	0.35611	0.09517	3.2658	3.6770	3.00	4.00	0.38	0.62	0.73
	Total	94	3.2699	0.38085	0.03928	3.1919	3.3479	2.40	4.00			
Effectiveness of Work	Matric	14	3.3286	0.32917	0.08797	3.1385	3.5186	2.80	3.80			
	Diploma	39	3.3000	0.36491	0.05843	3.1817	3.4183	2.60	4.00	0.08		
	Degree	27	3.2556	0.29396	0.05657	3.1393	3.3718	2.60	3.80	0.22	0.12	
	Honours Degree	14	3.2714	0.44103	0.11787	3.0168	3.5261	2.60	4.00	0.13	0.06	0.04
	Total	94	3.2872	0.34865	0.03596	3.2158	3.3586	2.60	4.00			
Learning	Matric	14	3.2143	0.33766	0.09024	3.0193	3.4092	3.00	4.00			
	Diploma	39	3.3013	0.42216	0.06760	3.1644	3.4381	2.50	4.00	0.21		
	Degree	27	3.1944	0.41216	0.07932	3.0314	3.3575	2.25	4.00	0.05	0.25	
	Honours Degree	14	3.2262	0.42546	0.11371	2.9805	3.4718	2.50	4.00	0.03	0.18	0.07
	Total	94	3.2465	0.40474	0.04175	3.1636	3.3294	2.25	4.00			
Forecasting	Matric	14	3.3750	0.41313	0.11041	3.1365	3.6135	3.00	4.00			
	Diploma	39	3.3718	0.48284	0.07732	3.2153	3.5283	2.50	4.00	0.01		
	Degree	27	3.2963	0.42197	0.08121	3.1294	3.4632	2.50	4.00	0.19	0.16	
	Honours Degree	14	3.5179	0.44359	0.11855	3.2617	3.7740	2.75	4.00	0.32	0.30	0.50
	Total	94	3.3723	0.44863	0.04627	3.2805	3.4642	2.50	4.00			

ANOVA testing was used to determine whether the constructs are a statistically significantly prediction of the outcome variable (Field, 2009:207). The sigma value should be $p < 0.05$ in order to be statistically significant. A practical significance factor of greater than 0.8 must be present to highlight a difference in the way which different groups answered the constructs. There is no practical significant difference as to how the various groups answered the different constructs. All the respondents, whether they had a matric, diploma, degree or honours degree tend to choose “Agree” on the Likert scale.

If an exception must be made however, the practical significance between the Honours degree and Degree respondents regarding their opinion on the benefit of PVF pertaining to the quality of work construct does tend towards a medium to high practical significance of 0.73. This means that Honours degree respondents feel they elicit greater benefit from PVF than Degree respondents, when it pertains to the quality of work construct which tests 5 underlying themes of quality of work.

Table 14: Testing for the statistical significant difference between respondents at different power stations

Construct	Respondent Power Station	Sum of Squares	df	Mean Square	F	Sig.
Working Enviroment	Between Groups	0.022	2	0.011	0.070	0.933
	Within Groups	15.354	99	0.155		
	Total	15.376	101			
Quality of Work	Between Groups	0.004	2	0.002	0.014	0.986
	Within Groups	14.682	99	0.148		
	Total	14.686	101			
Effectiveness of Work	Between Groups	0.019	2	0.009	0.078	0.925
	Within Groups	11.965	99	0.121		
	Total	11.984	101			
Learning	Between Groups	0.283	2	0.142	0.883	0.417
	Within Groups	15.874	99	0.160		
	Total	16.157	101			
Forecasting	Between Groups	0.273	2	0.137	0.703	0.498
	Within Groups	19.259	99	0.195		
	Total	19.532	101			

There is no statistical significant difference as to how the various groups answered the different constructs.

Table 15: ANOVA analysis of respondent power station against five operational constructs

Construct	Respondent Power Station	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum	Tango	Charlie
Working Enviroment	Tango	46	3.0913	0.3811	0.0562	2.9781	3.2045	1.60	4.00		
	Charlie	37	3.0721	0.4147	0.0682	2.9338	3.2103	2.20	4.00	0.05	
	Mike	19	3.0526	0.3821	0.0876	2.8685	3.2368	2.20	4.00	0.10	0.05
	Total	102	3.0771	0.3902	0.0386	3.0005	3.1538	1.60	4.00		
Quality of Work	Tango	46	3.2565	0.3902	0.0575	3.1406	3.3724	2.40	4.00		
	Charlie	37	3.2423	0.4001	0.0658	3.1090	3.3757	2.60	4.00	0.04	
	Mike	19	3.2526	0.3389	0.0777	3.0893	3.4160	2.80	4.00	0.01	0.03
	Total	102	3.2507	0.3813	0.0378	3.1758	3.3256	2.40	4.00		
Effectiveness of Work	Tango	46	3.283	0.3414	0.0503	3.181	3.384	2.60	4.00		
	Charlie	37	3.259	0.3452	0.0567	3.144	3.375	2.60	4.00	0.07	
	Mike	19	3.295	0.3674	0.0843	3.118	3.472	2.80	4.00	0.03	0.10
	Total	102	3.276	0.3445	0.0341	3.209	3.344	2.60	4.00		
Learning	Tango	46	3.2772	0.4321	0.0637	3.1488	3.4055	2.50	4.00		
	Charlie	37	3.1937	0.3558	0.0585	3.0751	3.3123	2.25	4.00	0.19	
	Mike	19	3.1447	0.4024	0.0923	2.9508	3.3387	2.50	4.00	0.31	0.12
	Total	102	3.2222	0.4000	0.0396	3.1437	3.3008	2.25	4.00		
Forecasting	Tango	46	3.4076	0.46951	0.06923	3.2682	3.5470	2.50	4.00		
	Charlie	37	3.3041	0.41305	0.06790	3.1663	3.4418	3.00	4.00	0.22	
	Mike	19	3.3026	0.42146	0.09669	3.0995	3.5058	2.75	4.00	0.22	0.00
	Total	102	3.3505	0.43976	0.04354	3.2641	3.4369	2.50	4.00		

There is no practical significant difference as to how the various groups answered the different constructs. All the respondents, whether they work at the Tango, Charlie or Mike power stations, the mean shows that the respondents tend to choose “Agree” on the Likert scale.

Table 16: Testing for the statistical significant difference between respondents at different departments

Construct	Respondent Department	Sum of Squares	df	Mean Square	F	Sig.
Working Enviroment	Between Groups	0.105	2	0.052	0.338	0.714
	Within Groups	14.704	95	0.155		
	Total	14.809	97			
Quality of Work	Between Groups	0.031	2	0.015	0.108	0.897
	Within Groups	13.463	95	0.142		
	Total	13.494	97			
Effectiveness of Work	Between Groups	0.158	2	0.079	0.681	0.508
	Within Groups	11.042	95	0.116		
	Total	11.200	97			
Learning	Between Groups	0.058	2	0.029	0.182	0.834
	Within Groups	15.110	95	0.159		
	Total	15.168	97			
Forecasting	Between Groups	0.007	2	0.004	0.020	0.981
	Within Groups	18.126	95	0.191		
	Total	18.133	97			

There is no statistical significant difference as to how the various groups answered the different constructs.

Table 17: ANOVA analysis of respondent department against five operational constructs

Construct	Respondent Department	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum	Tango	Charlie
						Lower Bound	Upper Bound				
Working Enviroment	Engineering	48	3.0528	0.3554	0.0513	2.9496	3.1560	2.20	4.00		
	Maintenance	24	3.1250	0.4821	0.0984	2.9214	3.3286	1.60	4.00	0.15	
	Operating	26	3.0436	0.3700	0.0726	2.8942	3.1930	2.20	4.00	0.02	0.17
	Total	98	3.0680	0.3907	0.0395	2.9897	3.1464	1.60	4.00		
Quality of Work	Engineering	48	3.2396	0.3918	0.0566	3.1258	3.3533	2.40	4.00		
	Maintenance	24	3.2833	0.3953	0.0807	3.1164	3.4502	2.40	4.00	0.11	
	Operating	26	3.2564	0.3259	0.0639	3.1248	3.3880	2.80	4.00	0.04	0.07
	Total	98	3.2548	0.3730	0.0377	3.1800	3.3295	2.40	4.00		
Effectiveness of Work	Engineering	48	3.252	0.3427	0.0495	3.153	3.352	2.60	4.00		
	Maintenance	24	3.342	0.3463	0.0707	3.195	3.488	2.80	4.00	0.26	
	Operating	26	3.242	0.3325	0.0652	3.108	3.377	2.60	4.00	0.03	0.29
	Total	98	3.271	0.3398	0.0343	3.203	3.340	2.60	4.00		
Learning	Engineering	48	3.1910	0.3912	0.0565	3.0774	3.3046	2.25	4.00		
	Maintenance	24	3.2500	0.4170	0.0851	3.0739	3.4261	2.50	4.00	0.14	
	Operating	26	3.2212	0.3958	0.0776	3.0613	3.3810	2.50	4.00	0.08	0.07
	Total	98	3.2134	0.3954	0.0399	3.1342	3.2927	2.25	4.00		
Forecasting	Engineering	48	3.3542	0.43096	0.06220	3.2290	3.4793	2.75	4.00		
	Maintenance	24	3.3750	0.42349	0.08645	3.1962	3.5538	2.50	4.00	0.05	
	Operating	26	3.3558	0.45920	0.09006	3.1703	3.5412	2.75	4.00	0.00	0.04
	Total	98	3.3597	0.43237	0.04368	3.2730	3.4464	2.50	4.00		

There is no practical significant difference as to how the various groups answered the different constructs. All the respondents, whether they work in the Engineering, Maintenance or Operating department, the mean shows that the respondents tend to choose “Agree” on the Likert scale.

Table 18: Correlation test between five different constructs

		Working Enviroment	Quality of Work	Effectiveness of Work	Learning	Forecasting
Working Enviroment	Correlation Coefficient	1.000	.422**	.388**	.329**	.309**
	Sig. (2-tailed)		0.000	0.000	0.001	0.002
	N	102	102	102	102	102
Quality of Work	Correlation Coefficient	.422**	1.000	.490**	.369**	.531**
	Sig. (2-tailed)	0.000		0.000	0.000	0.000
	N	102	102	102	102	102
Effectiveness of Work	Correlation Coefficient	.388**	.490**	1.000	.539**	.557**
	Sig. (2-tailed)	0.000	0.000		0.000	0.000
	N	102	102	102	102	102
Learning	Correlation Coefficient	.329**	.369**	.539**	1.000	.581**
	Sig. (2-tailed)	0.001	0.000	0.000		0.000
	N	102	102	102	102	102
Forecasting	Correlation Coefficient	.309**	.531**	.557**	.581**	1.000
	Sig. (2-tailed)	0.002	0.000	0.000	0.000	
	N	102	102	102	102	102

The Spearman's correlation coefficient was used to indicate the linear relationship between all the variables. In order to interpret Spearman's correlation coefficients, factors between 0.1 and 0.3 are indicative of a small correlation, between 0.3 and 0.5 as medium and above 0.5 as large. A medium correlation is visible between the Working environment and the Quality of work (0.422). This shows a medium positive linear relation between these two constructs. A medium correlation is indicated between Working environment and the effectiveness of work (0.388). This also indicated a medium positive linear relationship between the two constructs. Another medium correlation is noticed between the Working environment and Learning (0.329) and this shows a medium positive linear relationship between the two constructs. Lastly, a medium correlation is present between the Working environment and Forecasting (0.309). This represents a medium positive linear relationship between the two constructs. To summarise all of this data: all the constructs indicated a medium correlation with one another and this indicates that there is a linear relationship present between all the different variables.

5.4 QUESTIONNAIRE RESULTS

A total of 102 respondents from three different power stations took part in the study. Some of the respondents were directly involved in the exhibits presented in Chapter 3 where PVF was practically employed within their operations environment. Other respondents not directly involved in the exhibits were aware of the concept of PVF and had a general understanding of it by way of forming part of feedback and information sessions where the results of the PVF undertakings were discussed. Although an attempt was made to get an equal number of respondents from each power station, the fact that each power station has varying number of people in their employ also had an impact. The Charlie power station for instance is a much smaller power station than Tango power station.

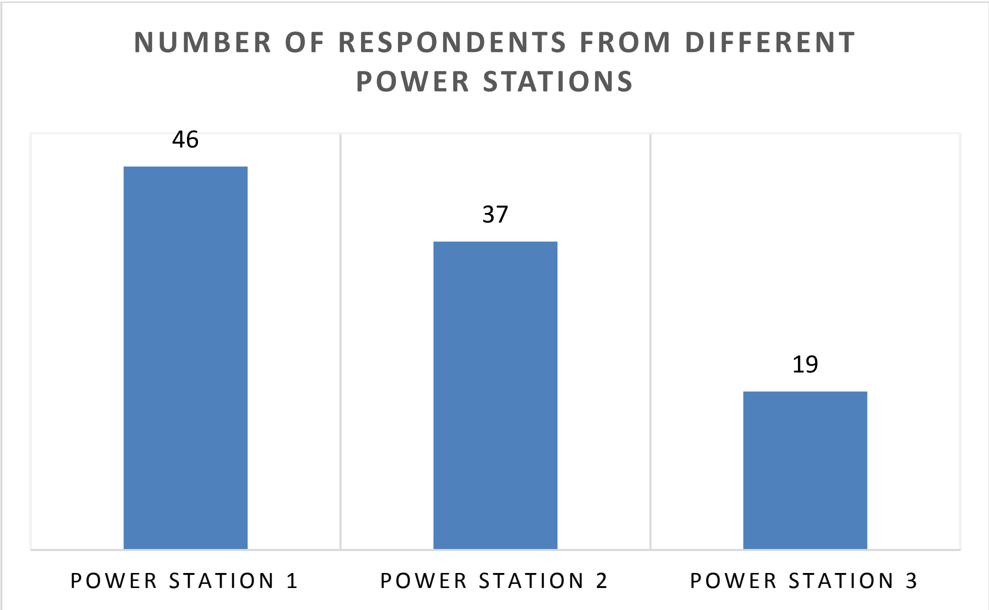


Figure 18: Number of respondents from three power stations

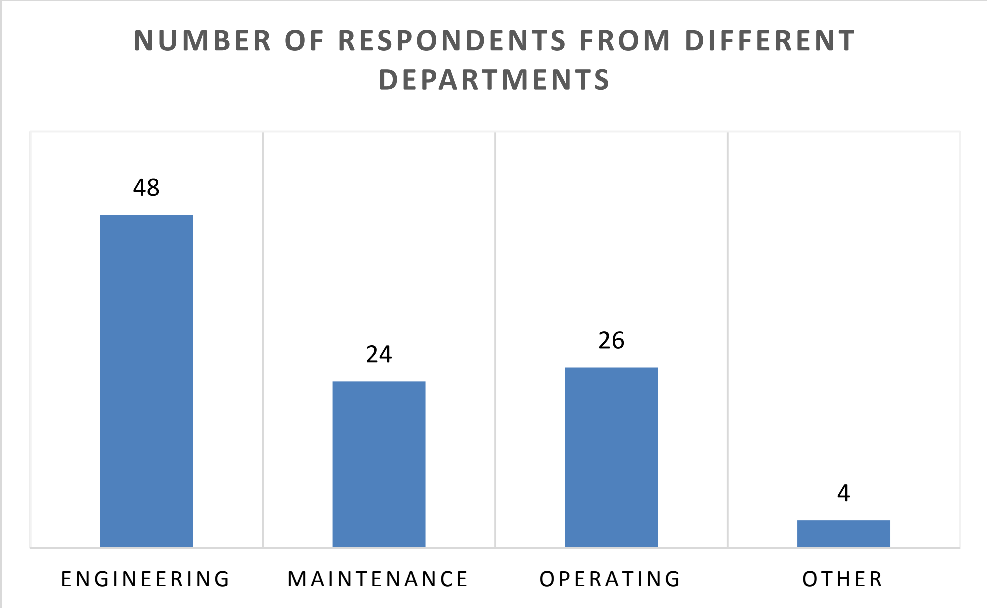


Figure 19: Number of respondents from different departments across three power stations

Respondents who completed the questionnaire came from three different departments between the three power stations namely the Engineering, Maintenance and Operating department. A 50/50 split was sought between the practical and theoretical approach to operations management between the three power stations was sought. The Maintenance and Operating departments were viewed as the practical enablers while the Engineering department was viewed as the theoretical enabler. To this end, 48 respondents from Engineering and 50 respondents from Maintenance and Operating took part. Four respondents from the Production departments of the stations also took part and were classified under ‘Other’.

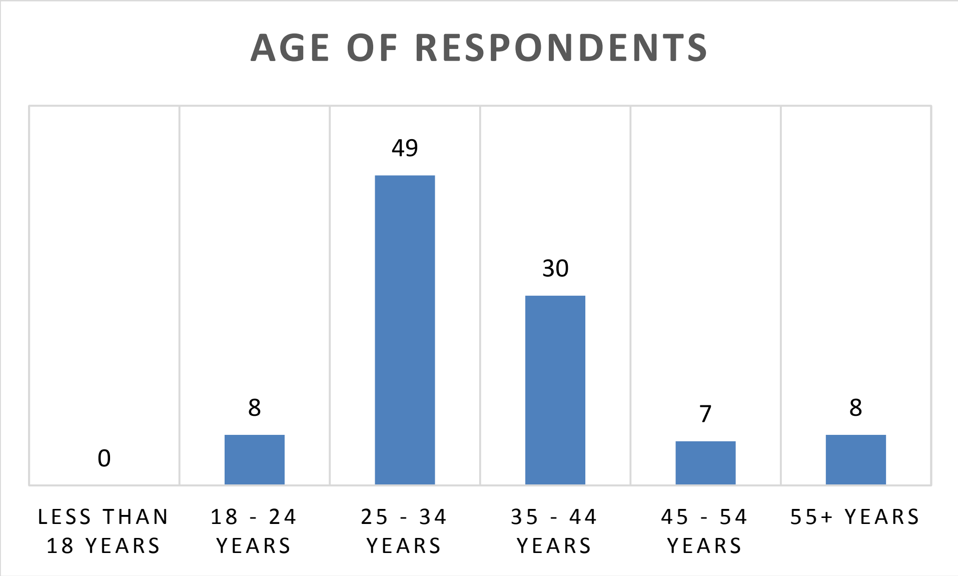


Figure 20: Age of respondents

Considering the spread in age, close to 50% of the respondents were 34 years and younger (57 respondents). The most important age groups in terms of experience and providing direction on best practices and operations excellence is the 45-54 year group and the 55 years and older group. These groups however did not even comprise 15% of the study population while every effort was made to keep the sample random and representative of the study population. From an operations management perspective the low representation of these two critical age groups poses a significant risk to the present and future operations success of the power stations. The experience they garnered over the years enabled them to make quick and accurate operations decisions which directly influence the reliability and effectivity of the production process. The role they play in transferring and imparting knowledge on the younger age groups will most likely either be comprised due to their low representation percentage or severely constrained due to operational engagements. The possibility is high that their primary focus will be tending to critical operations requirements with a low emphasis on vitally important skills transfer.

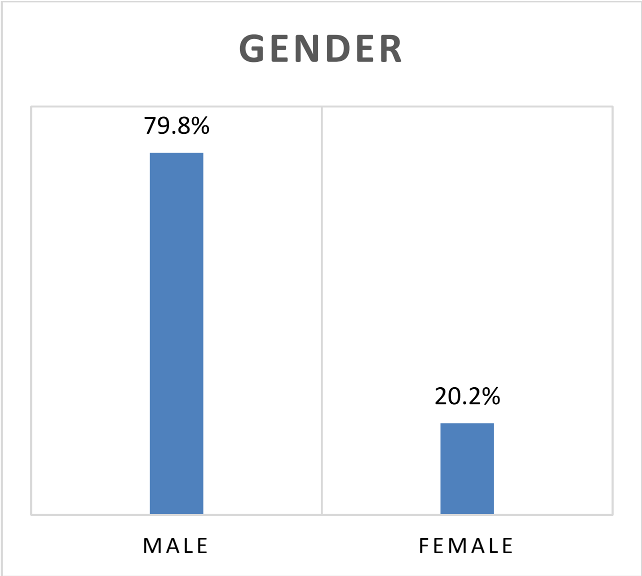


Figure 21: Gender of respondents

A big difference in the male to female ratio of respondents was noted. The possible difference in perception between these two respondent groups were analysed with a T-test and presented in Table 10. No statistical difference in their perceptions towards PVF was found.

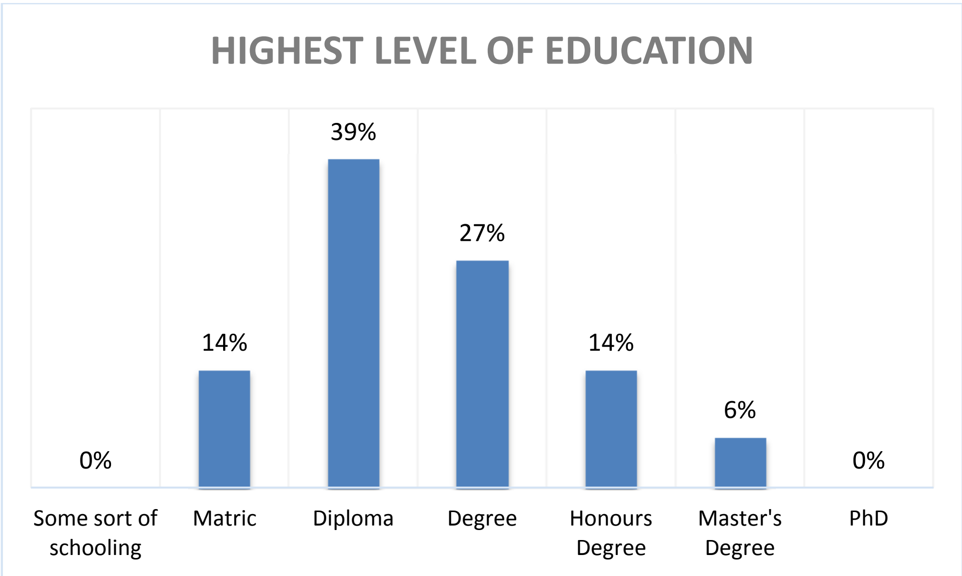


Figure 22: Highest level of education of respondents

In excess of 86% of the respondents had some sort of tertiary qualification and about 47% had a degree or higher qualification. As a result, the respondents were very well suited to understand the concept of PVF to predict future performance and provide support for operations management on the power station.

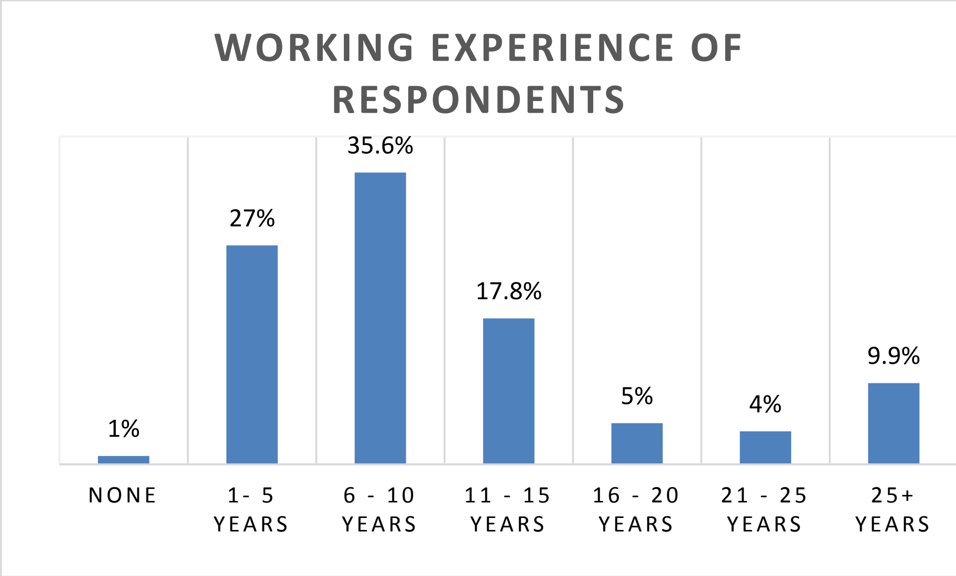


Figure 23: Years of working experience of respondents

The most significant margin (35.6%) of respondents had between 6-10 years of working experience. Close to 15% of respondents were highly experienced with more than 20 years of working experience. The most critical working experience groups are arguably the groups with 16 years and more working experience. With regards to Figure 20, these age groups fulfil very important functions in ensuring successful operations management. With a more significant skew towards the lesser experienced age groups three critical shortcomings might occur:

1. The potential quality with which work is executed in the operations environment might be less due to a lower representation of skilled employees.
2. The time required to execute tasks might be longer due to a greater likelihood that less experienced employees will execute the work (more than a quarter have less than 5 years' working experience and close to 10% (25+ years working experience) have reached an age where their physical presence in the operations environment might be limited.
3. The potential costs associated with the requirement for repetitive work or repairs due to unforeseen breakdowns brought about by operations and maintenance shortcomings as a result of a lack of working experience might potentially be higher.

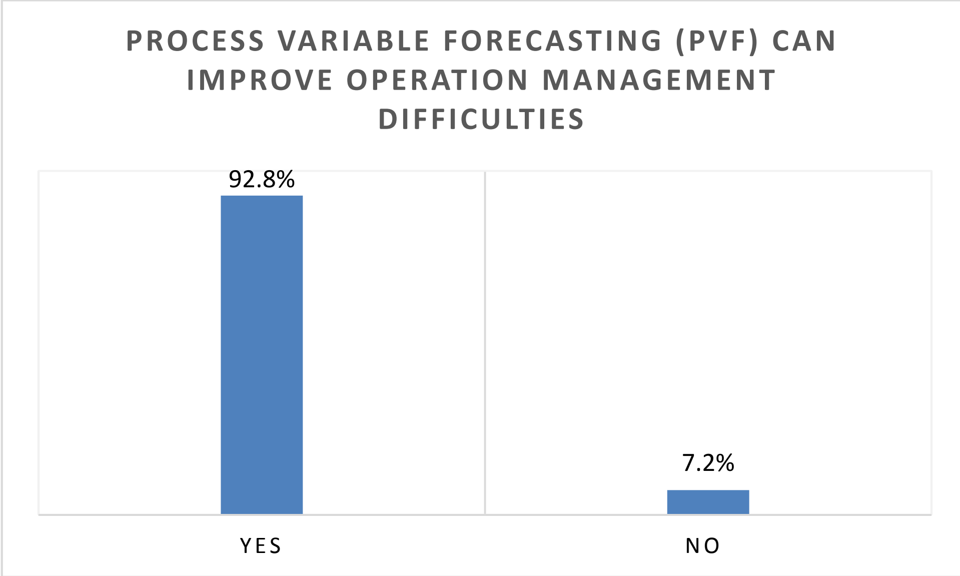


Figure 24: Respondents' opinion on whether PVF can improve operations management difficulties

An extremely high percentage of respondents agreed that PVF can improve operations management difficulties. Only 7.2% felt that PVF will not be able to make a difference. Two scenarios can be considered based on the results obtained:

1. The first question to ask is if any conditions were created which could lead to the very high positive result obtained? One condition which was created which could have led to the skewed result was that all respondents who formed part of the survey had been exposed to the concept of PVF. But the exposure to PVF by the respondents can be justified since they had to be placed in a position where they have an informed opinion regarding the concept.
2. The second possible scenario is that respondents did objectively feel that PVF can improve operations management.

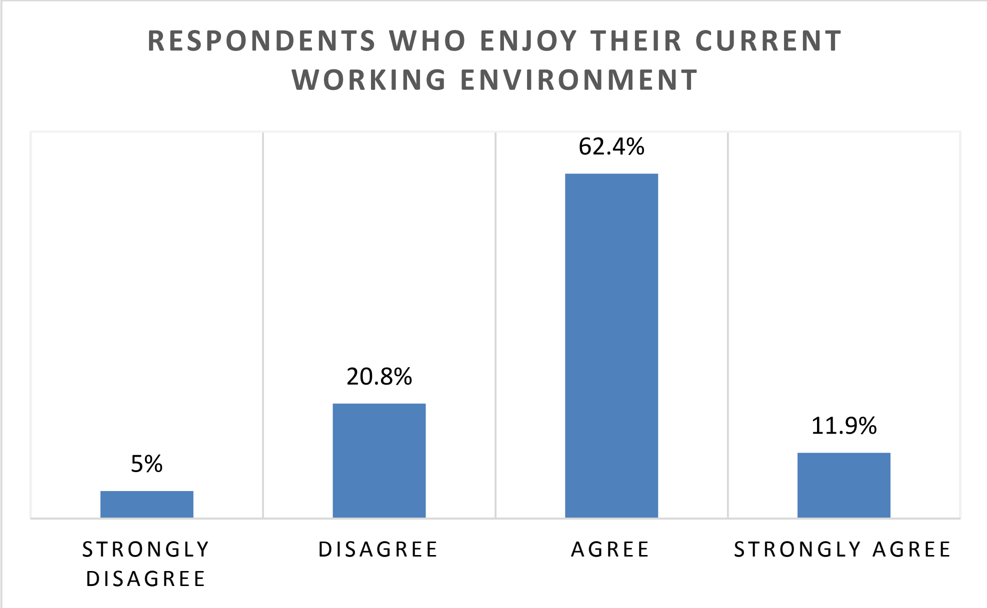


Figure 25: Respondents who enjoy their current working environment

Approximately three quarters of respondents agreed that they enjoy their current working environment. This question was relevant within the greater understanding of the contribution which PVF can make since literature reviewed in Chapter 2 showed a strong correlation between employee's satisfaction with their working environment and productivity and effectiveness. A quarter of respondents indicated that they did not enjoy their current working environment.

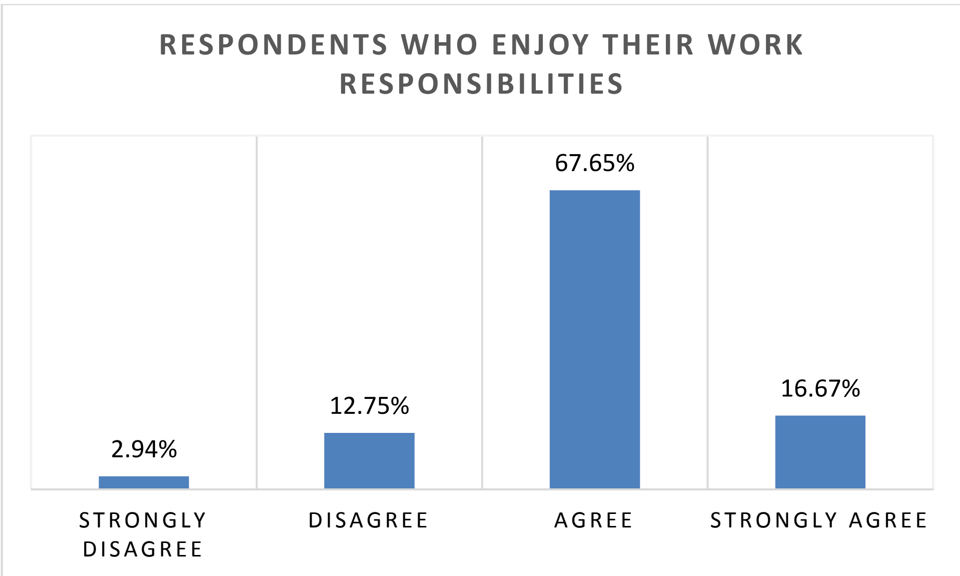


Figure 26: Respondents who enjoy their work responsibilities

A greater number of respondents replied positively to enjoying their work responsibilities (85%) than their working environment (74%). Reflecting on the results between these two questions were interesting since more respondents indicated that they enjoy their work but not always within the environment they have to execute their work.

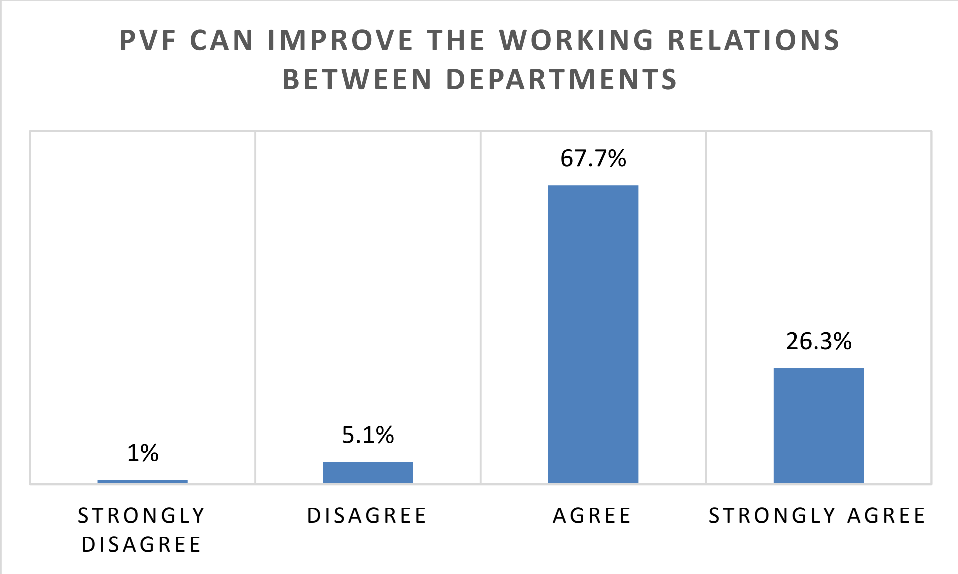


Figure 27: Respondents' opinion on whether PVF can improve the working relations between departments

Successful operations management at power stations requires good inter-departmental working relations in order to facilitate execution of tasks and duties between them. Some tasks require a collaborative effort between multiple engineering departments (turbine, electrical, control and instrumentation) as well as Mechanical maintenance department and the Operating department. If differing point of views arise regarding defect resolution between any of the entities, the mitigation of the defect or maintenance activity could be postponed or even deferred indefinitely. To overcome this, common ground must be found to ensure all departments agree on the most sustainable and effective solution. In order to achieve this, the benefit of PVF was proposed and the question posed to the respondents. Close to 95% of respondents agreed that it would improve working relations between departments.

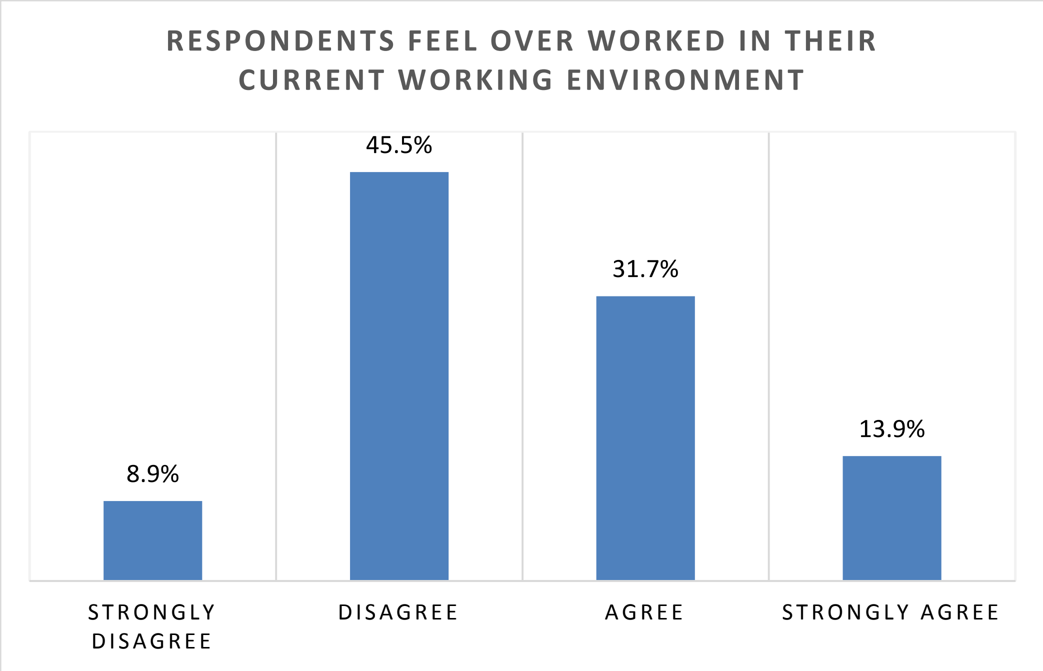


Figure 28: Respondents feel over worked in their current working environment

A very high percentage (46%) of respondents indicated that they feel over worked in their current working environment (Figure 28). As outlined in the literature review, when employees feel over worked their job satisfaction and work engagement also decline. This can then lead to the onset of negative performance results within the operational work environment. When the respondents were asked whether PVF can have a positive change on their working environment, 92% agreed that it can (Figure 29). This is an indication that PVF can possibly reduce the overburdened sentiment which the respondents experience within their operational working environment.

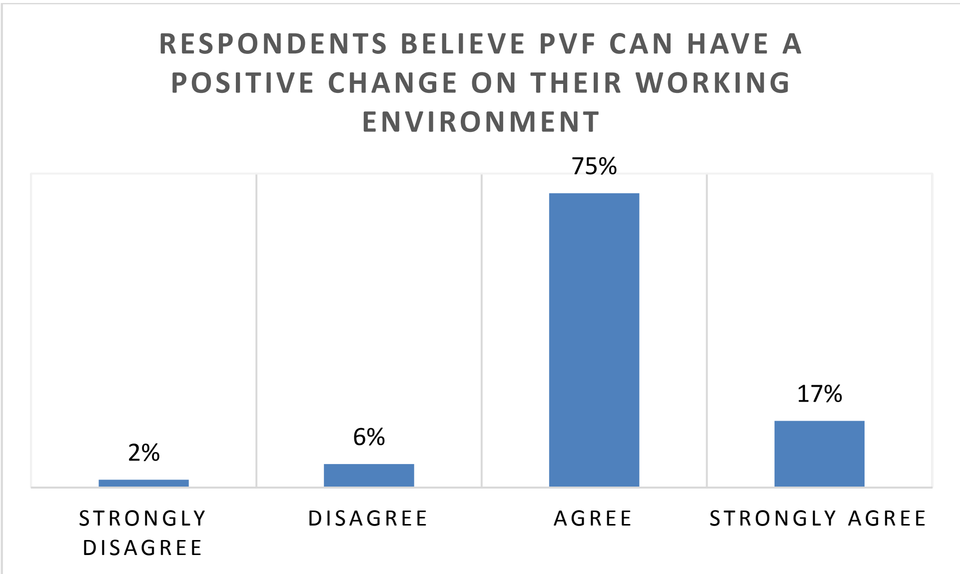


Figure 29: Respondents believe PVF can have a positive change on their working environment

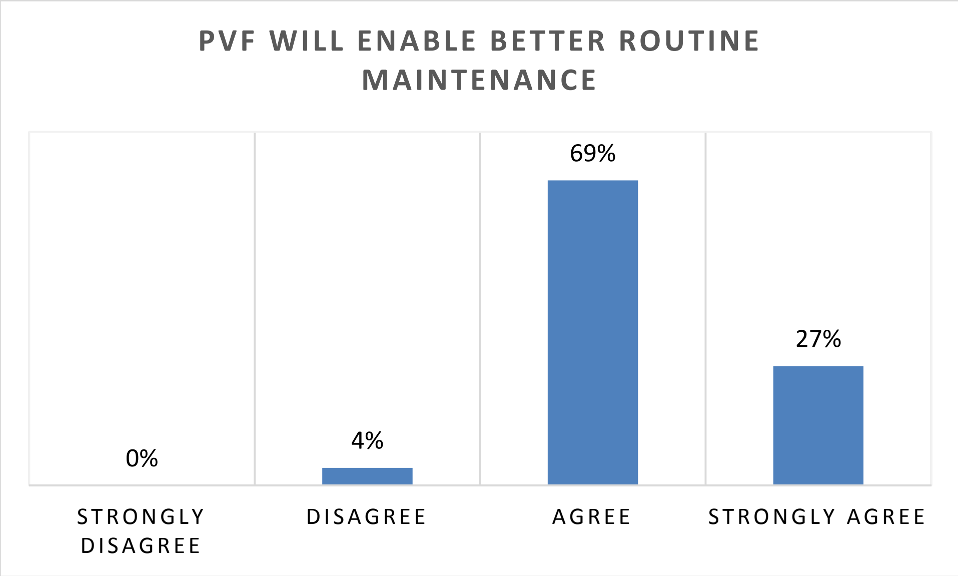


Figure 30: Respondents' opinion if PVF will enable better routine maintenance

Execution of proper routine maintenance is one of the most important aspects within an operational environment since it provides the platform for operational reliability. More than 95% of respondents agreed that PVF will enable better routine maintenance to be done (Figure 30). Many facets form part of sound routine maintenance including proper preparation, understanding the maintenance need, formulation of good SOW and more. To this end, respondents felt that PVF supports better routine maintenance.

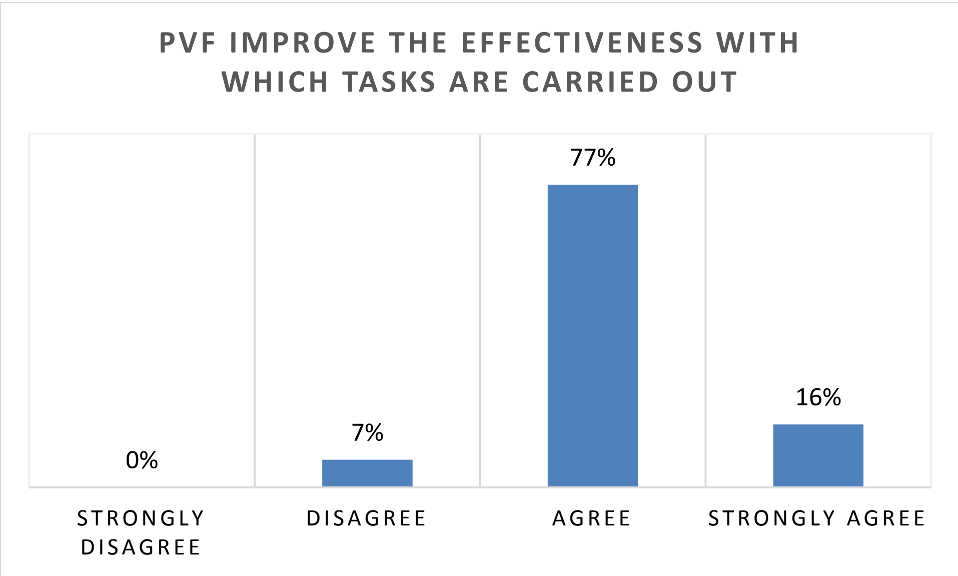


Figure 31: Respondents' opinion on whether PVF improves the effectiveness with which tasks are carried out

Within an operations environment the execution of tasks take place around the second, ranging from trivial to complicated and from quick to long and labour intensive tasks. Despite the necessity for a plethora of tasks which have to be completed on a daily basis within an operations environment, the effectiveness with which they are carried out can be managed.

When the effectiveness of tasks are improved, multiple operations benefits can be obtained. The time required to perform tasks are minimised, the quality of work improves and the reliability of work completed increase. More than 92% of respondents agreed that PVF improves the effectiveness of tasks carried out (Figure 31).

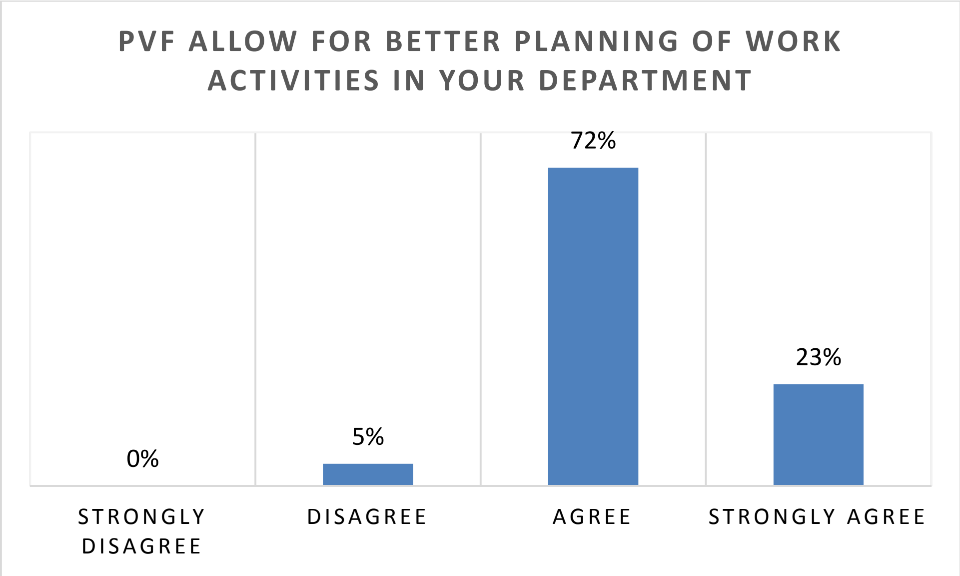


Figure 32: Respondents' opinion on whether PVF allows for better planning of work activities in your department

Planning of work activities are important in any work environment, however in an operations environment it is critical since the knock-on effect of poor planning leads to the decrease in the production process and can have vastly negative results. Poor planning of one individual or one department can severely hamper the success with which another is able to perform their duties. Respondents indicated that they agreed that PVF allows them to plan better for their work activities (Figure 32).

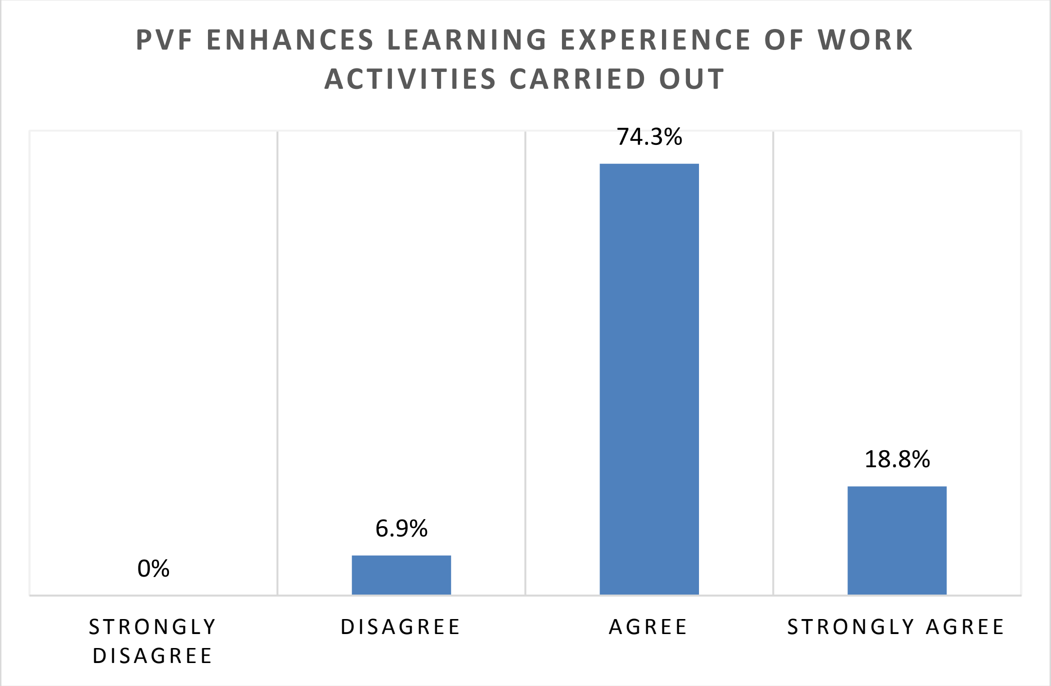


Figure 33: Respondents' opinion on whether PVF enhances the learning experience of work activities carried out

Reflecting on the substantial age difference between the respondents as highlighted in Figure 20, the importance of enhancing the learning experience of work activities carried out becomes vitally important. With a significant number of young respondents who form part of the working corpse at the various power stations, the opportunity for them to learn is critical in order to develop a sound foundation for current and future operations success. To this end, more than 92% of respondents agreed that PVF enhances the learning experience of work activities carried out (Figure 33). PVF provides a platform for upfront identification of future system or operations constraints before manifesting in the operations environment. The learning experience of understanding why a problem is not present today but most likely two days into the future, along with the mechanisms that will lead to the constraint, all forms part of PVF. Respondents also felt that enhancement of learning activities enables better quality work to be done (Figure 34), with all respondents answering positive to this question.

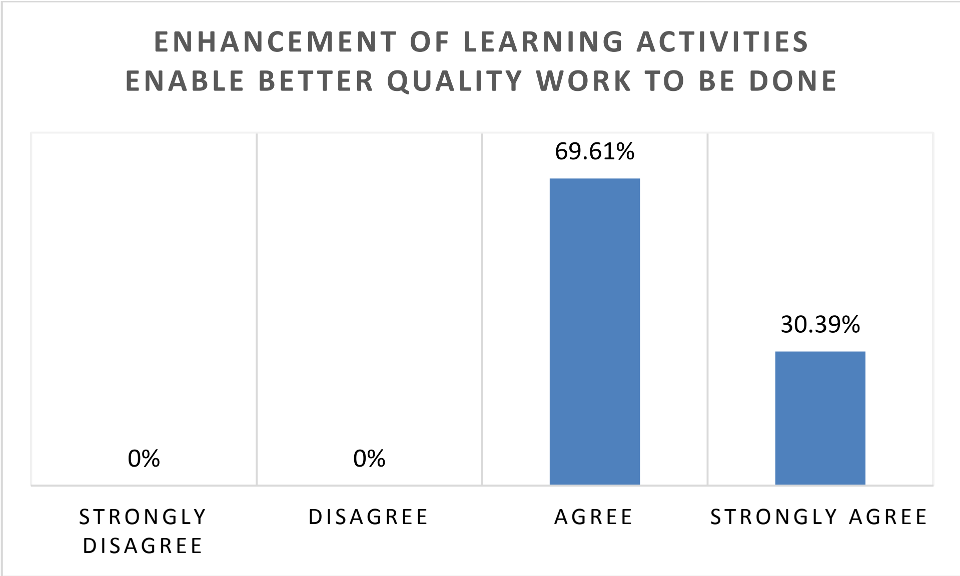


Figure 34: Respondents' opinion on whether enhancement of learning activities enables better quality work to be done

Given the benefits already experienced by respondents after exposure to PVF, respondents agreed that forecasting enables management to make better operational decisions, with as much as 45% strongly agreeing (Figure 35).

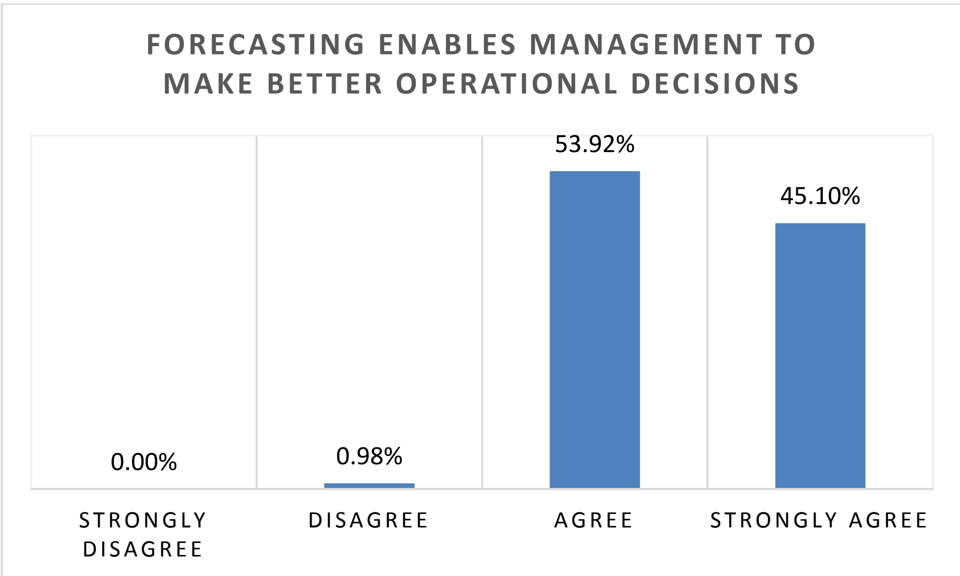


Figure 35: Forecasting enables management to make better operational decisions

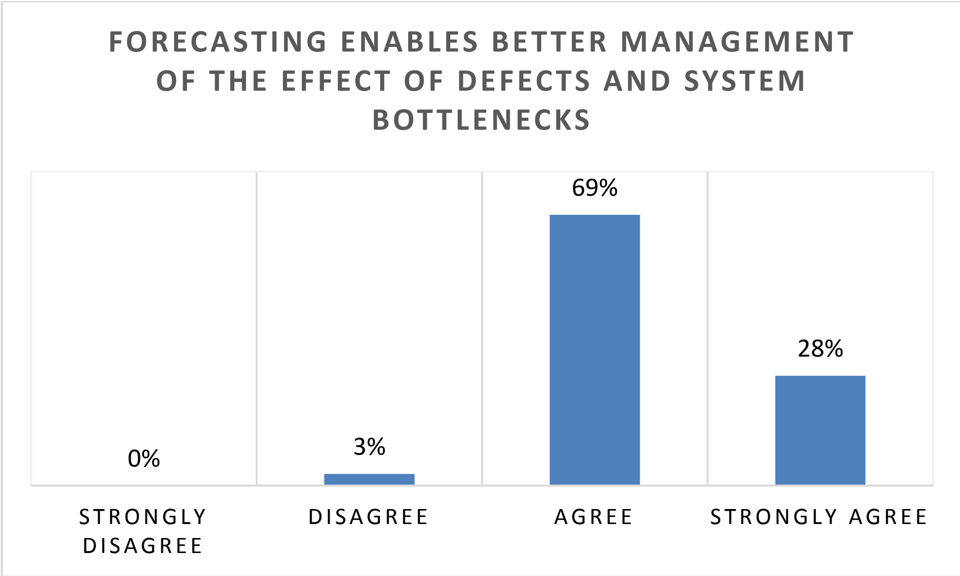


Figure 36: Forecasting enables better management of the effect of defects and system bottlenecks

System constraints and defects are part and parcel of operations management difficulties. The primary focus for operations management is to try and prevent defects and constraints as far as possible, however the reality is that their presence in the operational environment is a given. To this end the proper management of these constraints and defects are essential since they directly correlate with operations stability, throughput and operations cost. Respondents agreed that PVF enables better management of the effect of defects and system bottlenecks (Figure 36).

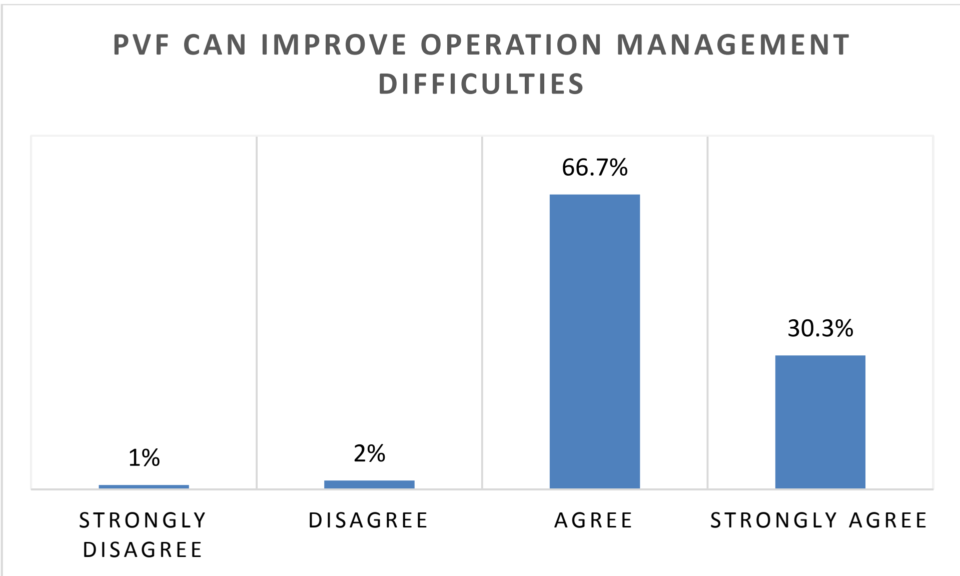


Figure 37: PVF can improve operation management difficulties

The final question which was posed to the respondents is the primary question of this study, that being whether PVF can improve operations management difficulties. More than 96% of respondents agreed that PVF can improve operation management difficulties. (Figure 37).

5.5 LIMITATIONS OF THE STUDY

The nature of the research study lends itself to be carried out on any industrial plant where operations management plays a role in the management of such a facility. However, the following limitations were encountered and future research ventures can focus on the following aspects:

1. Three power stations participated in the study by respondents completing the questionnaire. However, the implementation period of the PVF was not constant at each station. As a result, some respondents had a longer-term exposure to PVF than the other two stations and can therefore have an impact on the way they perceive this forecasting approach.
2. There is very limited research available which focus specifically on ways in which an entire process performance can be forecast. Most research make use of in-situ measurement of variables to provide predictions of performance for equipment or very small systems. PVF enables holistic performance forecasts for big, integrated systems. The limited research therefore meant limited guidelines or direction on ways to perform deep-dive research on the subject.
3. Only 102 respondents were willing to participate in the research study. Generally, it is prescribed that 300 respondents or more participate in surveys to enable more detailed statistically analysis of the results. The limited number of respondents might be due to fears that their opinions expressed in the questionnaires might not be anonymous, although every effort was made to ensure them that anonymity would exist.

5.6 CONCLUSION

Considering the investigations carried out as part of this study, a conclusion must be drawn which can substantiate whether forecasting, in the form of Process Variable Forecasting (PVF), is a possible solution for operations management difficulties in the energy sector of South Africa.

Two approaches were followed to determine the benefit of PVF within the energy sector in South Africa. The first approach was a practical roll out of PVF at power stations, and the second approach the collection of empirical data from respondents who work as employees at these power stations. Their opinion regarding PVF after exposure to PVF was collected by completing the questionnaire.

The first approach entailed implementation of PVF at coal fired power stations. Despite several reviews of the latest literature regarding forecasting in the energy sector, no literature was found where forecasts were done for coal fired power stations. In contrast, forecasting for solar power stations and wind farms are at the forefront of modern technology research. The main reason why forecasting has not been executed at coal fired power stations, and which make this approach unique, is the ability to integrate more than 21 power station operations systems into a consolidated thermo-hydraulic representation of the plant. As a result, a consolidated and holistic representation of the coal fired plant is achieved, which enables forecasting to be done when accurate weather data is used as inputs to the plant model, called Flowcast®. Weather influences the cycle efficiency of the water and steam cycle by way of cooling water temperature received from the cooling towers of a power station. Practical results had to be obtained by means of actual implementation of forecasting at coal fired power stations in order to quantify the contribution of PVF to operations management. In order to improve the reliability of the results, the implementation was not only done at one power station but at three coal fired power stations – Alpha, Kilo and Tango power stations (pseudonyms).

The second approach entailed the elicitation of empirical data from employees who work at coal fired power stations in order to garner their opinion on PVF after they had the opportunity of using it. The employees used PVF in their workplace and when having to perform their daily tasks and duties. A questionnaire with 25 questions grouped into 5 constructs relating to their Working Environment, Quality of Work, Effectiveness of Work, Learning and Forecasting was investigated. A total of 102 respondents from the Operating, Maintenance and Engineering departments took part in the study from three coal fired power stations – Charlie, Mike and Tango power stations.

5.6.1 Implementing Flowcast® at power stations in South Africa

The implementation of Process Variable Forecasting took place in the form of Flowcast®, which is a practical implementation of thermo-hydraulic results from the modelling of coal fired power stations in order to predict its future operational outputs. Flowcast® was developed based on the skills the researcher obtained as part of the NWU School of Business and Governance MBA course. Flowcast® is therefore a combination of financial, operational and strategic management courses which seeks to provide operations entities with operations performance forecasts.

Power station Alpha struggled with constant operational output constraints on one of their generating units. This was as a result of the unit's Induced Draft (ID) fans running out of operational capacity although the production capacity was not at full duty point. The constraint on the ID fans therefore limited production capacity. Expensive investigations, capital cost roll out and substantial allocation of manpower for operational inspections did not provide sufficient remedies for the operational constraint. Forecasting was used to analyse the power station's future generating performance to determine if a reprieve could be expected. Forecasting however showed that there was an inherent problem which pointed towards air ingress in the boiler gas pass which resulted in the poor operational performance. Management made use of the recommendation and discovered substantial ducting holes which were subsequently repaired and improved the operational output of the generating unit.

Power station Tango faced significant seasonal operational constraints on the Primary Air (PA) fans of the power station. During winter months their operational difficulties on this system decreased substantially, only for it to resurface again in summer months. Valuable engineering resources were used to investigate the intermittent PA fan problem which would grow in summer and subside in winter. This meant encumbering skilled resources on a very specific area of the plant while other operational challenges enjoyed less attention. Seasonal investments of expensive capital resources by way of hardware replacements along with maintenance crews which open up inspect and interrogate the mechanical parts of the Primary Air fans were undertaken. The repetitive investment of capital towards this plant area also meant constraining other operational systems from necessary funding and maintenance. Forecasting was employed which showed future operational gains could be achieved by removing a deflector plate in the Primary Air duct. Upon the removal of the deflector plate and subsequent mitigation of the PA fan problem, the benefit of successful forecasting had several positive impacts on operations at Power Station Tango. Engineering resources could be applied to other operational constraints and seasonal capital expenditure of hardware components on the PA fans could be diverted to cover operational costs incurred on other operating units. Maintenance crews which had to do repetitive inspections on the PA fans were freed up to be re-allocated to other balance of plant systems to perform preventative maintenance. The total generating output of Power Station Tango also increased, enabling more power to be produced and increasing the revenue of the station.

Power station Kilo deployed PVF in order to predict how long it would be until an upset in the generating unit's process would escalate to such a level that it would lead to the unit tripping PVF was used to identify which system process variable required intervention in order to create a positive impact on the overall process and change the outcome of the current scenario forecast which is a unit trip. This allowed for the specific direction of operational resources to the root of the constraint in order to mitigate the problem. The benefit of this successful forecast meant that a generating unit trip was averted which appeared to be inevitable up until the point at which process variable forecasting was deployed. Light-up costs between R400 000 and R800 000 were saved and could be used on alternative operational expenses. Throughout the forecasting process employees were empowered to understand the operational environment better, eventually leading to the identification of an operational shortcoming which was not originally considered by the personnel.

5.6.2 Empirical study results

In order to achieve efficiency and effectiveness in any operational environment, three critical factors need to be present (Gaither and Frazier, 2001:660):

1. Employee engagement and productivity
2. Maintenance management
3. Quality control

A total of 102 respondents from three different power stations took part in the empirical study by means of completing a questionnaire. Cronbach's alpha was used in order to determine the reliability of the constructs within the results obtained from the questionnaires. Cronbach's alphas obtained were as follows:

1. Working Environment: $\alpha = 0.606$
2. Quality of Work: $\alpha = 0.658$
3. Effectiveness of Work: $\alpha = 0.718$
4. Learning: $\alpha = 0.794$
5. Forecasting: $\alpha = 0.874$

The Cronbach's alpha of Effectiveness of work, Learning and Forecasting all showed acceptable reliability of the constructs.

Several T-tests were performed between the respondent age groups, gender and years of work experience. No statistically or practically significant difference between these population groups were observed regarding their opinion of the different constructs within the PVF questionnaire.

ANOVA analysis was also performed for different levels of qualification, different power stations and different departments. No statistical significant difference was noted between these population groups. The practical significance however between the Honours degree and Degree respondents regarding their opinion on the benefit of PVF pertaining to the quality of work construct does tend towards a medium to high practical significance of 0.73. This means that Honours degree respondents feel they elicit greater benefit from PVF than Degree respondents, when it pertains to the quality of work construct which tests 5 underlying themes of quality of work.

A very high percentage (46%) of respondents indicated that they feel over worked in their current working environment. As outlined in the literature review, when employees feel over worked their job satisfaction and work engagement drops. This can then lead to the onset of negative performance results within the operational work environment. When the respondents were asked whether PVF can have a positive change on their working environment, 92% agreed that it can. This is an indication that PVF can possibly reduce the overburdened sentiment which the respondents experience within their operational working environment.

Execution of proper routine maintenance is one of the most important aspects within an operational environment since it provides the platform for operational reliability. More than 95% of respondents agreed that PVF will enable better routine maintenance to be done. Many facets form part of sound routine maintenance including proper preparation, understanding the maintenance need, formulation of good scope of work and more. To this end, respondents felt that PVF supports better routine maintenance.

More than 92% of respondents agreed that PVF also improves the effectiveness of tasks carried out. When the effectiveness of tasks is improved, multiple operational benefits can be obtained. The time required to perform tasks are minimized, the quality of work improves and the reliability of work completed grows.

The primary focus for operations management is to try and prevent defects and constraints as far as possible. To this end the proper management of these constraints and defects are essential since they directly correlate with operational stability, throughput and operations cost. Respondents agreed that PVF enables better management of the effect of defects and system bottlenecks (97%). More than 96% of respondents agreed that PVF can improve operation management difficulties.

5.6.3 Concluding remarks on the unique nature of Process Variable Forecasting

What makes process variable forecasting unique from other forecasting approaches used in industry and why is it more successful to reduce operations management difficulties:

1. The first aspect is the removal of opinion: quantitative naïve time series forecast or alternatively, a qualitative Delphi forecast excludes prior performance and employs human opinion respectively. These inherent shortcomings could influence the success of the forecast. Process variable forecasting make use of historic process results along with engineering principles (free of opinion) in order to perform forecasts.
2. The second aspect is the time requirements to perform condition based inspections to obtain results. This could take anything from hours to days while PVF can be completed in minutes.

3. The third aspect is the costs associated with using different measurement techniques like vibrational analysis, wear debris in oil, thermography etc. PVF is a digital solution and as a result more economical for clients.
4. The fourth aspect is the potential omission of a crucial measurement technique which could identify a developing defect or risk not picked up by other condition monitoring measurement techniques. PVF is a holistic approach which considers all process variables within a system and therefore the omission of variables which can have a critical impact on the final forecast results is therefore minimal.

5.6.4 Recommendations and future studies emanating from this research

As part of the literature review, three critical factors were discussed which influence the efficiency and effectiveness of an operational environment. Two of these factors were **Employee Engagement** and **Productivity**. Along with these factors, two issues which came out as pertinent aspects during the execution of the pilot study was the issue of racism and gender based discrimination and the potential impact it has on operations management. Another aspect which was also raised was the issue and role of leadership and the impact it has on successful and productive operations management. In order to garner a more practical understanding of how these are relevant to a coal fired power station environment, the impact which discrimination and transformational leadership has on operations management can be investigated in future. The detrimental effect which racism can have on **employee engagement** can be reviewed, as well as the benefit of transformational leadership on **productivity**.

The Cronbach alpha's used in the study to determine the reliability of the constructs (Quality of Work and Working Environment) to measure the underlying theme as used for the PVF questionnaire did not produce acceptable Cronbach alpha results. It is recommended that future studies be done to repeat this part of the investigation on a wider and bigger population group along with amendment to specific questions (Question 3.5) in order to obtain more reliable results.

BIBLIOGRAPHY

Al-Najjar, B. and Alsyouf, I. 2003. Selecting the most efficient maintenance approach using fuzzy multiple criteria decision making. *International Journal of Production Economics,* 84:85-100.

Boyce, C. and Neale, P. 2006. Conducting in-depth interviews: A guide for designing and conducting in-depth interviews for evaluation input. Watertown, MA: Pathfinder International.

Brynard, P.A. and Hanekom, S.X. 2006. Introduction to research in management-related fields. 2nd ed. Pretoria: Van Schaik.

Chase, R.B., Aquilano, N.J. and Jacobs, F.R. 2006. Production and operations management for competitive advantage. 11th ed. Boston, MA: Irwin/McGraw-Hill.

Crespo Marquez, A. and Gupta, J.N.D. Contemporary maintenance management: process, framework and supporting pillars. *Omega,* 34(3):325-338.

Eisenhardt, K.M. 1989. Building theories from case study research. *Academy of management review*, 14(4):532-550.

Field, A. 2009. Statistics using SPSS. 3rd ed. London: Sage.

Finweek. 2015. On-life support: Eskom haemorrhaging money. *Business Source Premier*, EBSCOhost, p. 18 -19. Date accessed: 2016-02-02

Focken, U, Lange, M., Mönnich, K., Waldl, H., Beyer, H. and Luig, A. 2002. Short-term prediction of the aggregated power output of wind farms - a statistical analysis of the reduction of the prediction error by spatial smoothing effects. *Journal of Wind Engineering and Industrial Aerodynamics*, 90:231-246.

Foley, A., Leahy, P., Marvuglia, A., and McKeogh, E. 2012. Review: Current methods and advances in forecasting of wind power generation. *Renewable Energy*, 37:1-8.

Gaither, N. and Frazier, G. 2001. Operations management. 9th ed. Nashville, TN: South Western.

Gor, R.M. 2009. Industrial Statistics and Operational Management'

Heizer, J. and Render, B. 2014. Operations management. 11th ed. Essex: Pearson.

X. Huang, H., Qi, X. and Liu, A. 2006. Implementation of fault detection and diagnosis system for control systems in thermal power plants. In: Proceedings of the 6th World Congress on Intelligent Control and Automation, Dalian, China, June 21-23, 2006.

Kleissl, J, Bosch, J., Kurtz, B., Lave, M., Lopez, I., Mathiesen, P., Nguyen, A., and Urquhart, B. 2013,. Recent advances in solar variability modeling and solar forecasting at UC San Diego', *SOLAR Conference Proceedings*, pp. 1-2, Environment Complete.

Jacobs, F, and Chase, R 2010, *Operations And Supply Management : The Core*, n.p.: New York : McGraw-Hill Irwin, c2010.

Jagtap, H, and Bewoor, A. 2017. Development of an Algorithm for Identification and Confirmation of Fault in Thermal Power Plant Equipment Using Condition Monitoring Technique, *Procedia Engineering*, 181, 10th International Conference Inter-disciplinarily in Engineering, INTER-ENG 2016, 6-7 October 2016, Tirgu Mures, Romania, pp. 690-697

Jalal, H 2016. Improving employee productivity through work engagement: Evidence from higher education sector', *Management Science Letters,* 6(1):61-70.

Joffe, H. 2015. SA pays price of Eskom’s disastrous governance. http://www.bdlive.co.za/opinion/columnists/2015/03/25/sa-pays-price-of-eskoms-disastrous-governance Date accessed: 2016-02-02

Landberg, L. 2001. Short-term prediction of local wind conditions. *Journal of Wind Engineering and Industrial Aerodynamics*, 10th International Conference on Wind Engineering, 89:235-245.

'Physical approach to short-term wind power prediction. 2006. EDS consolidated

Li, Q. 2013. A novel Likert scale based on fuzzy sets theory. *Expert systems with applications*, 40(5):1609-1618.

Lindberg, P. 1990. Strategic manufacturing management: a proactive approach. *International Journal of Operations and Production Management*, 10(2):94–106.

Malhotra, N.K., Hall, J., Shaw, M. and Oppenheim, P. 2006. Marketing research: An applied orientation. 3rd ed. Sydney: Prentice Hall..

Maree, K. 2007. First steps in research. Pretoria: Van Schaik.

Moneyweb. 2015. The cost of Eskom’s three power station headaches. http://www.moneyweb.co.za/uncategorized/the-cost-of-eskoms-three-power-station-headaches/ Date accessed: 2016-02-02

Mutloane, O.E. 2009, Maintenance management for effective operations management at Matimba Power Station.

Nicholas, J 2016, 'Hoshin kanri and critical success factors in quality management and lean production', *Total Quality Management and Business Excellence*, 27(¾):250-264

Opdenakker, R. 2006. Advantages and disadvantages of four interview techniques in qualitative research. *Forum Qualitative Sozialforschung*

Pan, H., Sheng, A., Wang, Z., Han, X. 2016. Analysis of MTBF evaluation methods for small sample sizes, 11th International Conference On Reliability, Maintainability And Safety

Piyushsinh, Z.K. Application of monitoring approaches on steam turbine of thermal power plant for better performance, *International Journal of Mechanical Engineering and Robotic Research,* 3(2):63-67.

Osborne, S. 2017. Employee engagement and organizational profitability. *Dissertation Abstracts International Section A*, 78:5-A.

Pinjal, K., Pintelon, L. and Vereecke, A. 2005. An empirical investigation on the relationship between business and maintenance strategies. *International Journal of Production Economics*

Van Blerk, EJ 2012, *Employee Commitment And Its Impact On Process Quality In A Manufacturing Concern*, n.p.: 2012., NWU Library Catalogue.

Viljoen, J.N. 2015. The Impact Of Implementing Selected Lean Principles In A South African Gold Processing Plant. Johannesburg COM.

Welman, C., Kruger, F. and Mitchell, B. 2005. Research methodology. 3rd ed. Cape Town: Oxford University.

Whitley, B.E. 2002. Principles of research in behavioural science. 2nd ed. New York, NY: McGraw-Hill.

Widén, J, Carpman, N, Castellucci, V, Lingfors, D, Olauson, J, Remouit, F, Bergkvist, M, Grabbe, M, and Waters, R 2015, 'Variability assessment and forecasting of renewables: A review for solar, wind, wave and tidal resources', *Renewable And Sustainable Energy Reviews*, 44, pp. 356-375, ScienceDirect, EBSCO*host*

Zikmund, W.G., Babin, B.J., Carr, J.C. and Griffin, M. 2013. Business research methods. New York, NY: Cengage Learning.

ANNEXURES

ANNEXURE A: FREQUENCY TABLES

Table 19: Respondents' opinion on whether early notice of unplanned work will allow them to make better arrangements with their families

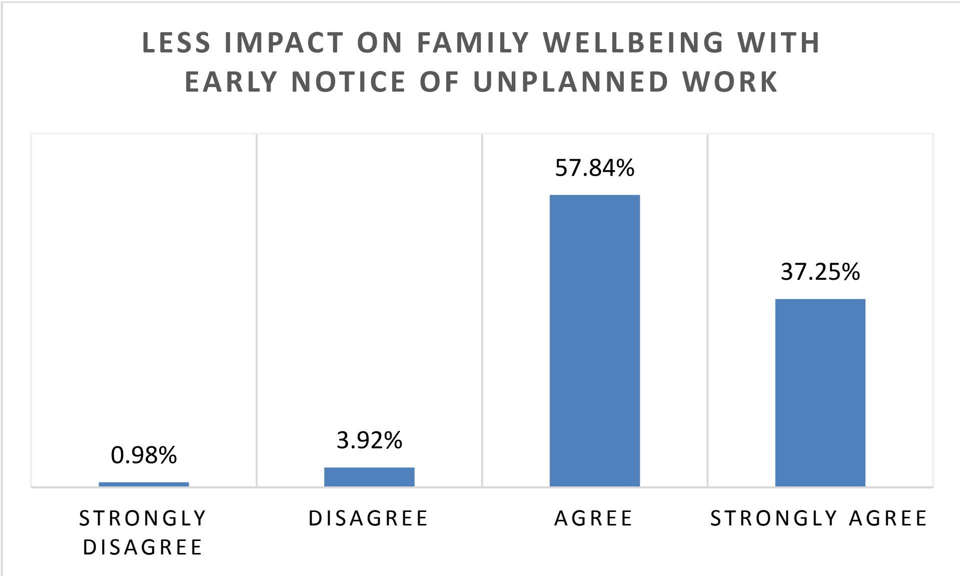


Table 20: Respondents opinion on whether working under the pressure of deadlines influence the quality of work performed

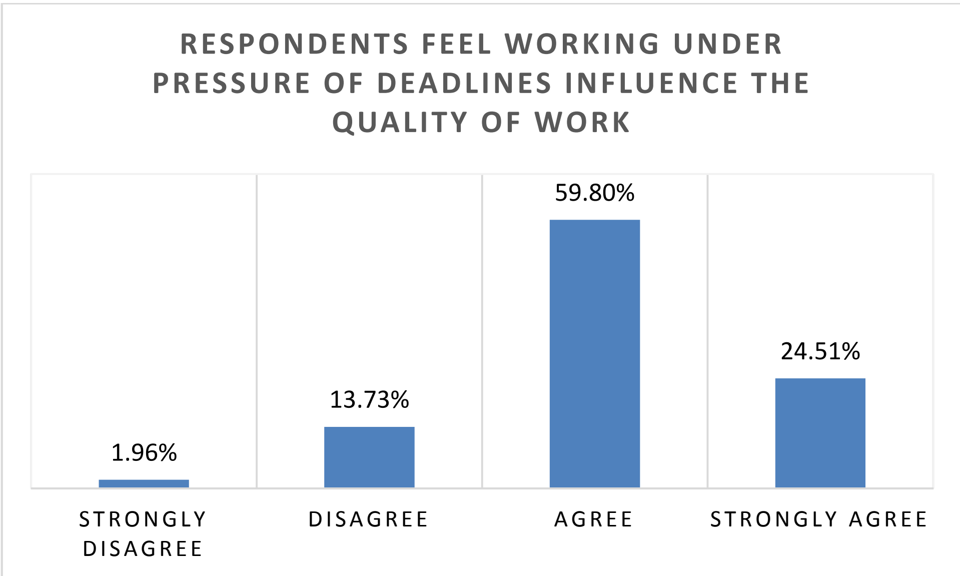


Table 21: Having more time to do work will lead to respondents have more confidence to ask for guidance on work activities

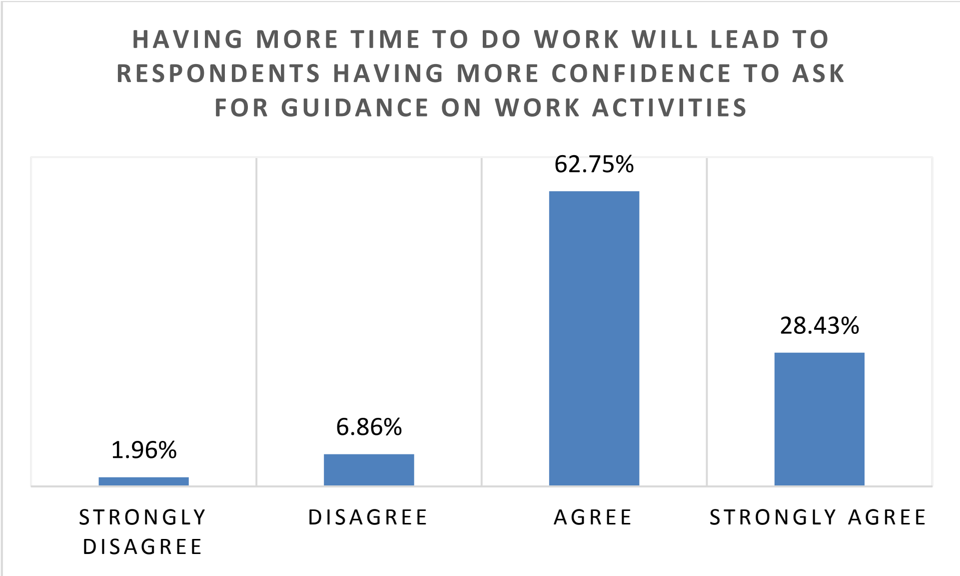


Table 22: Work responsibilities are more manageable when unplanned activities are minimal

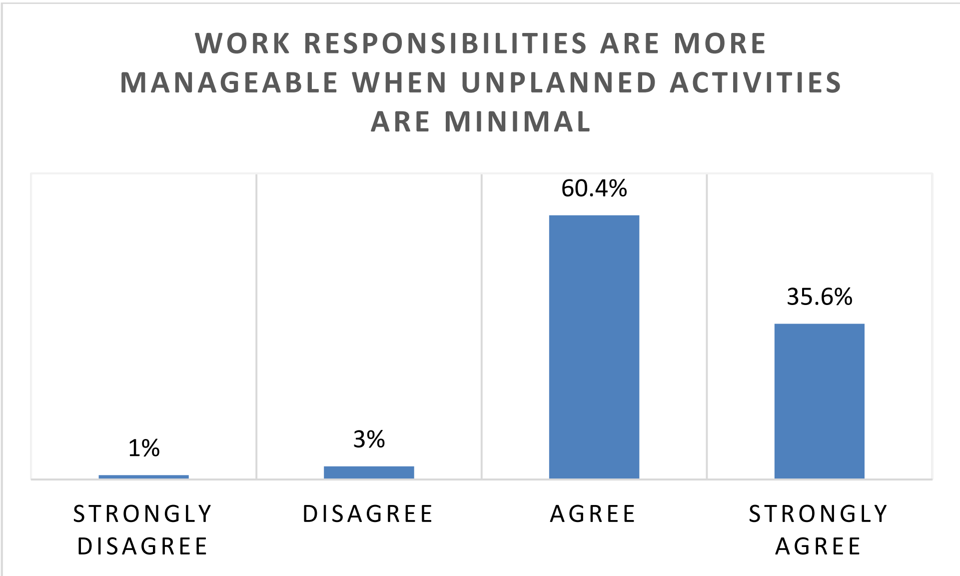


Table 23: Respondents opinion on whether knowing in advance of plant breakdowns will enable better maintenance SOW planning

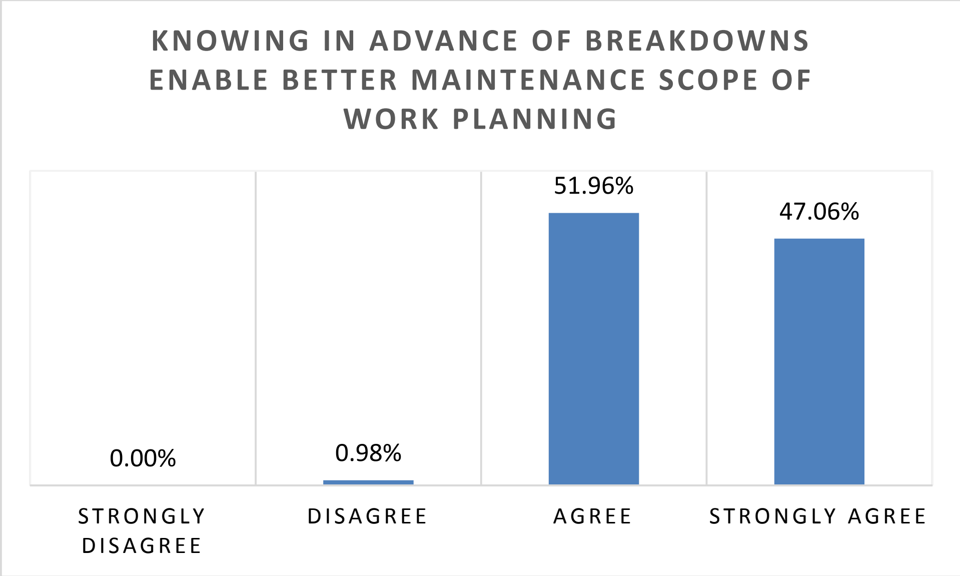


Table 24: Respondents' opinion on whether PVF allows for better inter-departmental planning of work activities

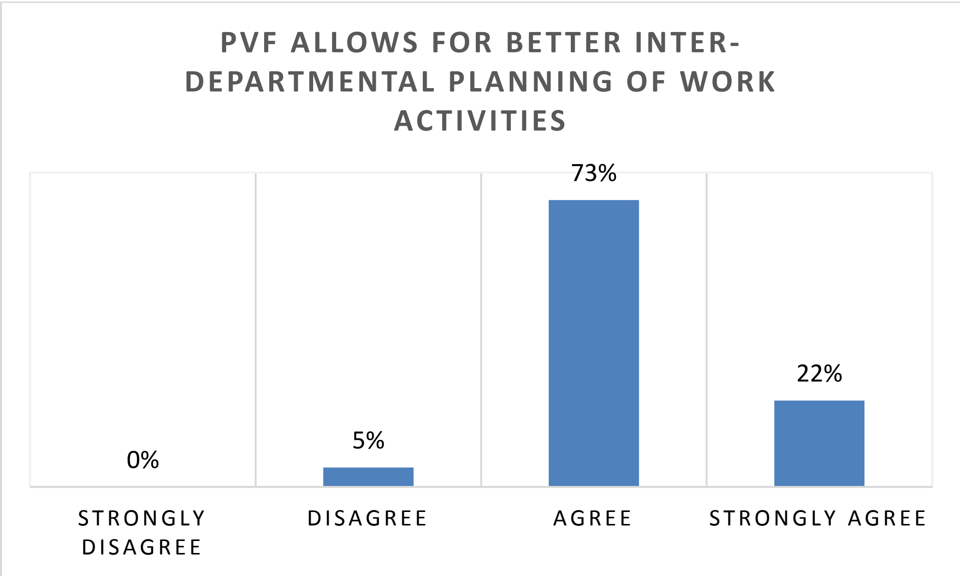


Table 25: Respondents' opinion on whether they feel more productive when there is time to plan for a work activity

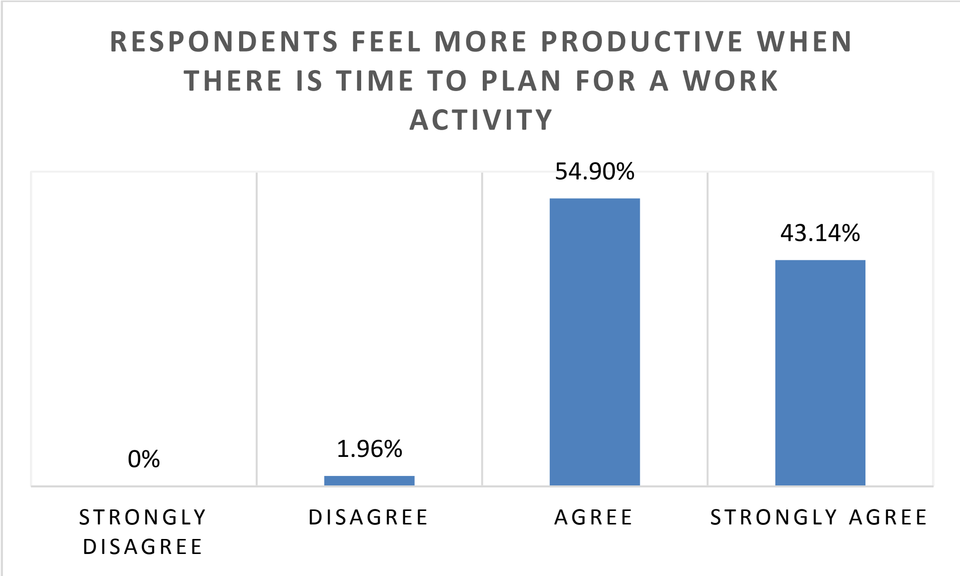


Table 26: Respondents' opinion on whether enjoying their work responsibilities enhances their productivity

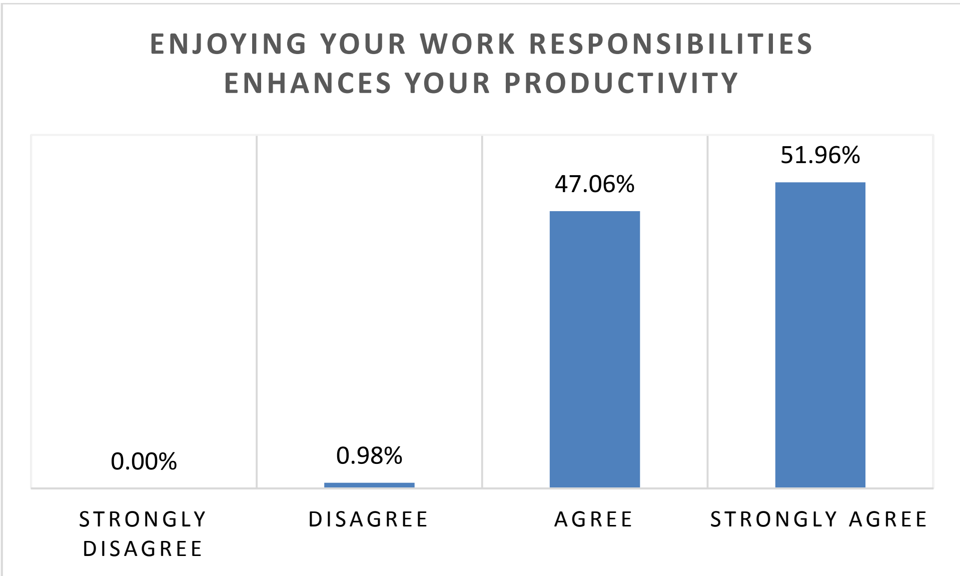


Table 27: Respondents' opinion on whether PVF provides them with more confidence to do work

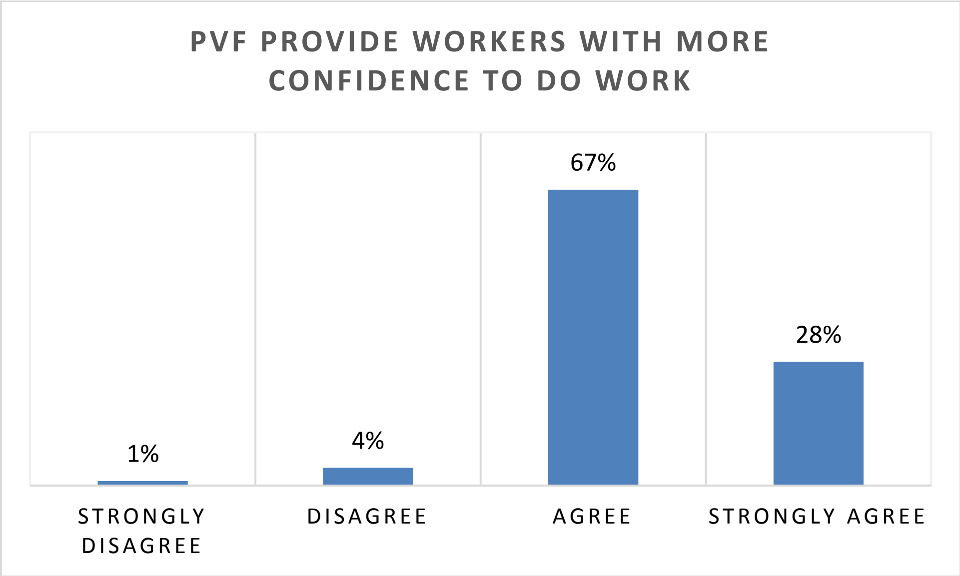


Table 28: Respondents' opinion on whether enhancement of learning activities enables work to be done on time

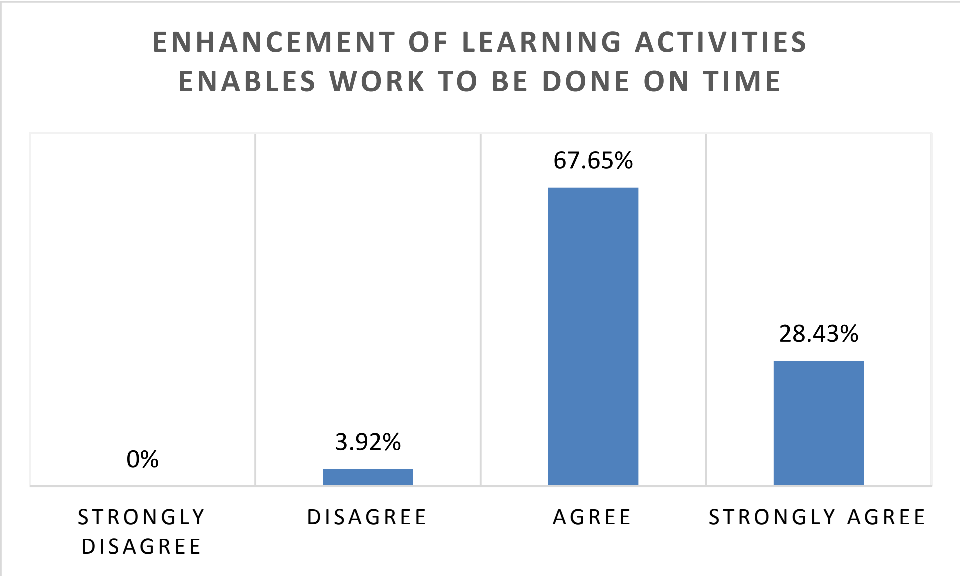


Table 29: Forecasting enables the plant to be operated more safely

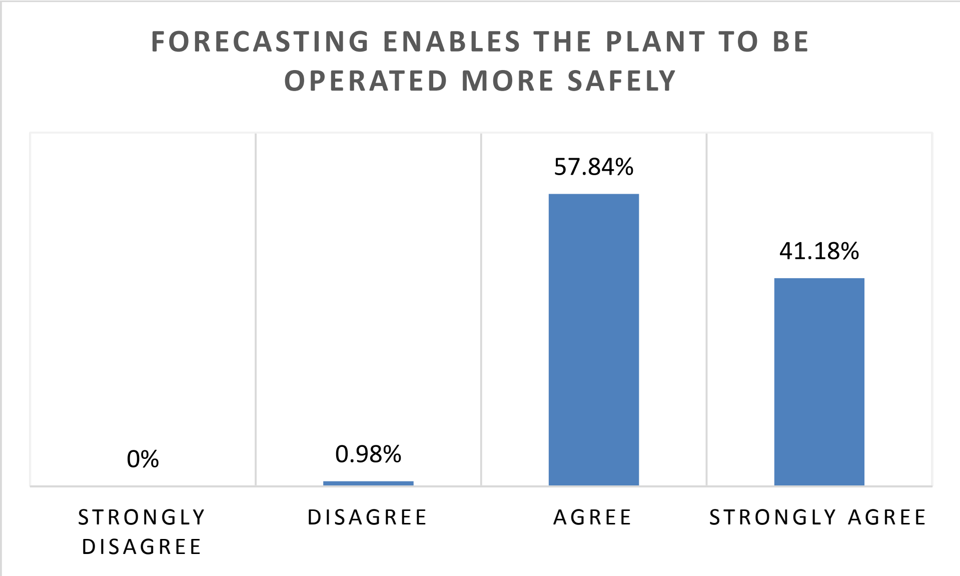
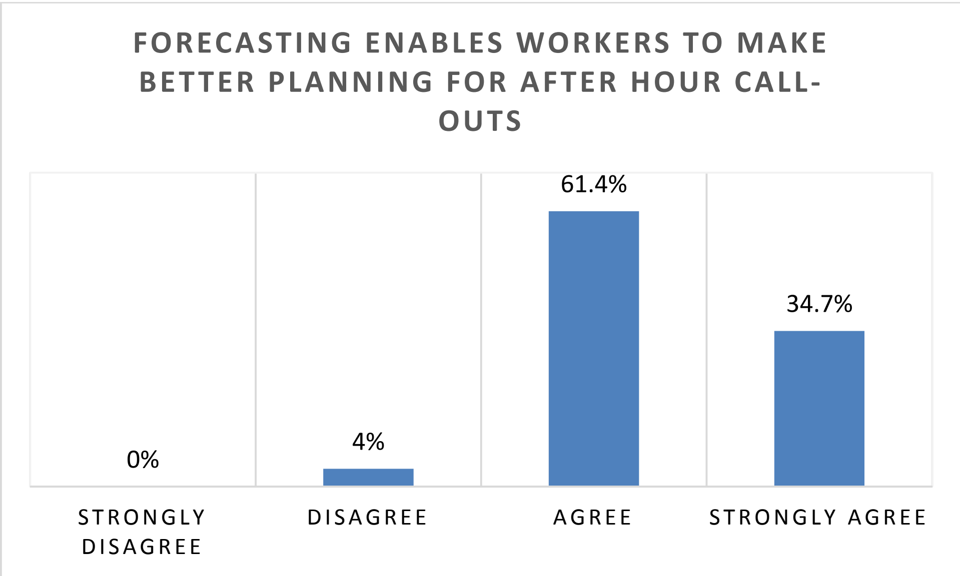


Table 30: Forecasting enables workers to make better planning for after hour call-outs



ANNEXURE B: QUANTITATIVE QUESTIONNAIRE

Dear Power Generation Utility employee

You are invited to participate in a research study conducted by Martin-David Coetzee, with regards to the Flowcast® process forecasting to be done at your power station. Your participation will involve the completion of this questionnaire.

This research may help us to establish if Process Variable Forecasting (PVF) can have an impact on Operation Management at a power station. This will determine if employees believe that PVF will be helpful for planning and routine maintenance endeavours. The possibility of knowledge transfer capacity through means of PVF will also be researched.

1.1 What is your age?

Less than 18 years	18 – 24 years	25 – 34 years	35 – 44 years	45 – 54 years	55+ years

1.2 Gender?

Male	Female	Prefer not to disclose this information

1.3 What is your highest level of education?

Some form of schooling	Matric	Diploma	Degree	Honours degree	Master's degree	PhD

1.4 How many years of work experience do you have?

None	1–5 years	6–10 years	11–15 years	16–20 years	21-25 years	25+ years

1.5 At which power station do you work? ______________________________________

1.6 At which department do you work at the aforementioned power station?

____

1.7 What is your job description in your department?

____

1.8 How long have you been working at this power station?

____

1.9 How long have you been working in your current department?

____

1.10 How many hours do you work per week in order to complete the tasks handed to you? ____________________________

2 Research question:

2.1 Do you believe that PVF can improve Operation Management difficulties at a power station? (PVF = predicting mill performance, draft group performance and condenser performance, etc. ahead of time)

Yes	No

3 Working environment:

3.1 Do you enjoy your current working environment?

Strongly disagree	Disagree	Agree	Strongly agree

3.2 Do you enjoy your work responsibilities?

Strongly disagree	Disagree	Agree	Strongly agree

3.3 Can PVF improve the working relations (team spirit) between the Maintenance, Operating and Engineering departments?

Strongly disagree	Disagree	Agree	Strongly agree

3.4 When workers are informed earlier of unplanned work to be done, will it enable them to make better arrangements with their families for call-out work to be done?

Strongly disagree	Disagree	Agree	Strongly agree

3.5 Do you feel over worked in your current working environment?

Strongly disagree	Disagree	Agree	Strongly agree

3.6 Do you believe that PVF can have a positive change on your work environment?

Strongly disagree	Disagree	Agree	Strongly agree

4 Quality of work:

4.1 Working under the pressure of deadlines influence the quality of work executed?

Strongly disagree	Disagree	Agree	Strongly agree

4.2 When afforded more time to do work activities, workers have more confidence to ask for guidance on work activities from supervisors or managers?

Strongly disagree	Disagree	Agree	Strongly agree

4.3 Will PVF enable better routine maintenance to be done?

Strongly disagree	Disagree	Agree	Strongly agree

4.4 Knowing in advance which equipment will break or require specific maintenance, enables better maintenance scope of work to be planned?

Strongly disagree	Disagree	Agree	Strongly agree

4.5 Your work responsibilities are more manageable when unplanned activities are minimal?

Strongly disagree	Disagree	Agree	Strongly agree

5 Effectiveness of work:

5.1 Will PVF improve (add value) to the effectiveness with which you carry out your tasks?

Strongly disagree	Disagree	Agree	Strongly agree

5.2 Will PVF allow for better planning of work activities in your department?

Strongly disagree	Disagree	Agree	Strongly agree

5.3 Will PVF allow for better planning of work activities when different departments are required to work together?

Strongly disagree	Disagree	Agree	Strongly agree

5.4 Are you more productive when you have more time to plan for a work activity?

Strongly disagree	Disagree	Agree	Strongly agree

5.5 Enjoying your work responsibilities enhances your productivity?

Strongly disagree	Disagree	Agree	Strongly agree

6 Learning:

6.1 Will PVF provide workers with more confidence to do work? (Confidence to do work is based on experience and understanding of the problem, achieved by means of training or through guidance.)

Strongly disagree	Disagree	Agree	Strongly agree

6.2 Does PVF enhance the learning experience of work activities carried out?

Strongly disagree	Disagree	Agree	Strongly agree

6.3 Enhancement of learning activities in the work place enables better quality work to be done?

Strongly disagree	Disagree	Agree	Strongly agree

6.4 Enhancement of learning activities in the work place enables work to be done on time?

Strongly disagree	Disagree	Agree	Strongly agree

7.1 Knowing in advance which equipment will break or require specific maintenance, enables the plant to be operated more safely?

Strongly disagree	Disagree	Agree	Strongly agree

7.2 Knowing in advance which equipment will break or require specific maintenance, enables management to make better operational decisions?

Strongly disagree	Disagree	Agree	Strongly agree

7.3 Knowing in advance which equipment will break or require specific maintenance, enables workers to plan better for after hour call-outs?

Strongly disagree	Disagree	Agree	Strongly agree

7.4 Knowing in advance which equipment will break or require specific maintenance, enables better management of the effect of defects and system bottlenecks?

Strongly disagree	Disagree	Agree	Strongly agree

8. Overall, can PVF improve Operation Management difficulties at a power station?

Strongly disagree	Disagree	Agree	Strongly agree

I have read the introduction, understand the purpose of this study and I give my consent to participate in this research study.

Participant's signature_________________________________ Date: __________________

Thank you very much for you willingness to participate in the research study

Dynamic Language &
Translation Specialists

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Saturday, 18 November 2017

To whom it may concern,

Re: Letter of confirmation of language editing

The dissertation **"Is forecasting the solution to operations management difficulties in the South African energy sector?" by M.D Coetzee (12333697)** was language edited. The referencing and sources were checked as per NWU referencing guidelines. Final corrections remain the responsibility of the author.

Antoinette Bisschoff

Officially approved language editor of the NWU since 1998
Member of SA Translators Institute (no. 100181)

Precision ... to the last letter