

**An investigation into optimizing
nuclear power plant outage durations**

Shaheed Obaray

Research dissertation in partial fulfilment
of the requirements for the degree of
Master of Engineering specializing in Nuclear Power at
University of Cape Town

**Supervisor: Dr Corrinne Shaw
October 2022**

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OBRSHA005

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Acknowledgements

I would like to express my greatest appreciation to all who supported me with their invaluable assistance in my dissertation and this degree.

1. Our Creator
 - a. Who has blessed me with health, happiness, and all I need to help others and make a meaningful contribution to society.
2. My beautiful wife and children
 - a. who sacrificed in countless ways while I was studying.
3. Dr Corrinne Shaw (Research Supervisor) for
 - a. firm, committed guidance and sharing of knowledge through many challenges
 - b. making time to evaluate my work
4. Research participants for their knowledge, experience, and views.

Abstract

There is a compelling rationale for outage optimization as it presents numerous benefits for the Nuclear Power Plant (NPP) and accordingly, for the economy of a country, the environment, and society. An outage delay of one day has been reported to be equivalent to a loss of USD1.5m-2m per day, not to mention the economic costs to a country's economy due to load shedding or disruption of the electricity supply. The reduction of average outage durations from 106 days to 38 days in the USA has been shown to negate the need to build 25-30 NPPs during a defined period. The main aims of this research study were to investigate the value of optimization and to explore practices and methods that contribute to successful outage optimization. There was limited published research on the topic and this dissertation aimed to contribute actionable knowledge to improve outage optimization. Optimization practices were investigated by accessing and reviewing a body of literature, followed by interviews with 12 nuclear outage maintenance specialists or experts from the USA and South Africa, with extensive experience to identify perspectives on trends and key information to answer the research questions.

The analysis identified key methods or practices that contribute to successful optimization. The factors that led to longer than required outages and outage delays were found to be closely related to the proposed optimization methods. These included, 1) the need to enhance planning, which includes scheduling, risk management and contingencies; 2) the importance of ensuring the right resources with the right skill levels of those executing outages featured high on the agenda; 3) the need for improved work practices as part of a continuous improvement effort and culture.

This study found that NPPs can do more to achieve optimized, best duration outages. There were indeed some key, immediately actionable practices and methods that if replicated, favored optimization success. It is evident that NPPs can do significantly better on outage durations, motivating for further investigation and improvement.

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List of acronyms and abbreviations

AOV	Air Operated Valve
BNPP	Barakah Nuclear Power Plant in the UAE
CM	Corrective Maintenance
EAF	Energy Availability Factor
FIN	Fix-It-Now
HPC	Hinkley Point C Nuclear Power Plant in the UK
HU	Human Performance
IAEA	International Atomic Energy Agency
KNPS	Koeberg Nuclear Power Station
LCOE	Levelized Cost of Electricity
MOV	Motor Operated Valve
NEA	Nuclear Energy Agency
NPP	Nuclear Power Plant
OE	Operating Experience
OECD	Organization for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
OLM	Online Maintenance
OL3	Olkiluoto 3 Nuclear Power Station in Finland
OTS	Operating Technical Specifications
PM	Preventive Maintenance
PM2	Project Management
RO	Refuel Outage (also called RFO)
SPV	Single Point Vulnerability
TECDOC	Technical Document Series by the IAEA also called TE

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND TO THE PROBLEM

This chapter contextualizes the need for and importance of outage duration optimization, hereafter referred to as outage optimization, for nuclear power plants (NPPs), but also for local and global economies. It describes the research problem and questions, the approach to answering the questions, the research scope and limitations and the structure of the dissertation.

As part of the energy mix, NPPs compete for a future with other sources of energy for electricity generation such as fossil fuels like coal and gas but also increasingly cheaper renewable energy sources like solar and wind power. Outages of any nature are lost opportunities to earn revenue and profit. According to the International Atomic Energy Agency (IAEA, 2002:1), “plant outages are shutdowns in which activities are carried out between disconnection and connection of the unit to the electrical grid” and furthermore, during this period substantial resources are spent on the plant, while substitute power must be purchased to meet the utility’s supply obligations. Therefore, it has a significant impact on plant availability and net income for the utility. In 2017, Professor Hyatt, head of nuclear materials chemistry at the University of Sheffield, said the lost revenue from the Flamanville reactor closure in Normandy could be £1m (\$1.2m) per day (Power Engineering International, 2017). With inflation, these costs would be significantly higher at present, and for new established markets with less localized and less optimized supply chains it could be closer to USD2m per day.

Shorter outages save time and money. In the South African context, it also reduces the incidence of load shedding. Whilst planned outages are a necessary requirement for refuelling, maintenance and repairs, outages longer than what is absolutely required not only loses revenue and profits, but it also makes nuclear power less competitive. The aim of this dissertation is to investigate practices or techniques that are effective to optimize and shorten planned nuclear outages.

Outages can be planned to execute certain activities or unplanned due to error or faults. Miller, Stakenborghs and Tsai (2011) explain that a planned outage is one where the utility replaces fuel and conducts maintenance but has adequate time to plan resources and events for the outage to optimize execution and minimize cost and duration of the outage. They further clarify that an unplanned outage is one of the worst situations for a utility where an unplanned scram of the reactor or another technical, safety or regulatory reason causes the plant to stop operating. The utility does

not have much time to plan, and resources must be mobilized immediately. Usually, the unplanned outage does not require the movement of fuel; therefore, it is typically shorter in duration.

Utilities normally invest significantly in planned outages to reduce the occurrence of unplanned outages. Utilities invest more resources in online maintenance to minimize the durations of planned outages. Many NPPs and even other industrial plants have varying durations for their outages. Outages that take longer than they need are a waste of money and other resources. Outages that are optimized for effectiveness and efficiency, and as safe and short as physically and economically possible, presents a distinct opportunity for NPPs to add value and remain competitive. McKendall, Noble and Klein (2008) adds that due to the high costs incurred from loss of production, the objective is to schedule maintenance activities such that the outage duration is minimized.

In a world where climate change events have intensified, nuclear power remains the only close to carbon free alternative to renewable sources like solar, wind and hydro. Fthenakis and Kim (2007) concluded similarly, that lifetime greenhouse gas (GHG) emissions from solar- and nuclear-fuel cycles in the United States are comparable under actual production conditions. In addition, Sadekin, Zaman, Mahfuz and Sarkar (2019) found that it was clearly visible that nuclear plants are more eco-friendly than fuel based plants along with hydro and renewable source plants and that nuclear produced electricity, is the path to choose to preserve the integrity of the environment and avoid global warming.

Nuclear power provides baseload electricity capacity which renewables are not yet able to and helps mitigate climate change when part of the energy mix with renewable forms of energy like wind, solar, and hydro. Suman (2018:176) notes that “renewables are intermittent but highly subsidized by funding agencies and readily accepted by the public while nuclear has high-capacity factor but little public trust at present. Evolving and bringing these two energy generation routes together will not only make power production continuous but also ease the apprehensions of people reserved for nuclear”. Solar panel and battery waste will soon be a problem of scale and importantly, not many countries have significant water bodies for pure hydro power. Thereby, reinforcing the need for nuclear as part of an optimally engineered energy mix.

The IAEA (2016) explained that to improve the overall economics of a nuclear power plant, a comprehensive understanding of the relationship between operations and maintenance (O&M) spending, and the performance of the plant is required. There is an actual cost associated with inferior performance (for example, lost opportunity for receiving revenues, higher than necessary cost to generate, etc.) as well as the corrective maintenance cost associated with repairing equipment. In addition, there is a reciprocal relationship between operations and maintenance spending and plant performance. Effectively, it means that too little proactive preventive

maintenance spending results in a higher frequency of unplanned breakdowns with higher corrective maintenance costs and the exceedingly high cost associated with energy or plant unavailability. On the other hand, the practice of excessive operations and maintenance spending can put the plant past the point of diminishing returns. The IAEA (2016) therefore advises that the goal is not to minimize operations and maintenance cost or to maximize performance (availability, etc.) but rather to minimize the total cost by optimizing the operations and maintenance cost, and to achieve this improvement, individual day-to-day decision making should be enhanced especially with a bottom-up approach.

The financial costs of implementing the optimization practices are not investigated in this research study but it is acknowledged that a Total Cost of Ownership (TCO) model, return on investment (ROI) and best shareholder value will determine which optimization practices NPPs should pursue. Shareholder value that focuses not only on short term profits but prioritizes sustainability and optimal environmental, social, and governance (ESG) factors should guide management decisions.

This dissertation intentionally focuses on the practical methods and techniques that if implemented correctly, will optimize outage durations and support management's optimization efforts to be successful. Thereafter, it is prudent for NPPs to consistently evaluate and implement those optimization practices that deliver the best shareholder value, sustainably.

With the economic uncertainties and repercussions brought about by global events including the Covid-19 virus pandemic, all organizations including NPPs will have to refocus on economic value and optimizing key aspects of the value chain to ensure cost and long-term sustainability. This introduction has shown that there are compelling reasons to optimize outages and that they are a definite source of competitive advantage and sustainable operations.

The author has over 26 years' experience in the electricity industry within South Africa and globally. He started his career as a technician and later became a manager and leader with cumulative experience in the Generation, Transmission and Distribution sectors and particular experience in maintenance, operations, engineering, project management, outages, and nuclear outages. He has worked on mega projects at the Koeberg Nuclear Power Station, the Barakah Nuclear Power Plant in the UAE, and on projects in France and the USA.

1.2 RESEARCH PROBLEM

This dissertation aims to identify practices that lead to consistent reduction in outage durations without a negative impact on plant reliability or nuclear safety. The overarching research question is, what are effective practices or methods to optimize durations of planned outages?

Additional questions that emanate from this research question are:

1. What is the best duration for a refuelling outage at a Pressurized Water Reactor (PWR), such as Koeberg Nuclear Power Stations (KNPS) in South Africa?
2. What are the most common reasons for delays in nuclear outages?
3. How are delays best avoided and mitigated?

1.2.1 Approach to answering the research questions

A literature review was conducted on refuelling outage (RO) durations and the most important practices that helped achieve optimized outage durations. This was followed by interviews with 12 nuclear outage specialists or nuclear professionals (as they are referred to in the nuclear industry) with significant outage experience, to investigate and understand their experience of practices and methods used to manage outages, optimally. Six of the 12 participants were from South Africa and the other six were from the United States of America (USA). The analysis of this data is presented, followed by a discussion drawing on literature and the interview findings.

1.3 RESEARCH SCOPE AND LIMITATIONS

This dissertation sought to identify best practices that provide consistent results for NPP outage optimization. The research was focused primarily on the Pressurized Water Reactor (PWR) technology, since most nuclear plants are of this technology and information more readily available. It was also the technology with which the author had experience. It focuses on finding crucial technical and practical methods that are reported to work consistently. As it is recognized in this study that financial and economic considerations will guide management decisions, a follow up study of the cost-benefit of each optimization method in context is recommended. The focus of the present research study was primarily on the qualitative data component, which involved structured questions used to interview 12 nuclear professionals about their experiences of outage optimization and identify useful and practical methods of optimization.

1.4 DISSERTATION STRUCTURE

Chapter two presents the literature review that includes the rationale and benefits of optimization, reasons for outage delays, recommended outage optimization practices and methods in industry, as well as some important concepts and terminology used in the research questions. Existing sources are used to clarify the research questions and provide greater understanding of the topic.

Chapter three provides the description and insights into the research approach. It discusses the research design, the population sample, data collection and analysis of how the interview questions were developed and interviews conducted to obtain industry professional's views on outage optimization practices. Ethical considerations, validity and trustworthiness are discussed to demonstrate confidence in the research process, findings, and conclusions.

Chapter four discusses the findings and results of the interviews in relation to the overarching research question and three derivative questions. This chapter relies on the interview transcripts and data as well as Appendix C which contains interview questions and answers that set the stage for the actual research questions. This appendix contained an initial analysis of the answers to all 15 interview questions, not only the research questions. It helped develop a better understanding of the topic and created context for the dissertation and interview questions for the participants and the author. The chapter concludes with a summary of the findings, leading into the discussion and analysis in chapter five.

Chapter five presents the findings and where appropriate, references are made to the literature review.

Chapter six provides a summary of the main findings, limitations of the study, priorities going forward and recommendations for further research.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents literature reviewed on the importance of optimization of outages at nuclear power plants and the different optimization practices in the industry. The benefits of optimization and what constitutes good optimization practices are also explored. An examination of the literature revealed limited volumes of scholarly publications on nuclear outage optimization but there were peer reviewed publications from organizations such as the International Atomic Energy Agency (IAEA), for example, TECDOC 1806 (2016), with substantial content on the topic.

Publications that focus on statistical analysis and mathematical programming to optimize outage windows between multiple nuclear reactors and maintenance periodicity dominate; however, it was not relevant to this study. This literature review found limited research and literature on practical methods, techniques, or practices to reduce planned outage durations on a single reactor that if replicated, provided consistently good outcomes. One plausible reason for the limited literature is that the industry is highly regulated. Privately owned for-profit NPPs strive to protect competitive advantage, intellectual property (IP) and know how, and therefore access to knowledge on these topics would be guarded thus limiting literature and dissemination thereof. This chapter focuses on the rationale for optimization, the reasons for outage delays and optimization practices in the industry.

2.2 RATIONALE FOR OUTAGE OPTIMIZATION

It is crucial to understand the key drivers for optimization. NPPs compete for a place in the energy mix for electricity provision of a country and globally. The competition is based primarily on the cost per MWh and typically calculated using a formula for Levelized Cost of Energy (LCOE) to compare energy prices. The International Energy Agency (IEA, 2018) explains Levelized Cost of Energy (LCOE) as the installed capital costs and ongoing operating costs of a power plant, converted to a level stream of payments over the plant's assumed financial lifetime and is the benchmark for comparing costs of power plants and a tool to make investment decisions.

Public perceptions of nuclear power play a role too. A Eurobarometer poll on Energy Technologies (OECD, 2010:20) showed only 20% of people were clearly in favor of nuclear compared to averages of 70-80% that support solar and other renewable sources. With fear of nuclear accidents and the climate change lobby, the call for renewable energy sources has increased. Whilst Germany opts

for renewables in favour of nuclear, the World Nuclear Association (2023) reported a poll held by ARD-DeutschlandTrend in August 2022 found that 41% of those surveyed believed that the Germany should continue to use nuclear energy in the long term and that only 15% were in favour of the remaining nuclear reactors being shut down at the end of 2022 – as was planned under Germany's nuclear phase-out policy. This support or lack thereof and evident uncertainty about nuclear, underpins the degree of investment which in turn drives costs. Outage optimization can reduce costs and improve overall economic efficiency along with safety to promote nuclear power and improve perception.

On the other hand, according to the IAEA (2016:1), the current generation of operating nuclear power plants has reached a high level of reliability and has increased stakeholder confidence in their safe operation. The IAEA (2016) adds that under more liberal market conditions prevailing currently, it is important to show that nuclear power plants are both cost effective and competitive in relation to other energy sources. One way of developing and maintaining the reputation and image of nuclear power plants is to enhance plant availability, cost effectiveness, and intentionally make stakeholders cognizant of the performance, economics, and safety. The optimization of outage durations is an effective means for contributing to these objectives.

Load shedding in South Africa has profound negative and frustrating consequences for all. Individuals, especially the poor suffer in numerous ways. One example, is where people living in shacks need to light candles and increase the use of typically unsafe paraffin or gas stoves, thereby increasing the risk of shack fires, and consequent risk to loss of life and belongings for hundreds in that township. Annegarn (2008) highlights the risk of paraffin stoves being knocked over and candles as a source of lighting in informal dwellings as frequent causes of shack fires and that the number of shack fires in informal settlements due to domestic use of energy with attendant loss of life and property are frequently documented in news reports.

Wroughton (2022) reports that loadshedding happens once a day, for two hours and on others, it lasts eight hours or more, crippling economic activity and disrupting life for 60 million people. Moreover, according to Arnoldi (2022), load shedding costs South Africa lost economic output of about R700-million per stage per day. With one stage being equivalent to a supply loss of 1000MW, and one KNPS reactor unit supplying 920MW to the electricity grid, this implies that by optimizing an outage and for each day saved, about R700-million per day of economic value is added, or not lost to the economy.

Load shedding is largely caused by a lack of investment in new power plants as well as poor outage and maintenance practices causing existing plants to fail more frequently than they should. Contributory factors include poor strategic energy capacity planning, bad management, lack of

engineering skills (an increasing brain drain), political interference, corruption, etc. The South African Government News Agency (2022) reported President Cyril Ramaphosa's explanation that Eskom deferred essential maintenance to keep the lights on, which is causing breakdowns and failures now. He added that the performance of some of Eskom's power stations has been further exacerbated by extensive theft, fraud, and sabotage. By implication, outage optimization keeps the lights on more and reduces costs and therefore, is one fundamental way to increase plant availability and thereby, mitigate load shedding.

Nuclear outage optimization has immense potential benefits for NPPs, the industry and other stakeholders. The IAEA (2016:2) states: "The duration and costs of an outage should be optimized to achieve the best possible result, without compromising personal, operational, or environmental safety. The best possible result is in an overall reduction in the cost of electricity generation over the life, or remaining life, of the plant." This means, NPPs can, (with safety as the overriding factor) reduce the cost of nuclear power, improve profitability, develop enhanced techniques and capabilities, and foster the culture of innovation and continuous improvement. It is prudent to, under all circumstances, take a long-term view and use a Total Cost of Ownership (TCO) model to manage a plant to increase returns on investment and sustainability.

Optimization of nuclear outage durations by shifting maintenance online can reduce costs and enhance competitiveness with different electricity sources. Lin (2002:1) elaborates that "on-line maintenance (OLM) has been practiced extensively in the U.S. to shift some of the outage work to be performed during power operations". Lin adds that by reducing the outage work scope and performing more OLM, nuclear plants can meaningfully reduce generation loss stemming from planned maintenance during outage. This is becoming increasingly important in a deregulated, competitive market environment for electric power supply. The OLM practice is an effective way to reduce outage durations and add economic value.

Nuclear power, with its low carbon emissions clearly competes on cost with 'dirty' coal, cheap gas, and diesel (cheap only in oil and gas producing countries), and subsidized solar and wind. In Figures 2.1, and 2.2 below respectively, Keppler (2010) demonstrates that at both a 5% and 10% discount rate, nuclear energy remains sufficiently cost competitive. Figure 2.3 demonstrates the cost inelasticity of nuclear compared to other energy sources such as gas and by implication oil, in relation to the fuel input costs.

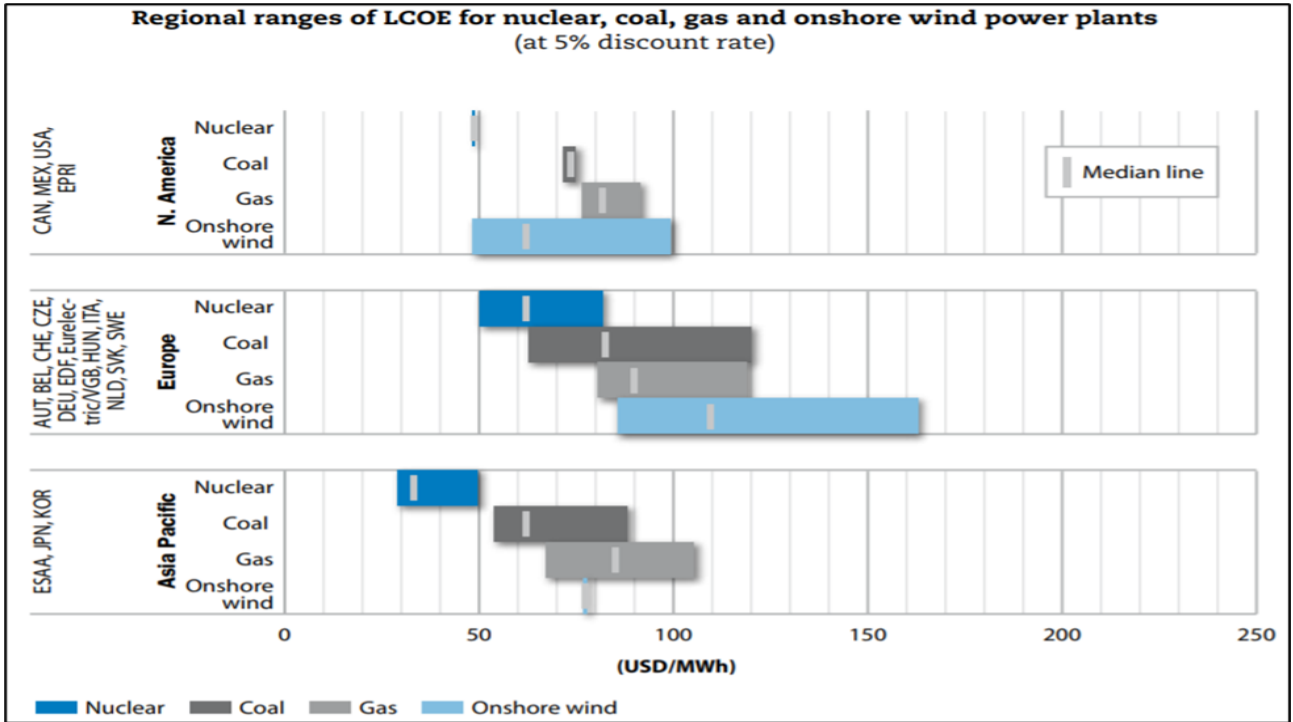


Figure 2.1: Regional ranges of LCOE for nuclear, coal, gas, and onshore wind power plants (5% discount rate).

Source: Keppler, J.H., 2010:5.

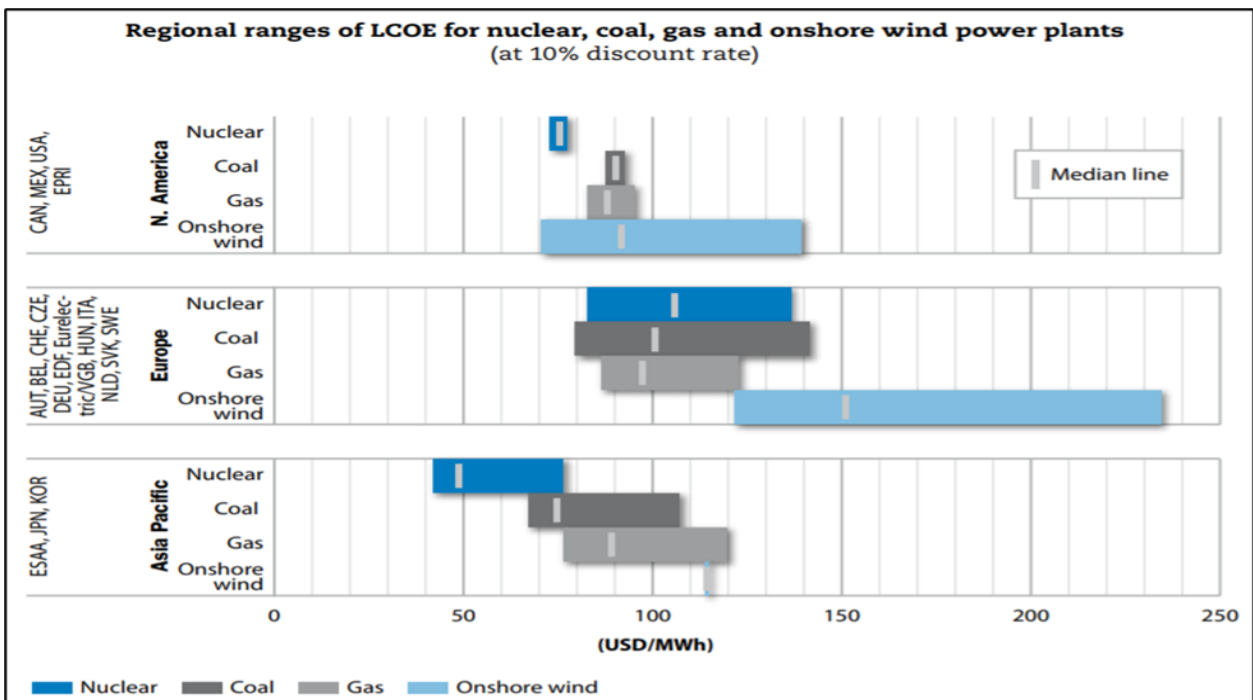


Figure 2.2: Regional ranges of LCOE for nuclear, coal, gas, and onshore wind power plants (10% discount rate).

Source: Keppler, J.H., 2010:5.

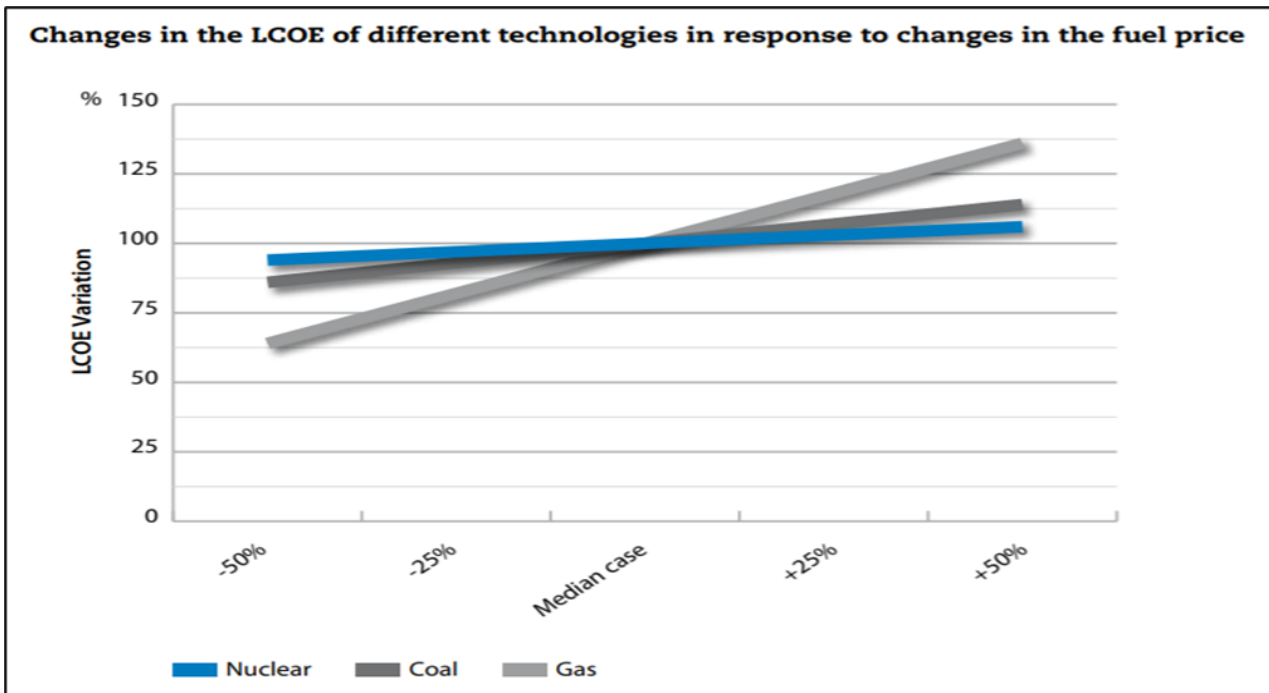


Figure 2.3: Regional in the LCOE of different technologies in response to changes in the fuel price.

Source: Keppler, J.H., 2010:6

What is not shown in the Figures 2.1 to 2.3 and similar graphs is the complementary value and future discounts of the low and zero carbon emissions of nuclear and renewables respectively, making them more cost competitive and attractive than coal and gas. Figure 2.3 demonstrates that nuclear costs do not fluctuate significantly with changes in the fuel price, creating predictability. Nuclear is significantly cheaper with a lower Levelized Cost of Energy (LCOE) than renewables. To reinforce, Figure 2.4 updated in March 2020 shows that the LCOE for nuclear remains competitive (world-nuclear.org, 2020). If more plants were built globally, the economies of scale would drive down the costs further, similar to what is being observed with solar and wind technologies. In addition, if NPPs were optimizing outages to enhance competitiveness, more plants could be built.

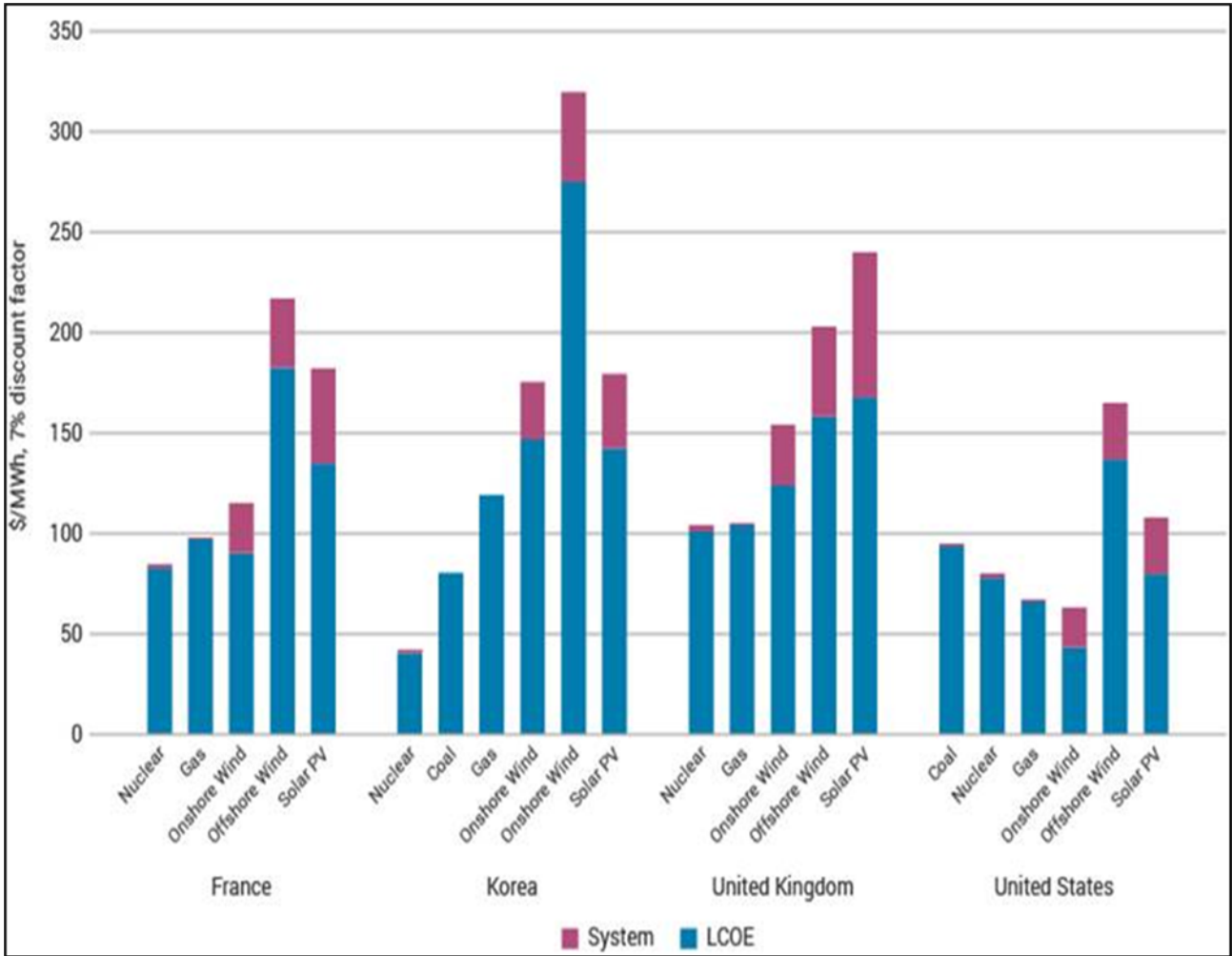


Figure 2.4: Comparative LCOEs and system costs in four countries (2014 and 2012)

Source: Economics of Nuclear Power, (world-nuclear.org, 2020)

Nuclear power has medium- and long-term environmental benefits that carbon fuels will never have and furthermore cannot be replaced as baseload capacity by intermittent wind and solar sources. The United Nations Sustainable Development Goals Report (2022) extensively discusses the destructive impacts of multiple global crises that impede the achievement of the Sustainable Development Goals (SDGs). Shorter outage durations means reduced reliance on and use of fossil fuels which in turn supports the United Nations Sustainability Development Goals (SDGs), particularly SDG7 – Affordable and Clean Energy.

Matek and Gawell (2015) concluded the value of a diverse portfolio of resources because intermittent sources alone cannot cost-effectively generate electricity for a balanced grid. Matek et al (2015) also found that a less diverse generation mix meant higher ratepayer costs because of the need for additional ancillary services to curtail generation. Efficiency and lower costs can be supported by outage optimization and associated savings, making nuclear more competitive. Miller et al (2011) reports that nuclear power plant outage management is a key factor for good, safe, and economic

nuclear power plant performance which involves many aspects and support with nuclear safety, regulatory and technical requirements. The competitive nature of the business environment for electricity generation contributes to nuclear power plant operations and according to Miller et al (2011), especially the efficient use of resources, efficient management of plant evolutions such as online maintenance, unplanned and planned outages. These economic benefits and financial savings can support an economy, build skills, capability, and know-how for generations to come, giving an organization and even a country a competitive advantage for foreign investment. In summary, investing in nuclear outage optimization to maximize generating capacity is a source of value and sustainability.

Continuous improvement over the years has and will continue to yield significant benefits. Past successes serve as inspiration. Miller et al (2011) reported on some successes indicating that the increase in nuclear generation has been achieved by a substantial increase in the overall capacity factor of the US plants from about 60% in 1980 to over 90%. They added that the large increase in capacity factor was achieved by reducing outages, having longer fuel cycles, using higher burnup fuel, reducing unplanned outages and fuel failures. Combined with increases in power in various plants (power uprates) this allowed nuclear to maintain and increase its share of electricity generation. Miller et al (2011) also propagated that by reducing planned outages from 106 days for an average operating plant in 1991 to 38 days in 2008 the cumulative effect was an increase in nuclear generation and availability, equivalent to having built 25-30 NPPs during that period. It's significant that innovation and continuous improvement negated the need to build an extra 25 to 30 NPPs and these success stories need to be shared pervasively to inspire further improvements.

There have been improvements in the overall performance of nuclear power in some countries. Miller et al (2011) reported that in the US, there were several initiatives that improved the performance of nuclear power stations thus providing adequate justifications to building more reactors in the USA. He noted that there was a reduction of unplanned outages from about 9 to 3 from the period of 1976-1979 to 1986-1991. The initiatives contributed not only to reductions in planned outage length and the number of unplanned outages (thus contributing significant improvement in the nuclear plant reliability, cost, and safety of nuclear power plants) but also power up-rates, and power plant life extensions. They added that the power up-rates, which allowed plants to operate at a higher power, and power plant life extension (PLEX), which extended the operating life of a power plant beyond 40 years allowed more electrical power to be generated at a reduced total production cost. In addition, fuel performance improved significantly over the last 20-30 years.

Miller et al (2011) explained that utilities in the US have invested copious resources in eliminating unplanned outages such as increasing scram reliability, identifying root causes of the unplanned events, and fixing them, and training operators and maintenance staff in proper techniques to ensure reliable operation. State owned NPPs do the same but are typically less competitive. South Africa's state owned KNPS executes a refuelling outage (RO) with standard maintenance in about 35 days. According to Hansen (2008), top quartile NPPs in the US average 25-27 days and the top 14 percent, less than 25 days. Optimization brings financial benefits and increases skills and capability. Optimization does not need to be driven by private shareholders. It should be business as usual. In the South African context, the national utility Eskom has the fiscal and moral obligation to optimization due to the country's dire economic circumstances.

Outage durations have decreased substantially over time and with optimization and innovation, this trend will continue. Hansen (2008) reported on NEI data that revealed that by April 2008, 41 reactors either completed or were undergoing outages and the average outage duration was 36.7 days compared with 104 days in 1990. Top performing units averaged 25 to 27 days for refuelling outage and a few units were even refueled in 15 to 20 days. Figure 2.5 below shows the improvements in shortening the average outage in the US from 1990 to 2019. This decline from an average outage length of 106 days in 1991 to 38 days in 2008 and 32 days in 2019 represents a significant saving and a noteworthy source of value to the utilities and ultimately to the consumer.

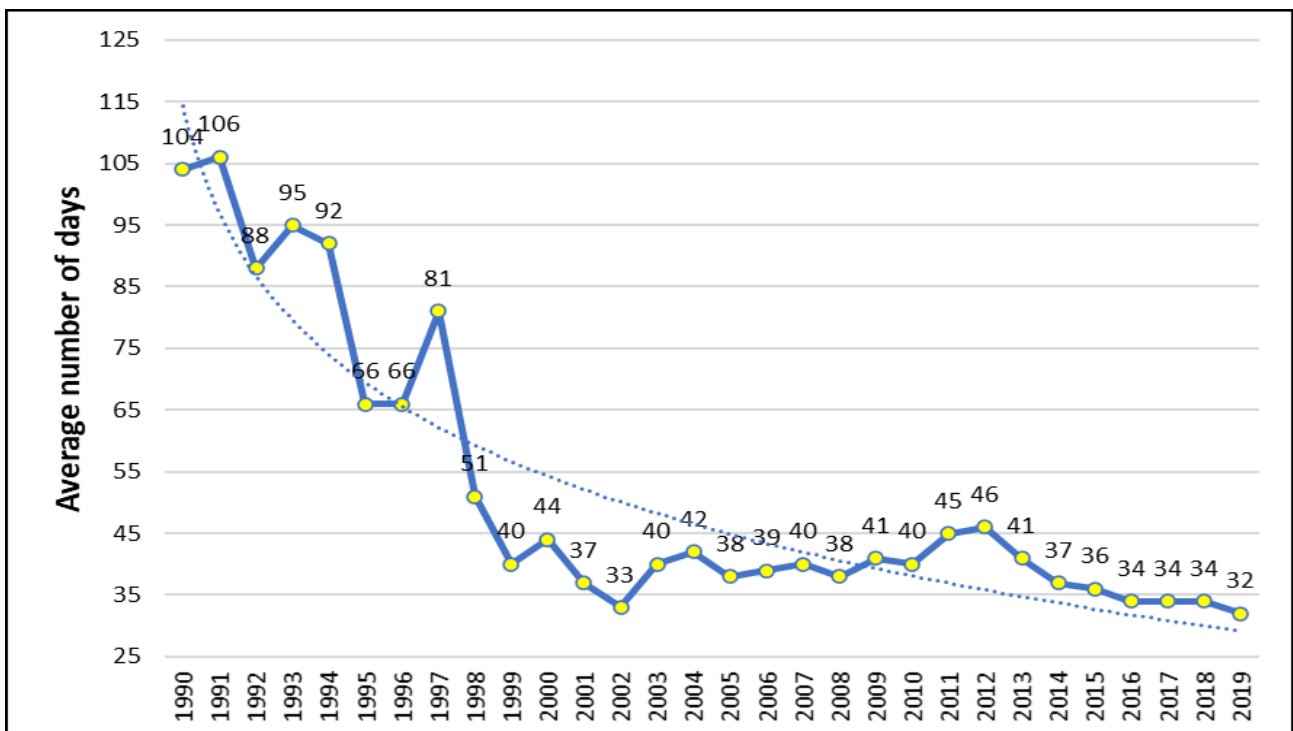


Figure 2.5: US Nuclear Refuelling Outage Days

Source: Nuclear Energy Institute Online, 2019

Even achieving an average five more days reduction in outage durations, across a fleet of reactors on a continuous basis would be a significant achievement. In the South African load shedding context, five days less outages at KNPS not only saves the associated outage costs of about USD1.2m plus per day, as already indicated, it also saves the overall economy about R700-million per stage per day. . If these practices are embedded in utilities like Eskom for nuclear, coal and other power stations, it unleashes the potential for considerable efficiencies, avoidance of load shedding, increased consumer, and investor confidence with potential for renewed investment in this currently ailing economy.

In summary, the literature has thus far confirmed the benefit of optimizing outages. Outage optimization presents opportunities for nuclear plants and utilities in general. The next section explores some of the reasons for outage delays followed by effective optimization practices in the industry.

2.3 REASONS FOR OUTAGE DELAYS

Before investigating effective methods for outage optimization, it is useful to first understand the common reasons for outage delays or extensions. According to IAEA (2016), an outage extension is the increase of outage duration beyond the planned time after the outage plan is frozen. It is a negative effect that should be avoided because it causes unplanned energy loss, requires additional manpower, increases outage cost, and may result in the production of additional radioactive waste and increase the collective dose exposure. Therefore, if the outage is planned and managed in accordance with the IAEA guidelines, the extension of the outage will most likely be initiated by a reason that has been discovered during the outage.

With the increase of NPP lessons learned (operating experience), the risk of outage extensions should be lowered. However, while optimization of planned outage duration is desirable, the IAEA (2002) cautions that making the planned outage shorter may increase the probability of the outage extension due to a reduction of the margin for resolving unanticipated problems in the defined time. The IAEA (2002) explains, that to handle these unexpected events, the plant management should make efforts from the very beginning in the outage planning phase to predict and prevent outage extensions by using proactive engineering approach, a questioning attitude, proper motivation, and operating experience feedback program results. Effectively, it requires proficient planning, scheduling, and risk management. The IAEA (1997) clarifies that a self-assessment process is an effective way for improving safety performance, safe operation, efficiency, reliability and overall economic performance. It can be used to assess outage performance and improvement.

The most frequent causes and their countermeasures to avoid outage extension according to the IAEA (2002) are presented in Appendix A. These causes should be used in the self-assessment

process to assess the probability that similar causes can occur and implement mitigation. The following are some of the causes of outage extension commonly encountered, identified by the IAEA (2002):

(1) Non identified system or equipment or component deficiency

- lack of condition monitoring and trending
- equipment or component failure during outage execution
- ISI program and tests results

(2) Quality of work performed

- lack of quality consciousness and procedure usage
- poor quality of material
- lack of mock-up structures
- lack of skilled or trained manpower
- improper work execution control
- casual attitude to work execution resulting in waste of working time
- improper implementation of Foreign Material Exclusion (FME) program

(3) Deficient outage management

- lack of leadership and control over the plan activities
- lack of motivation
- lack of budget
- late order of equipment, material, and spares
- insufficient cooperation among the parties
- deficiencies in interdisciplinary communication
- quality control deficiencies

(4) Regulatory impacts

- last moment regulatory requirements added
- misinterpretation of regulatory requirements

(5) Failure of inspection or special maintenance tools (lack of preventive maintenance of special tools)

(6) Inadequate spare parts or lack of spare parts

(7) Inadequate vendor support

- lack of technical support and unreliable sub-contractors
- lack of equipment or material supply or late delivery

(8) Deficient outage planning

- under estimation of activity duration or work force
- improper scheduling of work activities

- support activities (scaffolding, etc.), tools, materials not clearly defined
- plant status prerequisites, work permits, and approvals not clearly defined
- Operational Experience Feedback (OEF) program results were not considered or OEF actions were not adequately implemented while planning reoccurring outage activities.

The list above is comprehensive and provides a good reference of reasons for delays. Whilst it does not rank the reasons it helps develop a framework for grouping types of delay.

2.4 OUTAGE OPTIMIZATION PRACTICES IN THE INDUSTRY

Following the foundation presented to understand of common reasons for outage delays, it is beneficial to gain a deeper understanding of several optimization options in the NPPs strategy toolkit. Spring (2010) interviewed several industry professionals on outage management best practices and discovered that “advanced planning, a continuum of support, alliance contracting, improved workforce practices and safety” emerged as the leading best practices and that after reviewing the lessons learned and the best practices over the last 10 years, there are no “silver bullets”. There may or may not be any silver bullets but some NPPs do perform better than others and continued success implies a deliberate effort. They are replicating a combination of proven practices and therefore such success is achieved by design. Other NPPs who wish to replicate the success of top performing plants would do well to learn from them, rather than reinventing the wheel. This dissertation intends to highlight key practices that could be significantly beneficial to others in the industry.

2.4.1 Shifting Outage Work Online and Optimized Periodicity

It makes sense to always shift maximum or optimal amounts of preventative maintenance (PMs) online to reduce maintenance during outages, thereby reducing outage durations, and having less downtime and expensive outage crews. The work is done by the online maintenance team scheduled periodically and safely during the typical 18-month fuel cycle. Lin (2002) supports the practice, highlighting that shifting outage work to online and reducing PM/Surveillance frequency are effective strategies for reducing outage durations. Lin (2002) cautions that the risk of maximum online maintenance brings increased risk of tripping the reactor and highlights the need to have contingencies in place. In addition, minimizing outage PM/Surveillance frequency requires careful evaluation to ensure NPPs remain within operating technical specifications (OTS). Effective condition monitoring and predictive maintenance techniques, and tools are required to compensate for reduced maintenance frequencies.

From experience, most utilities normally have a cross function modification group that has the authority and mandate to maximize online work to reduce outage time. The value of increased online

maintenance is further underscored by Hadavi (2009) who reported that aside from Hadavi (1998) who for the first time introduced genetic algorithm (GA) to the outage maintenance optimization and Hadavi (2008), almost all researchers have put their efforts on optimizing the online maintenance, surveillance test, and inspection intervals. Miller, et al (2011) encouraged the optimization of outages by different initiatives including ensuring all that can be performed while online is completed, prior to the outage.

Optimization of test and maintenance intervals or frequency is a balancing act. Vaurio (1995:23) found that “engineered safety systems are usually standby systems that are tested periodically to reveal and repair failures that may have occurred since the previous activation or inspection. Downtime (unavailability) can be caused by testing or by failures and repairs caused by activations or occurring during standby, as well as by human errors associated with tests. Frequent testing increases the testing costs while infrequent testing leads to increasing downtime and risk”. Utilities require an optimized testing and maintenance program. Too much maintenance and testing wastes resources and increases the possibility of error. Too little, amplifies the probability of failure and consequently squanders resources. It is imperative to conduct testing and maintenance at that “sweet spot” where equipment is operating optimally, cost is minimized, yet still achieving requisite safety goals. In simple terms for example, outage PMs and surveillance frequencies are minimized by doing them online or if they had to be done in an outage, doing them every 36 months instead of every 18 months. These decisions are taken carefully with sufficient engineering data to support decisions.

In summary shifting work online or optimizing frequency of maintenance are the first two options for optimizing outage durations. The practices that follow are all related to actual optimizing and/or shortening outage durations after scope freeze and excludes shifting work online.

2.4.2 Planning and Scheduling Phase of Nuclear Outages

Depending on the plant strategy, outages are primarily planned according to scope and in line with refuelling frequency and duration. When planning outages, the IAEA (2016:20) indicates that it has become good practice to categorize outages based on duration to minimize the total outage time and categorizes the outages into four different kinds:

- Refuelling only, that could be performed in 7 to 18 days.
- Refuelling and standard maintenance, that could be performed in 14 to 23 days.
- Refuelling and extended maintenance, that could be performed in 15 to 40 days.
- Specific outages for major back fittings or plant modernization which could take more than 40 days to perform.

The above-mentioned durations are typical of top-tiered plants and whilst not easy, it serves as evidence that these durations are indeed achievable. At KNPS for example, the outages for refuelling plus extended maintenance typically last 35 days compared with the above-mentioned durations of about 15 to 40 days. Hickman (2017) shared several useful practices for outage management. He recalled that in 1990, the average planned outage took more than three months (>90 days). At the time of the article (27 years later), the average time for most US plant outages was 35 days. Hickman (2017) reminds us that history is marked with seemingly impossible tasks that were achieved through high levels of innovation and collaboration.

When planning for a short, medium- or long-term outage, the scope is always of prime importance. The IAEA (2006:1) identifies activities that define the scope of planned outages based on the type of NPP technology which for a PWR typically includes:

- Refuelling the reactor
- Inspection of different components and structures
- Tests and surveillance of process and safety systems
- Preventive and corrective maintenance
- Minor or major design modifications

In addition, the IAEA (2016) lists optimization practices that should be considered during planning and preparation related to mobilization of human, material and equipment resources but do not expound on the implementation and prioritization of these practices. These practices include (IAEA, 2016:24):

- Work scope predictable up to 95% and about 5–10% added work.
- Early walkdowns.
- Revision of frequency of inspections based on experience.
- Streamlining activities without influencing safety.
- Freeze outage scope and procedure for scope change.
- Utilization of computerized tools and robotics.
- Maintenance program optimization.
- Usage of international and own experience and benchmarking.
- Qualification and training of contractors on safety culture and work procedures.
- Involvement of the contractors from the early steps of outage preparation.
- Identification of critical work areas from the scheduling point of view.
- Preparation of site locations, workshops, and offices for contractors.
- Optimizing the mobilization of human and material resources.

- Signing all contracts according to the outage preparation schedule and in good time, before outage start.
- Planning and training in-house and outside human resources in advance.
- Implementing incentive programs for staff focusing on outage performance, e.g., incentives for outage schedule, quality, cost, and safety.
- Identifying shared resources and possible joint ventures in case of major back fittings.
- Checking for and reserving, material, spare parts, and consumables available on-site, in early stage enough before the outage start.
- Sharing human and material (cranes, hoist, special tools, etc.) resources in the utility and among utilities.
- Assigning additional coordinators for specific work areas, if necessary, e.g., crane usage or pressure vessel work.

Spring (2010) interviewed several industry professionals for their views on outage optimization and conveyed the consensus that there are many important aspects to every outage, but advanced planning was the first and most important step. They discussed various aspects with key features below:

- Those who have experienced an outage that has gone badly will likely tell you that poor planning led to the result.
- They emphasized that planning should start as early as possible
- For most outages, internal support and site teams should begin planning a minimum of 12 months in advance.
- Some outage types may even require starting the planning process up to two years in advance.
- The forecasts should include all aspects of the outage in addition to the resources required to execute it.

Spring (2010:2) advised that “producing a project schedule to assign and track tasks as well as to identify areas of concern is the next step and using the plan as a “road map” lays out the coordination strategy and directs the overall execution for both the interrelated and independent tasks”. The narrative showed that failing to follow the plan will likely lead to losing control of the outage and losing revenue but that it was important that the plan not be static. Instead, it was important to maintain flexibility and be able to change as needed throughout the outage.

Resource loaded schedules using appropriate software provide a distinct advantage and presents improvement opportunities on many levels. In an interview, Greg Kern VP for Day and Zimmerman

NPS articulated that “planning and scheduling continue to grow in sophistication, serving as the foundation for owners to optimize costs” Spring (2010:2). Kern provided examples, adding that scheduling outages, so that materials and contingency workforces are optimized has grown from a focused plant activity to fleet-wide assessment. Utilities can consider local and regional planning for outage scheduling when drawing on the same material and contingency workforce resources. He added that outage management techniques like these have maximized cost containment and enhanced the number of trained personnel at one fleet’s fossil outages, and substantial sums have been saved in duplicative in-processing and training requirements at nuclear facilities. Plants like KNPS should leverage the use of resource loaded schedule and the methods described above.

Pre-outage peer reviews by other plants and contractors is another useful technique. According to Spring (2010:2), it involves an independent challenge review of every outage management activity including scheduling, cost control, specialized tooling assessments, craft needs and field administration. Spring (2010:2) also reported that “plant owners who involve contract leaders to review outage plans and assess readiness to execute work scopes will generally see a stronger performance in the contracted workforce”. Some see this as an extra cost, but it should be seen as an investment in the expertise and commitment of contractors who often work at multiple plants and bring lessons learnt through this exercise that ultimately help avoid unnecessary overruns.

Planning and scheduling underpin outage success. Hickman (2017) noted that some say 18 to 24 months is an appropriate amount of time to plan for an outage, but experience proves a longer time is key to improving outcomes and minimizing outage durations. He added that at Hatch, pre-outage planning extended to almost three years before work began on the two most recent outages and Southern Nuclear also develop very specific milestones during the planning process to track progress. Planning in advance for some outages like replacing steam generators or reactor pressure vessel heads should start as early as 24 months or more in advance. David Vineyard, Site Vice President for Edwin Irby Hatch Nuclear Plant in Hickman (2017) shared that they have used the advance-planning time to work closely with their alliance contractors to ensure all their workers were fully trained and certified when they arrive on site, and this helped them get to work right away.

Miller, et al (2011) reinforces the emphasis on advanced planning by saying “Plan, Plan, Plan – A successful outage always has a plan that was rehearsed and reviewed many times.” Miller, et al (2011) adds that the detailed planning and preparation phase should consider the following:

- Pre-outage milestones including planning, materials, schedule development, external service contracts, clearance preparation, ALARA reviews, design issues, regulatory issues, etc.
- Outage duration for all 3 phases: shutdown, execution of work and start-up.
- Final scope of work/activities.

- Outage schedule, including the main outage schedule and work and safety related schedules (separate schedules for systems, reactor, turbine, start-up, etc.). Those schedules shall comply with the main outage schedule. For each activity in the critical path, a separate schedule is made.
- Work packages, including work orders and permits, instructions and procedures, materials, spare parts, consumables, human and material resources, special tools, post maintenance testing and start-up programs, etc.

Extensive efforts are usually directed towards detailed and comprehensive pre-planning to minimize outage duration, avoid outage extensions, ensure future safe and reliable plant operation, and minimize personnel radiation exposures. Planning and preparation are important phases in the optimization of the outage duration which should ensure safe, timely and successful execution of all activities in the outage. To this end, the IAEA TRS449 (2006:4) states: "Plant management needs to establish effective mechanisms to monitor outage planning, preparation, and execution. These should include the establishment of suitable milestones and performance indicators, as well as effective means for the continual monitoring of performance based upon these expectations. Early identification of problems/issues is the most important factor in minimizing the impact on the outage." It becomes increasingly clear that extensive planning and scheduling is one of the most important, if not the most important success factor to managing an effective outage and reducing outage times.

2.4.3 Outage Execution Phase

Following the planning phase, the next important phase is execution of the plan and execution is underpinned by integration and communication. Planning the outage is identified by the IAEA (2016:26) as "the foundation of success for managing the outage execution in an optimal manner". It elaborates on the importance of having the same team responsible for outage planning, manage the execution. This helps with understanding, continuity and integration of the detailed schedules which are frequently updated and used for preparation and execution. Planning and scheduling occur typically 18 months before the outage but continues throughout the outage at a granular level, sometimes hour by hour or even, minute by minute. This reinforces the good practice that the same team who planned the outage sees it through to the end in their respective roles to achieve a seamless outage.

Effective execution involves strong communication, directing and controlling of resource efforts. The IAEA (2016:30) highlights the importance of coordination and communication for execution by affirming: "The coordination between the outage participants, operations, electrical, instrumentation and control (I&C), mechanical, health physics, contractors and the respective execution and commissioning staff is the fundamental precondition for successful execution of work." The IAEA

(2016:30) also underscores the Outage Manager's daily or twice daily coordination meeting as one of the most important tools to communicate and resolve daily problems. It is at this meeting that important problems and concerns should be highlighted and resolved whilst the main workflow (approx. 95%) must be handled in the normal work control management. The next section describes some of the key execution activities where optimization is possible.

2.4.3.1 *Work Practices During Outages*

Whilst it is emerging that effective planning and scheduling are the crucial first steps, effective work preparation and work practices are complimentary and equally important. Work preparation refers to tasks performed to prepare the worker, the work site and the piece of equipment or system to be worked on for the job. When these work practices are honed for precision, time is optimized.

The NEA OECD report (1997:14) affirms: "To begin with, the work site can be optimized, in terms of the placement and availability of support equipment (scaffolding, temporary shielding, ventilation, area decontamination, insulation removal, etc.)." Knowing and implementing the best work practices require a deep level of experience in that discipline as they are not typically written about in research papers and require tailoring to a specific site's design and layout as well as the types of support equipment in that market or on that plant. Support equipment differs in design, dimension, strength, etc., and it is sometimes those nuances that enable effective optimization. Ensuring that the scaffolding or shielding is in the right place, at the right time can make or break outage schedule success.

2.4.3.2 *Risk Management*

Managing risks proactively and pre-emptively helps take advantage of and amplify opportunities and control the probability and impact of negative events during outages. Most organizations focus on the latter. The IAEA (2016:25) advocates conventional project management approaches for risk management, indicating that a risk assessment shall be performed for each outage and that both qualitative and quantitative risks should be considered. Quantitative risks would include, for example, outage prolongation or additional costs and a qualitative analysis would include risk identification and the consequences for each risk. Performing effective risk management has the following time optimization benefits:

- Ensures risks (negative and positive) are well managed and saves time for the outage
- Ensures risks are well managed and does not add time to the outage
- Risks are managed to the extent it can be and limits negative time extension effects

2.4.3.3 *Fuel Reloading*

Refuelling outages occur at predefined periodicities, typically 24, 18 or 12 months depending on plant design and philosophy. Most PWR plants have 18-month cycles. Regardless of the periodicity, there is immense value in reducing refuelling time. This is achievable by optimizing the core design and the shuffling sequence as well as having the best fuel handling tools with highly skilled fuel handling experts that execute refuelling activities with speed and minimal risk. Wakker, et al, (2003) concluded that both core design and shuffling sequence optimization can be exploited to reduce the time needed for reloading a core with an in-core shuffling campaign. In one study by Wakker, et al, outage time was reduced by seven hours with the possibility of further reductions of five hours. This is a saving of between USD500k-600k per outage. They concluded that ex-core shuffling campaigns for PWRs can still have substantial benefit from a core design with a minimized number of insert shuffles.

2.4.3.4 *Alliance Partnership Contracting*

Alliance contracting tends to yield a few benefits. Mercado (1994) suggests that alliance contracting, and partnerships between the utility and the vendor is a way to reduce refuelling outage durations and control cost and that parts/inventory management programs that would lower or eliminate the utility's stocking requirements. Mercado (1994) adds that "as in any partnership relationship, there are roadblocks and hardships along the way" and suggests the following for effective partnerships:

THE VENDOR MUST:

1. Commit to provide technical expertise, both people and equipment, to deliver high quality services and products to meet the outage goals on schedule, safety, ALARA and quality.
2. Provide effective communication and continuous dialogue which could be essential to find solutions that utilities can't solve themselves and to share experiences.
3. Commit to stay current or ahead of the state of the art concerning industry technology.

THE UTILITY MUST:

1. Treat the Vendor as part of the team, not just a labor broker. If the vendor gets in trouble, work as a team to solve problems.
2. Constantly communicate goals and objectives, and expectations of the vendor.
3. Define the vendor's scope early and award the contract early.
4. Give the vendor technical ownership.

The proposals from Mercado are intuitive to some. However, it has been observed in the industry that instead of alliance and collaboration, many utilities and their staff treat contractors in a very

transactional and adversarial manner. The World Bank Contract Management Practice (2018:17) emphasizes each contract is different, “so careful considerations of the parties/groups involved, the nature of the contract, and its value, scope and complexity need to be taken into account when developing a relationship management strategy, as part of the Contract Management Plan”. They add that the hallmarks of good relationships include: 1. commitment to the relationship; 2. honesty; 3. trust; 4. goodwill; 5. effective two-way communications; 6. common understanding; 7. mutual respect; 8. openness and accountability. Most contemporary literature echo similar sentiments and it is in the interest of success to build relationships with contractors, enhancing synergy and mutuality to foster reciprocity.

2.4.3.5 *Training and Mock-ups*

Training and mock-ups play a significant role in work and especially outage preparation. According to the IAEA (2002: 10), training not only provides knowledge of state-of-the-art technology but also keeps plant and contractor staff motivated during outages. Training and retraining programs also can improve readiness of operating and maintenance staff for appropriate actions and reactions “in case of malfunctions, incidents or accidents that could occur at any time” (IAEA, 2002:10). Similarly, the report says training/re-training of the manpower can be deployed as a countermeasure to the causes of the outage extension. Contractors typically make up for shortfalls in permanent worker numbers and expertise in focused areas and the IAEA (2016:3) advises that “contractors should be trained and qualified according to the utility’s training and qualification programs”. Under the nuclear license, NPPs have accountability to ensure safety and quality are foremost and therefore are required to buy into this approach to provide a sufficient degree of oversight and craft success.

The IAEA (2002:26) encourages that staff are to be “trained and familiar with the plant design and relevant procedures. A special session on safety issues will be arranged every year to subcontractors’ outage personnel”. The IAEA (2002:50) adds that outage preparation training is intensive, and the report emphasizes that NPPs must do the following from 15 days to 1 week before the outage:

Provide for personnel training on mock-up or on testing stands, for the following operations:

- installation of the Steam Generator nozzle dams, and drain plugs
- multi-stud tensioning machine use, reactor vessel, steam generator manhole
- control rod drive shaft latching and unlatching handling tool.

NPPs make use of mock-ups for specialized tasks and do repeat training of the specific tasks at hand to eliminate mistakes and to optimize time. These mock-ups are typically full-scale models of

an actual component or system, and workers repeatedly practice the task in full until it is mastered in preparation for the impending outage.

2.4.3.6 *Tooling and Equipment*

Having the right tools and equipment can go a long way in optimizing outages. The OECD (1997:14) advises that in certain situations, the use of specialized tooling and/or robotics can be both economical and effective. This can include tools used at the work site, as well as tools used in specialized "hot workshops". In particular, the availability of a well-equipped hot workshop can improve maintenance quality and save time and cost. The effective use of supporting equipment, such as ventilation and filter systems, or remote communications and monitoring equipment, can also save dose, time, and money. Ensuring tools, equipment, scaffolding, barricading, etc. are in sound working condition and placed strategically prior to a job, placed, and removed with just-in-time principles can reduce outage time. In addition, this helps demobilizing unnecessary staff as quick as reasonably possible which in turn saves money too.

Hansen (2008) reports that improved refuelling equipment reliability – such as the manipulator crane, the fuel transfer system, and polar cranes – has also led to shorter outage durations. Hansen elaborated, that utilities have upgraded their plants for faster outages with modifications like improving the speed of the fuel handling equipment and installed improved reactor head packages. The polar crane and other cranes unique to the reactor building can be a source of efficiency and at the same time a source of immense risk. The cranes are used for multiple activities and jobs and need to be scheduled correctly. Furthermore, when one of the cranes break down, these specific activities and jobs standstill until the cranes are repaired. There is no substitute. Proper maintenance of these cranes and manipulating equipment is crucial and having the crane technician close by during the outage, equally important. Neglecting tooling and equipment can add significant time to an outage.

2.4.3.7 *Work Control*

According to the IAEA (2016:32), managing work and work permits using computerized methods is helpful during online or outage periods and a key method to shorten outage durations. An IAEA report (2002:17) advocated for an efficient process and procedure for work control management supported by a computerized work control system for shortening the outage duration. Work control systems (work orders and work permits) should follow the same procedures as during normal plant operation. Supporting the control room to handle work permits is needed during outage execution due to the large work volume. A multi discipline team from operations and maintenance should schedule, prepare, and perform a significant amount of tag-in, tag-out and line-up and can also be

used for tests before start-up. The IAEA (2002) advocates that best practice work control computerized information systems include:

- Work order and permit administration,
- Project planning,
- Material and spare parts management,
- Plant technical data,
- Plant operation and maintenance history,
- Radiation dose control,
- Personnel database,
- Account control

The OECD (1997:15) adds that effective Work control systems are essential because it pulls work together through the Outage Control Centre (OCC) and keeps people on schedule. It helps with sufficient data for the real-time review of worker radiation doses and simultaneously keeps work flowing. It helps assure that all necessary job prerequisites (valve line-ups, electrical circuit set-ups, hazardous work permits, etc.) have been fulfilled prior to the start of work. The objective of Work Control Management is the optimization of work such that its successful completion fulfils the set objectives.

2.4.3.8 *Role of the Outage Control Centre (OCC)*

As in project management more generally, the management of outages relies on integration. This role can be allocated to the Outage Control Centre (OCC). An OCC plays an important role in coordinating, integrating, and communicating outage activities. According to IAEA (2016:33) it is a nuclear industry good practice to establish an OCC to manage and coordinate the multiple workgroups to smoothly execute many outage activities in the field and to solve the unforeseen problem and issues timely. The OCC members come from the Outage Management Department, Operations Department, Maintenance Department, Technical Department, Safety Department, Chemical Department and main contractors and it is the center of outage management. The IAEA (2016:34) explains that: "OCC personnel are selected before the outage and senior plant management will approve the organization. OCC members are trained prior to the outage to clearly understand management expectations, outage goals and performance, and the OCC's responsibilities. OCC personnel will participate in both outage preparation and execution. During preparation, OCC members should meet periodically to discuss scheduling, critical path, and trace preparation plan in detail. During the outage, OCC members spend much of their time physically in the OCC. The OCC is typically located in the protected area, close to work control, the plant and work activities and main responsibilities include:

- Outage activities are tracked, monitored closely.
- Maintain focus on nuclear, radiological, and industrial safety.
- Monitor critical path and near critical path outage progress intensely.
- Look ahead to prepare for upcoming milestones, activities, and evolutions, then make sure workers are informed of important activities.
- The status of key activities is communicated frequently and clearly to staff involved,
- Establish outage priorities.
- Emergent issues are identified and assigned to the responsible team to be addressed promptly, and to report to senior managers in a timely manner.
- Evaluate emergent work items for implementation during the outage and for their effects on shutdown safety.

The IAEA (2016) accentuates the modus operandi of the OCC, denoting the criticality of daily meetings to communicate critical and near critical path status, major work that may impact nuclear safety and conventional safety, emergent issues, and protected equipment status. The OCC is the nerve center of planning the work and working the plan and aims to ensure outage execution is as smooth as possible.

2.4.3.9 *Information and Communication Technology*

The IAEA (2016) explains that the current technologies employed at most NPPs to communicate critical information are slow, inaccurate at times, and rely on the physical presence of outage staff and key personnel to obtain and validate critical system and work progress status information. Information and communication technology (ICT) is integral for quick and effective communication and nuclear plants have not yet tapped the full potential thereof, with cyber-nuclear risks cited as the major concern.

As recently as 2016, the IAEA reported that most of the outage communication is done using processes and technologies that do not take advantage of advances in modern communication technology. They add that common communication practices include runners that deliver paper-based requests for approval, radios, landline telephones, email, desktop computers, daily printouts of the schedule, and static whiteboards that are used to display information. The IAEA (2016) explains that outage experts across the industry have identified areas of need that will have the biggest return on investment and that it has become clear to the research staff that communication and collaboration technologies could be used to improve schedule management, resource allocation, and emergent issue response. The use of mobile smart devices may yet bring the most significant advance in outage durations. Most NPPs will benefit from implementing an electronic work order system where work orders on a tablet rather than paper are used in the field.

2.4.3.10 *Post Outage Evaluation (Reviews / Wash-ups)*

A lessons learned review has become increasingly important for project organizations and outage organizations alike. Hickman (2017) asserted that understanding and celebrating outage success go hand-in-hand and that reviewing lessons learned and applying it to future outages is how the best plants achieve even better results. He evidenced an example of Southern Nuclear that evaluates successes across the entire fleet, so it can apply best practices broadly. Hickman (2017) cautioned that there's no silver bullet to driving down outage duration but when they analyze everything comprehensively, they are able to shave time off a single activity that impacts their ability to be more efficient with other activities. Lessons learned are rich and inexpensive ways to make leaps in improvement. It is beneficial for the nuclear industry to be collaborative and share best practices. Outside partners bring lessons learned from other jobsites and organizations. Plants operators should also share and benchmark with other independent plants, or fleets to compare best practices and improve overall outage performance.

The IAEA (2016:2) states: "After outages, it is extremely important to get feedback from all personnel who were involved in the outages. Operating experiences, which are collected during the outages, are also very useful in improving and developing future outages to achieve better results. Collected and useful operating experience should be stored in a system, which is easy to use and available for all. Sharing operating experience between nuclear power plants should also be a high priority in an effort to continually look for best practices". The post outage washup or review is a precious source of lessons learned and provides important feedback for the optimization of the next outage planning, preparation, and execution. The lessons learned should be captured as soon as practicably possible and focus the "what, when, how, who, and why". It can be argued that that the washup is as important as the planning and preparation phases and without it the next outage planning and execution is flawed.

2.4.3.11 *Creating a Culture of Strong Leadership and Engagement*

It is very common to hear and experience the disconnect between leadership and their people, often leading to low morale, errors and of course, poor execution. Hickman (2017) emphasized that even with the most thorough and well-organized plan, it's people that execute the work and they need to be motivated. He added that empowering every worker to be a leader and take ownership of every project is critical to achieving success and creating an environment where workers feel comfortable making process improvement suggestions to management. Establishing this culture starts at the top with company leaders demonstrating they are truly open to hearing from every member of the organization. Vineyard informed Hickman (2017) that at Southern Nuclear, they have a leadership and teamwork model that is embedded in everything they do, to ensure that everyone in the organization is engaged with their work and understands the important role they play in making a

project successful). Vineyard added that on any given outage, there are 1,000 or more workers on-site, and we need them all to be leaders if we're going to be successful. Excellent leadership at the strategic, management and operational levels is what creates synergy, and cohesiveness to pull the whole team together, striving for the same goals, ultimately setting the organization up for success.

2.4.3.12 *Innovation, Creativity and Continuous Improvement*

Innovation and incremental, yet consistent, improvements are a foundation for organizational long-term success. Hickman (2017) described an interview where Vineyard reported that they recently took a different approach by opting for a new contractor after working with another provider for 20 years. This change could have created a large learning curve and potential speed bumps, but instead, the new partner ended up being one of the driving factors that allowed them to achieve record-breaking outage performance. Vineyard added that at Southern Nuclear, new technologies are being used like robots for remote inspections, drones for dry well work, and data analytics to assist with planning. These technologies serve as additional tools that complement more traditional approaches, but they may someday become a primary aspect of operations. Almost all work in the outage planning process, and all nuclear plants for that matter, is designed to minimize risk, maximize plant operating time, and achieve outage goals. One of the key tenets of nuclear relevance must be innovation. The solution to effective outage planning is taking deliberate steps that won't derail an outage or cause an irreversible issue if unsuccessful but are instead indicative of the success NPPs can achieve, through innovation and thinking differently.

2.5 CONCLUSION

Reducing outage durations at individual reactors incrementally, aggregated, sets the foundation to benefit an entire industry. Hansen (2008) reported that the industry has been able to shorten steam generator replacement (SGR) outages and optimize resources through better planning, better welding techniques, better contingency planning, and better risk assessment. In the same article, there is a vision and belief that there is room for further improvement and that these opportunities may exist in advances in rigging and construction sequencing without having to increase manpower. It is important to make optimization part of the culture with effective performance indicators. One would argue that optimization and innovation at NPPs should have their own R&D budgets.

The literature highlighted that outage optimization brought about several benefits. The key views expressed were that it improved plant availability, mitigated power outages and load shedding, caused an overall reduction in the cost of electricity generation over the life, or remaining life, of the plant. Therefore, making nuclear power more cost competitive and reducing the need to build more power stations over time. The literature also revealed a range of optimization practices with the role of planning and scheduling emerging to be of prime importance and that some practices are more

effective and provide more value than others. Views are presented that optimization is subject to the law of diminishing returns and at some point, the cost-benefit reaches equilibrium. However, as history shows, when someone thought they had reached the limits, another comes along to break those limits. With a culture that promotes innovation, infinite possibility and sustainability, new opportunities and new frontiers present themselves.

CHAPTER 3

RESEARCH APPROACH

3.1 INTRODUCTION

This chapter describes the research approach employed in this study focusing on the research design, population sample, and the methods used for data collection and analysis. It describes how the structured interview questions were developed and how the interviews conducted to obtain the views of industry professional on outage optimization practices. The reasons for a qualitative approach and structured interviews as a data collection technique are explained. The chapter is concluded with ethical considerations and trustworthiness.

3.2 THE RESEARCH DESIGN

The research focused on the experience of 12 nuclear outage and maintenance professionals in relation to practices that optimize and shorten nuclear outage durations. A qualitative approach using structured interviews with 15 questions were used to solicit information, as shown with participants' transcripts in Appendix B. The first four questions explored demographical data to assess the participants' experience relevant to the topic. Thereafter, the questions explored the participants' understanding of acceptable durations for different outage types, causes of outage delays, benefits of optimization and importantly, methods to optimize outages with the objective of answering the key research questions. Appendix B contains all 15 interview questions with answers and analysis of those answers, which creates a deeper appreciation of outage optimization.

3.3 THE SAMPLE

Structured interviews were conducted with twelve nuclear professionals who had a wide range of outage and maintenance experience. The participants were from two countries, six from South Africa, and the other six from the USA. The sample's demographics varied substantially. The participants had worked and participated in outages at different NPPs throughout their careers. Details on the sample of research participants are included in Table 3.1 below. The first six participants in Table 3.1 and in all representations are from the USA and the remaining six are from South Africa. Names have been removed to maintain confidentiality. The study and data collection were limited to nuclear outage professionals, effectively industry practitioners who have been and still participate in nuclear outages. The reasons for the limitation were primarily to source feedback, data and information that was focused, relevant, reliable, and well informed.

Table 3.1 Research participants biographical information

Participant	Years' experience	Current Role	No. outages participated	Nationality
1	33	Previously I&C Supervisor/ I&C Engineer, Maintenance. Current I&C Job Path Lead, Outage Management.	50	USA
2	41	Outage Maintenance Services Manager-Components	22	USA
3	40	Outage Services Turbine Manager	35	USA
4	15	Maintenance Programs - Outage Support Manager	20	USA
5	30	Outage Turbine Lead	40	USA
6	29	Field Inspection Services Manager - Outage Maintenance Services	15	USA
7	23	Director Maintenance Governance	26	South Africa
8	34	Technical Contracts Manger - Nuclear Performance Management	50	South Africa
9	31	Snr Mechanical Maintenance Specialist - Outage Maintenance Services	20	South Africa
10	30	Head of Contracts Administration - Maintenance and Outages	36	South Africa
11	27	Lead - Outage Preparation and Execution	25	South Africa
12	27	Head of Outage Preparation and Execution	15	South Africa

The average experience per participants was 30 years and the average number of outages each person participated in was thirty. The minimum years of experience was fifteen and the maximum 41. The minimum number of outages per person was fifteen and the maximum was fifty or more. The inclusion of participants from two countries in the study allowed for variety in responses not only between participants but also between countries, which may have either similar or diverse cultures, methodologies, and operating models for NPPs and outages. Participants were keen to support and participate in the research, especially given that it is a field that they have experience in. This experience was very evident from the considerable years of nuclear experience and number of outages they have been involved in. The author noted all answers during the interview and checked understanding (with participants) of the answers after each question. Some participants explained in more detail whilst others were very concise.

3.4 DATA COLLECTION

The structured interviews were conducted with the twelve nuclear outage and maintenance professionals. The objectives were to source rich information, to develop a deeper understanding of the topic by tapping into what people thought, and importantly, why they thought that way. Virginia Tech University (2022) explains that interviews are most effective for qualitative research and helps explain, understand, and explore research subjects' opinions, behavior, experiences, phenomenon, etc.

There were fifteen structured questions including a final question allowing participants to provide final feedback, ideas, and comments. Each interview took approximately 75 minutes. Efforts were made to keep the questions and responses unbiased and avoid leading participants to pre-conceived conclusions. The interview transcripts with names of participants removed for confidentiality are presented as Appendix B.

3.5 DATA ANALYSIS

The approach to data analysis was content analysis which Stemler (2000) explains as a systematic, replicable technique for compressing many words of text into fewer content categories based on explicit rules of coding and is useful for examining trends and patterns. The interview responses were captured in MS Excel spread sheets and analyzed by comparing interview text and coding similar responses into themes. An example of the coding of the interview question 8 is presented in Table 3.2. Graphs were developed, e.g., Figure 3.1 which represent the frequency of types of practices to mitigate delays. These findings are presented in chapter 4 and the discussion thereof, in chapter 5. The information from the research participants were analyzed to understand outage optimization best practices and identify trends and highlight differences.

Table 3.2 Example coding of interview question 8

Question 8: Best Practices to Mitigate Delays			Participants											
No	Best Practices to Mitigate Delays	Best methods count	1	2	3	4	5	6	7	8	9	10	11	12
1	Effective Scheduling and Planning	13	1	3	1	2				2	1		2	1
2	Sufficient, Skilled Resources	7		1				1	1	1	1	1	1	
3	Risk management / Contingency Planning	6		1	1		1			2				1
4	Effective Execution to Schedule	4	1				1						1	1
5	Effective Scope Control	3				1	1						1	
6	Spares Management	2									1	1		
7	Benchmark Other Plants	2						2						
8	Practice Drop and Swap	1		1										
9	Optimize Use of Equipment (Polar Cranes, etc.)	1										1		
10	Effective Contractor Oversight	1				1								
11	Effective Walkdowns	1	1											
12	Pre-outage Readiness Assessments	1						1						
13	Open, Transparent Communication Trust Environment	1								1				
14	Effective Processes	1										1		

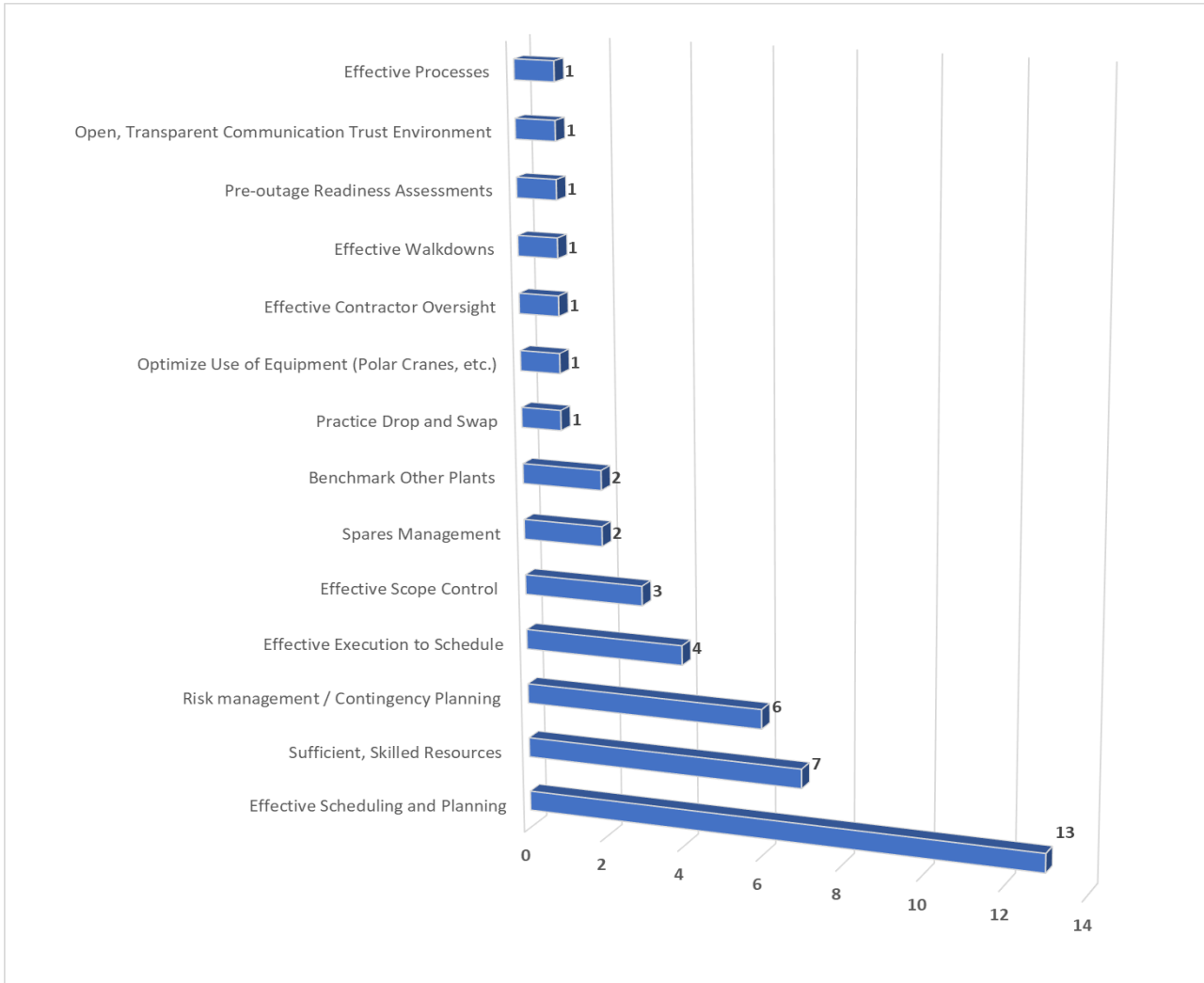


Figure 3.1: Example of graph used to demonstrate outcomes of interview question 8.

3.6 ETHICAL CONSIDERATIONS

Consideration was given to ethical practices to meet the goals of the research and maintain the rights of interview participants. Orb, Eisenhauer and Wynaden (2001) emphasize that researchers are ultimately responsible for protecting the participants and that the researcher/participant relationship, the researcher's subjective interpretations of data, and the design itself is usually equated with confidentiality, informed consent, and privacy. The research was conducted in a manner that complied with plagiarism and copyright practices. Throughout, emphasis was placed on reliability, validity, and trustworthiness of information. The purpose of the research was discussed with the participants prior to the interviews, allowing them to time to consider their own suitability for the interviews and whether they wanted to participate or not. Participants were reminded at the beginning of the interview, that they were entitled to highlight any concerns they may have with regards to any breach or potential breach of ethics by the researcher or the interview questions. Ethics clearance was obtained in 2019 from the EBE faculty at the University of Cape Town.

3.7 TRUSTWORTHINESS AND VALIDITY

Reed, Ingerman and Berglund (2009) explain that trustworthiness in phenomenographic research is a vital part of establishing rigor in the research process and that trustworthy research contributes toward building a body of knowledge that can play a significant role in societal change. Reed et al (2009) highlight that trustworthiness is underpinned by criteria of credibility, dependability, confirmability, and transferability. They further describe 'validity' as the extent to which it is possible to show that a study measures what it sets out to measure and argue that credibility is a more appropriate substitute for validity in interpretive, qualitative research. Table 3.3 based on extracts on approaches to establish criteria for trustworthiness from Reed et al (2009) demonstrates by example how trustworthiness was established to give credence to the research, to make it valid, reliable, and generalizable. Furthermore, this research aims to contribute to societal change, since effective outage optimization can reduce power outages and load shedding, conserve resources, and improve the economy.

Table 3.3 Examples establishing research trustworthiness

Criteria for trustworthiness	Approaches for establishing criteria	Application in this research study
Credibility	<ul style="list-style-type: none"> • Use of well-established research methods • Researcher's familiarity with the subject matter. • Prolonged engagement in field or research site • The researcher's ability to argue their interpretation of the data. • Confidence that can be placed in the truth of the research findings 	<p>An interview protocol was established.</p> <p>The interview questions were aligned with the research questions.</p> <p>Content analysis is well established as an analytical technique.</p> <p>The researcher works in the field of nuclear outages, maintenance, and project management.</p> <p>Corroboration by literature.</p>
Dependability	<ul style="list-style-type: none"> • Appropriate selection of participants • Structured questions • Audit trail • The stability of findings over time 	<p>The participants were very experienced in the field of nuclear outages and maintenance which improved reliability and validity of information collected.</p> <p>Interviews were planned and agreed in advance, allowing participants to be fully engaged and focused.</p>

		<p>Questions were designed with the aim of removing ambiguity.</p> <p>During the interviews, if any participant did not understand the question the first time, time was taken to provide assure understanding.</p> <p>Before moving to the next question, researcher confirmed understanding of the response, often through 3-way communication, a practice entrenched in the nuclear industry and familiar to the participants.</p> <p>Transcripts provided.</p>
Confirmability	<ul style="list-style-type: none"> • Establish that interpretations of the findings are clearly derived from the data • Degree to which the results of the inquiry could be confirmed or corroborated by other researchers 	<p>Findings based on data from interviews and explained in chapter.</p> <p>Data provided as attachments.</p> <p>Reviewed multiple times to ensure interpretation was appropriate.</p> <p>Appendix C – investigated answers to all the interview questions as a means to focus on the main research questions and to interpret the findings with deeper understanding.</p>
Transferability	<ul style="list-style-type: none"> • Have solid description and purposeful sampling • Can be transferred to other contexts or settings with other participants – it is the interpretive equivalent of generalizability 	<p>Good descriptions provided.</p> <p>Participants were highly experienced in the field of nuclear outages and maintenance.</p> <p>Participants were from different nuclear plants and countries.</p> <p>Participants had different roles and experiences within outages.</p>

3.8 CONCLUSION

This chapter demonstrated the effort exerted to ensure trustworthiness and credence of this dissertation and established the foundation for the next chapter that discusses the findings. The research approach, the design, population sample, how data were collected and analyzed were discussed. Ethics, validity, and trustworthiness were considered to enhance the rigor, credibility, and transferability of the research.

CHAPTER 4

RESEARCH FINDINGS

4.1 INTRODUCTION

In this chapter, the findings from the analysis of the data are presented. To understand the practices and methods that are most effective for outage optimization, it is crucial to first understand durations for outages at a Pressurized Water Reactor (PWR), reasons for delay and thereafter, focus on the most effective optimization practices. This chapter reports on the findings in this sequence.

4.2 DURATIONS FOR OUTAGES ON PRESSURIZED WATER REACTOR (PWR)

4.2.1 Acceptable Outage Durations for Refuelling and Statutory Maintenance

Participants were asked what they believed to be an acceptable or reasonable duration for an outage for refuelling and statutory maintenance on a PWR. Note, the IAEA (2016) refers to statutory maintenance as standard maintenance whereas numerous plants use the terminology differently. Therefore, the participants and interviewer use the words statutory maintenance independently of standard/extended maintenance. In this case, statutory maintenance included refuelling plus maintenance that had to be done to meet license or code requirements. Standard/extended maintenance generally refers to statutory (refuel plus license or code compliance) plus any other additional maintenance included in the official scope but excludes major modifications.

Table 4.1 below shows the responses of each candidate. The responses have been grouped into three categories and color coded for easy visualizing. The white color coding represents a lower set of durations, typically less than 30 days. The yellow coding represents durations between 30 to 45 days. Orange coding represents 46 days and more. The participant responses varied quite significantly. Four participants indicated that acceptable or reasonable outage durations for refuelling and statutory maintenance was in a range of 18 to 26 days, and these represented the shortest durations. Seven responses advocated a longer acceptable duration ranging from 30 to 45 days. One participant was not able to provide a duration and answered that “it depends” and when probed did not elaborate except to say, “each outage is different”. This candidate was a system specialist and worked at a more operational level, executing maintenance and outages on emergency diesel generators (EDGs), rather than planning or managing outages. The shortest, longest, and average durations were 18, 45 and 29.6 days respectively. The range between lowest and highest acceptable durations was 27 days.

Table 4.1: Acceptable Duration for Refuel and Statutory Maintenance

Participant	1	2	3	4	5	6	7	8	9	10	11	12
Q 5a. Outage Duration (days) Refuelling & Statutory Maintenance	30-45	20	30-35	28-40	30-40. (Some in 16)	30-35	18-20	33-35	It depends. No number given.	25	18-26	28-40

Some responses were similar, for example participant two from the USA and participant 7 from South Africa. However, the majority expressed different durations, for example participant one said 30-45 days whereas participant 3 said 30-35 days and participant 4 said 28-40 days. There is no correlation between participants from the same country.

4.2.2 Acceptable Outage Durations for Refuelling, Statutory and Standard/Extended Maintenance

To recap, standard/extended maintenance was considered over and above statutory maintenance, if it was scoped in. Table 4.2 below shows the responses of each candidate. Participant number 9 gave the same response as before saying, "it depends". Participant number seven provided a response of 18 to 20 days, consistent with the response given in question 5a. Eight responses reported durations in the 28–40-day range. Two responses (in orange) indicated 45-60 days. In this scenario the shortest, longest, and average durations were 18, 60 and 36 days respectively. The range between lowest and highest was 42 days. On average, standard/extended maintenance took 6 days longer than refuel with statutory maintenance. This is a very small yet useful sample, and a larger sample would provide more reliable statistical results.

Table 4.2: Acceptable Duration for Refuel, Statutory and Standard Maintenance

Participant	1	2	3	4	5	6	7	8	9	10	11	12
Q 5b. Outage Duration (days) Refuelling, Statutory & Standard Maintenance	45-60	28	30-35	30-40	30-35	30-35	18-20	33-35	It depends. No number given.	38-40	35-43	45-60

4.2.3 Best Outage Duration for Refuelling and Statutory Maintenance

After determining the views on “acceptable” outage durations, the interviews explored participants’ knowledge, experience, and views on “best” or “fastest” outage durations for refuelling and statutory maintenance outages in the industry. The responses are shown in Table 4.3 below. Six participants answered in the range of 16-25 days. Four answered in the range of 35-40 days. The remaining two indicated 45-60 days. The shortest, longest, and average durations were 16, 60 and 27.88 days respectively. The range between longest and shortest duration was 44 days. More participants decreased durations which demonstrated overall awareness that best durations in the industry are lower than what is seen as ‘acceptable’.

Table 4.3: Best Duration for Refuel and Statutory Maintenance

Participant	1	2	3	4	5	6	7	8	9	10	11	12
Q 6a. Outage Duration (days) Refuelling & Statutory Maintenance	60	22	25	16	25	20	35- 38	35- 38	45	21	35	35- 40

4.2.4 Best Outage Duration for Refuelling, Statutory and Standard/Extended Maintenance

For best outage durations including standard/extended maintenance, three participants’ answers were in a range of 16-28 days. Four responded in a range of 30-40 days. Another four responded in a range of 45 right up to 70 days. One responded that “no plant has the same standard maintenance activities”. This response was somewhat simplistic, not accurate and due to respect for the interview time and to avoid bias in the participant’s responses to other questions, was not probed further. However, it should be clarified that whilst not each plant will maintain the exact same pump in a specific outage, NPPs do have standard maintenance regimes, in the same way motor vehicles have similar maintenance regimes. Furthermore, literature review supports comparing and improving outage durations. The shortest, longest, and average durations were 16, 70 and 35.18 days. The range between longest and shortest was 54 days. The results are shown in Table 4.4.

Table 4.4: Best Duration for Refuel, Statutory and Standard/Extended Maintenance

Participant	1	2	3	4	5	6	7	8	9	10	11	12
Q 6b. Outage Duration (days) Refuelling, Statutory & Standard Maintenance	70	28	25	16 up to 90 (depends on the scope)	30-35	no plant has the same standard maintenance activities	35-38	35-38	45	55	35-40	50

Table 4.5 highlights the differences between shortest, longest, average durations and range for each scenario of Refuelling, Statutory and Standard/Extended Maintenance. For refuelling and statutory maintenance only, the best shortest duration was shorter than the acceptable duration. However, the best longest duration was longer than the longest acceptable duration.

For refuelling, statutory, and standard maintenance, the best shortest duration was shorter than the acceptable duration. The best 'longest' duration was again longer than was longest acceptable duration. To reiterate, whilst this sample is small it is useful to glean insights and set the stage for a bigger sample and study where more data will support a thorough statistical review. However, this information was helpful as it provided a frame of reference and served as a basis for the other interview questions.

Table 4.5: Best Duration (days) for Refuel, Statutory and Standard/Extended Maintenance

Maintenance Type	Shortest Duration	Longest Duration	Average Duration	Range
Acceptable Refuelling & Statutory Maintenance	18	45	29.6	27
Best Refuelling & Statutory Maintenance	16	60	27.88	44
Acceptable Refuelling, Statutory & Standard Maintenance	18	60	36	42
Best Refuelling, Statutory & Standard Maintenance	16	70	35.18	54

4.3 MOST COMMON REASONS FOR DELAYS IN NUCLEAR OUTAGES

Interview question 7 inquired into reasons for delays. Figure 4.1 shows the participants' responses ranging from most common to least common reason. A total of thirteen reasons emerged with the most prominent reason being ineffective planning, scheduling, and risk management. The second most common reason was discovery and emergent work, followed by a lack of the right resources and non-availability of replacement parts.

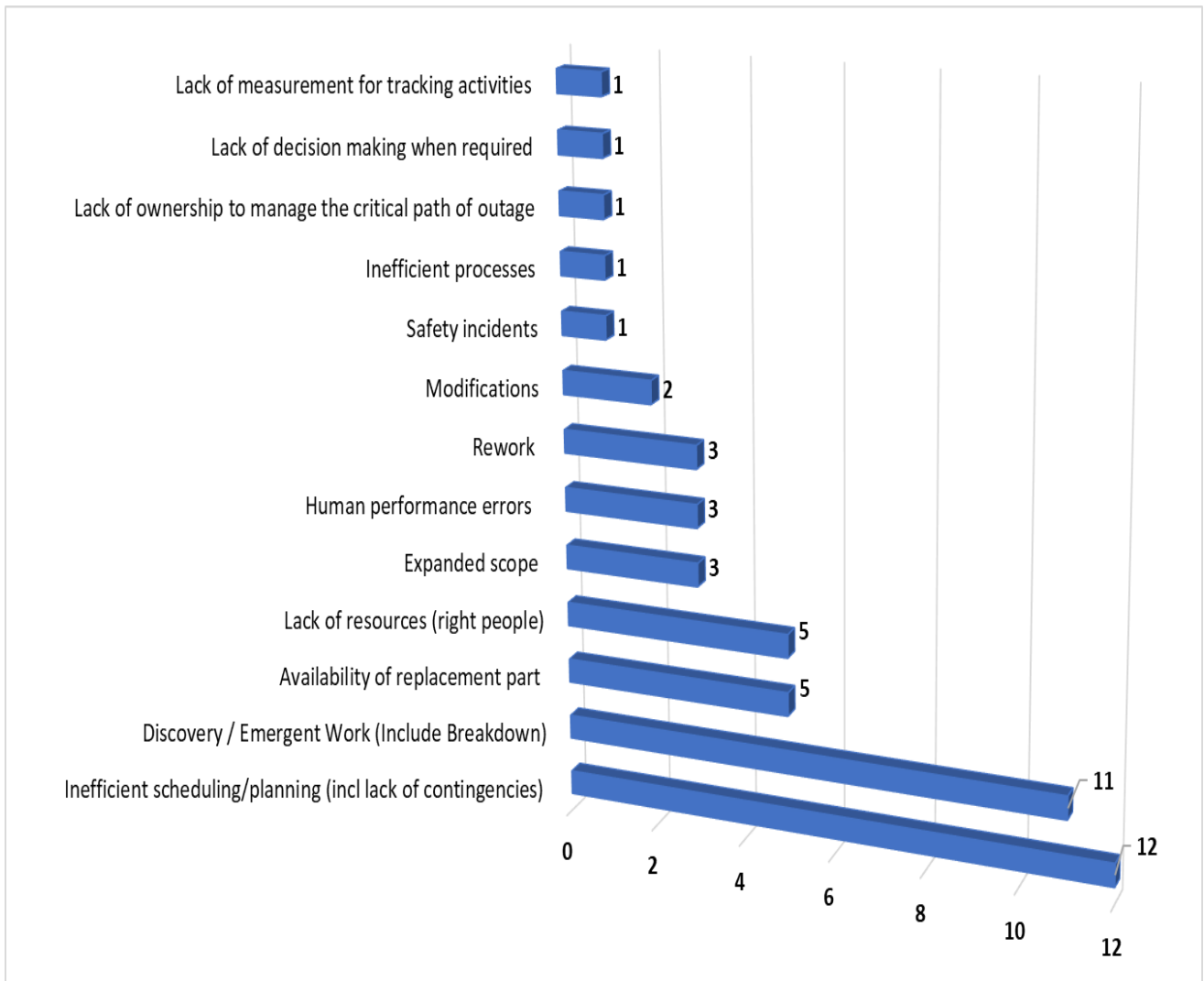


Figure 4.1: Most Common Reasons for Outage Lateness

The reasons for inefficient scheduling, planning and risk management were clarified by participants in several ways. One explained that “modifications are harder to estimate because they are not routine”. Another highlighted “aggressive scheduling without fully understanding the capabilities of your organization and processes” and others discussed planning was not done correctly due to a lack of knowledge and skills, poor work practices and discipline, and even forgetting to do work.

Discovery and emergent work ranked second and was found to be less controllable by individuals as they just did not know when something would go wrong. They did believe being prepared for such events was within the control of the organization.

4.4 HOW BEST TO AVOID AND MITIGATE DELAYS

Interview question 8 investigated how delays are best avoided or mitigated. This question approached the topic from the perspective of how to avoid or minimize delays rather than optimization. The participants had some varied and some consistent responses about mitigating delays. The answers are summarized in the Figure 4.2 below. Each participant ranked the practice from his perspective and there was no correlation on ranking between participants.

The practice that best mitigated delays was effective planning and scheduling. One participant said, “schedule the outage properly and follow the schedule as it is scheduled”. The second practice was to ensure the organization has sufficient skilled resources. One participant emphasized that “one common thing is having a skilled workforce in the organization. People that know what is needed and have an ability to drive and achieve it.” This was followed by risk management and contingency planning and effective or sound execution.

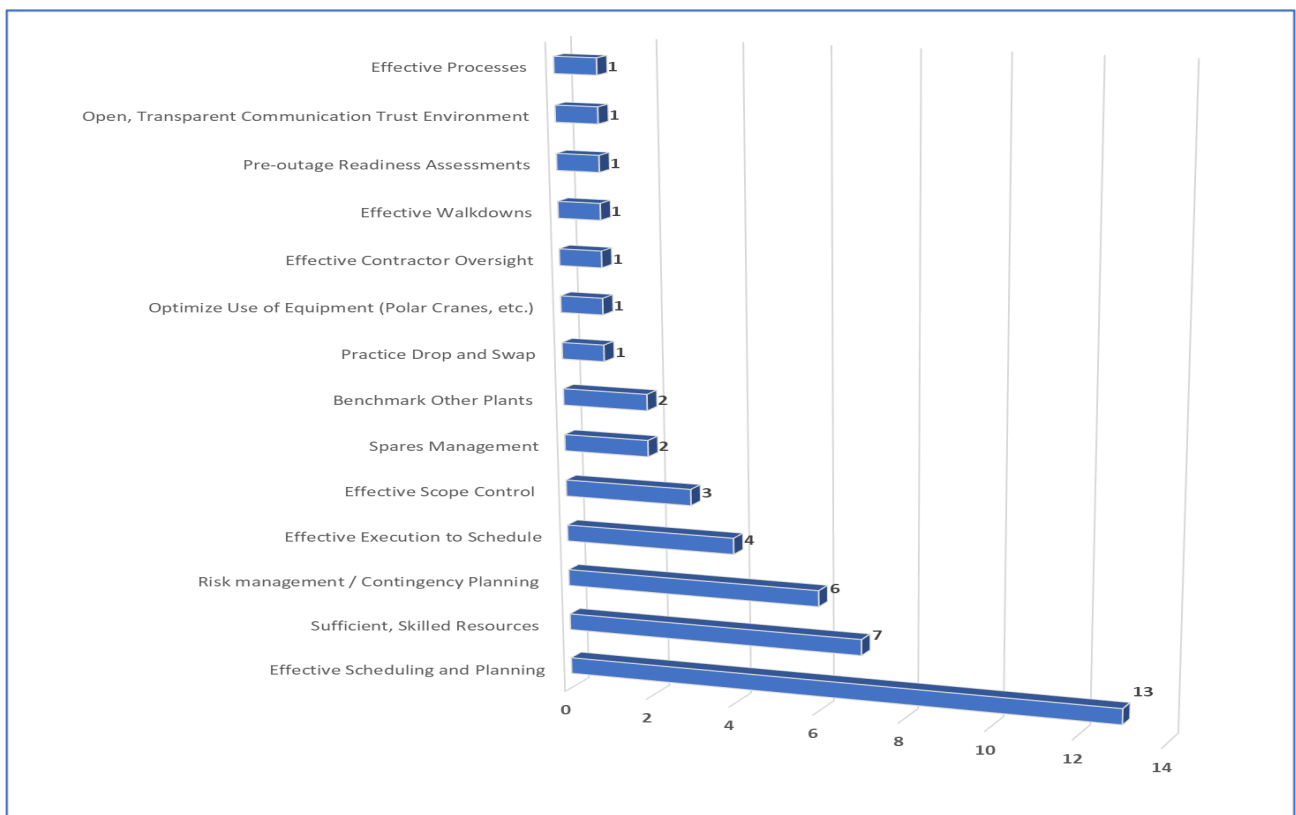


Figure 4.2: Best Practices to Mitigate Outage Delays

4.5 EFFECTIVE PRACTICES TO OPTIMIZE DURATIONS OF PLANNED OUTAGES

The preceding findings set the scene for the main research question. Question 10 of the interview schedule probed the methods and practices that were perceived as most effective for optimizing outage durations. The participants provided varied responses and they were grouped as per the Figure 4.3 below. Some participants provided 3-5 responses and others less. They ranked their individual responses but there was no clear correlation of ranking between them. Effective scheduling and planning, including risk and contingency planning was viewed as the most valuable way to optimize or shorten outage durations. This was followed by having sufficient skilled resources and implementing better or more effective work practices.

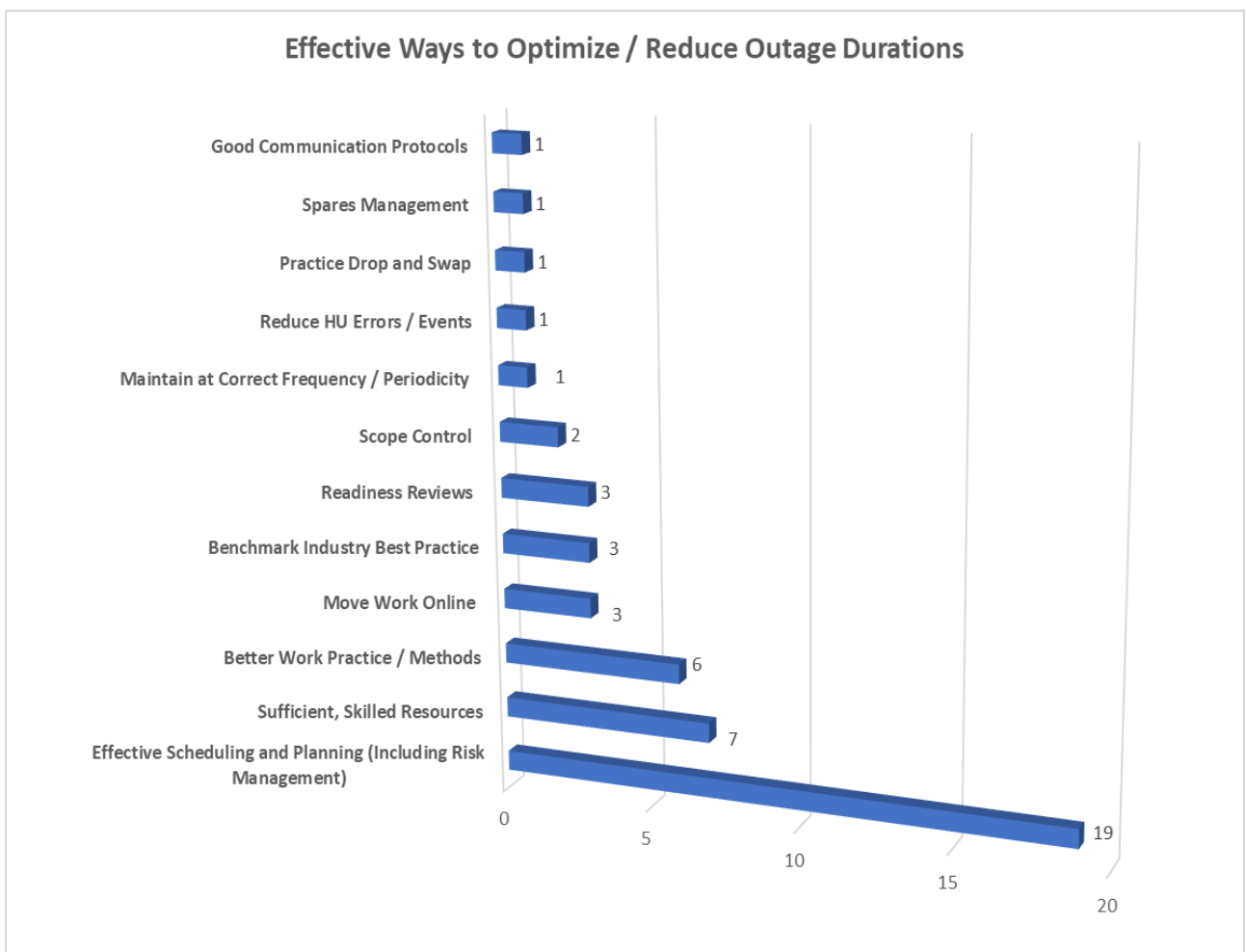


Figure 4.3: Effective Practices to Optimize / Reduce Outage Durations

Table 4.6: Interrelationships between delay causes, mitigation, and optimization practices

Reasons for delay	Best practices to mitigate	Best practice to optimize
A Poor planning, scheduling, risk management	A Effective scheduling, planning and risk management	A Effective scheduling, planning and risk management
Discovery/Emergent work	B Sufficient, skilled resources	B Sufficient, skilled resources
B Lack of resources (right people)	Effective execution to schedule	Better work practices (Improve current ways of doing)
Unavailability of spare parts	Effective scope control	Move work online

As indicated in Table 4.6, the four main reasons for delay are depicted in relation to the four best mitigation and optimization practices, respectively. The letters (A, B,) depict the interrelationships. It highlights that planning, scheduling and risk management are paradoxically the key weaknesses and the key opportunities for success. Having the right resources are the second key weakness and opportunity. The other items in the table are not directly related, yet important for outage optimization success. There were indeed some key practices that helped mitigate outage delays and optimized planned outages. In some cases, the practices were common. Effective scheduling, planning and risk management was the practice that was considered most valuable for optimizing outage durations.

4.6 CONCLUSION

Participants' views on acceptable durations and best durations for nuclear PWR outages varied significantly. Acceptable durations ranged between 18 and 45 days and best durations ranged between 16 and 60. The most common reason for delays was ineffective planning, scheduling, and risk management and evidently the greatest opportunity for improvement. The second most common reason was a shortage of sufficiently skilled resources, skilled in outage planning and execution and it also emerged as the next best source of improvement. The richness of the data collected from the participants provided valuable insights that are discussed in the next chapter.

CHAPTER 5

DISCUSSION

5.1 INTRODUCTION

This chapter discusses the findings in relation to the research questions and the literature, focusing on acceptable and best durations for nuclear outages, reasons for delays and best practices to optimize outages.

5.2 BEST DURATIONS FOR OUTAGES ON PRESSURIZED WATER REACTORS (PWR)

5.2.1 Acceptable Outage Durations for Refuelling and Statutory Maintenance

The participants' views were based on their knowledge and experience of outage durations on their own work experience, knowledge of the broader industry norms (other NPPs) and their experience of companies that others benchmarked against. The discussion below elaborates on the similarities and differences of the findings.

The IAEA (2016) reported refuelling and standard (statutory) maintenance outages could be done in 14 to 23 days, with an average of 18.5 days. The 12 participants' average acceptable and best durations were 29.6 days and 27.9 days respectively, approximately 25% and longer, than the IAEA benchmark. The lower 18–26-day range for acceptable durations reported by four of the participants was marginally higher, yet close to the IAEA benchmarks and what top performing NPPs should be striving for according to the IAEA. These four participants are more aware of what was acceptable and the performance at other plants through various means such as personally keeping abreast of industry norms and standards, or their work involved benchmarking and improving outage durations.

Most participants (seven) stated the higher range of 30–45 days, indicating that in practice, the outage durations were perceived as higher than what was considered acceptable by the IAEA and that some outage durations were not aligned with industry norms. NPPs who do not focus on pursuing the shortest possible outages, are often state owned with a different mandate, and driving short outages and hence profits were not the highest priority. As intimated in the literature review, optimized outage durations are beneficial for organizations driven by profits and the bottom line as well as for state owned and even hybrid organizations.

With at least seven participants believing that durations of 30 days and more are acceptable, it shows that they were not aware or orientated towards achieving the shortest and most optimized outage

durations. This presents an opportunity to further study the thinking, culture, and practice in each NPP and where required, reinforce the benefits of optimized outage durations, and make it part of the strategic and operational objectives. It is an opportunity to educate staff and entrench continuous improvement on the journey towards optimized outages. For KNPS, there is a clear benefit to increase the Energy Availability Factor (EAF) and reduce load shedding to the benefit of South Africa. In the case of new plants preparing for a first planned outage, it is recommended to set clear objectives, make the outage goals and durations visible to all, and building it into the performance contracts of all relevant employees. A new plant has the time advantage to invest in planning and resourcing, to achieve the shortest possible outage early and build on this foundation. Placing this high-performance peg in the ground early on, sets the tone for future outages.

5.2.2 Acceptable Outage Durations for Refuelling, Statutory and Standard/Extended maintenance

The IAEA (2016) reported that refuelling plus standard/extended maintenance could be completed in 15 to 40 days. The duration can vary based on the standard/extended scope. The participants' average acceptable and best durations were 36 days and 35.18 days respectively, approximately 29% longer than the IAEA benchmark. One participant responded with 18-20 days, which was ambitious and aspirational and more in line with refuel plus statutory maintenance. The nine responses ranging from 18-43 days were near the IAEA benchmarks and on average, consistent with the 35 days average duration reported by Hickman (2017). Those who stated the durations greater than 35 days were likely exposed to NPPs who were not top performers or were not necessarily aiming for the shortest possible outages. If their paradigm is that the norm was in the higher range 35-60 days, it could translate into their beliefs, actions and communication when doing work, in which case that would not be planning and executing optimally. This notion is supported with commentary from one participant stating that "we also were not very concerned about cost as we were government funded". This could be significantly restricting the performance of an organization without managers and leaders knowing about it. This presents an opportunity for further investigation, rectification, and improvement to achieve outage durations closer to IAEA benchmarks, industry top quartile or at least in line with the individual NPPs objectives.

5.2.3 Comparing Acceptable Outage Durations for Refuelling and Statutory with added Standard/Extended Maintenance

Table 5.1 compares the participants' responses to questions 5a and 5b. Four of the participants' responses remained the same, whilst seven increased for standard/extended maintenance. Those who kept the durations the same may believe that statutory and standard/extended maintenance could be optimized and managed in parallel and online such that it did not add to the outage duration and that the extended maintenance may add only a small percentage of extra time. Four participants

reported that standard maintenance added 33%-65% extra time. It is probable that this reflects their own experiences at their previous NPPs and how work was practiced there. It is not aligned to any of the literature or best practice and is an opportunity to investigate and change for the better.

Table 5.1: Comparison of Questions 5a and 5b Acceptable Outage Durations

Participant	1	2	3	4	5	6	7	8	9	10	11	12
5a. Outage Duration (days) Refuelling & Statutory Maintenance	30-45	20	30-35	28-40	30-40. (Some in 16)	30-35	18-20	33-35	It depends. No number given.	25	18-26	28-40
5b. Outage Duration (days) Refuelling, Statutory & Standard Maintenance	45-60	28	30-35	30-40	30-35	30-35	18-20	33-35	It depends. No number given.	38-40	35-43	45-60

Table 5.2 below provides an overview of acceptable durations specifically related to shortest, longest, average and the range of each scenario. The shortest durations were the same when comparing refuel and statutory with added standard/extended maintenance. As mentioned above, participants may believe that there are opportunities for statutory and standard/extended maintenance to be optimized and managed in parallel and online such that it did not add to the outage duration and that the extended maintenance may add only a small percentage of extra time. The longest duration increased by 15, from 45 to 60 days, likely due to experiences with the varied amounts of scope added for extended maintenance. More importantly, the average duration increased by only 6.4 days, which is a better indication of the difference between statutory and extended maintenance. A larger sample of participants will produce a more statistically reliable value; however, this is a good start to show more investigation is required as it will assist NPPs with developing strategies that are suitable for optimization.

Table 5.2: Acceptable Duration (days) for Maintenance Compared

Maintenance Type	Shortest Duration	Longest Duration	Average Duration	Range
Acceptable Refuelling & Statutory Maintenance	18	45	29.6	27
Acceptable Refuelling, Statutory & Standard Maintenance	18	60	36	42

5.2.4 Best Outage Durations for Refuelling and Statutory Maintenance

Six of the participants are aware of sub-25-day outages which can contribute to organizational success. One participant responded with 60 days which was very long. This specific participant was from the USA and his responses were generally on the higher end of the spectrum. This is indicative of his personal experiences, and possibly also not being aware of industry performance benchmarks. This participant had the most years working in nuclear and the responses with such long durations are likely due to not keeping up with the latest trends and advances. To focus the interview on the interview questions and considering the interview time, the author did not probe extensively.

A second participant indicated that the best outage duration was 45 days. This too is substantially higher than the industry benchmarks. Whilst it may be a best duration based on the participant's own knowledge, it was surprising that that the participant was unaware of the industry norms especially in the USA. Importantly, this participant was the same person who in questions 5a and 5b responded with "it depends". There is benefit in investigating to what extent these views are shared within an organization. If widespread, it presents both a risk and opportunity. The risk is that if nothing is done to change these views or paradigms, it may become the prevailing culture of the workplace. The opportunity is the work to be done to understand the rationale behind these views and implement a change initiative to shift towards a paradigm and culture for higher performance and faster outages.

5.2.5 Best Outage Durations for Refuelling and Statutory with added Standard/Extended Maintenance

Three participants responded with durations between 16 and 28 days. The 16 days duration was very optimistic and more inclined towards refuelling and statutory maintenance. Once standard maintenance is added the number tends to increase. Collectively, seven responses ranged between

16 and 40 days. This is to a large extent in line with the average duration of 35 days reported by Hickmann (2017). Four responses ranged between 45 to 70 days, with 50, 55 and 70 days on the higher end of the spectrum. These longer durations mean further investigation is required because if this thinking of 45 to 70 days permeates an organization, deliberate effort is required to improve knowledge, awareness and thinking to reduce outage durations.

5.2.6 Comparing Best Outage Durations for Refuelling and Statutory with added Standard/Extended Maintenance

Seven participants increased their duration estimates when adding standard maintenance. The increase ranged between five and 34 days and the average increase was seven days. Table 5.3 shows the comparison. From the literature, standard maintenance generally could add 10-15 days. If the increase is far beyond 15 days, it is typically due to plant modifications that have been added to the scope. The individual who reported a change from 21 to 55 days may be recalling experiences from their own plants where the outages went more than 15 days over. Typical reasons for significantly increased durations include equipment breakdowns during the outage (e.g., polar crane), or spares that arrive late. The reasons can only be a few and again presents an opportunity for further investigation. Either way, allowing the mindset in an organization to tend towards outages longer than 40 days including standard maintenance is not beneficial to an NPP aiming to set high standards.

Table 5.3: Comparison of Questions 6a and 6b Best Outage Durations

Participant	1	2	3	4	5	6	7	8	9	10	11	12
6a. Outage Duration (days) Refuelling & Statutory Maintenance	60	22	25	16	25	20	35 38	35 38	45	21	35	35 40
6b. Outage Duration (days) Refuelling, Statutory & Standard Maintenance	70	28	25	16 up to 90 (depends on scope)	30 - 35	no plant has same standard maintenance. activities	35 - 38	35 - 38	45	55	35 - 40	50

For a plant like KNPS, low morale and lack of resources may be a direct cause of less stellar performance. This is further discussed in causes of delay and optimization best practices. For a new plant, it will take time to find a rhythm where sub-40-day outages are a norm but setting the reference objectives and tone up front is essential. Whilst it has been observed in industry that outages gone wrong due to reasons such as faulty polar cranes or late spares can easily add 10 to 20 days to an outage, taking it from 35 days to 55 or from 40 days to 60 days quickly do happen, one cannot allow this to be the norm. Consequently, NPPs new or mature, cannot allow its employees to think that 55-60- or 70-day outages are acceptable.

Table 5.4 below specifically compares IAEA (2016) durations with the best durations related by the interview participants. The average duration of 27.88 for statutory maintenance is only five days more than the IAEA longest duration. The average duration for extended maintenance is five days less than the longest IAEA duration. These appear reasonable given the small sample used for the interviews. The longest durations in both maintenance scenarios are however substantially longer than the IAEA durations and reinforces the need to rectify any thinking or culture that may permeate a large enough proportion of an NPP organization.

Table 5.4: Best Duration (days) for Refuel, Statutory and Standard/Extended Maintenance

Maintenance Type	IAEA Durations	Shortest Duration	Longest Duration	Average Duration	Range
Best Refuelling & Statutory Maintenance	14-23	16	60	27.88	44
Best Refuelling, Statutory & Standard Maintenance	15-40	16	70	35.18	54

Overall, the outage durations from the interviews were longer and sometimes significantly longer than IAEA benchmarks or best durations in the industry. In any NPP, it is recommended to survey the maintenance and outage organization. Survey instruments that test participants' knowledge, experience and views can be set up to objectively measure the gap between best practice and the organizational mindset. This will help implement the correct measures to work towards a top tier outage organization.

5.3 MOST COMMON REASONS FOR DELAYS IN NUCLEAR OUTAGES

This section discusses the most common reasons for outage delays. It compares the feedback from the interviews with existing literature and seeks to identify complementary and contradictory characteristics.

5.3.1 Inefficient planning and scheduling (including lack of contingencies)

All 12 (100%) participants said that inefficient scheduling and planning was the main reason for outage lateness, and some commented that this specific reason included a lack of contingency plans. This is consistent with Spring (2010) who reported that several industry professionals concurred that advanced planning was the most important step towards optimization and that poor planning was the biggest factor that led to outages failing. It's significant that 100% of participants who have participated in an average of 30 outages each, expressed this view. None of the literature reviewed ranked common reasons for delay. However, the findings from this research does and it paves the way for further investigation into ranking the most common reasons for delay. Planning and developing schedules typically start 18-24 months before an outage and it's the part of the work that NPPs have the most control over and appears to be the aspect most attributed to delays. A conclusion is that NPPs can do much better when scheduling / planning outages and presents the case not only for further research but rather evidence that there is an imperative to act and start the process for improvement.

This dissertation did not investigate which cause of lateness caused the longest delay which presents an additional opportunity for further research. It will be challenging for a new plant without any outages on its record to do this research. It will have to rely on other plants for data as well as feedback from employees with experience from other plants that they have worked at. On the other hand, established plants like KNPS can mine the rich data of past outages seeking trends going back to 1984. An organization like the IAEA or WANO may have access to the data from multiple plants globally and be able to facilitate comparative studies. NPPs need to appreciate the value of research and using data to make informed decisions.

5.3.2 Discovery and emergent work including breakdowns

Eleven of the 12 participants cited discovery and emergent work as the next most frequent cause of outage delays. The IAEA (2002) cited "equipment or component failure during outage execution" as a common cause of outage extensions. One participant explicated that "emergent work is going to happen so building a cushion is a key defense", implying the prerequisite for advanced planning, scheduling, and contingency management. Discovery is while doing maintenance, the technicians and engineers discover something that requires further investigation and/or correcting. After investigation, a decision can be made whether the issue needs immediate correcting, or if it can wait

till a future outage. Emergent work means they discover something, or something breaks down which requires immediate repair and not doing this repair will extend the outage duration.

Due to the nature of “discovery and emergent” work, one does not know what will go wrong and when. However, because discovery and emergent work is common at power plants, it is worth recording these trends to have a distinct data set of types and frequencies of the most discovery and emergent work issues. This can be compared with other plants as well. Based on those trends, the NPPs can enhance contingency planning. The IAEA (2016) highlights the role of the OCC in coordinating emergent work. Contingency planning includes the following:

- OE of what typically goes wrong and then as a standard, plan for the top five things that go wrong most often. For example, several participants mentioned the polar crane break down and the fact that the polar crane is often on the critical path.
- Ensure spare parts are readily available.
- Improve Predictive Maintenance and Reliability Monitoring

With 50% of the participants from different plants in the USA and 50% from KNPS and collectively they believed that discovery and emergent work were collectively the second biggest contributor to outage delays, there is sufficient rationale for it to be studied further.

5.3.3 Availability of replacement parts

The third most common cause for outage delays was availability of replacement parts. The IAEA (2002) similarly described this as a key cause for outage delays. The one scenario where this has a very significant negative impact is when during the outage, there is emergent work, or a breakdown and the requisite spare parts or single part is not readily available because it is a scarce part, and it was not kept in the warehouse as standard inventory. In this case, if the part had been available as a stock item, the repair might have been done immediately and in parallel to other work and have little to zero effect on the outage critical path. Depending on the part, the lead time could be hours, days, weeks or in some cases months. In some cases, NPPs even fly individuals to another country to collect the item if there is a risk of expedited courier taking too long or going awry. Mercado (1994) emphasized alliance and partnership contracting help improve inventory/part management, reduce outage durations and costs.

The other key scenario is where parts are not available for the outage planned work due to poor spares and inventory management by the NPP itself. It is a cause that is completely avoidable yet NPPs and other industries still get this wrong. It is mostly due to poor planning and preparation, underpinned by the NPP not having a sound parts strategy and inventory management system. The reasons for poor strategy and inventory management systems are often caused by poor

management and leadership who did not create the right culture, appoint the right people with the right skills, implement good systems and have the foresight and resilience to do effective monitoring and controlling and even improvements along the way. This is interrelated to the next reason for outage delays and had the same frequency as lack of spare parts, namely a lack of resources. The IAEA (2002) recommends a partnership with vendors and joining a pool for common spare parts or inventory management. These have the added benefit of partners being willing to share spare parts when they have it and don't need it immediately. In this way, they share theirs with enough time to repurchase a new part. This collaboration creates reciprocity and synergy in all spheres of operating the plant, which tends towards lowering the cost of doing business.

5.3.4 Lack of resources (right skills and right number of skills)

A lack of resources was a shared third, most common reason for outage delays. This included not having the right caliber of people for specific roles (suitably qualified and experienced) and in addition, not having enough of them. One participant declared "most importantly, there is not a good resource pool for the money we offer which will result, most likely, with numerous errors and mistakes causing outage delays. The adage, "you get what you pay for" may end up ringing true". Having the right caliber people who are qualified and experienced and have the right attitudes can be significantly more advantageous than just having people fill positions. One participant added that sufficient personnel are required to prevent testing from causing delays. As an example, have 2 MOV/AOV diagnostic test assessors; one per shift instead of having only one on day shift. This will prevent delays in reading the tests so that the work orders can be closed promptly, and the schedule maintained.

Another participant articulated some examples where the NPP was focused on saving money only instead of a shorter outage which could lead to the saving. Instead, the NPP cut support resources (i.e., Radiation Technicians, Truck Drivers, Crane Operators, NDE Inspectors, etc.). This reduces the outage budget on paper but immediately causes a longer outage than required, which in turn results in increased outage costs, fatigued workers, and declining morale.

One participant opined that the nuclear industry is confronted with an ageing workforce. Compounding this issue is where millennials are job hopping and seeking jobs in high tech industries and NPPS struggle to retain institutional know how. According to Herrera (2019), the greatly reduced tenure by millennials has produced a large disparity between the money invested in each new employee's recruitment, training, qualification, and certification, and the company's ability to recoup their investment once they are fully qualified and certified and added that they typically leave for their next position within their first two to five years whilst the qualification and certification process takes an average of eighteen months to two years.

Another participant added that the migrant workforce from especially KNPS was contributing to a lack of skills and people moving onto other areas like the UAE and Finland. With an exodus of technical people, Koeberg no longer has certain skills, which contributes to outage duration extensions. Approximately 200 (10% of workforce) highly skilled employees left KNPS within a period of 2-3 years from 2016 to 2019. They either retired or found alternative employment which brought exciting prospects, better remuneration and the excitement of working on new projects, recognized globally. This exodus caused a brain drain at KNPS and for the first time in 37 years, KNPS had an outage of greater than 200 days in 2021-2022. When speaking off the record to people working there or who have worked there, they tell stories about the organization not caring about them, which causes the employees not to care. The senior management treat people poorly. The company is constrained by the state capture loss of funds, so people are less motivated. They do only what they are told, nothing more. Even if they did more, no one appreciates it in any form. In summary, the station's performance is at an all-time low. This can happen at any organization that has little regard for employee well-being. Part of having the right resources means retaining top performers and dealing effectively with the issues described.

Creamer (2022) recently reported that Generation group executive Phillip Dukashe described "the performance of certain power station managers and employees as "disappointing" and reiterated that Eskom was experiencing a skills deficit in certain areas". Similarly, an interview with Eskom COO Jan Oberholzer revealed he was "absolutely horrified" by the number of experienced staff lost at the Koeberg nuclear power station and the staff morale has hit an all-time low, partly caused by the general negativity around load-shedding and the general negativity around the company and further, what was particularly alarming was that Eskom employees were prepared to resign without having alternative employment (MYBROADBAND, 2022).

Several factors could mitigate this skills predicament, including but not limited to:

- Hiring people with adequate skills, knowledge, experience and good behavior and attitudes.
- Ensure continuous training to keep up with best practice and help people grow.
- Fair skills retention including remuneration and rewards.
- Creating an environment where they feel they can make a difference and are appreciated.
- Adequately defined roles and responsibilities.
- An environment where people take ownership and accountability.
- An environment of continuous improvement.

5.3.5 Expanded scope

Three of the participants said that expanded or additional scope made outages run later than planned. Sometimes scope is added after scope freeze, typically one or two months before an outage. This happens typically when someone was running late with their scope, it was excluded at the time of scope freeze, and later made a justification why it should be included. This additional scope may or may not be on the critical path but if it comes in this late, there is the possibility that it was not planned well, leading to time extensions and possibly errors. Frequently this additional scope is not essential for the current or impending outage and can be delayed to a future outage. Often the expanded scope is added due to an overly conservative engineering department that justifies the need in the impending outage.

5.3.6 Human Performance (HU) errors

Human Performance (HU) errors lead to injury, death or plant and equipment being affected, all of which means delays and extra costs. One participant provided the example of misalignments of equipment. A second participant said that these HU errors result in additional work to recover from mistakes. It's not only the delay of the error and time taken to deal with the actual error but also the time taken for additional work or rework to recover from the event. Most HU errors can be minimized or eliminated by carefully following procedure. A third participant explicated that "shorter outages provide company employees with a higher quality of living. Normally, personnel work 72 hours/week during an outage. The longer this goes on, the more risk to emotional and physical health". HU error traps need to be engineered away. As attention spans decline due to emotional stress/burnout, the risk of injury/accident goes up. HU errors creep in with pushing the schedule too hard, focusing on irrational cost cutting, egos, bad leadership and management, and lack of training.

5.3.7 Rework

Rework was mentioned by three participants. One explained "poor maintenance, lack of maintenance, leaving out a gasket, then when doing requalification of component, it fails". Rework is related to a deficiency of skills and lacking a culture of accountability. NPPs have enough procedures on how to conduct maintenance but if someone is not adhering to the procedures they need to be coached and if there is no improvement, then let go.

5.3.8 Modifications

Modifications or at least those that are poorly prepared were slated as the next most frequent cause of outage lateness. The reason is because specific modifications are usually done once off in a 10, 20 year or longer period and there is not enough operating experience to plan the modification accurately. One important modification is the replacement of steam generators which happens only

once in about 40 years. With that, goes the possible replacement of a hot leg elbow or other modifications which are not done often. This unfamiliarity brings uncertainty, which in turn creates risk in a schedule and is often the cause of outage delays. This unfamiliarity can apply to smaller modifications too.

5.3.9 Safety incidents

Safety incidents were mentioned by one participant because of standdowns following injury or sometimes death, which causes significant delays. A plausible rationale for safety incidents only being mentioned once is that nuclear plants place significant emphasis on nuclear and industrial safety. There are normally several barriers that prevent safety incidents and when they do happen, they are infrequent. However, when there is low morale or a lack of skilled resources, safety incidents are likely to increase. A new plant with new maintenance technicians or craft from multiple origins may have a particularly high risk of safety incidents, particularly lost time injuries or even fatalities. KNPS, on the other hand, who has seen a high resignation rate of skilled craftsmen over the last three or more years and is plagued by the various consequences of corruption that led to shortfalls in funding are at a morale precipice. Under these circumstances, managers and supervisors must do more to avoid safety incidents.

5.3.10 Inefficient processes

One participant mentioned inefficient process and offered a solution. The example provided was “when you have a plant defect, the Planner technician goes to the Plant to find the root cause of the defect and then prepares a work package and has the work package issued, and then only does the repair take place. To reduce the response time, you should send Planner in to do the investigation or send FIN (Fix-It-Now) team technician in. They do the analysis and will record the fault and repair in a work instruction which is far quicker than a work package. The artisan will do the work and then record what work has been done. In essence, the paperwork process is less and shorter with FIN than with the normal technician. In emergency some processes can and should be done in parallel.” Given these circumstances, it is questionable to have two different processes. Instead, NPPs should revisit the procedures and find a process that is optimal for all scenarios.

5.3.11 Lack of ownership to manage critical path of outage

Lack of ownership to manage the critical path was presented as a reason for outage lateness. Ironically, the participant who highlighted this point works in the Outage Preparation and Execution department who controls the OCC. The IAEA (2016) underscores the OCC as the nerve center for managing the schedule. The Outage Manager who leads the OCC is accountable. While possible, of all the reasons causing lateness, this one is least likely to happen. Instead, if the OCC Outage Manager does not have the support of the Executive Sponsor to resolve emergent issues and rally

the necessary resources to attend to emergent issues, then this will affect outage duration. This lack of sponsorship ties in with the next reason for outage lateness related to decision making.

5.3.12 Lack of decision making when required

Outage lateness caused by lack of decision making is driven by a multiplicity of other reasons. The one reason relates to the situation above where there is a lack of Executive sponsorship and hence the decision maker, i.e., the Outage Manager is uncertain or sometimes afraid to make decisions. Some other reasons include a lack of a robust decision-making process, lack of experience (appointing the wrong people or not giving the right people the right support), time pressure, conflict, ego, and power. A participant added that “supervisors need to know that they will be supported with decisions to incur additional cost when necessary, such as unanticipated overtime, or emergent material requests”

The IAEA (2002) attributed outage delays to a “lack of leadership and control over the plan activities” and offered solutions to improve outage management by (a) implementing management and project management development programs to strengthening the leadership and control of outage activities and (b) establishing clear goals, responsibilities, and ownership. Similarly, Hickman (2017) reported that Southern Nuclear “have a leadership and teamwork model that is embedded in everything they do”. Often it is not one factor but instead a combination of factors that converge when an ‘incorrect decision’ is made. Simultaneously, often peers or subordinates find it easy to critique or criticize the manager without having all the information and perspectives of the one who needed to make the decision. Once they find themselves in the same shoes, they may reconsider. For the organization and individuals to thrive, an environment and culture that allows people to feel safe in making decisions with the best information they have must be created and sustained.

5.3.13 Lack of measurement for tracking activities to be executed

The final reason for outage lateness and verbalized by a participant “is a lack of measurement for tracking activities to be executed”. Effectively, once a person has been given a task to, for example, to replace a valve and has been given 36 hours to complete the activity, nobody really investigates whether the activity could have been done quicker. The technician does the work and if he finishes in the 36 hours, even if it could have been done in 18 hours and a new 18-hour benchmark could be established for future outages, the Outage team continues to use 36 hours for future outages. Clearly this is a lost opportunity. It does get questioned during the wash-up but instead, the supervisor and NPP should be doing a time study of the valve replacement and other activities with the goal of continuous improvement. Activity starts and finish times with reasons for variances should be captured in real time.

5.3.14 Summary of Most Common Reasons for Outage Delays

Each participant shared their personal views and experiences, and all were relevant. The following items emerged as the most frequent causes for outage delays.

1. Inefficient scheduling/planning
2. Discovery / Emergent Work
3. Availability of replacement parts
4. Lack of the right resources
5. Expanded scope, human performance errors and rework all had an equal mention

None of the participants mentioned the lack of using technology such as tablet, phablet, or digital wrist devices to manage work orders. Incentives for performance was also not cited. One participant revealed that a lot of staff thought that the longer the outage, the more the overtime, which became the incentive. A deficiency of suitable incentives runs the risk of unnecessarily increasing outage durations. These factors are undeniably worth further investigation.

5.4 BEST PRACTICES OR METHODS TO MITIGATE OUTAGE DELAYS

There were 14 main best practice themes identified by the participants that mitigate outage delays. The method or practice most emphasized to mitigate outage delays was effective scheduling and planning. Ensuring sufficient skilled resources received the second highest emphasis. Third and fourth respectively were risk management / contingency planning and effective execution to schedule which are both closely related to effective scheduling and planning.

5.4.1 Effective scheduling and planning

Poor scheduling and planning were the primary reasons for outage delays. Consistent with the literature review, participants emphasized that effective scheduling and planning was the primary driver for mitigating delays. One participant commented on the need for OCC flexibility and upfront assumptions for anticipating delays. Essentially risk management, contingency planning and using experience to determine common mode failures that lead to discovery and emergent work scenarios. The example provided by a participant was that “if 10 MOVs (motor operated valves) are being tested, assume at least one will require a shaft replacement or actuator work and could easily lead to one shift delay” (between 12 and 24 hours). Another example by the same participant, was where at a previous station he worked, “schedulers were embedded in the shop war-rooms and would adjust each shop’s schedule throughout the shift as work was completed or delayed”. Another participant reinforced this by emphasizing the importance of “detailed and timeous feedback of critical and sub-critical activities which can best be done when in the shop war-rooms or providing oversight of activities”.

One participant emphasized the need for detailed manpower levelling charts where supervisors know hour by hour where each team member is. In this way, if a refuel crane broke, he knew immediately where to find the resource to do the repair. Similarly, it is an opportunity for supervisors to “know by the day, by the shift, and by the hour how many workers are on site and what their qualifications are. If someone needs a Firewatch you know how many you have on site at that moment and where they are”.

A third participant placed emphasis on the Lock-Out-Tag-Out (LOTO) times. This activity is where the Operations department’s Local Operators will go to each relevant panel and lock it in the desired position and place tags that clearly indicate the position of the equipment which allows all staff to know what work is and is not allowed, on that panel. The LOTO process is critical for safety of people and plant and always on the critical path. The participant shared that “accurate LOTO times will not be known until the first performance but keeping notes to accurately reflect future outages is a key evolution”. Another participant shared a similar view saying that “Operations take as long as they do”. Therefore, doing time and motion studies with the aim of (a) ensuring the durations are well known and can be programmed accurately into a schedule and (b) finding ways to reduce the LOTO times as part of the evolution, would bring immense value.

A participant proposed that “only scheduling to 80% of your craft resources allows for a 20% emergent work cushion”. This proposal should be considered in the context that some plants are often not resource loading at all, and some are not resource levelling their schedules effectively. In cases where loading and levelling are well established, actual outage durations will be closer to the planned durations.

One participant said that lots of things do not get adequately planned, and when you get to the execution you realize you left out something important, preventing you from working on the necessary component. For example, this might include incorrect isolation or forgetting about scaffolding to get to the valve. Correcting scaffolding or isolation may take a few hours to rectify. Forgetting to order a component can be disastrous. If the component needed to be ordered at that late stage, it could take days or longer and if this activity is on the critical path, it is an unacceptable waste of resources and outage lateness. Reflecting on these issues, especially the simple process of planning and erecting scaffolding, it seems unthinkable for a nuclear plant, yet happens often enough. Not having adequate skills is a major contributing factor. To overcome this, robust planning tools are essential. This could include tools that prompt job or activity requirements to the requisite degree. If job planning is done electronically, algorithms can be built to create prompts or checks and balances, thereby reducing or eliminating the need to rely on memory or manual systems. In the context of a shortage of suitably qualified people, systems could provide some mitigation.

Two participants emphasized the requirement for Outage project leaders to have tabletop exercises to discuss work scope, possible delays, and actual staging of work beforehand. These tabletops can be done as frequently as required and adjusted from informal to formal, depending on the agenda. These tabletops are useful and efficient ways of getting work or issues clarified or moving quickly and should be kept as informal as possible, yet never losing the actions and due dates to be taken. It has become commonplace for some to insist on formal minutes of meetings, which takes too much time for an engineer or outage worker, who are very technically orientated and generally have very limited administrative support. Simple emails or action registers with short descriptive actions and due dates are sufficiently underpinned with a strong culture of accountability.

5.4.2 Sufficient skilled resources

The need for sufficient, skilled resources was the next priority. One participant highlighted the need for sufficient personnel to prevent testing from causing delays. He provided the example of having two MOV/AOV diagnostic test assessors; one per shift, saying it will prevent delays in reading the tests so that the work orders can be closed promptly, and the schedule maintained. Another participant suggested that dedicated resources for all critical and sub-critical activities. These suggestions are completely rational, yet not always done. Instead, there is one person pushed to work maximum hours, quickly gets fatigued and human error creeps in. This was reinforced by another participant who shared his concern about rework with examples being poor maintenance, lack of maintenance, and even leaving out a gasket so that when doing requalification of the component, it fails.

Another participant recognized the need to employ experienced and knowledgeable planners and schedulers who can develop a logical and detailed overall plan which avoids conflicting actions. Planners and schedulers of this nature are abundant in industry and the imperative is on the NPP to recruit the best and retain them to ensure institutional memory is retained.

One participant emphasized that the common need is “having a skilled workforce in the organization. People that know what is needed and have an ability to drive and achieve it”. Sometimes companies appoint people who are not ready for the role, lacking technical or managerial competence (or both). The companies don’t support them once appointed or they do not do enough to retain and appreciate those who have the competence, with disastrous consequences.

The next participant echoed similar views emphasizing the need for having the “right people on site”. He went on to offer a solution saying that NPPs need to identify upfront where they have a deficit in skills, local or international. He provided an example where Koeberg has a big issue with support for polar crane maintenance and is having big delays and long response times to repairs. He explained that Person A and Person B who are known as experts in their field both left Koeberg about the same

time and Koeberg having lost inhouse capability, now needs to mitigate by having the OEM to support. This is more cumbersome and more expensive. KNPS needs to do a risk analysis before outages and decide if they need the OEM. The OEM is very expensive, and KNPS needs to be based on risk, decide if it is beneficial to have the OEM on standby at a certain cost in case of a breakdown versus not having the OEM. It is also far more sustainable to retain the people who left.

Most technical nuclear workers such as the valve technicians can be considered scarce skills and require attracting, retaining and continuous training. In 2020 and 2021, in the South African context particularly where Eskom finds itself cash strapped and with a workforce having low morale, this is particularly relevant. Many skilled artisans and technicians from KNPS are making their way to perceived greener pastures, i.e., OL3, HPC, BNPP and elsewhere. More countries such as Egypt, Turkey and the UK have nuclear new build programs that attract skilled nuclear workers away from South Africa or from each other. With new nuclear plants being built in these and other countries, the competition for scarce resources will continue. Organizations like Eskom need to adapt to retain its people and enhance its pipeline for these resources.

5.4.3 Risk management and contingency planning

This method was mentioned six times. Participants mentioned the need to plan for contingencies, have good or adequate risk management and have in place contingency plans. One participant advised to always assume that a percentage of work will be delayed. Another shared experience that he always tells people to anticipate what could go wrong because from his experience people only look at what is happening on their current shift. Instead, they should be looking at the bigger picture and get a helicopter view. He explained that the maintenance support team generally looks at the first week of the outage and sets up scaffolding accordingly. They think they have bought themselves seven days to adjust for the next week. They often do not plan for contingency scaffolding in case of emergent work and sometimes must delay some planned work to use the scaffolding for the emergent or more urgent work.

Risk management and contingency planning success is underpinned by a culture of risk management and having experienced, capable personnel. It cannot be a haphazard activity to tick a box. The people delivering inputs into the process need to know the work well. They need to know how nuclear outages work and how to perform risk management, to analyze the risks and as a team put in place contingency plans. Contingency plans in themselves need to undergo a cost benefit analysis. To be successful at-risk management and contingency planning, having enough skilled resources is a necessity. Risk management goes together with effective planning and scheduling and should be consciously treated as such.

5.4.4 Effective Execution to the Schedule

Effective execution was mentioned four times. The first advice emphasized the need to “schedule the outage properly and follow the schedule as it is scheduled”. The participant explained, “do not try to jump ahead of the schedule because all the work will be tied in a process that ensures all work is performed and when completed opens up the next activity.” He added that all work orders had to be walked down by all disciplines and documented, which improves the probability for effective execution.

Another participant highlighted the importance of an adequate execution strategy for bulk work in the maintenance shops. These workshops become rather busy during an outage and there can be no bottlenecks. Part of the execution strategy includes protecting the critical path and sub critical paths resolutely by having a team looking at upcoming activities and ensuring those activities are ready to be executed and directing resources accordingly. Another method was to timeously complete the paperwork and update the various systems/tools, e.g., SAP and Primavera to ensure execution is tracked in real time and focus is placed where it is needed most.

Most workers will follow the schedule. The real delays come from work taking longer than planned due to an incorrect pre-estimation, lack of skill or tools and equipment failure. Staging of the workshops to avoid bottlenecks and staging the other work areas can make a significant difference. Having spare tools, equipment and spare parts fall into a different section of best practice but as indicated before, they are all interrelated. The theme of effective planning and scheduling which includes risk management emerged as the most important success factor to avoid delayed outages.

5.4.5 Effective Scope Control

Scope control was mentioned thrice as an effective means to avoid outage delays. Scope creep or growth occurs when there is an inadequate system for change management. One participant elaborated saying one needs to minimize scope growth and investigate means/justifications to postpone repairs if possible. The risk for delaying repairs is somewhat uncertain at times. It is easier and risk averse to do the repair as soon as possible, to avoid a reactor trip during the typical 18-month fuel cycle. Engineering departments are traditionally risk averse and prefer repairs to take place at the earliest. However, having sufficient trend data from the system itself as well as similar issues at other plants can help inform risk-based decisions and delay repairs. Due to the safety risks associated with nuclear and even the perceptions to be managed, nuclear engineering departments are and should be more conservative than other types of power plants. This conservatism bias should be balanced with the need for outage duration optimization and the related benefits.

5.4.6 Spares Management

Spares management was mentioned by two participants. The proactive approach is crucial. In addition to warehouse inventory levels and reorder points, one participant advised to do proper spares inventory check before the outage. The other went on to explain the requirement to have the available spares to fix those components that breakdown. In effect, there are spares required for the outage maintenance but also spares required if some equipment, systems or even tools break down during, immediately before or even after the outage. Therefore, it is necessary to look at OE and history from one's own station as well as other similar plants and use that OE to perform a risk assessment and order the optimal number of contingency spares. The secondary, yet important reactive approach if some spares were not provisioned for, would be to have a good relationship with suppliers and utilize the emergency purchase process and wait until the spares arrive. With international suppliers, this may add significant time to the outage and should be avoided.

5.4.7 Benchmark Other Plants

One participant emphasized benchmarking and provided two good examples. One example was to do benchmarking visits to high-performing plants during their outages. This involves a short period of about 35 to 40 days, depending on the planned outage duration. The other method was to second workers to high performing plants for outage support for longer periods at a time, typically 6-12 months. Both these methods are used in the industry. However, with the Covid-19 pandemic and associated travel restrictions, the option to conduct benchmarking or secondment physically is less viable, riskier, and more expensive.

For refuelling outages including standard maintenance, there is a clear argument to be made that sending people to other plants has a lower ROI. However, if the outage involved a major modification such a steam generator replacement that occurs on average once in 40 to 60 years, the modification often cannot happen without exposing key people to these benchmarking exercises. NPPs need to carefully select the right people for these assignments, ensure the outputs will be used, ensure the person/s delegated are retained after the benchmarking is complete and there is knowledge transfer to the rest of the outage organization to maintain the institutional memory. It cannot be where one or more people are sent, they acquire profound knowledge and experience and within months of their return, they resign. More needs to be done to tighten these employment contracts.

Covid-19 has expedited and intensified the use of online meetings and collaboration. This is an exciting opportunity to find ways to do benchmarking virtually. With online collaboration tools and virtual meetings, there are distinct opportunities for some outage workers at one NPP to attend key meetings with NPPs in other locations and countries. This can be done at an appropriate frequency, even daily. It will be an inexpensive way to collaborate and speed up the sharing of OE. Many more

people can participate, and knowledge transfer can be expedited. People who could not participate even in the online meeting, can watch, or listen to the recording later, like webinars.

It is important to recognize these benefits and simultaneously recognize that it is not the same as witnessing work and activities in-person or doing it yourself. This brings a value of sharing knowledge that cannot be accomplished by sending one or a few individuals. A balanced approach needs to be sought. One thing is certain is that the benchmarking in whatever format is absolutely required and online collaboration is the future. A further study of the value of benchmarking and its ROI is required. Coupled with a structured approach to do online benchmarking, NPPs can improve performance significantly and simultaneously reduce cost.

5.4.8 Practice Drop and Swap

One participant recommended drop and swap. This is essentially when you remove equipment, replace it with a spare, which saves a lot of time, and maintain the removed equipment in the workshop. At the next outage, you do the same by using the equipment removed last time. Further research is required to know for which components or systems this has economic value and for which it does not. The author expected this method to be more prominent in the interviews and could be a topic of further investigation.

5.4.9 Optimize Use of Equipment (Polar Cranes, etc.)

One participant reported that from experience at KNPS, he was aware that optimizing the use of the polar crane availability can save as much as 24 hours per outage. One full day just by planning the efficient use of the polar crane is a significant saving. It costs just about nothing, only advanced effective and efficient planning. It's a 3% (1/35 days) saving on a typical planned outage duration. Investigating to what extent this is practiced and what the associated time and costs savings are or could be, presents an excellent opportunity for further study.

5.4.10 Effective Contractor Oversight

One participant reported the need for good oversight of the contract workforce, ensuring they have and work to the right standards. Contractors work for various customers and customers have varying standards of quality, safety, culture, etc. Usually, NPPs have the highest industrial and safety standards, and this comes at a cost. For various reasons such as gaps in knowledge, understanding, complacency, cost frugality, etc., contractors don't always adhere to the highest standards.

Therefore, apart from working with them on improving to reach the quality standards expected by NPPs, there is a clear requirement for effective contractor oversight in all phases of the outage, especially the planning and execution. This oversight helps significantly to reduce errors and improves people and plant safety. Practical methods to help identify contractors include specific

uniforms. Some plants in the US, even place stickers on hardhats and badges to identify new to nuclear workers. Mercado (1994) highlights the value of alliances and partnerships with contractors. This partnering will make them adopt the nuclear safety culture and other good practices as their own. In-turn, it will result in a reduction of incidents and consequent delays.

5.4.11 Effective Walkdowns

One participant expressed the importance of making sure all work orders are walked down by all disciplines and documented. Multiple walkdowns are normal practice with every job, for both online and offline work. This may be the reason why others did not mention it as a means for mitigating delayed outages. Multiple walkdowns for the same job allows the team to think through the various planning and execution stages. It also helps with arranging staging of the work area.

5.4.12 Pre-outage Readiness Assessments

Only one participant mentioned readiness assessments. This was somewhat surprising in that it these formal assessments help with significantly better planning. However, it could also be because it is such a well-practiced method, it did not require special mention. From experience, these assessments require a standard checklist which helps one set up successfully. These assessments take on various forms. Sometimes they are done by the outage department itself. The outside-in assessments are the most beneficial. In some cases, other parts of the organization observe and challenge readiness whilst at other times, outside organizations like other NPPs and Contractors are invited to challenge outage readiness. When conducted properly, these challenges bring immense value.

5.4.13 Open, Transparent Communication Trust Environment

One participant emphasized the need for an open, transparent communication and high trust environment. He said this allows people to share information freely and importantly ask for help when required. In this way, people don't struggle with a problem until it becomes a bigger problem because the environment and culture allow sharing and trust. One example that has resonated with the author throughout his career is if someone drops a foreign object like a nut or similar into a system in error, the person should feel completely at ease to inform their supervisor knowing there will not be negative repercussions. Knowing about the foreign object at time of the error is far less expensive and damaging than commissioning that system with the foreign object inside. Similar examples are available for the planning phases of outages. Here, sharing information earlier allows more time to adapt and address the challenges at hand, and is always less expensive too.

5.4.14 Effective Processes

During the discussion of most common reasons for delay, inefficient processes were discussed with examples in Section 4.3.10. Whilst exploring delay mitigations with participants, there emerged the recommendation for more effective processes, with examples. Such process improvements are integral component of continuous improvement and establishing a learning organization.

5.4.15 Summary of Best Practices or Methods to Mitigate Outage Delays (Question 8)

Participants shared the experiences and knowledge on the best methods to avoid outage delays. Their experiences are all valuable and personal based on their career experiences. Even though each one ranked the methods, there was no common theme or inference that could be made from the ranking. What was evident was that the following practices were most mentioned.

1. Effective Scheduling and Planning
2. Sufficient Skilled Resources
3. Risk Management / Contingency Planning
4. Effective Execution to Schedule
5. Effective Scope Control

A commonality is evident between question 7 that dealt with causes for outage delays and question 8, that deals with ways to mitigate outage delays. Once again, there was no mention of a lack of using technology such as tablets and phablets. This may be because they have become too used to having paper-based work orders and accepted it as the status quo. However, using tablets or phablets should be investigated further. There are numerous opportunities to mitigate delays and optimize outages. Interestingly, incentives were not mentioned as a tool for mitigating outage delays. Finally, there is sufficient cause to study each topic in depth to better understand each and help the NPP improve performance.

5.5 MOST EFFECTIVE PRACTICES OR METHODS TO OPTIMIZE OUTAGE DURATIONS (QUESTION 10)

The participants provided varied responses and they were grouped as per Figure 5.1 below. Some participants provided 3-5 responses and others less. They ranked their individual responses but there was no clear pattern of ranking between participants.

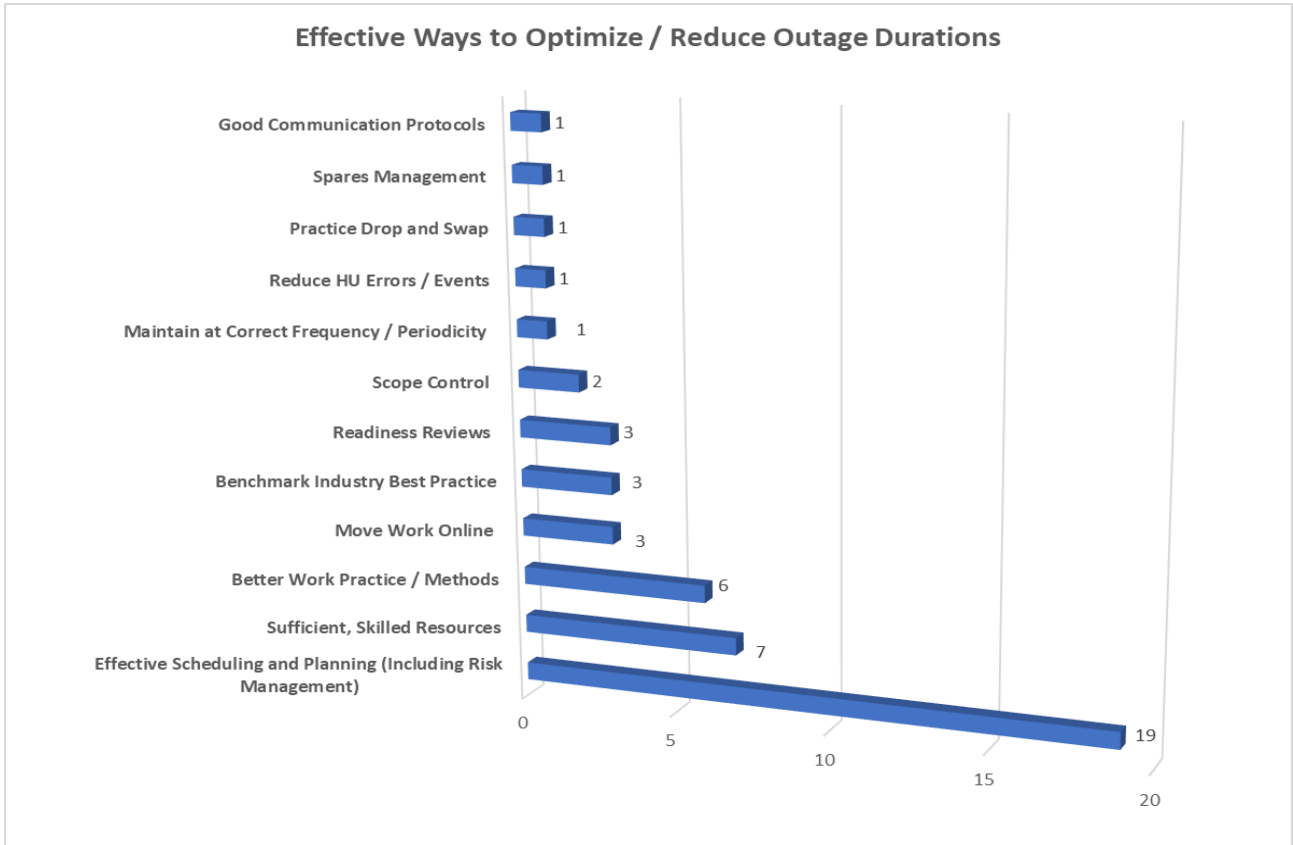


Figure 5.1: Effective Ways to Optimize / Reduce Outage Durations

It is evident that effective scheduling and planning, including risk and contingency planning is viewed as the most effective way to optimize or shorten outage duration. Some practical methods from participants included:

1. Organize work into windows, based upon clearance boundaries. Maximize the amount of work that can be done inside a single clearance. E.g.: Maximize the EDG work when it must have any maintenance done.
2. Detail levelling of resources across the organization with qualified and experienced people.
3. Schedule to 80% because emergent work is going to happen so building a cushion is a key defense.
4. Realistic timelines. Providing accurate job times and ensuring they fit into the outage is key. A big error that occurs often is that the work is “shortened” to fit into an outage window by someone who is not a technical expert (for example a scheduler). This can cause unnecessary outage delays.
5. Plan smarter and work smarter. I asked this participant to provide one or two examples of what ‘smarter’ meant to him and he replied with: He said first they need to ask themselves, how KNPS could work smarter and plan smarter. He thought KNPS could plan better. They should ask what else could go wrong and have contingencies in place if something goes

wrong. Another way of working smarter is to have swop outs (drop and swap). Instead of opening, testing, and repairing a valve, rather have swop outs to replace the valve. Replace vs repair is often quicker. You can also increase productivity on back shifts. Nights shifts are often very slow vs day shifts, he said.

6. Cut down on duration, for example optimize all work in a specific location and at approximately the same time, and optimize support required in that area. Don't go back two weeks later to do work in the same room. Avoid duplication.

The need for sufficiently skilled was ranked second and better work practice or methods was third. Some items may have been mentioned, but here some pragmatic better work practices that are worth considering:

1. Give artisans or discipline / job supervisors the ability to do more. E.g., "when artisan works on a valve and needs a block and tackle for rigging and lifting, he can do this himself. Instead, it is typically given to the support function that adds resources and often causes delays. Another example is allowing the artisan or job supervisor to do the radiological survey when valve is open. At Koeberg they have to phone RP to do the survey. They should rather let the artisan and his assistant do this". Another example is sometimes there are different requirements from Maintenance compared with Engineering. For example, Maintenance needs to do visual inspection and Engineering requires someone qualified on ASME to do VT 3 inspection. They send two resources, often at different times but the higher qualified person could add 15 minutes to the task and do both whilst at that component.
2. Entrench project management training, systems, and culture as a foundation for how to plan and execute outages.
3. Implement new / innovative methods of performing activities.
4. Challenge the norm while staying within the rules.
5. Change the rules of acceptance.
6. Perform more continuous improvement programs/initiatives.

Upfront planning, scheduling, risk management and contingency planning remains the most effective way to reduce outage durations. It provides the reasonable luxury of time, typically 18 months between outages but typically starts 24 months in advance. This planning needs to be done with skilled resources and the execution of the outage too. NPPs need to evaluate its human capital in relation to the work at hand. What skills and people will they require going forward and what needs to be done to retain them?

Finding new, innovative ways of conducting any aspect of outage management is crucial and exciting. Even though nuclear workers are trained to be conservative in their decision making, it is

innovation that moves us forward. In the context of the IAEA (2016) advocating that the use of mobile smart devices may yet bring the most significant advance in outage durations, it was significant that none of the participants specifically highlighted the opportunity to use more advanced technologies like tablets and phablets instead of paper-based work order systems.

Apart from time and cost savings, there are several other benefits already discussed, that in the end translates to savings for the company. As one participant aptly said in this question, "if outages are too long, people get tired or fatigued and leads to mistakes. In nuclear especially, you want to avoid that."

This question about optimizing outages was similar to Question 8, seeking methods to avoid outage delays. The answers were mostly similar. This is useful as it reinforces the practices to be further studied as means to optimize outages.

The industry would benefit immensely from improved collaboration with the key objectives being reducing carbon footprint and sustainable energy for all (not just a few). Lessons learned or operating experience (OE) in optimization is something to be shared ubiquitously because it helps the nuclear industry globally, be cost competitive with other electricity sources. It must become imperative to make nuclear and other carbon free sources preferred to protect the planet from global warming and climate change. Ultimately, a portion of every dollar saved through optimization can be reinvested in other zero / low carbon emission energy sources, avoid load shedding, and promote the cause for nuclear.

CHAPTER 6

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

The purpose of this dissertation was to investigate the optimization of outages at nuclear power plants with the aims of identifying trends and gaps, highlight opportunities and propose ideas for improvement. This research could have been approached in several ways. The approach chosen was to interview 12 nuclear outage specialists with significant experience in outages and maintenance to collect rich data on perspectives, practices, and approaches to optimization and to answer the research questions. This chapter highlights the main findings and conclusions, discusses the limitations, and makes recommendations for priorities and future research.

6.2 SUMMARY OF MAIN FINDINGS

6.2.1 Primary research question, effective practices for outage optimization

The overarching research question asked, “what are effective practices or methods to optimize durations of planned outages?” The analysis of the interview feedback showed that there are some very specific practices that if done correctly results in optimized outages. An effective approach was found to require priorities, that primarily included: (a) effective planning, which encompasses scheduling and risk management with the right contingencies, (b) to have sufficient skilled resources, the right people, with the right skills and attitudes, (c) effective execution to schedule, (d) effective scope control, and (e) better work methods which include doing work correctly the first time, working smarter or improving on work methods and techniques (Kaizen). There were additional key practices that supported optimized outage durations that ranked lower on the priority list but that certainly deserve attention.

6.2.2 Best duration for a refuelling outage at PWR

Table 5.1 below demonstrates the typical durations reported in practice by the research participants compared with top tiered NPPs in the industry as reported by the IAEA (2016). The average duration from the interview results were markedly longer and is attributed to participants' individual experiences at some NPPs for which they worked. The longer durations emanate from plants whose main objective is not profit and state owned NPPs typically have different objectives and constraints and therefore, less ability to shorten outage durations. Most top tiered NPPs are privatized and driven by profits, hence the lower durations. Outage durations in the industry have however improved

significantly over the years (Hansen, 2008) and with continuous improvement and disruptive interventions can improve further.

Table 6.1: Best Duration for outage

Type of Outage	IAEA	Average of Interview Results
Refuelling and statutory maintenance	7 to 18 days	29.6 days
Refuelling and standard / extended maintenance	14 to 40 days	36 days

6.2.3 What are the most common reasons for outage delays in nuclear outages?

Ineffective and inefficient planning and scheduling ranked as the most common reason for outage delays. This was followed by discovery and emergent work. The lack of skilled resources and availability of spare parts or, put differently, ineffective spare parts management ranked a joint third. Except for discovery and emergent work, the other three causes were within the direct control of NPPS and more should be done to reduce the impact of these. The literature reviewed did not rank reasons for delay and this presents a significant opportunity for future research, in nuclear outages, at single NPPs and better yet, across the industry.

6.2.4 How are delays best avoided and mitigated?

The participants' responses indicated that more effective scheduling and planning combined with risk management and contingency planning were the best ways to mitigate outage delays; this was consistent poor planning and scheduling being the main cause of delays. Similarly, the need for sufficient skilled resources was next, followed by improved work practices and execution according to the schedule.

6.2.5 The quintessential opportunities that will result in outage duration reduction?

Savings in time and money were ranked as the greatest benefit. However, the savings from shorter outages need to be balanced with the money and resources spent to achieve those optimization benefits, which becomes an important future research topic. The second highest ranking benefit was an improved Energy Availability Factor (EAF). A longer operating cycle improved safety and reduced radioactive dose. Shorter outage durations also meant an improved quality of life as the demands during outages meant people typically worked 12 hours per day on a 24 hours, 7 days per week, basis, for the full outage duration, which adversely impacts physical and family well-being. An

optimized shift roster can easily be designed to optimize outages and give workers adequate rest and good quality of life. There is no need to reinvent the wheel on shift rosters. If effectively implemented, a few key methods in the proverbial toolbox, goes a long way to shorter duration, optimized outages.

Poor planning, scheduling and risk management, and a lack of adequately skilled resources emerged as the main reasons for delays and simultaneously as the main solutions to optimizing outages. It is recommended to provide outage specialists in charge of leading outage planning and execution, with quality project management training which includes all project management knowledge areas. This will significantly improve their skills. Frequently the people managing outages are knowledgeable about the plant components and systems and performing maintenance but lack formal project management training and skills.

6.3 LIMITATIONS OF THIS STUDY

This dissertation was a qualitative review based on 12 structured interviews. The scope of the study could be extended, for example, by doing a survey to assess a whole organization or the very key parts of an organization that play important roles in outages. Such a survey could ask similar questions as this dissertation did but to a considerably broader sample. The aim would be to understand the culture, knowledge, experience, beliefs, strengths, and areas for improvement (AFIs) of the sample, to improve outage thinking, culture, alignment and develop programs that are best fit for the organization being assessed. Most NPPs would benefit from research or benchmarking of another NPP but it is always better to do the assessment on the organization itself so that optimization programs are tailored, effective and incurs minimal cost. An in-depth empirical and statistical analysis to test the hypothesis is recommended. The empirical and statistical analysis should assess methodologies that if replicated and repeated, investigate if they provide consistently effective outcomes. Conducting similar studies and even comparative studies across multiple NPPs with similar and different operating models would prove useful and facilitate further industry collaboration.

A cost benefit analysis of each optimization methodology at a macro level and micro level is recommended. The macro level will test cost benefit of each optimization program that could be used at any NPP. The micro-level will be station specific as each station has its own dynamics and resource constraints. The key objective must be for the optimization efforts to be effective, efficient, and sustainable. In addition, benchmarking other NPPs in industry leading countries like the USA and France is certainly useful but benchmarking with other similar industries in the same geographical proximity and the same business environment could yield worthwhile comparable information. For KNPS as the only nuclear plant in Africa, they could benchmark with the coal power stations or even the organizations like SASOL, other oil and gas plants, mining or other huge

manufacturing plants like Toyota, VW, BMW, or SAPPI in South Africa. Furthermore, instead of a 2-unit or 4-unit NPP benchmarking only with industry leaders in the USA and France who have fleets close to 100 reactors, they should benchmark with utilities or operators with similar fleet sizes as their own.

Surprisingly, there was no mention of incentives as a practice or approach to improve optimization and warrants further investigation to evaluate whether well-structured incentives will help optimize outage durations or at the very least, avoid outage delays. The literature did not specifically rank and discuss the practices or methods that yielded the best results, and it is worthwhile to investigate ranking further. In terms of improving physical work practices, it is recommended to employ a time study comparing paper-based vs mobile smart technology like tablets and wrist devices to evaluate potential time savings along with the cost benefit analysis thereof and always keeping safety as the overriding priority.

6.4 PRIORITIES GOING FORWARD

There are four broad priorities going forward that aim to increase the ambition to optimize outages. The highest priority is to conduct further research to better understand the main reasons for outages delays and the best opportunities for outage optimization better. This could be approached with empirical and statistical analysis of the subject and with a systems-thinking approach. The complementary methods would help reinforce and build on the findings of this qualitative report. In the process, a deeper understanding of the topics and sub-topics will emerge. It is important to understand a specific plant's outage capability. This includes culture, skills, experience, etc. Are they reaching their objectives? If yes, is there a desire for further improvement. If not, why? An enhanced study of the organization with a broader sample and development of reliable statistics and findings will enable focus on the specific root causes and improvements required in each unique setup.

Secondly, in the further research, it is crucial to take the key stakeholders along to ensure they support the improvements needed. The most important and impacted stakeholders are the Outage Maintenance, Engineering and Operations teams. Including the support teams like procurement for example is crucial, keeping in mind the findings thus far, in relations to spares and inventory management shortages.

Third, include the cost benefit analysis that shows the executives the financial and efficiency benefits of conducting planning, scheduling and risk management using specific tools and methods or the benefits of hiring, retaining, or training some of the key skills. They need to understand the benefits. Show them a statistical correlation to improved EAF. In the case of Eskom and load shedding, show them how their investment will save money for the company but also statistically, show them the

benefit a specific intervention will have on reduced load shedding and the consequent benefits to the country's economy.

Fourth, it is appropriate to conduct deeper longitudinal studies of outage optimization in specific NPPs and use these references for future work to become industry trendsetters for the global nuclear industry and any other industry that may benefit. In the end, optimization benefits environmental sustainability. In fact, it also contributes favourably and notably to at least five of the United Nations Sustainable Development Goals (SDGs), especially:

- SDG 7 – Affordable and Clean Energy
- SDG 9 – Industry, Innovation, and Infrastructure
- SDG 11 – Sustainable Cities and Communities
- SDG 12 – Responsible Consumption and Production
- SDG 13 – Climate Action

All these recommendations could be implemented within six months and the results would emerge in the very next outage with synergy effects in subsequent outages.

6.5 RECOMMENDATIONS AND FURTHER RESEARCH

The findings from this dissertation and further research may be used to improve the understanding of organizational thinking about outages and outage shortcomings and start the journey to investigate and improve outage durations further at any NPP. The study may form the basis for ongoing research given the limited literature on the topic. It can additionally be used as a starting point to conduct comparative studies between NPPs or even multiple stations within a fleet. NPPs may think they are doing enough or do not need to optimize outages, but this research shows otherwise.

It is evident from this dissertation that NPPs can do significantly better to improve outage durations, motivating for further investigation and improvement. Knowing what caused the delays presents an opportunity for improvement. In any NPP, it is recommended to survey the maintenance and outage organization, holistically. Survey instruments that test participants' knowledge, experience and views can be set up to objectively measure the gap between best practice and the organizational mindset. This will help implement the correct measures to work towards becoming a top tier outage organization and industry trendsetter.

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APPENDIX A – IAEA EXTENSION OF OUTAGE (2002)

Outage extension is the increase of outage duration beyond the planned time if this happens after the outage plan is frozen. It is a negative effect that should be avoided because it causes unplanned energy loss, requires additional manpower, increases outage cost, and may result in the production of additional radioactive waste and increase the collective dose exposure. Generally, if the outage is planned and managed accordingly, the extension of the outage may be initiated by a reason that has been discovered during the outage. With the increase of NPP operating experience, the risk of outage extensions could be reduced. However, it may be recognized that while optimization of planned outage duration is desirable, making the planned outage shorter may increase the probability of the outage extension due to minimization of margin for resolving unexpected problems in given time. To handle these unexpected events, the plant management should make efforts from the very beginning in the outage planning phase to predict and prevent outage extensions by using proactive engineering approach, questioning attitude, proper motivation, and operating experience feedback program results. The most frequent causes and their counter measures to avoid outage extension are listed in section 6.1 and 6.2. These causes should be used in the plants self-assessment process to assess the probability that similar causes can occur. The following are some of the causes of outage extension commonly encountered:

Causes for outage extensions

(1) Non identified system or equipment or component deficiency

- lack of condition monitoring and trending
- equipment or component failure during outage execution
- ISI program and tests results

(2) Quality of work performed

- lack of quality consciousness and procedure usage
- poor quality of material
- lack of mock-up structures
- lack of skilled or trained manpower
- improper work execution control
- casual attitude to work execution resulting in waste of working time
- improper implementation of Foreign Material Exclusion (FME) program

(3) Deficient outage management

- lack of leadership and control over the plan activities
- lack of motivation
- lack of budget

- late order of equipment, material, and spares
- insufficient cooperation among the parties
- deficiencies in interdisciplinary communication
- quality control deficiencies

(4) Regulatory impacts

- last moment regulatory requirements added
- misinterpretation of regulatory requirements

(5) Failure of inspection or special maintenance tools (lack of preventive maintenance of special tools)

(6) Inadequate spare parts or lack of spare parts

(7) Inadequate vendor support

- lack of technical support and unreliable sub-contractors
- lack of equipment or material supply or late delivery

(8) Deficient outage planning

- under estimation of activity duration or work force
- improper scheduling of work activities
- support activities (scaffolding, etc.), tools, materials not clearly defined
- plant status prerequisites, work permits, and approvals not clearly defined
- Operational Experience Feedback (OEF) program results were not considered or OEF actions were not adequately implemented while planning reoccurring outage activities.

Countermeasures to avoid outage extension

Taking into consideration the causes of the outage extension mentioned in the previous section, the following possible countermeasures can be applied:

(1) Improve condition monitoring by:

- reviewing and revising the condition monitoring, trending and preventive maintenance programs using industrial experience
- conducting ISI program on critical components in the initial phase of outage.

(2) Improve work quality through:

- development of quality consciousness among the employees and put quality check/hold points in the maintenance procedures
- pre-qualification of the spares and supplies
- development of mock-up facilities based on the industrial experiences
- training/re-training of the manpower to be deployed
- strict control of work execution to avoid extension.
- early warnings on critical items or milestones

- analyzing time spent on work to increase effectiveness
- applying proper workers motivation such as incentives and awards
- development of the FME program based on the latest industrial experience.

(3) Improve outage management by:

- implementing management and project management development programs to strengthening the leadership and control of outage activities
- establishing clear goals, responsibilities, and ownership
- implementing self-assessment processes on plant and individual level
- prioritizing activities according to their sensitivity and selectivity
- strengthening safety awareness and culture
- conducting organizational development programs with cohesive approach and motivation
- promoting a "do it right the first time" approach
- anticipating of budgetary requirements and ensuring allocation of the same
- preparation of well documented quality assurance (QA) and quality control (QC) program for the outage activities with the help of QA/QC group
- listing and ordering spare parts to assure their availability at warehouse well in time based on the past experiences
- interdisciplinary communication on critical subjects, support, approvals, tools, etc.
- using of fixed teams of very experienced specialists for critical jobs (integrity checking, etc.)

(4) Anticipate regulatory requirements based on in-house and industrial experiences

(5) Ensure reliable inspection and maintenance tools through:

- pre-qualification of special inspection and maintenance tools
- redundancy of special tools

(6) Spare Part Policy

- QC of received material well in advance
- spare part storage control system
- partnership with vendors
- joining a pool for common spare parts or inventory management

(7) Deploy reliable and experienced contractor or subcontractors by:

- seeking international nuclear industry help through international networks
- establishing long term partnership
- providing timely and clear purchase orders, signing the contracts, and controlling the process development

(8) Improve outage planning based on in-house and industrial feedback by:

- setting-up clear goals
- defining outage milestones and freeze dates for different phases of outage

- proactive planning and scheduling, i.e., predicting and considering possible problems and planning the time for corrective actions
- considering OEF program and plant history files during the planning phase.

The list of causes and countermeasures could be used for self-assessment of plants own performance and, in that way, identify areas for improvement in optimizing outages.

APPENDIX B – 12 INTERVIEW TRANSCRIPTS

Topic Nuclear Outage Optimization

Participant: 1

Purposes:

- Identifying most common reasons for longer or delayed outages
- Identifying most effective ways to optimize outages
- Based on personal views and experience, not theory
- Interview is voluntary
- You may and should express your views freely and challenge the interviewer at any time
- You may and should raise ethical concerns you may have and if necessary, withdraw from the interview.

Interview Questions

A: Biographical questions

1. What is your current or most recent role in the nuclear power plant?

I was previously an I&C Supervisor/ I&C Engineer in Maintenance

I am currently an I&C Job Path Lead with Outage Management

2. How long have you worked in the nuclear industry or at the NPP?

I have currently been working in the nuclear industry for 33 years.

3. How many outages have you participated in?

I have participated in at least 50 outages

4. Describe your main role or roles in nuclear outages (the bulk of them or most recent of them).

My main roles in nuclear outages have been in supervision or engineering or journeyman positions.

B: Outage Questions

5. What is an acceptable/reasonable duration of a planned outage for similar design to NPP where you worked before for?

- a. Refuelling and statutory maintenance,
- b. Then refuelling plus statutory plus standard maintenance at PWR,
- c. How or by whom is 'acceptable' determined?

30-45 days

45-60 days

The durations are determined by Corporate or Headquarters

6. To your knowledge, what is the best duration for a planned outage for a PWR, similar design to NPP where you worked before for?

- a. Refuelling and statutory maintenance,
- b. Then refuelling plus statutory plus standard maintenance

60 days to 70 days

7. Sometimes outages run later than planned. In your experience, what are the 3 or ideally 5 most common reasons for outages running later than planned (late or longer than planned outages)?

- a. Please rank these reasons for outages running late from most common to least common.

- 1. Discovery
- 2. Expanded scope
- 3. Availability of replacement parts
- 4. Modifications that don't go to plan. Modifications are harder to estimate because they are not routine.

8. What are the best methods and techniques to avoid or mitigate outage delays?

- a. Can you rank them from what is most effective to least effective? Provide at least 3 to 5.

(If necessary, I could provide the techniques and they rank them, but I am hopeful a skilled outage specialist will be able to list and rank.)

- 1. Schedule the outage properly and follow the schedule as it is scheduled.
- 2. Do not try to jump ahead of the schedule because all the work will be tied in a process that ensures all work is performed and when completed opens up the next activity.
- 3. Make sure all work orders are walked down by all disciplines and documented.

9. What are the main benefits to optimizing outages? (Establishes how different stakeholders perceive benefits and may show competing objectives.). Why do we want to, or should we optimize outages?

By optimizing you can determine what work can be performed online safely therefore freeing up or maybe shortening the outage. Typically, only necessary work should be performed during an outage. i.e., Tech Spec PM's that will not have any grace left prior to the next outage. Even if it requires a clearance, OPS should be able to help determine whether the work can be performed safely prior to the outage.

10. What are the most effective ways to optimize/reduce outage durations (not avoiding delays but rather optimizing from acceptable planned standards/durations)? Can you rank them from what is most effective to least effective? Provide at least 3 to 5. If necessary, I could provide the techniques and they rank them, but I am hopeful a skilled outage specialist will be able to list and rank.

More accurate and earlier planning to ensure the schedule is as good as it can be.

Do as much online maintenance as possible.

Have experienced, knowledgeable resources to ensure work is done correctly, quickly, and safely.

11. At your plant or previous plants, what were/are the constraints or inhibitors to implement shorter outage durations?

- a. Tech Spec requirements
- b. Personnel safety
- c. Equipment safety
- d. Performing the correct work on the right equipment
- e. Schedule adherence

12. In your view what are the 5 things NPP Outage Organizations or their Leaders (CNO, VPs or Senior Managers) need to do to ensure Outages run on time or are optimized? The emphasis here is what Senior Leadership needs to drive...

- a. Support the outage management team
- b. Optimize scope and manage scope changes through participating in readiness challenges
- c. Provide adequate financial and human resources to be successful

13. Are you aware of any outage optimization programs in your current plant or previous plants and can you name the top 1 to 3 in terms of what durations/time it could save? Are plants actively managing optimization or are they just taking it as it comes?

We had a PM Optimization program that belonged to engineering.

14. What other advice or feedback would you give to NPP leaders wrt outage optimization? 1 or more bits of advice that you feel strongly about.

Ensure Maintenance, Engineering, Operations are all involved in the optimization program. This will ensure the items scheduled for outage are for outage and all things that can be done online should be done safely and can be accomplished online. These actions will free up time for actual outage work.

15. Do you have any other feedback, ideas, suggestions, and comments?

Work the scheduled as scheduled, this will ensure the plant does not enter into an unwanted condition and slow down the outage.

Topic Nuclear Outage Optimization

Participant: 2

Purposes:

- Identifying most common reasons for longer or delayed outages
- Identifying most effective ways to optimize outages
- Based on personal views and experience not theory
- Interview is voluntary
- You may and should express your views freely and challenge the interviewer at any time
- You may and should raise ethical concerns you may have and if necessary, withdraw from the interview.

Interview Questions

A: Biographical questions

1. What is your current or most recent role in the nuclear power plant?

My current role is Outage Maintenance Services Manager-Components

Previous roles include:

- a. Manager of Maintenance Technical Support
- b. Head of Maintenance Programs
- c. Corporate Functional Area Manager (CFAM) - Maintenance
- d. Manager of Maintenance Programs
- e. Supervisor of Non-Accredited Training
- f. Senior Lead Instructor – I&C
- g. Non-Licensed Operator Instructor
- h. I&C Training Instructor
- i. Manager of Fix-It-Now Team
- j. Supervisor of Fix-It-Now Team
- k. 20 years of US Navy Nuclear Power Program – Submarines which included various roles, with 10 years as electrician, 10 years as manager.

2. How long have you worked in the nuclear industry or at the NPP?

I have 41 years of nuclear power experience. 20 years in US Navy, 21 years commercial experience.

3. How many outages have you participated in?

About 22

4. **Describe your main role or roles in nuclear outages (the bulk of them or most recent of them).**
- a. I spent approximately 3 RFO's as a First Line Supervisor (Head)
 - b. I spent 2 Outages as the FIN manager for the running Unit
 - c. I spent 8 Outages as the OCC Maintenance Representative.
 - d. I spent 9 Outages as the backshift Maintenance Outage Manager.

B: Outage Questions

5. **What is an acceptable/reasonable duration of a planned outage for similar design to NPP where you worked before?**
- a. **Refuelling and statutory maintenance:**
 - b. **Then refuelling plus statutory plus standard maintenance at PWR:**
 - c. **How or by whom is 'acceptable' determined?**
 - a. Approximately 20 days to refuel and do statutory maintenance only.
 - b. Approximately 28 days to perform standard maintenance in addition to refuel and statutory.
 - c. First, by the regulator, by establishing the statutory minimums. This includes Tech Spec and EQ requirements,
Then by the Plant Manager by evaluating and comparing risk of fixing online vs in an outage. This includes nuclear risk and industrial risk,
Then by Corporate with Plant Manager by determining cost benefit of repairing/maintaining equipment vs. running to failure.
6. **To your knowledge, what is the best duration for a planned outage for a PWR, similar design to NPP where you worked before?**
- a. **refuelling and statutory maintenance:**
 - b. **then refuelling plus statutory plus standard maintenance**
- I am defining best as maximum nuclear/industrial/personnel safety compared to cost/duration.
- a. approximately 22 days
 - b. approximately 28 days.
7. **Sometimes outages run later than planned. In your experience, what are the 3 or ideally 5 most common reasons for outages running later than planned (late or longer than planned outages)?**

Please rank these reasons for outages running late from most common to least common

- a. Expanded scope as equipment is initially inspected.
- b. Closely related to it. is delays due to obtaining unexpected parts/materials.
- c. Inefficient scheduling
- d. Failure of the OCC to re-schedule/re-prioritize while waiting for parts/resolution of critical path issues.
- e. Failure of PMT/ST testing. E.g.: POSRV's failing ST and having to go back several modes to repair.

8. What are the best methods and techniques to avoid or mitigate outage delays?

Can you rank them from what is most effective to least effective? Provide at least 3 to 5.

(If necessary, I could provide the techniques and they rank them, but I am hopeful a skilled outage specialist will be able to list and rank.)

- a. Plan for contingencies, including scheduling. Assume that a percentage of work will be delayed. As an example: if testing 10 MOV's, then assume one will need a shaft replacement or actuator work that will require a one-shift delay. Obtain these parts in advance. Another thing I have seen at a previous station was to imbed schedulers in the shop war-rooms. These schedulers would adjust each shops schedule throughout the shift as work completed or delayed.
- b. Perform as much 'drop and swap' work as possible. This involves significant up-front cost in purchasing additional components but over the course of 2 or more outages, costs can be recovered in shorter outage durations.
- c. The OCC must be flexible to allow for rescheduling as delays are encountered.
- d. Have sufficient personnel to prevent testing from causing delays. As an example: 2 MOV/AOV diagnostic test assessors; one per shift. This will prevent delays in reading the tests so that the WO's can be closed promptly, and the schedule maintained.

9. What are the main benefits to optimizing outages? (Establishes how different stakeholders perceive benefits and may show competing objectives.). Why do we want to, or should we optimize outages?

- a. Shorter outages are less expensive to the company. Its approximately 3.5 million AED/day, depending upon time of year and cost of replacement power.
- b. Shorter outages provide company employees with a higher quality of living. Normally, personnel work 72 hours/week during an outage. The longer this goes on,

the more risk to emotional and physical health. As attention spans decline due to emotional stress/burnout, the risk of injury/accident goes up.

- c. Shorter outages allow for more work to be done online, equalizing the workload across the year. This allows for better planning and scheduling of work items. This, in turn, allows employees to work consistently over the course of the year and not at a fast pace, then a slow pace.

10. What are the most effective ways to optimize/reduce outage durations (not avoiding delays but rather optimizing from acceptable planned standards/durations)? Can you rank them from what is most effective to least effective? Provide at least 3 to 5. If necessary, I could provide the techniques and they rank them, but I am hopeful a skilled outage specialist will be able to list and rank.

- a. Organize work into a window, based upon clearance boundaries and maximize the amount of work that can be done inside a single clearance.
- b. Organize the work into component windows. E.g.: Maximize the EDG work when it must have any maintenance done.
- c. Based upon risk, move as much work as possible online.
- d. To the maximum extent possible, use personnel that are familiar with the work and familiar with this particular plant. New to Nuclear personnel have troubles meeting standards, finding locations, understanding the importance of documentation and PU&A.

11. At your plant or previous plants, what were/are the constraints or inhibitors to implement shorter outage durations?

- a. Age of Units always contributed to discovery and/or expanded scope.
- b. Tight space constraints can make it difficult to reach equipment or to move it if being replaced.
- c. Lack of rigging/lifting points. It can take a full shift just to set up rigging/lifting if the plant is not engineered for it (lifting lugs, pad eyes, etc.).
- d. Poor scheduling of the work, leading to inefficiencies, especially when a specific task qualification is needed for the work and the only person with that qualification is on a day off or the opposite shift.
- e. Insufficient numbers of specific personnel. E.G.: insufficient engineers to read MOV/AOV traces; or insufficient civil engineers to review/approve rigging scaffolds.

12. In your view what are the 5 things NPP Outage Organizations or their Leaders (CNO, VPs or Senior Managers) need to do to ensure Outages run on time or are optimized? The emphasis here is what Senior Leadership needs to drive...

- a. Multiple schedule reviews with cross-discipline personnel in the same review.
- b. Talk to the Discipline/Area Managers, understand what their concerns are and be willing to act upon their concerns.
- c. Don't be afraid to spend money on the quality of personnel that you need (e.g.: extra diagnostic assessors, NDE personnel, etc.).
- d. Be flexible, work with the OCC to determine alternate work when delays occur.
- e. Do not allow the mood to become oppressive. This can lead to mistakes in the OCC and in the field. The mood needs to stay alert and calm.

13. Are you aware of any outage optimization programs in your current plant or previous plants and can you name the top 1 to 3 in terms of what durations/time it could save? Are plants actively managing optimization or are they just taking it as it comes?

- a. The single biggest optimization program I have seen is moving work from outage to online based upon risk.
- b. Next is managing the work windows by optimizing the amount of work per necessary component per outage.
- c. The US has started the Value Based Maintenance initiative. I was heavily involved with this for about 2 years. It has significantly reduced O&M operating costs and outage durations by expanding maintenance frequencies and allowing more equipment to 'Run to Maintenance' (or run to failure). Over the years, Engineers have promoted zero failure criteria to all components. Now the US is returning to a managed failure criteria.

14. What other advice or feedback would you give to NPP leaders wrt outage optimization? 1 or more bits of advice that you feel strongly about.

- a. Refer to #12 as this covers it.
- b. Additionally, don't micro-manage. This invariably reduces the initiative that Line personnel are willing to take to optimize work.
- c. Allow Discipline/Area Leaders to lead. I hate it when the VP or Plant Manager walks through a space, sees someone sitting down, and then explodes in the OCC about how Electrical Maintenance isn't working. Inform the leader and then allow them to address it. There may even be a good reason they were in the shop. I.e.: on standby after being given their 30-minute heads-up to support Mechanical maintenance by de-termining a motor.

15. Do you have any other feedback, ideas, suggestions, and comments?

a. Noting further.

Topic Nuclear Outage Optimization

Participant: 3

Purposes:

- Identifying most common reasons for longer or delayed outages
- Identifying most effective ways to optimize outages
- Based on personal views and experience not theory
- Interview is voluntary
- You may and should express your views freely and challenge the interviewer at any time
- You may and should raise ethical concerns you may have and if necessary, withdraw from the interview.

Interview Questions

A: Biographical questions

1. What is your current or most recent role in the nuclear power plant?

Outage Services – Turbine Manager

2. How long have you worked in the nuclear industry or at the NPP?

NPP – 40 years, BNPP 4 years

3. How many outages have you participated in?

Approximately 35

4. Describe your main role or roles in nuclear outages (the bulk of them or most recent of them).

It is always changing. I started out as an RP tech, became a Containment building Coordinator for 5 outages, became Scaffold, Insulator, Painting, and Labour Manager for contractors, Safety Manager, Head of Mechanical, Head of Mechanical and Small Projects (<3 million) and Turbine Manager.

B: Outage Questions

5. What is an acceptable/reasonable duration of a planned outage for similar design to NPP where you worked before for?

- a. refuelling and statutory maintenance,
- b. then refuelling plus statutory plus standard maintenance at PWR,
- c. How or by whom is 'acceptable' determined?

30 to 35 days

SAME, 30 to 35 days

Constant measurements against Industry best practices and how well the unit runs (capacity and availability factors) after a short outage

6. To your knowledge, what is the best duration for a planned outage for a PWR, similar design to NPP where you worked before for?

- a. **refuelling and statutory maintenance and**
- b. **then refuelling plus statutory plus standard maintenance**

25 days approx., there may have been one shorter

Same

7. Sometimes outages run later than planned. In your experience, what are the 3 or ideally 5 most common reasons for outages running later than planned (late or longer than planned outages)?

Please rank these reasons for outages running late from most common to least common.

- a. Emergent Work. This can be discovery, or something breaks during work.
- b. Aggressive scheduling without fully understanding the capabilities of your organization and processes. Often tags are not hung on schedule and valve work always presents issues.
- c. Lack of Manpower. Being too focused on saving money, not just on short outages but for outage budget typically we cut support resources required to get the technical worker working i.e., Rad Techs not available, Truck drivers, Crane operators, NDE Inspectors, etc.

8. What are the best methods and techniques to avoid or mitigate outage delays?

- a. **Can you rank them from what is most effective to least effective? Provide at least 3 to 5.**

(If necessary, I could provide the techniques and they rank them, but I am hopeful a skilled outage specialist will be able to list and rank.)

- a. Good risk management plans
- b. Very detailed manpower leveling charts (this is not done, supervisors should know by the day, by the shift, by the hour how many folks are on site and what their qualifications are. If someone needs a Firewatch you know how many you have on at that moment and where they are. If your refuel crane breaks you have a qualified PAR Tech on shift and available and you know exactly where he/she is.

9. What are the main benefits to optimizing outages? (Establishes how different stakeholders perceive benefits and may show competing objectives.). Why do we want to, or should we optimize outages?

Do the right maintenance at the correct time as safely and efficiently as possible to save Time, Money, Dose and improve worker/supervisor/manager life quality.

10. What are the most effective ways to optimize/reduce outage durations (not avoiding delays but rather optimizing from acceptable planned standards/durations)? Can you rank them from what is most effective to least effective? Provide at least 3 to 5. If necessary, I could provide the techniques and they rank them, but I am hopeful a skilled outage specialist will be able to list and rank.

- a. Industry best practice and OE, see what others are doing and how.
- b. Ensuring you are doing maintenance at the correct frequency. Often, we push critical items off just to keep duration low and then they negatively affect us during the cycle run. Likewise, our back up diesel may very infrequently run except for operational checks, and we could be doing part replacement on a scheduled based on a diesel running nearly 100% of the time, therefore fixing or preventing something that does not warrant it.
- c. Detailed levelization of manpower across the organization. This is done by qualification, experience, supervisors, foreman. Everyone one of these needs to be properly levelized. Say you have 21 experienced workers and 28 inexperienced you should have 18 experienced worker every day and 24 inexperienced with 3 and 4 off respectfully each day. If you let this bounce around, you could have 7 experienced off one day and 1 inexperienced which would be a bad ratio and likely a low productive day with 14 experienced workers and 27 inexperienced, so little oversight.

11. At your plant or previous plants, what were/are the constraints or inhibitors to implement shorter outage durations?

System windows and protected trains.

12. In your view what are the 5 things NPP Outage Organizations or their Leaders (CNO, VPs or Senior Managers) need to do to ensure Outages run on time or are optimized? The emphasis here is what Senior Leadership needs to drive...

- a. State of the art tooling
- b. Correct window durations
- c. Enough Operation folks to hang tags effectively and per schedule at start of outage
- d. Proper levelized manpower across all days and all shifts. This is very difficult but essential.

- 13. Are you aware of any outage optimization programs in your current plant or previous plants and can you name the top 1 to 3 in terms of what durations/time it could save? Are plants actively managing optimization or are they just taking it as it comes?**

Yes, we had simplified head packages to shorter critical path reactor vessel disassembly, major changes to large snubbers making the maintenance virtually non-existent.

Looking at best practices and measuring their success and pay back in the industry is key.

- 14. What other advice or feedback would you give to NPP leaders wrt outage optimization? 1 or more bits of advice that you feel strongly about.**

Don't Americanize it. Just making people work longer hours with less resources is not the answer. We have the opportunity to think differently from schedules, to work hours, to every aspect of how we conduct ourselves, don't get stuck with "This is how we always do it".

- 15. Do you have any other feedback, ideas, suggestions, and comments?**

Levelization is so little understood, and its impact is crucial.

Folks think we have 80 people here every day of the week, and its 40 per shift we are levelized. Not even close. You need to know your skills sets and leadership are levelized down to the smallest detail.

Topic Nuclear Outage Optimization

Participant: 4

Purposes:

- Identifying most common reasons for longer or delayed outages
- Identifying most effective ways to optimize outages
- Based on personal views and experience not theory
- Interview is voluntary
- You may and should express your views freely and challenge the interviewer at any time
- You may and should raise ethical concerns you may have and if necessary, withdraw from the interview.

Interview Questions

A: Biographical questions

1. What is your current or most recent role in the nuclear power plant?

I am currently Manager Maintenance Programs - Outage Maintenance Support Manager

2. How long have you worked in the nuclear industry or at the NPP?

I have been in nuclear for 15 years and at BNPP for 3.5 years.

3. How many outages have you participated in?

Around 15-20 as both in-house and loaned employee

4. Describe your main role or roles in nuclear outages (the bulk of them or most recent of them).

Welder/valve technician when I was craft, Maintenance Support Manager and Maintenance Outage Manager.

B: Outage Questions

5. What is an acceptable/reasonable duration of a planned outage for similar design to NPP where you worked before for?

- a. refuelling and statutory maintenance,
- b. then refuelling plus statutory plus standard maintenance at PWR,
- c. How or by whom is 'acceptable' determined?

Outage length is determined by many factors, some of which are cost, scope of work (safety related or broken items), grid demand, and project scope. For example, we had to modify our containment structure which was pushing the outage durations as well as cost. Most

plants strive for 30–40-day outages. Some plants use rapid refueling packages and have done them in 16 days.

6. To your knowledge, what is the best duration for a planned outage for a PWR, similar design to NPP where you worked before for?

- a. refuelling and statutory maintenance and
- b. then refuelling plus statutory plus standard maintenance

It depends. Some have done it in 16 days with a very limited scope while others have done outages in 90 days. Again, it depends on the SOW, cost, grid demands and projects.

7. Sometimes outages run later than planned. In your experience, what are the 3 or ideally 5 most common reasons for outages running later than planned (late or longer than planned outages)?

- a. **Please rank these reasons for outages running late from most common to least common.**
 - a. Emergent work
 - b. Poor work validation
 - c. Human performance errors
 - d. Venting and draining evolutions
 - e. Sufficient craft to perform

8. What are the best methods and techniques to avoid or mitigate outage delays?

- a. **Can you rank them from what is most effective to least effective? Provide at least 3 to 5.**

(If necessary, I could provide the techniques and they rank them, but I am hopeful a skilled outage specialist will be able to list and rank.)

- a. Dedicated team to walkdown/review packages prior to outage
- b. Successful oversight of contract workforce, ensuring they have the right standards
- c. Accurate LOTO times. This will not be known until the first performance but keeping notes to accurately reflect future outages is a key evolution.
- d. Only scheduling to 80% of your craft resources. This allows for a 20% emergent work cushion.
- e. Scope control

9. What are the main benefits to optimizing outages? (Establishes how different stakeholders perceive benefits and may show competing objectives.). Why do we want to, or should we optimize outages?

Optimizing outages reduces costs, both O&M and Capital, maintains margin and capacity factor on the grid and also conveys to the stakeholders that we know what we are doing and do it as scheduled. This reinforces our brand and confidence from the public.

10. What are the most effective ways to optimize/reduce outage durations (not avoiding delays but rather optimizing from acceptable planned standards/durations)? Can you rank them from what is most effective to least effective? Provide at least 3 to 5. If necessary, I could provide the techniques and they rank them, but I am hopeful a skilled outage specialist will be able to list and rank.

- a. Only schedule to 80%. Emergent work is going to happen so building a cushion is a key defense.
- b. Controlling the scope of work and only doing what is outage work. Many times, plants allow online type activities to enter into the outage. Outage work needs to be tightly controlled.
- c. Realistic timelines. Providing accurate job times and ensuring they fit into the outage is key. A big error that occurs often is that the work is “shortened” to fit into an outage window by someone who is not a technical expert (for example a scheduler). This can cause outage delays.
- d. Reduce HU events that require stand downs and work stoppages.
- e. Ensure alignment to standards with the supplemental workforce.

11. At your plant or previous plants, what were/are the constraints or inhibitors to implement shorter outage durations?

At my old plant, outages were never done on time. My plant was built in the 1960's and we always had a bunch of mod work. We also were not very concerned about cost as we were government funded. Our outage group also was very accepting of work, some of which should have been done online.

12. In your view what are the 5 things NPP Outage Organizations or their Leaders (CNO, VPs or Senior Managers) need to do to ensure Outages run on time or are optimized? The emphasis here is what Senior Leadership needs to drive...

- a. Be demanding customers and hold the groups accountable to meet their milestones and commitments
- b. Be engaged in the outage and not assume it is going well without checking.

- c. Knock down barriers (such as parts, SOW determination, etc.) to support the overall team
- d. Communicate, communicate, communicate to ensure alignment
- e. Be transparent in the drivers for the outage.

13. Are you aware of any outage optimization programs in your current plant or previous plants and can you name the top 1 to 3 in terms of what durations/time it could save? Are plants actively managing optimization or are they just taking it as it comes?

- a. Scope control was always a constant focus
- b. Using the vendor to provide trained resources (training certifying their programs)
- c. Using large tooling sharing programs between plants. For example, numerous plants share outage components and transport them from site to site based on outage dates.

14. What other advice or feedback would you give to NPP leaders wrt outage optimization? 1 or more bits of advice that you feel strongly about.

BNPP will not survive if we do not get the scope control process figured out. The PAT check outage is over 70% scope change which is not a good indication. Parts is another issue we will have to work on. And most importantly, there is not a good resource pool for the money we offer which will result, most likely, with numerous errors and mistakes causing outage delays. The old adage, "you get what you pay for" may end up ringing true for BNPP.

15. Do you have any other feedback, ideas, suggestions, and comments?

No. I have shared my ideas and experience. If you have further questions, let me know. I am always happy to help.

Topic Nuclear Outage Optimization

Participant: 5

Purposes:

- Identifying most common reasons for longer or delayed outages
- Identifying most effective ways to optimize outages
- Based on personal views and experience not theory
- Interview is voluntary
- You may and should express your views freely and challenge the interviewer at any time
- You may and should raise ethical concerns you may have and if necessary, withdraw from the interview.

Interview Questions

A: Biographical questions

1. **What is your current or most recent role in the nuclear power plant?**

Outage Turbine Lead

2. **How long have you worked in the nuclear industry or at the NPP?**

30 years

3. **How many outages have you participated in?**

At least 40

4. **Describe your main role or roles in nuclear outages (the bulk of them or most recent of them).**

Directly responsible for all preplanning and outage execution aspects for Turbine, Main Generator, and Auxiliary system Maintenance as the Sr Project Manager for the Entergy Fleet

B: Outage Questions

5. **What is an acceptable/reasonable duration of a planned outage for similar design to NPP where you worked before for?**

- a. **refuelling and statutory maintenance,**
- b. **then refuelling plus statutory plus standard maintenance at PWR,**
- c. **How or by whom is 'acceptable' determined?**

30-35 days or less with the Refuel project taking 25 days

6. **To your knowledge, what is the best duration for a planned outage for a PWR, similar design to NPP where you worked before for?**
- a. **refuelling and statutory maintenance and**
 - b. **then refuelling plus statutory plus standard maintenance**
- 30-35 days with Refueling taking 25 days
7. **Sometimes outages run later than planned. In your experience, what are the 3 or ideally 5 most common reasons for outages running later than planned (late or longer than planned outages)?**
- a. **Please rank these reasons for outages running late from most common to least common.**
 - a. Emergent Work is the most common followed by
 - b. Too much scope in schedule to execute and then
 - c. Improper planning or contingency plans
8. **What are the best methods and techniques to avoid or mitigate outage delays?**
- a. **Can you rank them from what is most effective to least effective? Provide at least 3 to 5.**
(If necessary, I could provide the techniques and they rank them, but I am hopeful a skilled outage specialist will be able to list and rank.)
 - a. Scope control
 - b. Adequate contingency plans
 - c. Adequate execution strategy for bulk work in the maintenance shops
9. **What are the main benefits to optimizing outages? (Establishes how different stakeholders perceive benefits and may show competing objectives.). Why do we want to, or should we optimize outages?**
- Due to expense of outages and lost generation for the company
10. **What are the most effective ways to optimize/reduce outage durations (not avoiding delays but rather optimizing from acceptable planned standards/durations)? Can you rank them from what is most effective to least effective? Provide at least 3 to 5. If necessary, I could provide the techniques and they rank them, but I am hopeful a skilled outage specialist will be able to list and rank.**
- a. Risk management planning
 - b. Properly trained personnel in key positions
 - c. Proper outage scoping

d. Proper planning for scope with adequate contingency plans

11. At your plant or previous plants, what were/are the constraints or inhibitors to implement shorter outage durations?

Funding was limited

12. In your view what are the 5 things NPP Outage Organizations or their Leaders (CNO, VPs or Senior Managers) need to do to ensure Outages run on time or are optimized? The emphasis here is what Senior Leadership needs to drive...

Proper scoping

Adequate funding to support contingency plans

13. Are you aware of any outage optimization programs in your current plant or previous plants and can you name the top 1 to 3 in terms of what durations/time it could save? Are plants actively managing optimization or are they just taking it as it comes?

Just outage procedure used by my previous company

14. What other advice or feedback would you give to NPP leaders wrt outage optimization? 1 or more bits of advice that you feel strongly about.

Procedurize the outage process and perform bench marking of good performance plants

15. Do you have any other feedback, ideas, suggestions, and comments?

Outage performance is a team sport, and everyone has to be engaged and proper communication is key

Topic Nuclear Outage Optimization

Participant: 6

Purposes:

- Identifying most common reasons for longer or delayed outages
- Identifying most effective ways to optimize outages
- Based on personal views and experience not theory
- Interview is voluntary
- You may and should express your views freely and challenge the interviewer at any time
- You may and should raise ethical concerns you may have and if necessary, withdraw from the interview.

Interview Questions

A: Biographical questions

1. What is your current or most recent role in the nuclear power plant?

My current title is Field and Inspection Services Manager in the Outage Maintenance Services function at BNPP. That position is responsible for planning and coordinating outage scope for activities associated with In-Service Inspections and Flow Accelerated Corrosion (ISI/FAC), Local and Integrated Leak Rate Testing (LLRT/ILRT), and Snubber testing. I am also responsible for assisting KEPCO with preparing for and executing some special outage work such as warranty repairs and wheel alignment on the Unit 1 Polar Crane.

2. How long have you worked in the nuclear industry or at the NPP?

I have been working in support of commercial nuclear power production for over 29 years.

3. How many outages have you participated in?

Hard to say exactly; probably at least 15

4. Describe your main role or roles in nuclear outages (the bulk of them or most recent of them).

This has varied widely over the years. During my most recent outage I was a contract Field Engineer responsible for ensuring work packages for all small-bore piping were properly carried out during a steam generator replacement project. For several previous outages, I was in charge of data collection and analysis of steam generator secondary side tube support inspections.

B: Outage Questions

- 5. What is an acceptable/reasonable duration of a planned outage for similar design to NPP where you worked before for?**
- a. refuelling and statutory maintenance,**
 - b. then refuelling plus statutory plus standard maintenance at PWR,**
 - c. How or by whom is 'acceptable' determined?**

For the plant where I spent the bulk of my career, my recollection is that getting through a refuelling outage in 30 days was a stretch goal. This was a Combustion Engineering System 80 NSSS design, which is the basis for the BNPP design. This was a plant that had been running for several cycles and had performed many RFOs. It was an organization that for many years was more driven by the Engineering organization rather than Operations, which tended to result in longer outages for installing new upgrades.

The acceptability question can be very complicated. In the US, local regulatory structures which govern each utility can produce significantly different drivers for what scope should be included into an outage. If a modification can be capitalized and included into the rate base, there is a strong financial motivation by the utility to do the work, even if it might extend the outage. On the other hand, expensive replacement power costs always result in an incentive to minimize outage time. In the final analysis, the outage must at a minimum be long enough to cover the refuelling and statutory requirements, and after that it's a negotiation on budget, efficiency, and reliability involving Engineering, regulators, distribution companies, and backup power providers, among others. At BNPP, we will have the additional factor of the priorities of our Team Korea partners to consider.

- 6. To your knowledge, what is the best duration for a planned outage for a PWR, similar design to NPP where you worked before for?**
- a. refuelling and statutory maintenance and**
 - b. then refuelling plus statutory plus standard maintenance**

For case (a), I think I've heard of CE plants getting refueled in about 20 days breaker to breaker.

Case (b) is too open-ended to answer – no plant has the same standard maintenance activities.

- 7. Sometimes outages run later than planned. In your experience, what are the 3 or ideally 5 most common reasons for outages running later than planned (late or longer than planned outages)?**

a. **Please rank these reasons for outages running late from most common to least common.**

- a. Emergent unanticipated issues, such as unexpected equipment failure
- b. Human performance issues, which results in additional work to recover from mistakes
- c. Stand downs following events which resulted in significant injury to personnel

8. What are the best methods and techniques to avoid or mitigate outage delays?

a. **Can you rank them from what is most effective to least effective? Provide at least 3 to 5.**

(If necessary, I could provide the techniques and they rank them, but I am hopeful a skilled outage specialist will be able to list and rank.)

- a. Employ experienced and knowledgeable planners and schedulers who can develop a logical and detailed overall plan which avoids conflicting actions
- b. Extensive pre-outage review sessions including vertical slice reviews and executive challenges
- c. Benchmarking visits to high-performing plants during their outages
- d. Seconding workers to high performing plants for outage support

9. What are the main benefits to optimizing outages? (Establishes how different stakeholders perceive benefits and may show competing objectives.). Why do we want to, or should we optimize outages?

- a. Cost: Outages are expensive to run with all the extra people on site, and every moment you're not online is lost revenue.
- b. Human performance: Operators get rusty over time when they are not keeping the routine of running an operating plant – long outages can increase the risk of performance problems on restart.
- c. Security: Minimize the number and duration of non-essential personnel in the Protected Area to maximize plant security

10. What are the most effective ways to optimize/reduce outage durations (not avoiding delays but rather optimizing from acceptable planned standards/durations)? Can you rank them from what is most effective to least effective? Provide at least 3 to 5. If necessary, I could provide the techniques and they rank them, but I am hopeful a skilled outage specialist will be able to list and rank.

- a. Same answers as to no. 8 for the most part
 - o Employ experienced and knowledgeable planners and schedulers who can develop a logical and detailed overall plan which avoids conflicting actions

- Extensive pre-outage review sessions including vertical slice reviews and executive challenges
 - Benchmarking visits to high-performing plants during their outages
 - Seconding workers to high performing plants for outage support
- b. I would also suggest ensuring that efforts are made to include the external stakeholders into the outage planning process, to ensure that any assumptions being made about grid capacity and backup power availability are validated
- c. Also encourage participation in industry forums and working groups (can be virtual, not necessarily requiring expensive missions); increase awareness of the tools and resources provided by our membership in organizations such as EPRI, INPO, PWROG, etc.

11. At your plant or previous plants, what were/are the constraints or inhibitors to implement shorter outage durations?

Every modification we made went into the rate base, which generated profit for the parent company – we never saw a project we didn't like. So, there was a predisposition to maximize profit at the expense of minimizing outage duration. Plus, there was plenty of backup power which the company also made money on, so no one was too concerned about reducing outage duration. Ratepayer advocates were ineffective in raising awareness of this. In summary, minimizing outage duration was not a priority. It was not considered to be a problem if our capacity factor was in a lower quartile

12. In your view what are the 5 things NPP Outage Organizations or their Leaders (CNO, VPs or Senior Managers) need to do to ensure Outages run on time or are optimized? The emphasis here is what Senior Leadership needs to drive...

- a. More than anything else by far, Senior Leadership should be regularly in the field seeing conditions for themselves, and talking to craft and supervision at the job site – this builds morale and greatly enhances comprehension of the challenges each job may face
- b. Ensure that we have alignment with our Korean partners on the expectations for running the outage 24/7, and that resources are made available to support that schedule
- c. Drive accountability with effective schedule updates at least shiftily, led by the OCC with a focus on completion of critical path and near critical path activities.
- d. Ensure that critical path job supervisors know they must come to OCC very quickly when problems arise which may affect schedule – OCC needs to be seen as a resource to help resolve problems, rather than an administer of pressure

- e. Manage the budget issues quickly and away from the OCC – supervisors need to know that they will be supported with decisions to incur additional cost when necessary, such as unanticipated overtime, or emergent material requests

13. Are you aware of any outage optimization programs in your current plant or previous plants and can you name the top 1 to 3 in terms of what durations/time it could save? Are plants actively managing optimization or are they just taking it as it comes?

The suggestions made in responses to questions 8 and 10 above are based on what I have seen at previous plants. I'm confident that the schedule review suggestions I've listed will be implemented by our Nawah Outage group, as I believe that we share similar backgrounds and standards in these areas.

14. What other advice or feedback would you give to NPP leaders wrt outage optimization? 1 or more bits of advice that you feel strongly about.

I believe that mutual respect and true teamwork are going to play a bigger role during outages here at BNPP than anyone has ever previously experienced. The pressure that most Americans are used to has a tendency to shorten tempers and occasionally erupt into anger and frustration. This will be very damaging if it occurs in this multicultural environment, and we all must take extra efforts to ensure that we act with dignity and professionalism at all times.

15. Do you have any other feedback, ideas, suggestions, and comments?

Nothing more

Topic Nuclear Outage Optimization

Participant: 7

Purposes:

- Identifying most common reasons for longer or delayed outages
- Identifying most effective ways to optimize outages
- Based on personal views and experience, not theory
- Interview is voluntary
- You may and should express your views freely and challenge the interviewer at any time
- You may and should raise ethical concerns you may have and if necessary, withdraw from the interview.

Interview Questions

A: Biographical questions

Opening statement is that participant is talking from a state-owned entity perspective and also only utility NPP in SA. Talks to availability of skills.

1. What is your current or most recent role in the nuclear power plant?

Part of maintenance governance meant to provide a framework for maintenance. In line with international maintenance standards to help the organization stretch itself to meet and achieve international standards. I had 3 maintenance specialists. However, the organization is busy changing. Not filling specialist positions. Requested to support maintenance to be ready to perform maintenance for unit 1. Recently maintenance restructured and the governance function is now redundant.

2. How long have you worked in the nuclear industry or at the NPP?

Since 1997. About 23 years. Progressed through maintenance and engineering at KNPS. Till about 2017. The last 3 years at BNPP in maintenance organization.

3. How many outages have you participated in?

Too many to count. Probably about 26 outages at Koeberg.

4. Describe your main role or roles in nuclear outages (the bulk of them or most recent of them).

On the execution side, supporting outage maintenance, maintenance support function like scaffolding, welding, rigging, etc.

Later maintenance Engineering programs. FAC, ISI, BAC, 1/3 of my career.

Last 3rd establishing maintenance work scopes and I&T and executing.

70-80% in execution.

Maintenance manager supervisor role.

5. What is an acceptable/reasonable duration of a planned outage for similar design to NPP where you worked before for?

a. refuelling and statutory maintenance and

b. then refuelling plus statutory plus standard maintenance at PWR?

c. How or by whom is 'acceptable' determined?

RFO duration typically like Koeberg. EDF benchmarks. About 46 hours unloading and 46 hours loading. Plant shutdown and restart. 21 days for start-up. 2 weeks to shut down. Plus 4 days. 35 days. Some in the USA has done refuel and statutory maintenance in 18 days.

There are other variables that one must factor in. There are more statutory things that must happen when you ramp down and ramp up.

About RFO and statutory maintenance outage, then in addition there is extra statutory maintenance. Based on regulator risk appetite, it can go from 18 to 20 days. Look at risk appetite. Try to bring as much scope online as possible to reduce outage work. Consider risk appetite of station to rely on built in redundancies. Koreans as I understand is very risk averse.

With standard maintenance, I would say it is a subset you need to look at maintenance regimes you can decide to run to failure. You need to develop a risk informed program for it. E.g., I have 4 similar sets of valves, not all 4. If I find something wrong with one valve only then do I maintain all the valves?

Refuel is a must. You must do all statutory inspections and maintenance. Non-stat maintenance should not extend the critical path.

How by whom is acceptable duration determined?

Outage duration is determined by the bean counters. At BNPP it was already determined by the PPA. This is where the prime assumption starts. Should also be part of your procurement specification. I want a unit that can deliver a specific available factor for example 95%.

Station management and CNO must ensure plant is reliable.

After that, the group responsible for pushing a shorter outage is the planning and production team.

In case of BNPP what is in the PPA is contracted and if they do not deliver, they are not performing.

At Koeberg outage durations were driven by the CEO. When WANO gives feedback, it is briefed at CEO level and if KNPS does not meet certain durations, it gets raised.

- 6. To your knowledge, what is the best duration for a planned outage for a PWR, similar design to NPP where you worked before for?**
- a. refuelling and statutory maintenance and**
 - b. then refuelling plus statutory plus standard maintenance**

Gave best durations from Koeberg plant with 157 elements and similar to majority of units in France and WEC units in the USA.

BNPP has 241 fuel elements. So will take more time than Koeberg.

For BNPP with 2 significantly large SGs vs Koeberg 3 SGs, BNPP might be a little longer.

Koeberg outage durations of 35 to 38 days. Koeberg can do better if they do more maintenance online. Maybe risk informed IST and risk informed maintenance.

- 7. Sometimes outages run later than planned. In your experience, what are the 3 or ideally 5 most common reasons for outages running later than planned (late or longer than planned outages)?**
- a. Please rank these reasons for outages running late from most common to least common.**
 - a. It's not normally the maintenance that extends outage durations. Operations activities tend take as long as they do. When plans are put together, it is often an aspirational plan. E.g., Mode durations/windows and often those windows are exceeded. And outage organization has very little control over operations.
 - b. Maintenance overruns often a lack of anticipation, not having contingencies to deal with scenarios that can come up and things that can go wrong.
 - c. Maintenance work actually going wrong adding to work durations.
 - d. What Koeberg has experienced is spares availability issues and contributed to outage durations.
 - e. Lack of skills. Have an ageing workforce.
 - f. Migrant workforce – people moving onto other areas like to BNPP. With an exodus of technical people to BNPP, Koeberg no longer has certain skills, and this contributes to outage duration extensions.

8. What are the best methods and techniques to avoid or mitigate outage delays?

- a. **Can you rank them from what is most effective to least effective? Provide at least 3 to 5.**

(If necessary, I could provide the techniques and they rank them, but I am hopeful a skilled outage specialist will be able to list and rank.)

One common thing is having a skilled workforce in the organization. People that know what is needed and have an ability to drive and achieve it.

9. What are the main benefits to optimizing outages? (Establishes how different stakeholders perceive benefits and may show competing objectives.). Why do we want to, or should we optimize outages?

- a. Production performance and cost factor. Maximize availability of units. Max revenue. The longer the outage the bigger the costs. The shorter the duration, the less the cost. Biggest driver is the money.
- b. Secondly is around safety. If you have a core, you want to have all safety systems operable to deal with the core. If you have your core in your spent fuel pool you have to keep certain safety systems going, like cooling. If you lose cooling for a certain duration, you have a certain time to boil. You are at greater risk.
- c. In western industry it's all about the money. That is why the west often criticize Europe and France. 70 to 80% in France and Europe vs 90% in USA. But France largely runs on load following. If load is low production goes down. That is a topic of another discussion.

10. What are the most effective ways to optimize/reduce outage durations (not avoiding delays but rather optimizing from acceptable planned standards/durations)? Can you rank them from what is most effective to least effective? Provide at least 3 to 5. If necessary, I could provide the techniques and they rank them, but I am hopeful a skilled outage specialist will be able to list and rank.

- a. For me, it is not effective way of optimizing questions. We should not keep scope constant. We must reduce outage scope. If you keep scope the same, you need to introduce smart way of working. Also, you need to add number of people which brings other burdens. The better way is to reduce the scope.
- b. After scope is reduced as much as possible what will you do. Plan smarter and work smarter.
- c. As a reference, I need to ask myself how Koeberg could work smarter and plan smarter. I think Koeberg could plan better.

- d. Have contingencies in place if something goes wrong.
- e. Another way of working smarter is to have swap outs, instead of opening, testing, and repairing a valve, rather have swap outs to replace the valve. Replace vs repair. Often quicker.
- f. Can also increase productivity on back shifts. Nights shifts are often very slow vs day shifts.

11. At your plant or previous plants, what were/are the constraints or inhibitors to implement shorter outage durations?

- a. Lack of skilled resources
- b. Non effective scope management
- c. Spares management was always a challenge. Often did not have essential spares in time for the outage.
- d. The station was ineffective in moving work online
- e. Discovery and breakdowns

12. In your view what are the 5 things NPP Outage Organizations or their Leaders (CNO, VPs or Senior Managers) need to do to ensure Outages run on time or are optimized? The emphasis here is what Senior Leadership needs to drive...

Participate in outage readiness reviews and help with those challenges, unlock challenges

13. Are you aware of any outage optimization programs in your current plant or previous plants and can you name the top 1 to 3 in terms of what durations/time it could save? Are plants actively managing optimization or are they just taking it as it comes?

The station had industry stakeholders assist with readiness reviews, especially for outages that included modifications. KNPS had a Maintenance Optimization Program, but it needed more focus and priority.

14. What other advice or feedback would you give to NPP leaders wrt outage optimization? 1 or more bits of advice that you feel strongly about.

Nothing further to add.

15. Do you have any other feedback, ideas, suggestions, and comments?

No, I'm good, thank you.

Topic Nuclear Outage Optimization

Participant: 8

Purposes:

- Identifying most common reasons for longer or delayed outages
- Identifying most effective ways to optimize outages
- Based on personal views and experience, not theory
- Interview is voluntary
- You may and should express your views freely and challenge the interviewer at any time
- You may and should raise ethical concerns you may have and if necessary, withdraw from the interview.

Interview Questions

A: Biographical questions

1. What is your current or most recent role in the nuclear power plant?

Nuclear Performance Management department. I deal with contractual issues related to maintenance and engineering functions.

2. How long have you worked in the nuclear industry or at the NPP?

Started in nuclear industry in 1987. About 33 years.

3. How many outages have you participated in?

When I left Koeberg, did outage 122. Therefore 44 scheduled outages.

Plus 5 or 6 forced outages.

4. Describe your main role or roles in nuclear outages (the bulk of them or most recent of them).

In my earlier days as a young person, I was involved with a lot of running around on the plant. Picked up lots of experience on the actual plant. Later moved in organization from one level to the next. Moved into supervisory and management roles in outage. Large part of my involvement was in non-outage before the outages by establishing contractual readiness. I was both the project manager and contract manager. My main focus was NDT in the group. Then veered into specialist of steam generator inspections. Qualified in NDE disciplines., ND, PT, UT, RT. Have certifications. Did plant inspections with techniques achieved. Mainly related to inspection activities. I was involved with turbine rotor inspections. Also was involved on secondary side in charge of all OSH Act inspections. Competent inspector for pressure vessels. Also got a GCC. Involvement on nuclear side mainly NDT. SGs, primary loops. RX pressure vessel, internals, fuel items like control rod guide card, CRDM, Eddy current, 1 RO activity. Involved with top head inspections following David Besse

incident. I continued to remain the senior advisor lead role for the big-ticket items SG, RPV, control rod, top head inspections, etc. From contract establishment. Positions in the group where I stood in as manager of I&T for a few years. Took over when my manager left.

B: Outage Questions

- 5. What is an acceptable/reasonable duration of a planned outage for similar design to NPP where you worked before for?**
- a. refuelling and statutory maintenance, 35 days**
 - b. then refuelling plus statutory plus standard maintenance at PWR, 45 days**
 - c. How or by whom is 'acceptable' determined?**

Two ways to classify outage. Refuel or maintenance.

Refuel you shut down, unload, reload. Min maintenance in that window where fuel is being refueled. Normal duration for refuel is 4 to 5 days both ways so total 8 to 10 days. 1 RO statutory is 12 days. When shutting down you cannot do certain things. The shutdown process is 10 days. With 10 days ramp up activities. Outage activities about 12 days in the middle. 33-to-35-day outages are very good.

1RO and statutory that needs to be done but there is also your 24 months and 36 months activities that need to be done. This is what can extend your maintenance window.

The 6 RO 10 yearly maintenance is when you do RP inspection. In these outages it can take longer. Eddy current also becomes critical path. The SGs at BNPP are a mandatory requirement but is only 10% sample. For SGs, you must take fuel out before doing any maintenance. For turbine, as soon as turbine stops spinning you can start maintenance. Does not depend on having fuel out. Can work on 1 train of feedwater.

Again, reasonable duration is 35 days.

Best at Koeberg was 38 days.

35 to 40 days is a good outage.

Long 10 yearly outages can be up to 60 days.

Aware of shorter durations

Must have got some relief on cool down temperatures.

Koeberg did not approach regulator for cool down temp relief.

Maybe they operate with nozzle dams to unload fuel while doing maintenance.

I would like to understand how they do it.

- 6. To your knowledge, what is the best duration for a planned outage for a PWR, similar design to NPP where you worked before?**
- 1. refuelling and statutory maintenance and**
 - 2. then refuelling plus statutory plus standard maintenance**

Koeberg, 35 days to 38 days

Private is shorter, aware but would like to know more.

US guys thinking about 30 days, would be interesting to see.

7. Sometimes outages run later than planned. In your experience, what are the 3 or ideally 5 most common reasons for outages running later than planned (late or longer than planned outages)?

a. Please rank these reasons for outages running late from most common to least common

1. Poor planning: Highest ranking.

Start at the front end. It goes around adequate planning. Lots of things don't get adequately planned and when you get to the execution you realize you left out something important that allows you to get to the component. Could be an incorrect isolation, forgot about scaffolding to get to the valve. Solution, sometimes not enough challenging by others who have more experience. Have you thought about things. Sometimes challenge sessions are seen as a waste of time but they are very important to make sure plan is accurate and best as possible. Sometimes it is personally difficult to hear people point out holes in plans, so people avoid being criticized.

2. Plant delays. Knock on effect of certain delays. For example, PMC crane breaks down. Or fuel rod gets stuck. Cannot be recovered easily. Can't really work faster. Not always a problem but can be a problem. Next highest if it happens.

3. Last one is rework. Poor maintenance, lack of maintenance, leaving out a gasket, then when doing requalification of component, it fails.

8. What are the best methods and techniques to avoid or mitigate outage delays?

a. Can you rank them from what is most effective to least effective? Provide at least 3 to 5.

(If necessary, I could provide the techniques and they rank them, but I am hopeful a skilled outage specialist will be able to list and rank.)

Refer to the previous question for some of the answers.

But in addition:

I always said to guys, anticipate what could go wrong. Risk management. Don't only look at what is happening on current shift. Look at bigger picture. Get a helicopter view.

Another point is communication. Be open about what you find. Don't hide behind smoke screen. Be honest and say this is a problem and this is how long you will take to fix it. Let people know they can be free to talk.

He did mention this, but I asked participant about staging, to get tools, equipment, spares, scaffolding, ladders, etc. Reply: It must be ready in advance, so this does not take up time. By time fuel is unloaded ECT team is relaxed and know all equipment is ready. Comms links and electronics are all set up in advance. Do plants get staging right most of the time? In early days we were not good at it but nowadays staging is very good. Where people do panic is with corrective work, cannot do staging in advance. Some additional info is that the maintenance support team generally looks at first week of outage and get ready accordingly. With 7-day plan, they set up scaffolding accordingly. They need to expect contingency scaffolding in case of emergent work. From experience they did not have the contingency scaffolding ready, sometimes scaffolding from planned work was taken to deal with emergent work.

9. What are the main benefits to optimizing outages? (Establishes how different stakeholders perceive benefits and may show competing objectives.). Why do we want to optimize outages?

The shorter your outage, the more you are online, the more money you will make.

10. What are the most effective ways to optimize/reduce outage durations (not avoiding delays but rather optimizing from acceptable planned standards/durations)? Can you rank them from what is most effective to least effective? Provide at least 3 to 5. If necessary, I could provide the techniques and they rank them, but I am hopeful a skilled outage specialist will be able to list and rank.

- a. Cutting down on duration. If you can for example optimize all work in specific location and at same time and optimize support required in that area. Don't 2 weeks later do work in the same room. You should have planned all activities in that location and room at the same time. Avoid duplication.
- b. One way of optimizing is good but at Koeberg we did not really get it right and probably will not get it right in BNPP. They do it in France and maybe in the US. Giving artisans or supervisors the ability to do more. E.g., when artisan works on a valve and needs

a block and tackle. He can do this himself. Instead, they give it to the support function. E.g., Lyndon. Instead, they should give the work to the artisan for certain types of rigging and lifting activities. The other skills that can be used is allowing them to do radiological survey when valve is open. At Koeberg we phone RP to do the survey. Should rather let the artisan to this. He and his assistant can do this.

- c. Sometimes having different requirements from Maint vs Eng. E.g., maintenance needs to do visual inspection. But same activity on valve that is qualified on ASME code to do VT 3 inspection. Someone working on a different program on same component on same system. E.g., corrosion plus VT can be done by the same person.

11. At your plant or previous plants, what were/are the constraints or inhibitors to implement shorter outage durations?

People were resistant to change, mindset, just don't like change to accept new challenges or do something differently. Might also be mindset of people as well, the way people do it, if people understand you are a qualified artisan. Now if I ask him to be mechanic, plus rigger plus, RP reader/monitor. If people see the benefit in getting qualification, more can be achieved.

12. In your view what are the 5 things NPP Outage Organizations or their Leaders (CNO, VPs or Senior Managers) need to do to ensure Outages run on time or are optimized? The emphasis here is what Senior Leadership needs to drive...

- a. The leaders should have experienced outages. Everyone in an outage management position should have outage experience in some or more ways. Reflect on PSC colleagues who don't understand plant. They come back with textbook solutions that do not work.
- b. What always impressed me was the presence of leaders in the work front. The manager did tube plugging. He said qualify me as well and got down to work. Being on the plant, following activities, saying if you need anything tell me. It adds value.
- c. Positive reinforcement motivation from managers.
- d. Pre-outage preparation, when you have challenge sessions have the senior management involved so that they understand the requirements and sequences. Their presence and participation.

13. Are you aware of any outage optimization programs in your current plant or previous plants and can you name the top 1 to 3 in terms of what durations/time it could save? Are plants actively managing optimization or are they just taking it as it comes?

I think it goes through phases. For example, getting people skilled in multi-disciplined. Koeberg tried this and got hit by unions. Seen as taking jobs from people.

Also, at BNPP onboarding process optimization is good. First time at BNPP. Good work being done to optimize this process. When FOSAR was done there was a 2-week delay that costed millions.

Training can be improved. Training aspect at BNPP is going to hurt us. Dealing with foreign countries and differences in training programs. A fair amount of work needs to be done with this.

VP has mentioned all training must be done off site. If our training programs have not accredited the contractor training programs, it will be a challenge. In France with 52 units people go from one station to the next. If they have done radworkers and FME for example is done at one station and then it is valid at the next plant and so on. It optimizes the in-processing time.

14. What other advice or feedback would you give to NPP leaders wrt outage optimization? 1 or more bits of advice that you feel strongly about.

I think they some managers don't really respect the skills that people have because there are some people who are very skilled in specific activities (not at BNPP). You mentioned something earlier on when I mentioned my own experience, am I in the right role? Are our skills being adequately utilized. For example, (name removed) is a skilled MMIS technician. He is working in PSC only because he wanted a foot in the door at BNPP. How many other people are in a similar situation. Another example is (name removed) as very qualified in NDT Phased Array inspections. Should we be using his skills better? Another person is (name removed) as very qualified in NDT Phased Array inspections. Should we be using his skills better?

15. Do you have any other feedback, ideas, suggestions, and comments?

No, I think we covered it.

Topic Nuclear Outage Optimization

Participant: 9

Purposes:

- Identifying most common reasons for longer or delayed outages
- Identifying most effective ways to optimize outages
- Based on personal views and experience, not theory
- Interview is voluntary
- You may and should express your views freely and challenge the interviewer at any time
- You may and should raise ethical concerns you may have and if necessary, withdraw from the interview.

Interview Questions

A: Biographical questions

1. What is your current or most recent role in the nuclear power plant?

Senior Mechanical Maintenance Specialist - Working for Outage Maintenance Services

2. How long have you worked in the nuclear industry or at the NPP?

31 Years

3. How many outages have you participated in?

More than 20

4. Describe your main role or roles in nuclear outages (the bulk of them or most recent of them).

Supporting the outage as the maintenance lead on the Balance of Plant Team.

B: Outage Questions

5. What is an acceptable/reasonable duration of a planned outage for similar design to NPP where you worked before for?

- a. refuelling and statutory maintenance, 35 days
- b. then refuelling plus statutory plus standard maintenance at PWR, 45 days
- c. How or by whom is 'acceptable' determined?

It depends on the amount of activities to be performed.

- 6. To your knowledge, what is the best duration for a planned outage for a PWR, similar design to NPP where you worked before for?**
- a. refuelling and statutory maintenance and
 - b. then refuelling plus statutory plus standard maintenance
- 45 days
- 7. Sometimes outages run later than planned. In your experience, what are the 3 or ideally 5 most common reasons for outages running later than planned (late or longer than planned outages)?**
- a. **Please rank these reasons for outages running late from most common to least common.**
 - a. Too much work scheduled into outage.
 - b. People not adhering to the outage schedule
 - c. Defects that need to be repaired during commissioning
- 8. What are the best methods and techniques to avoid or mitigate outage delays?**
- a. **Can you rank them from what is most effective to least effective? Provide at least 3 to 5.**
(If necessary, I could provide the techniques and they rank them, but I am hopeful a skilled outage specialist will be able to list and rank.)
 - a. Outage project leaders to have tabletop exercises with plant to discuss work scope and possible delays.
 - b. Ensure plant do proper spares check before outage.
 - c. Plant to ensure enough and qualified resources.
- 9. What are the main benefits to optimizing outages? (Establishes how different stakeholders perceive benefits and may show competing objectives.). Why do we want to, or should we optimize outages?**
- To ensure that the plant is well maintained during an outage and that unit can perform at its best during the next cycle
- 10. What are the most effective ways to optimize/reduce outage durations (not avoiding delays but rather optimizing from acceptable planned standards/durations)? Can you rank them from what is most effective to least effective? Provide at least 3 to 5. If**

necessary, I could provide the techniques and they rank them, but I am hopeful a skilled outage specialist will be able to list and rank.

- a. Ensure you have a good plan for the outage
- b. Ensure you have good resources
- c. Ensure you have all available spares

11. At your plant or previous plants, what were/are the constraints or inhibitors to implement shorter outage durations?

Short outage durations do not allow for proper plant maintenance

12. In your view what are the 5 things NPP Outage Organizations or their Leaders (CNO, VPs or Senior Managers) need to do to ensure Outages run on time or are optimized? The emphasis here is what Senior Leadership needs to drive...

- a. Ensure good communication
- b. When there are delays, ensure a proper plan is in place.
- c. Provide all necessary support to plant to execute activity.
- d. Leadership should be visible on plant to support.

13. Are you aware of any outage optimization programs in your current plant or previous plants and can you name the top 1 to 3 in terms of what durations/time it could save? Are plants actively managing optimization or are they just taking it as it comes?

Plant should support the outage 24/7

14. What other advice or feedback would you give to NPP leaders wrt outage optimization? 1 or more bits of advice that you feel strongly about.

None

15. Do you have any other feedback, ideas, suggestions, and comments?

No

Topic Nuclear Outage Optimization

Participant: 10

Purposes:

- Identifying most common reasons for longer or delayed outages
- Identifying most effective ways to optimize outages
- Based on personal views and experience, not theory
- Interview is voluntary
- You may and should express your views freely and challenge the interviewer at any time
- You may and should raise ethical concerns you may have and if necessary, withdraw from the interview.

Interview Questions

A: Biographical questions

1. What is your current or most recent role in the nuclear power plant?

Currently retired as of 2 months.

Previous role of contracts admin on a new build project, BNPP.

2. How long have you worked in the industry or at the NPP?

30 years.

3. How many outages have you participated in?

36

4. Describe your main role or roles in nuclear outages (the bulk of them or most recent of them).

My role at KNPS was reactor building coordinator for about 4 outages. Prior to that was maintenance outage manager working in a matrix structure working with maintenance manager at KNPS. Worked with all disciplines. Assisted with meeting outage preparation milestones. Coordinated with execution of maintenance in the outages.

5. What is an acceptable/reasonable duration of a planned outage for similar design to NPP where you worked before for?

- a. Refuelling and statutory maintenance,
- b. Then refuelling plus statutory plus standard maintenance at PWR,
- c. How or by whom is 'acceptable' determined?

Some NPPs shut down and only do statutory maintenance required and do the minimum maintenance that is required to start up again. Then there are maintenance outages where there is statutory maintenance per license agreement.

Plus, maintenance and corrective action.

Ideal refuelling and stat maintenance is about 25 days.

Ideal refuel plus CM and PM 38 to 40 days.

If certain modifications can be done, then outage durations can be reduced.

An upgrade to the refuelling cranes can make cranes go faster. How much time? You can probably save about 24 hours.

Modifications or revisions to the OTS which means for example certain equipment needed at certain stages of plant operation. E.g., Nawah going through the modes. Allows certain equipment to be operable in certain modes which restricts work at times. OTS looks at defense in depth, the more appetite you have for risk, the more you can do.

6. To your knowledge, what is the best duration for a planned outage for a PWR, similar design to NPP where you worked before for?

a. Refuelling and statutory maintenance and

b. Then refuelling plus statutory plus standard maintenance

Refuel and stat, CMs and PMs at Koeberg was 35 days. Before it was refuelling and maintenance in general.

From industry knowledge I am aware of 21 days refuelling and stat maintenance. In about 1998-1999.

From industry knowledge seen 55 days as full maintenance. Refuel. Stat. CMs and PMs in Koeberg.

7. Sometimes outages run later than planned. In your experience, what are the 3 or ideally 5 most common reasons for outages running later than planned (late or longer than planned outages)?

Please rank these reasons for outages running late from most common to least common.

- a. Equipment breakdown e.g., polar cranes, refuel cranes, etc. Fuel cranes do standard pre-outage maintenance and cannot know what can happen.
- b. The time taken (response) by maintenance to respond (response time) fix the breakdowns.
- c. Skills, having the right people on site. Identify upfront where you have a deficit in skills. Local or international. E.g., Koeberg has a big issue with support for polar crane maintenance. Koeberg having big delays and response to repairs. E.g., Lyndon and Christo don't work for Koeberg anymore. Mitigate by having OEM to support. This helps with skills. Do a risk analysis before outage and decide if they need the OEM. Is it more beneficial to have OEM at a certain cost when a breakdown happens.
- d. The other issue is when you have a plant defect, the Planner technician goes to Plant and does root cause of defect and then prepares a work package and has work package issued and then only does the person do the work. To reduce the response time, you send planner in to do the investigation or send FIN team technician in. FIN tech will do analysis. Will record in work instruction. Then artisan will do the work and then record what work has been done. So, the paperwork process is less with FIN than with the normal technician. In emergency, some processes are in parallel.
- e. The available spares to fix those components that breakdown to do repairs. How to mitigate this? Proactively as part of work package prep procedure, the technician planner does a risk assessment every time they prepare a work package, they must look at OE. See what spares are required based on history. Contingency spares must be ordered. Also, when the warehouse and maintenance department decide stock levels in stores and make provisions in stock levels. Reactively, if you did not make provision, then have a relationship and use emergency buy process and wait till the spare comes.

8. What are the best methods and techniques to avoid or mitigate outage delays? Can you rank them from what is most effective to least effective? Provide at least 3 to 5. If necessary, I could provide the techniques and they rank them, but I am hopeful a skilled outage specialist will be able to list and rank.

Same as number 7.

9. What are the main benefits to optimizing outages? (Establishes how different stakeholders perceive benefits and may show competing objectives.). Why do we want to, or should we optimize outages?

There is no direct answer to this. It depends based on the stakeholder being government owned or the perspective of a private stakeholder for revenue. For Koeberg utilities with current circumstances it is satisfying demand of country energy needs. In SA a dependable supply of electricity is favorable for foreign direct investment. How you get the balance? You don't want to spend money on outages and the benefit is not worth it. If you spend double warehouse stock but if no real demand for electricity, then it is not worth it. In SA right now there is a big need for optimization because of unreliability of coal plants. The outage does not run by itself. At Koeberg we use WEC FROM windows. Compared to other plants in France and we benchmark with those plants. If outages are too long, people get tired or fatigued and it leads to mistakes. In nuclear especially you want to avoid that.

- 10. What are the most effective ways to optimize/reduce outage durations (not avoiding delays but rather optimizing from acceptable planned standards/durations? Can you rank them from what is most effective to least effective? Provide at least 3 to 5. If necessary, I could provide the techniques and they rank them, but I am hopeful a skilled outage specialist will be able to list and rank.**

I see this the same as number 7 also. We discussed quite a bit on that topic.

- 11. At your plant or previous plants, what were/are the constraints or inhibitors to implement shorter outage durations?**

Who gets skills from various equipment OEMs like Fischer, German Schneider for pumps and valves Not in order. Spares availability. The ability of organization to adhere to schedule – big stopper at Koeberg, talking about performing activity when it is due. It's caused by unavailability of adequately skilled resources. There is now a dependence on so called OEMs like Framatome.

Also, the incentive where a lot of staff believe the longer the outage is, the more overtime there is. The money earned in overtime was far more than the incentive. Eskom is a government institution so organized labor comes into play. In SA it is difficult to penalize lack of performance in outage. They hide behind nuclear safety, saying "don't push me to get the job done".

Whereas at Nawah you don't have this constraint. For example, during startup at Koeberg there was a steam trap that was leaking. It was a little too high to reach. From a safety perspective we don't work on ladder as it is unsafe. We had to build a 2m squared scaffold. A ladder could have sufficed. Participant will tell me about this one day. If someone has it in his mind... don't preach safety and don't walk the talk. Then people work slowly and use safety as an excuse.

12. In your view what are the 5 things NPP Outage Organizations or their Leaders (CNO, VPs or Senior Managers) need to do to ensure Outages run on time? The emphasis here is what Senior Leadership needs to drive...

Adequate work package preparation. So, work package preparation in itself talks to a lot of things that go into an outage. There are 2 things, PMs and CMs. PMs, if you have all planning and materials, it is done well in advance. Planning work package and work instruction is ready. CM is different. Have to look at and project manpower to do the work. Koeberg does not have a resourced schedule. Just activities and a pipe dream or best estimate. A lot of companies will do resource planning. Koeberg works on lots of activities and say, "let's do in 35 days". Work package prep and info that goes into P6 from SAP is useful. P6 will take resource loading. Nawah has the ability to do resource levelling. The schedule must be realistic. Senior management should ensure resource levelling. I don't know if Nawah will have ORCC drive for outages.

13. Are you aware of any outage optimization programs in your current plant or previous plants and can you name the top 3 in terms of what durations/time it could save?

I'm not aware of any. There was an initiative to move maximum work online, but this has not received focus recently.

14. What other advice or feedback would you give to NPP leaders wrt outage optimization? 1 or more bits of advice that you feel strongly about.

Take care of your people and they will take care of you.

15. Do you have any other feedback, ideas, suggestions, and comments?

I think we discussed a lot in depth and hope you found it useful.

Topic Nuclear Outage Optimization

Participant: 11

Purposes:

- Identifying most common reasons for longer or delayed outages
- Identifying most effective ways to optimize outages
- Based on personal views and experience, not theory
- Interview is voluntary
- You may and should express your views freely and challenge the interviewer at any time
- You may and should raise ethical concerns you may have and if necessary, withdraw from the interview.

Interview Questions

A: Biographical questions

1. What is your current or most recent role in the nuclear power plant?

Outage preparation and execution

2. How long have you worked in the nuclear industry or at the NPP?

27 years (24 years at Koeberg Nuclear Power Station and 3 years at Barakah Nuclear Power Station)

3. How many outages have you participated in?

In excess of 25 refuelling outages, excluding Forced Outages (Short Duration Outages / Unit Trips)

4. Describe your main role or roles in nuclear outages (the bulk of them or most recent of them).

- Review proposed work scope as assigned to myself (per components or functional areas)
- Review schedules and the Critical Path
- Establish mitigations for high-risk activities
- Identify and coordinate contingencies
- Monitor and review execution of activities during outages
- Review new work

- 5. What is an acceptable/reasonable duration of a planned outage for**
- a. Refuelling and statutory maintenance and**
 - b. Then refuelling plus statutory plus standard maintenance at PWR**
 - c. How or by whom is 'acceptable' determined?**
- a. This depends on various strategies, plant rules, regulator commitments, programs requirements (statutory requirements) and corrective maintenance. Very short duration outages (less than 25days) have different rules and strategies (for example short shutdown duration, Unload of Fuel and immediate Reload of Fuel followed by start-up, minimal statutory and corrective maintenance activities) than longer duration outages. Stations with short outage durations do a lot of minor outages in-between and are not focused on extensive breaker to breaker operations. This duration reflects 18 – 26 days outage durations
 - b. This would be more relevant to KNPS than BNPP as BNPP will minimize the amount of activities allowed vs KNPS wanting to do as much as possible to have a plant returning to service with minimal defects/concerns. This duration reflects 35 – 43 days outage durations
 - c. This is determined by the Production Plan of each unit which is based on the Financial Model of that organization. National grid management also determines the acceptable allowable duration by considering other utilities.
- 6. To your knowledge, what is the best duration for a planned outage for a PWR, similar design to NPP where you worked before for?**
- a. Refuelling and statutory maintenance and**
 - b. Then refuelling plus statutory plus standard maintenance**
- a. 35 days with no modifications
 - b. 35 – 40days
- 7. Sometimes outages run later than planned. In your experience, what are the 5 or more most common reasons for outages running later than planned (late or longer than planned outages)?**
- a. Please rank these reasons for outages running late from most common to least common.**
- a. Unforeseen defects – 1st time events
 - b. Modifications which are poorly prepared

- c. Insufficient resources
- d. Emergent spares from abroad
- e. Poor maintenance of which the effects show in the PMT's
- f. Human error like misalignments

8. What are the best methods and techniques to avoid or mitigate outage delays?

- a. **Can you rank them from what is most effective to least effective? Provide at least 3 to 5.**

(If necessary, I could provide the techniques and they rank them but I am hopeful a skilled outage specialist will be able to list and rank.)

- a. Thorough reviews and tabletops together with actual staging of work areas beforehand.
- b. Dedicated resources for all critical and sub-critical activities
- c. Detailed and timeous feedback of critical and sub-critical activities
- d. Timeous completion of paperwork and updating of the various systems/tools, e.g., SAP and Primavera
- e. Minimize scope growth, investigate means/justifications to postpone repairs if possible

9. What are the main benefits to optimizing outages? (Establishes how different stakeholders perceive benefits and may show competing objectives.). Why do we want to, or should we optimize outages?

- a. Cost benefit – Shorter outage duration, means less manpower bill, more revenue for being online, less time to include additional work, and more time online reduces the insurance costs
- b. Dose reduction - Shorter outage duration and less work implies less accumulated radiation dose
- c. Safer plant - Less work, less opportunities for injuries to occur
- d. Better image - INPO level will become more positive

10. What are the most effective ways to optimize/reduce outage durations (not avoiding delays but rather optimizing from acceptable planned standards/durations)? Can you rank them from what is most effective to least effective? Provide at least 3 to 5. If necessary, I could provide the techniques and they rank them, but I am hopeful a skilled outage specialist will be able to list and rank.

- a. Perform more effective reviews throughout the preparation phase
- b. Move more work to online than doing it during outages

- c. Implement innovative methods of performing activities
- d. Challenge the norm while staying within the rules
- e. Change the rules of acceptance
- f. Perform more continuous improvement programs/initiatives

11. At your plant or previous plants, what were/are the constraints or inhibitors to implement shorter outage durations?

- a. Surveillances and programs requiring excessive activities to be done during outages
- b. Being heavily reliant on the OEM and foreign experts to influence decisions
- c. Accepting new works into the outage scope after scope freeze (increased scope growth)
- d. Lack of sufficient supervision

12. In your view what are the 5 things NPP Outage Organizations or their Leaders (CNO, VPs or Senior Managers) need to do to ensure Outages run on time or are optimized?

The emphasis here is what Senior Leadership needs to drive...

- a. Agree to which KPI the organization must focus, e.g., Duration vs Cost vs Scope vs Procedure Use and adherence vs Dose
- b. Once accepted not to allow any additional activities into the outage, to realize when new activities will be slotted in and the consequences to those outages

13. Are you aware of any outage optimization programs in your current plant or previous plants and can you name the top 1 to 3 in terms of what durations/time it could save?

Are plants actively managing optimization or are they just taking it as it comes?

- a. Vacuum filling – Filling the Steam Generator tubes prior to Reload, resulting in no to minimal need for dynamic filling, time saving of up to 2 days
- b. We implemented task teams to focus on specific activities e.g., nuclear valves, pump station works, turbine auxiliary works, LLRT group
- c. We upgraded Tech Specs to allow some of the following:
 - a. Not 100% of the Steam Dump valves have to be tested every outage, but rather staggered out
 - b. Distinguished between containment closure vs containment integrity
- d. Manufactured special temporary devices for each unit, eliminating cross unit use of equipment

14. What other advice or feedback would you give to NPP leaders wrt outage optimization? 1 or more bits of advice that you feel strongly about.

Listen to the people doing the works and give them an opportunity to execute their ideas, within reason that is. More often the success lies in the obvious suggestions.

15. Do you have any other feedback, ideas, suggestions, and comments

- Ensure proper training is given to employees who have to use tools in place, e.g., SAP and Primavera, as it is intended to be used, not butchered to what individuals think it should do.
- Do benchmarking to utilities where these tools are being used and are actually interfacing, not only looking at utilities for their INPO status or plant designs.

Topic Nuclear Outage Optimization

Participant: 12

Purposes:

- Identifying most common reasons for longer or delayed outages
- Identifying most effective ways to optimize outages
- Based on personal views and experience, not theory
- Interview is voluntary
- You may and should express your views freely and challenge the interviewer at any time
- You may and should raise ethical concerns you may have and if necessary, withdraw from the interview.

Interview Questions

A: Biographical questions

1. **What is your current or most recent role in the nuclear power plant?**
Head of Outage Preparation/ Execution
2. **How long have you worked in the nuclear industry or at the NPP?**
27 years
3. **How many outages have you participated in?**
15
4. **Describe your main role or roles in nuclear outages (the bulk of them or most recent of them).**
My role at the Koeberg NPP was to manage the preparation and execution of Refuelling outages. In addition to that a secondary function was to manage Forced outages. Currently my function at the Barakah NPP is to establish processes to manage the preparation phase of the warranty outage after the power ascension testing is completed and then progress to the Refuelling outages later.

B: Outage Questions

5. **What is an acceptable/reasonable duration of a planned outage for?**
 1. Refuelling and statutory maintenance and
 2. Then refuelling plus statutory plus standard maintenance at PWR?
 3. How or by whom is 'acceptable' determined?

- a. Depending on the strategy as well as the limitations of the specific Technical Specifications, it could range from 28 days to 40 days)
- b. 45 to 60 days.
- c. This could be determined by Snr Leadership/Board of directors if financial returns for life of plant is taken into consideration. It could also be determined by the need for electricity availability, and if this case it would be the owner of the electricity grid owner.

6. To your knowledge, what is the best duration for a planned outage for a PWR, similar design to KNPS or BNPP for?

- 1. refuelling and statutory maintenance and
 - 2. then refuelling plus statutory plus standard maintenance
- a. 35 to 40 days
 - b. 50 days

7. Sometimes outages run later than planned. In your experience, what are the 5 or most common reasons for outages running later than planned (late or longer than planned outages)?

- 1. **Please rank these reasons for outages running late from most common to least common.**
 - a. Outage preparation not completed with quality
 - b. Discovery work during the execution phase of the outage
 - c. Lack of ownership to manage the critical path of the outage
 - d. Lack of decision making when required
 - e. Lack of measurement for tracking activities to be executed

8. What are the best methods and techniques to avoid or mitigate outage delays?

- 1. **Can you rank them from what is most effective to least effective? Provide at least 3 to 5.**

(If necessary, I could provide the techniques and they rank them, but I am hopeful a skilled outage specialist will be able to list and rank.)

- a. Protect the critical path by having a team looking at upcoming activities and ensure those activities are ready to be executed
- b. Establish communication protocol to communicate the progress of the outage
- c. Ensure contingencies are in place for high-risk activities

9. What are the main benefits to optimizing outages? (Establishes how different stakeholders perceive benefits and may show competing objectives.). Why do we want to, or should we optimize outages?

- a. By optimizing outages, we can determine when equipment maintenance will take place (Strategic engineering)
- b. It is more beneficial to stay online for as long a period as possible to generate an income (Board of Directors/Grid owners)
- c. It is also safer to be online than to be in specific plant shutdown conditions (Regulator)
- d. Also, good to have shorter outages to minimize fatigue of the staff

10. What are the most effective ways to optimize/reduce outage durations (not avoiding delays but rather optimizing from acceptable planned standards/durations)? Can you rank them from what is most effective to least effective? Provide at least 3 to 5. If necessary, I could provide the techniques and they rank them, but I am hopeful a skilled outage specialist will be able to list and rank.

- a. Establish good communication protocols
- b. Don't deviate from the plan unless absolutely necessary
- c. Ensure contingencies are in place
- d. Challenge durations during the preparation phase
- e. And remember work vs duration vs resources

11. At your plant or previous plants, what were/are the constraints or inhibitors to implement shorter outage durations?

- a. Operation Technical Specification constraints
- b. Being isolated by only having 2 commercial reactors
- c. Being dependent on international resources availability
- d. And over conservatism with regards to risk taking

12. In your view what are the 5 things NPP Outage Organizations or their Leaders (CNO, VPs or Senior Managers) need to do to ensure Outages run on time or are optimized? The emphasis here is what Senior Leadership needs to drive...

- a. Drive the preparation to execute window
- b. Be visible to support the outage organization
- c. Establish a senior leader window owner
- d. Drive organizational accountability and
- e. Minimize scope

- 13. Are you aware of any outage optimization programs in your current plant or previous plants and can you name the top 1 to 3 in terms of what durations/time it could save? Are plants actively managing optimization or are they just taking it as it comes?**

I am not aware of any optimization programs for outages. The only strategy that I know of is the alignment to the preparation documentation which covers milestone adherence. After that during the execution phase it is managed as the need arises

- 14. What other advice or feedback would you give to NPP leaders wrt outage optimization? 1 or more bits of advice that you feel strongly about.**

Establish a clear strategy and ensure the organization is completely aligned to it

- 15. Do you have any other feedback, ideas, suggestions, and comments?**

Outages is a team sport. This requires complete alignment from all. Celebrate successes and seek to understand challenges as they arise. Operation experience is important to a successful outage.

APPENDIX C – A PROCESS USED TO INTERPRET THE FINDINGS

4.1 INTRODUCTION

The literature review has been a means to ascertain answers to the research questions, mainly seeking to identify the most effective methods to optimize durations of planned outages. This chapter reports on findings from interviews with 12 nuclear outage professionals who have extensive experience in outages and maintenance. Their perspectives on the research questions provide valuable insights and opportunity to compare with the literature and with each other. The first four questions are biographical questions that provide the reader with a good sense of the participants' experience and suitability as participants. The remaining questions 5 to 15, deal specifically with the research questions regarding optimization.

The sample of six participants from the USA and six from South Africa presents an additional opportunity to identify any possible similarities and differences not only between participants but also between countries, which may have either similar or different cultures, methodologies, and operating models for NPPs and outages. Participants were keen to support and participate in the research, especially given that it is a field that they have significant experience in. This experience was evident from the considerable years of nuclear experience and number of outages they have been involved in. The author noted all answers during the interview and validated understanding of the answers after each question. Some participants explained in more detail whilst others were very direct. Interviews took about 60-75 minutes each. This chapter presents each question in sequence followed by the answers and an analysis thereof. It concludes with a summary of key findings and analysis.

4.2 INTERVIEW QUESTION 1

What is your current or most recent role in the nuclear power plant?

4.2.1 Question 1 Answers

Participants provided their current roles in the nuclear industry and one elaborated on his overall experience. Below is a summary of their responses.

- a. Previously I&C Supervisor/ I&C Engineer in Maintenance on BNPP 1&2. Currently I&C Job Path Lead with Outage Management at BNPP.
- b. Outage Maintenance Services Manager-Components
- c. Outage Services – Turbine Manager
- d. Manager Maintenance Programs - Outage Maintenance Support Manager
- e. Outage Turbine Lead
- f. Field and Inspection Services Manager - Outage Maintenance Services

- g. Director – Maintenance Governance
- h. Technical Contracts Manger - Nuclear Performance Management
- i. Snr Mechanical Maintenance Specialist - Outage Maintenance Services
- j. Head of Contracts Administration - Maintenance and Outages
- k. Lead - Outage Preparation and Execution
- l. Head of Outage Preparation and Execution

4.2.2 Question 1 Analysis

All participants are currently active in the nuclear power plant industry. Their role descriptions show they are working directly in the outage and maintenance disciplines in various senior or specialist roles. The roles are also varied, for example Outage Services Turbine Manager and another is Technical Contracts Manager for Outages. This diversity and depth demonstrate good work experience relevant to the subject matter of this dissertation.

4.3 INTERVIEW QUESTION 2

How long have you worked in the nuclear industry or at the NPP?

4.3.1 Question 2 Answers

Table 4.1 shows the participants' years of experiences categorized and Figure 4.1 below provides a graphical view of the participants' nuclear experience.

Table 4.1: Participant Years' Nuclear Experience

Years' Experience	10-20	21-30	31-40	41-50
Participant Count	1	6	4	1

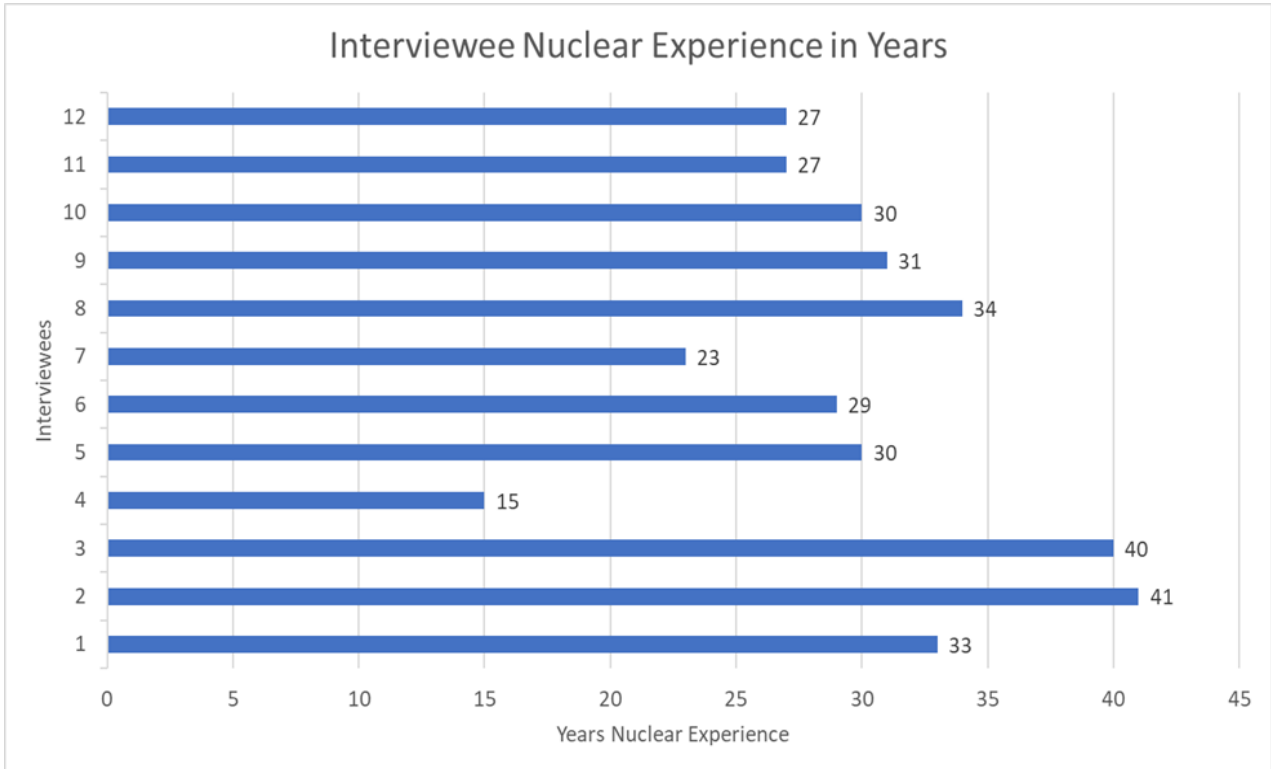


Figure 4.1: Participant Nuclear Experience in Years

4.3.2 Question 2 Analysis

The 12 participants collectively have 360 years of work experience in the nuclear industry and on average, they each have 30 years’ experience. The person with least experience has 15 years and the one with the most has 41 years. In summary, the participants have significant nuclear experience, and their views could be considered credible, even if they have different experiences and perspectives on topics.

4.4 INTERVIEW QUESTION 3

How many outages have you participated in?

4.4.1 Question 3 Answers

Table 4.2 shows the number of outages participants had participated in, categorized in ranges. Figure 4.2 shows the number of outages each participant has participated in.

Table 4.2: Participant Years’ Nuclear Experience Grouped

Number of Outages Participated	10-20	21-30	31-40	40-50
Participant Count	4	3	3	2

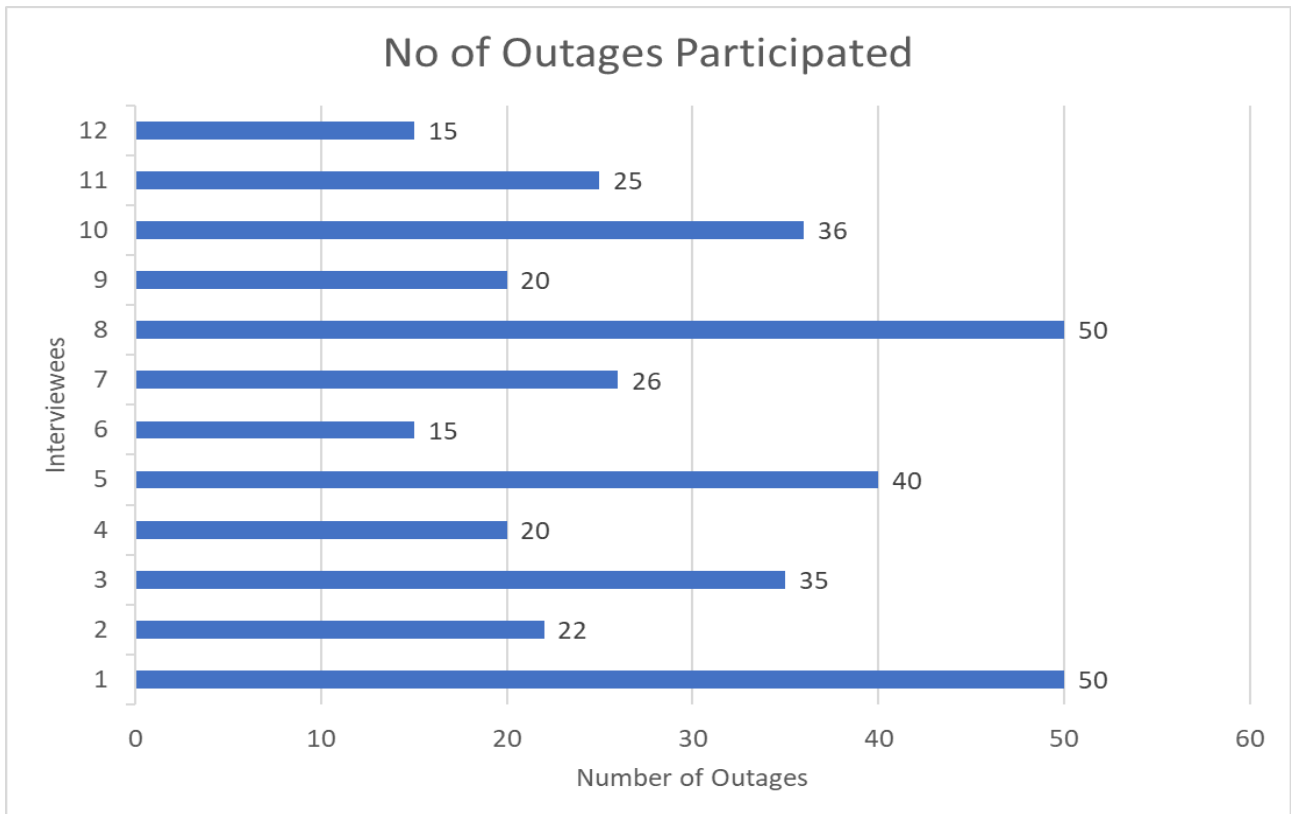


Figure 4.2: Number of Outages Each Participant Participated In

4.4.2 Question 3 Analysis

The 12 participants have collectively participated in at least 354 outages. They indicated that they participated in “at least” the amount stated as none of them kept an exact tally, but the figure could be higher. On average, they have each participated in 30 outages. The minimum outages participated in by one person was at least 15 and the most was 50 or more. It is fair to conclude that together with the roles they fulfil, the individual and collective years’ experience in nuclear and now the number of outages each participant has participated in, the participants have significant specific nuclear outage experience and their views on outages could be considered credible.

4.5 INTERVIEW QUESTION 4

Describe your main role or roles in nuclear outages (the bulk of them or most recent of them).

4.5.1 Question 4 Answers

The participants described some of the positions they held over the years in performance of outages to fall typically into one of or close to the following categories:

- Journeyman / Craft
- Supervisor
- RP Tech

- Engineering
- FIN Manager
- OCC
- Maintenance Outage Manager
- Reactor Building/Containment Coordinator
- Maintenance Support Manager (Outages)
- Mechanical Maintenance Manager
- Safety Manager
- "Outage Planning and Execution
- Project Manager"

4.5.2 Question 4 Analysis

The roles that the participants have played during outages demonstrated that they all have depth of experience as well as diversity in experience, all related to nuclear outages and maintenance. This brings meaningful and different perspectives. Their demonstrable work experience gives credibility to the views they expressed during the interviews.

4.6 INTERVIEW QUESTION 5

What is an acceptable/reasonable duration of a planned outage for similar design to NPP where you worked before or BNPP or both?

- a. Refuelling and statutory maintenance
- b. Refuelling, statutory and standard/extended maintenance

4.6.1 Question 5a Answers (Refuelling and Statutory Maintenance)

Question 5a tested participants' views on what they believed to be an acceptable or reasonable duration for an outage with refuelling and statutory maintenance for a PWR. Note, the IAEA refers to statutory maintenance as standard maintenance whereas different plants may use the terminology differently. Therefore, in the interviews, the participants and interviewer use the words statutory independently of standard/extended maintenance. Statutory maintenance was for refuelling plus maintenance that had to be done to meet license or code requirements. Standard/extended maintenance generally refers to statutory plus any other additional maintenance included in the official scope but excludes major modifications.

Table 4.3 below shows the responses of each candidate. The responses have been grouped into three categories and color coded for easy visualizing. The participant responses varied quite significantly. Four participants indicated that acceptable or reasonable outage durations for refuelling and statutory maintenance was in a range of 18 to 26 days. Seven responses advocated a duration ranging between 30 and 45 days. One participant was not able to provide a duration and answered

that “it depends” but did not elaborate except to say each outage is different. This candidate was a system specialist and worked at a more operational level, executing maintenance, rather than planning or managing outages.

Table 4.3: Acceptable Duration for Refuel and Statutory Maintenance

Participant	1	2	3	4	5	6	7	8	9	10	11	12
5a. Outage Duration (days) Refuelling & Statutory Maintenance	30-45	20	30-35	28-40	30-40. (Some in 16)	30-35	18-20	33-35	It depends. No number given.	25	18-26	28-40

4.6.2 Question 5a Analysis (Refuelling and Statutory Maintenance)

Recall the literature review where the IAEA (2016) reported refuelling outages could be done in 7 to 18 days; and refuelling and standard (statutory) maintenance outages could be done in 14 to 23 days. The lower 18–26-day range by the four participants was reasonably close to the IAEA benchmarks and what top NPPs should be striving for. These four participants must be more aware of what was acceptable and what is happening at other plants through various means such as personally keeping abreast of industry norms and standards, or their work involved benchmarking and improving outage durations.

The seven participants who stated the higher range of 30-45 days were likely exposed to plants and experience where optimizing outage durations were not a significant focus and possibly, they did not follow industry norms. NPPs who do not focus on pursuing the shortest possible outages, are often state owned with a different mandate, and driving short outages and hence profits were not a priority. As intimated in the literature review, optimized outage durations are beneficial for organizations driven by profits and the bottom line as well as for state owned and even hybrid organizations.

These results show that not enough employees are aware or orientated towards achieving the shortest and most optimized outage durations. This presents an opportunity to further study the thinking, culture, and practice in each NPP and where required, reinforce the benefits of optimized outage durations, and make it part of the strategic and operational objectives. It is an opportunity to educate staff and entrench continuous improvement on the journey towards optimized outages. For KNPS, there is a clear benefit to increase the Energy Availability Factor (EAF) and reduce load shedding to the benefit of South Africa. In the case of new plants preparing for a first planned outage, it is recommended to set clear objectives, make the outage goals and durations visible to all, and building it into the performance contracts of all relevant employees. A new plant has the time

advantage to invest in planning and resourcing, to achieve the shortest possible outage early and build on this foundation. Placing this high-performance peg in the ground early on, sets the tone for future outages.

4.6.3 Question 5b Answers (Refuelling, statutory and standard/extended maintenance)

Question 5b tested participants' views on what they believed to be an acceptable or reasonable duration for an outage with refuelling, statutory plus standard/extended maintenance. Table 4.3 below shows the responses of each candidate. The responses have been grouped into four categories and color coded for easy visualizing. Participant number 9 gave the same response as before saying, "it depends". Participant number seven provided a response of 18-20 days, consistent with the response given in question 5a. Eight responses reported durations in the 28–40-day range. Two responses (in orange) indicated 45-60 days.

Table 4.4: Acceptable Duration for Refuel, Statutory and Standard Maintenance

Participant	1	2	3	4	5	6	7	8	9	10	11	12
5b. Outage Duration (days)												
Refuelling, Statutory & Standard Maintenance	45-60	28	30-35	30-40	30-35	30-35	18-20	33-35	It depends. No number given.	38-40	35-43	45-60

4.6.4 Question 5b Analysis (Refuelling, statutory and standard/extended maintenance)

The literature review showed the IAEA believed that refuelling plus standard/extended maintenance could be completed in 15 to 40 days. The one response stating 18-20 days appeared ambitious. The nine responses ranging from 18-43 days were in close proximity to the IAEA benchmarks and somewhat consistent with the 35 days average duration reported by Hickman (2017). Those who stated the higher range greater than 35 days were likely exposed to NPPs who were not top performers or were not necessarily aiming for the shortest possible outages. If their paradigm is on the higher side of 35-60 days, it could translate into their beliefs when doing work and they may not be planning and executing optimally. This could be restricting the performance of an organization without managers and leaders knowing about it. This presents an opportunity for further investigation, rectification, and improvement to achieve outage durations closer to IAEA benchmarks.

4.6.5 Question 5a and 5b comparison

Table 4.5 compares the participants' responses to questions 5a and 5b. Most of the participants' responses remained the same or changed just a little when adding standard/extended maintenance. This could imply that statutory and standard maintenance could be optimized and managed in parallel such that any standard maintenance did not add to the outage duration and that the extended maintenance usually added only a small percentage of extra time. Four participants reported that standard maintenance added 33%-65% extra time. This is likely a reflection of their own experiences at their previous NPPs and how work was practiced there. It is not aligned to any of the literature or best practice.

Table 4.5: Comparison of 5a and 5b Acceptable Outage Durations

Participant	1	2	3	4	5	6	7	8	9	10	11	12
5a. Outage Duration (days) Refuelling & Statutory Maintenance	30-45	20	30-35	28-40	30-40. (Some in 16)	30-35	18-20	33-35	It depends. No number given.	25	18-26	28-40
5b. Outage Duration (days) Refuelling, Statutory & Standard Maintenance	45-60	28	30-35	30-40	30-35	30-35	18-20	33-35	It depends. No number given.	38-40	35-43	45-60

4.7 INTERVIEW QUESTION 6

To your knowledge, what is the **best** duration for a planned outage for a PWR, similar design to NPP where you worked before or BNPP or both for?

- a. Refuelling and statutory maintenance
- b. Refuelling, statutory and standard/extended maintenance

4.7.1 Question 6a Answers (Refuelling and statutory maintenance)

Question 5 evaluated responses about acceptable/reasonable outage durations. On the other hand, Question 6 investigated participants' responses to what the "best" duration could be, raising the bar.

The question aimed to evaluate participants' knowledge, experience, and views on best or fastest outage durations for refuelling and statutory maintenance outages in the industry. The responses are shown in Table 4.6 below. Six participants answered in the range of 16-25 days. Four answered in the range of 35-40 days. The remaining two indicated 45-60 days.

Table 4.6: Best Duration for Refuel and Statutory Maintenance

Participant	1	2	3	4	5	6	7	8	9	10	11	12
6a. Outage Duration (days) Refuelling & Statutory Maintenance	60	22	25	16	25	20	35-38	35-38	45	21	35	35-40

4.7.2 Question 6a Analysis (Refuelling and statutory maintenance)

It was encouraging that six of the participants are aware of sub-25-day outages. This sets up the organization for success. One participant responded with 60 days. This participants' responses thus far have all been on the higher end of the spectrum which may suggest his personal experiences, and possibly also not being aware of industry performance benchmarks. This participant had the most years working in nuclear and the responses with such long durations are surprising. To focus the interview on the interview questions and considering the interview time, the author did not probe extensively. A second participant indicated that the best outage duration was 45 days. This too is substantially higher than the industry benchmarks. Whilst it may be a best duration based on the participant's own knowledge, it was surprising that that the participant was unaware of the industry norms especially in the USA. Importantly, this participant was the same person who in questions 5a and 5b responded with "it depends". There is benefit in investigating to what extent these views are shared within an organization. If widespread, it presents both a risk and opportunity. The risk being that if nothing is done to change these views or paradigms, it may become the smell of the place, the way we do things around here. The opportunity is the work to be done to understand the rationale behind these views and implement a change initiative to shift towards a paradigm and culture for higher performance and faster outages.

4.7.3 Question 6b Answers (Refuelling, Statutory and Standard/Extended maintenance)

For best outage durations including standard/extended maintenance, three participants' answers were in a range of 16-28 days. Four responded in a range of 30-40 days. Another four responded in

a range of 45 right up to 70 days. One responded that “no plant has the same standard maintenance activities”. The responses are shown in Table 4.7.

Table 4.7: Best Duration for Refuel, Statutory and Standard/Extended Maintenance

Participant	1	2	3	4	5	6	7	8	9	10	11	12
6b. Outage Duration (days) Refuelling, Statutory & Standard Maintenance	70	28	25	16 up to 90 (depends on the scope)	30-35	no plant has the same standard maintenance activities	35-38	35-38	45	55	35-40	50

4.7.4 Question 6b Analysis (Refuelling, Statutory and Standard/Extended maintenance)

Three participants responded with durations between 16 and 28 days. The 16 days duration was very optimistic and more inclined towards refuelling and statutory maintenance. Once standard maintenance is added the number tends to increase. Collectively, seven responses ranged between 16 and 40 days. This is to a large extent in line with the average duration of 35 days reported by Hickmann (2017). Four responses ranged between 45 to 70 days, with 50, 55 and 70 days on the higher end of the spectrum. Further investigation is required because if this thinking permeates an organization, deliberate effort is required to improve knowledge, awareness and thinking to reduce outage durations.

4.7.5 Question 6a and 6b Compared

Seven participants increased their duration estimates when adding standard maintenance. The increase varied between 5 and 34 days. Table 4.8 shows the comparison.

Table 4.8: Comparison of 6a and 6b Best Outage Durations

Participant	1	2	3	4	5	6	7	8	9	10	11	12
6a. Outage Duration (days) Refuelling & Statutory Maintenance	60	22	25	16	25	20	35 - 38	35 - 38	45	21	35	35 - 40
6b. Outage Duration (days) Refuelling, Statutory & Standard Maintenance	70	28	25	16 up to 90 (depends on scope)	30 - 35	no plant has same standard maintenance activities	35 - 38	35 - 38	45	55	35 - 40	50

From the literature, standard maintenance generally could add 10-15 days. If it goes far beyond 15 days extra, this is normally due to modifications. Individuals who reported far more, may be recalling experiences from their own plants where the outages went more than 15 days over, but they did not specify the reasons. Typical reasons include equipment breakdowns during the outage (e.g., polar crane), or spares that arrive late. The reasons can only be a few and again presents an opportunity for further investigation. Either way, allowing the mindset in an organization to tend towards outages longer than 40 days including standard maintenance is not beneficial to an NPP aiming to set high standards.

For a plant like KNPS, low morale and lack of resources may be a direct cause of less stellar performance. For a new plant, it will take time to find a rhythm where sub-40-day outages are a norm but setting the reference objectives and tone up front is essential. Whilst it has been observed in industry that outages gone wrong due to reasons such as faulty polar cranes or late spares can easily add 10 to 20 days to an outage, taking it from 35 days to 55 or from 40 days to 60 days quickly do happen, one cannot allow this to be the norm. Consequently, NPPs new or mature, cannot allow its employees to think that 55-, 60- or 70-day outages is acceptable.

In any NPP, it is recommended to survey the maintenance and outage organization as a whole. Survey instruments that test participants' knowledge, experience and views can be set up to

objectively measure the gap between best practice and the organizational mindset. This will help implement the correct measures to work towards a top tier outage organization.

4.8 INTERVIEW QUESTION 7

Sometimes outages run later than planned. In your experience, what are the 3 or ideally 5 most common reasons for outages running later than planned (late or longer than planned outages)?

4.8.1 Question 7 Answers

The question looked for common reasons for outages running later than planned. Figure 4.3 shows the participants' responses ranging from most frequent to least frequent reason.

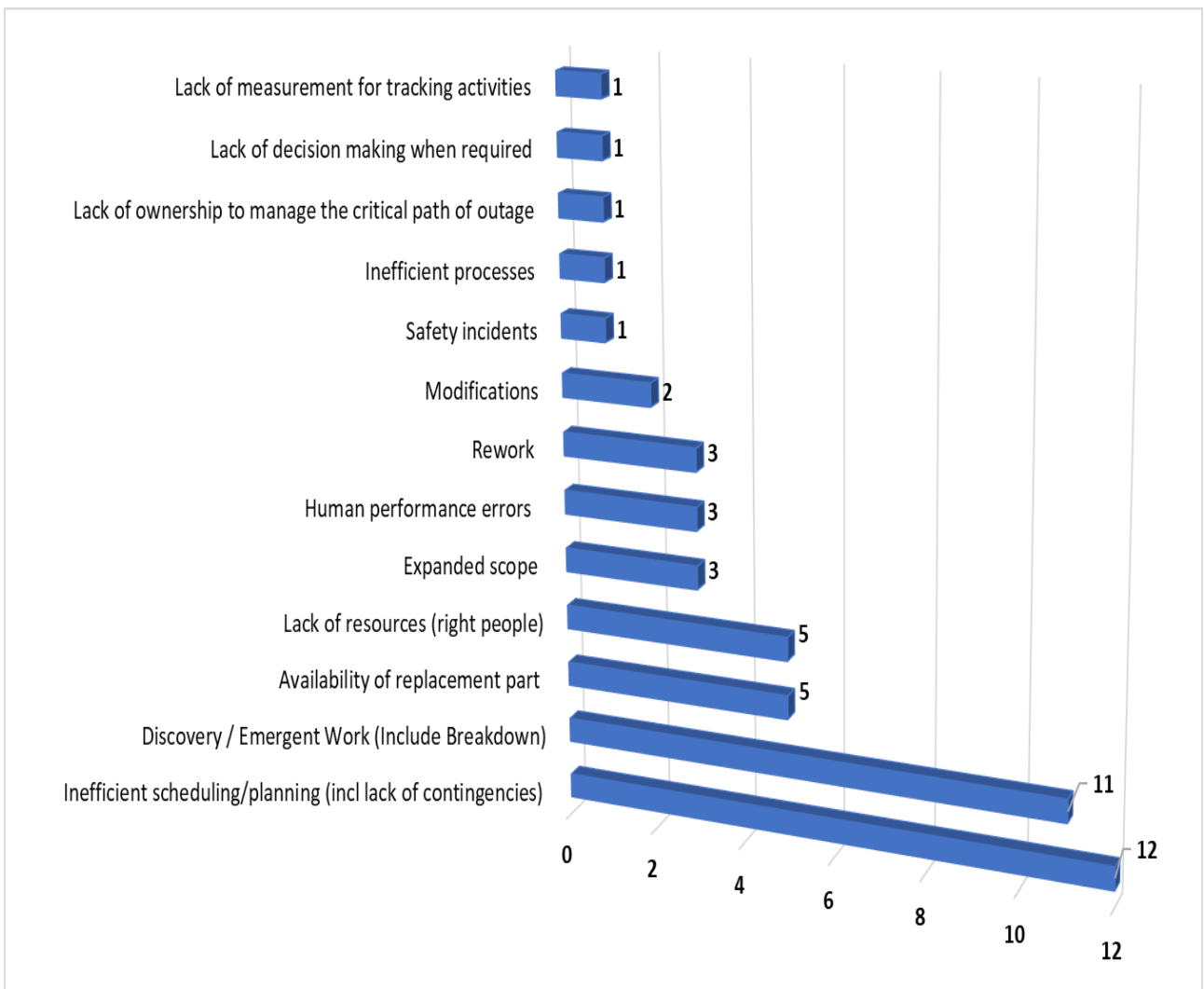


Figure 4.3: Most Common Reasons for Outage Lateness

4.8.2 Question 7 Analysis

4.8.2.1 *Inefficient scheduling and planning (including lack of contingencies)*

All 12 (100%) participants said that inefficient scheduling and planning was the main reason for outage lateness, and some commented that this specific reason included a lack of contingency plans. This is consistent with the literature review. It's also significant that 100% of participants who have participated in an average of 30 outages each, expressed this view. Planning and developing schedules typically start 18-24 months before an outage and it's the part of the work that NPPs have the most control over yet appears to be the aspect most attributed to delays. The conclusion is that NPPs can do much better when scheduling / planning outages and presents the case for further investigation and improvement. This dissertation did not investigate which cause of lateness caused the longest delay which is a subject that presents an opportunity for further research. It will be challenging for a new plant to do this research as it will have to rely on other plants for data. On the other hand, KNPS can mine the data of outages seeking out trends going back 37 years to 1984. An organization like the IAEA or WANO may have access to the data from multiple plants globally and be able to facilitate comparative studies.

4.8.2.2 *Discovery and emergent work including breakdowns*

Eleven of the 12 participants raised discovery and emergent work as the next most frequent cause of outage delays. Discovery is when doing maintenance, the technicians and engineers discover something that requires further investigation and/or correcting. After investigation, a decision can be made whether the issue needs immediate correcting, or if it can wait till a future outage. Emergent work means they discover something, or something breaks down which requires immediate repair. Not doing this repair will extend the outage duration.

Due to the nature of "discovery and emergent" work, one cannot know what will go wrong and when. However, as a trending and common issue, and assuming the trend is visible for many plants, it is worth recording trends of the most discovery and emergent work as well as investing in contingency planning. After all, 50% of the participants were from different plants in the USA and 50% from KNPS and this topic should be studied further. Contingency planning includes the following:

- OE of what typically goes wrong and then as a standard, plan for the top five things that often go wrong. For example, several participants mentioned the polar crane break down and the fact that the polar crane is often on the critical path.
- Ensure spare parts readily available.
- Improve Predictive Maintenance and Reliability Monitoring

4.8.2.3 *Availability of replacement parts*

The third most common cause for outage delays was availability of replacement parts. The one scenario where this occurs is when during the outage, there is emergent work, or a breakdown and the requisite spare parts or single part is not readily available because it is a scarce part. In this case, if the part had been available the repair might have been done immediately and in parallel to other work and have little to zero effect on the outage critical path. Depending on the part, the lead time could be hours, days, weeks or in some cases months.

The other scenario is where parts are not available for the outage planned work due to poor spares and inventory management. It is completely avoidable yet NPPs and other industries still get this wrong. Most of the time this is due to poor planning and preparation. The NPP did not have a sound parts strategy and inventory management system. The reasons for poor strategy and inventory management systems are often caused by poor management and leadership who did not create the right culture, appoint the right people with the right skills, implement good systems and have the foresight and resilience to do effective monitoring and controlling and even improvements along the way. This is linked to the next reason for outage delays and that had the same frequency as lack of spare parts, namely a lack of resources.

4.8.2.4 *Lack of resources (right skills and right number of skills)*

A lack of resources was a shared third, most common reason for outage delays. This included not having the right caliber of people for specific roles (suitably qualified and experienced) and importantly, not having enough of them. Several factors could mitigate this predicament, including but not limited to:

- Hiring people with adequate skills, knowledge, experience and good behavior and attitudes.
- Ensure continuous training to keep up with best practice and help people grow.
- Fair skills retention including remuneration, rewards.
- Creating an environment where they feel they can make a difference and it is appreciated.
- Adequately defined roles and responsibilities.
- An environment where people take ownership and accountability.
- An environment of continuous improvement.

Approximately 200 (10%) highly skilled employees left KNPS within a period of 2-3 years. They either retired or found alternative employment which brought exciting prospects, better remuneration and the excitement of working on new projects, recognized globally. This exodus caused a brain drain at KNPS and for the first time in 37 years, KNPS had an outage of greater than 150 days in 2021. When speaking off the record to people working there or who have worked there, they tell stories about the organization not caring about them, so they do not care. The senior management treat people poorly. The company is constrained by the state capture loss of funds, so people are less motivated. They

do only what they are told, nothing more. Even if they did more, no one appreciates it in any form. In summary, the station's performance is at an all-time low. Part of having the right resources means retaining top performers and dealing effectively with the issues described.

4.8.2.5 *Expanded scope*

Three of the participants said that expanded or additional scope made outages run later than planned. Sometimes scope is added after scope freeze, typically one or two months before an outage. This happens typically when someone was running late with their scope, it was excluded at the time of scope freeze, and later made a justification why it should be included. This additional scope may or may not be on the critical path but if it comes in this late, there is the possibility that it was not planned as well as other scopes submitted before the scope freeze. Often this additional scope is not essential for the current or impending outage and can be delayed to a future outage. Often the expanded scope is added due to an over conservative engineering department that over justifies the need to be done in the upcoming outage.

4.8.2.6 *Human Performance (HU) errors*

Human Performance (HU) errors lead to injury, death or plant and equipment being affected, all of which means delays and extra costs. One participant provided the example of misalignments of equipment. Another said that these HU errors result in additional work to recover from mistakes. It's not only the delay of the error and time taken to deal with the actual error but also the time taken for additional work or rework to recover from the event. Most HU errors can be minimized or eliminated by carefully following procedure. HU error traps need to be engineered away. HU errors creep in with pushing the schedule too hard, focusing on irrational cost cutting, egos, bad leadership and management, and lack of training.

4.8.2.7 *Rework*

Rework was mentioned by three participants. Some examples include poor maintenance, lack of maintenance, leaving out a gasket and then when doing requalification of a component it fails. Rework is related to a lack of skills and lacking a culture of accountability. NPPs definitely have enough procedures on how to conduct maintenance but if someone is not adhering to the procedures they need to be coached and if there is no improvement, then let go.

4.8.2.8 *Modifications*

Modifications or at least those that are poorly prepared was slated as the next most often cause of outage lateness. The reason why it adds to lateness is because specific modifications are usually done once off in a 10, 20 year or longer period and there is not enough operating experience to plan the modification accurately. One important modification is the replacement of steam generators

which happens only once in about 40 years. With that, goes the possible replacement of a hot leg elbow or other modifications which are not done often. This unfamiliarity brings uncertainty, which in turn creates risk in a schedule and is often the cause of outage delays. This unfamiliarity can apply to smaller modifications too.

4.8.2.9 *Safety incidents*

Safety incidents were mentioned by one participant because of standdowns following injury or sometimes death, which causes significant delays. The possible rationale for safety incidents only being mentioned once is that nuclear plants place significant emphasis on nuclear and industrial safety. There are normally several barriers that prevent safety incidents and when they do happen, they are infrequent. However, when there is low morale or a lack of skilled resources, safety incidents are likely to increase. A new plant with new maintenance technicians or craft from multiple origins have a particularly high risk of safety incidents. KNPS on the other hand who have lost many skilled craftsmen over the last three years and who are plagued by the various consequences of corruption that led to shortfalls in funding are at a morale, low. Under these circumstances, managers and supervisors must do more than usual to avoid safety incidents.

4.8.2.10 *Inefficient processes*

One participant mentioned inefficient process and offered a solution. The example provided was “when you have a plant defect, the Planner technician goes to the Plant to find the root cause of the defect and then prepares a work package and has the work package issued, and then only does the repair take place. To reduce the response time, you should send Planner in to do the investigation or send FIN team technician in. They do the analysis and will record the fault and repair in a work instruction which is far quicker than a work package. The artisan will do the work and then record what work has been done. In essence, the paperwork process is less and shorter with FIN (Fix-It-Now) than with the normal technician. In emergency some processes can and should be done in parallel.” Given these circumstances, it is questionable to have two different processes. Instead, NPPs should revisit the procedures and find a process that is optimal for all scenarios.

4.8.2.11 *Lack of ownership to manage critical path of outage*

Lack of ownership to manage the critical path was presented as a reason for outage lateness. The participant who mentioned this factor works in the Outage Preparation and Execution department. Whilst this may play a role, usually, it is very clear that the OCC owns the outage schedule and all paths. The Outage Manager who leads the OCC is accountable. While possible, of all the reasons causing lateness, this one is least likely to happen. Instead, if the OCC Outage Manager does not have the support of the Executive Sponsor to resolve emergent issues and rally the necessary

resources to attend to emergent issues, then this will affect outage duration. This lack of sponsorship ties in with the next reason for outage lateness related to decision making.

4.8.2.12 Lack of decision making when required

Outage lateness caused by lack of decision making is driven by a multiplicity of other reasons. The one relates to the situation above where there is a lack of Executive sponsorship and hence the decision maker, i.e., Outage Manager is uncertain or sometimes afraid to make decisions. Some other reasons include a lack of a robust decision-making process, lack of experience (appointing the wrong people or not giving the right people the right support), time pressure, conflict, ego, and power. Often it is not one factor but instead a combination of factors that converge. Simultaneously, often peers or subordinates find it easy to critique or criticize the manager without having all the information and perspectives of the one who needed to make the decision. Once they find themselves in the same shoes, they may reconsider. For the organization and individuals to thrive, an environment and culture that allows people to feel safe in making decisions with the best information they have must be created and sustained.

4.8.2.13 Lack of measurement for tracking activities to be executed

The final reason for outage lateness is a lack of measurement for tracking activities. Essentially, what the participant is suggesting is that once a person has been given a task to for example replace a valve, and he has been given 36 hours to complete the activity, nobody really investigates whether the activity could have been done quicker. The technician does the work and as long as he finishes in the 36 hours, even if it could have been done in 18 hours and the new benchmark could be used for future outages, the Outage team continues to use 36 hours for future outages. Clearly a lost opportunity. It does get questioned during the wash-up but instead, the supervisor and NPP should be doing a time study of the valve replacement and other activities with the goal of continuous improvement.

4.8.3 Conclusion of Question 7 Analysis

Each participant shared their personal views and experiences, and all were relevant. The following items emerged as the most frequent causes for outage delays.

1. Inefficient scheduling/planning
2. Discovery / Emergent Work
3. Availability of replacement parts
4. Lack of the right resources
5. Expanded scope, human performance errors and rework all had an equal mention

None of the participants mentioned the lack of using technology such as tablet or phablet devices or the lack of incentives. These two factors are worth further investigation.

4.9 INTERVIEW QUESTION 8

What are the best methods and techniques to avoid or mitigate outage delays? Can you rank them from what is most effective to least effective? Provide at least 3 to 5.

4.9.1 Question 8 Answers

The participants had some varied and some consistent responses about mitigating delays. The answers are summarized in the Figure 4.4 below. Each participant ranked the technique from his perspective and there was no correlation on ranking between participants.

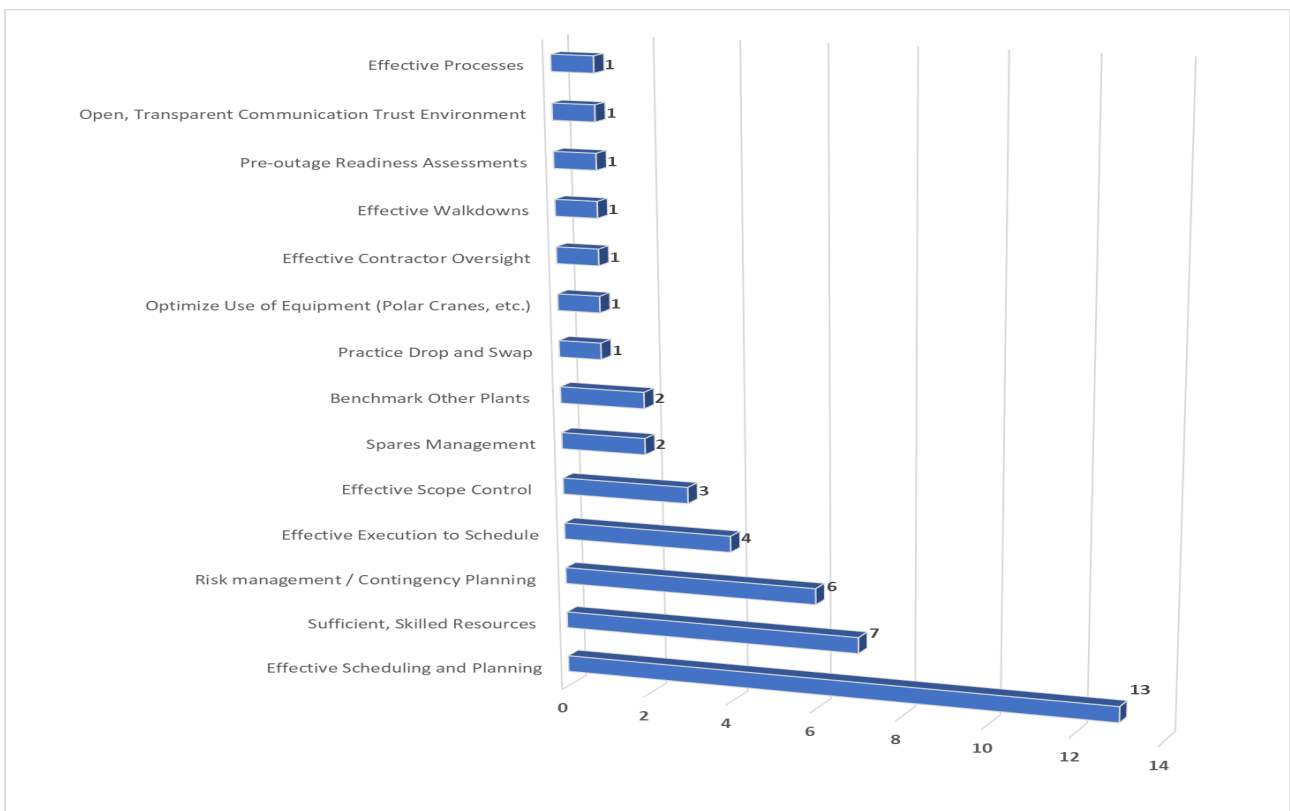


Figure 4.4: Best Methods to Mitigate Outage Delays

4.9.2 Question 8 Analysis

There were 14 main mitigation themes identified by the participants. The method or practice most emphasized to mitigate outage delays was effective scheduling and planning. Ensuring sufficient skilled resources received the second highest emphasis. Third and fourth respectively was risk management / contingency planning and effective execution to schedule which are both closely related to effective scheduling and planning.

4.9.2.1 Question 8 Analysis – Effective scheduling and planning

Poor scheduling and planning were the primary reasons for outage delays. Consequently, participants emphasized that effective scheduling and planning provide the best chances for

mitigating delays. One interview commented on the need for OCC flexibility and upfront assumptions for anticipating delays. Essentially risk management and contingency planning and using experience to determine common mode failures leading into discovery and emergent work scenarios. The example provided was where if 10 MOVs (motor operated valves) are being tested, assume at least one will require a shaft replacement or actuator work and could easily lead to one shift delay (between 12 and 24 hours). Another example by the same participant, was where at a previous station he worked, schedulers were embedded in the shop war-rooms and would adjust each shop's schedule throughout the shift as work was completed or delayed. Another participant reinforced this by emphasizing detailed and timeous feedback of critical and sub-critical activities which can best be done when in the shop war-rooms or providing oversight of activities.

One participant emphasized the need for detailed manpower levelling charts where Supervisors know hour by hour where each team member is. In this way, if a refuel crane broke, he knew immediately where to find the resource to do the repair. Similarly, it is an opportunity for supervisors to know by the day, by the shift, and by the hour how many workers are on site and what their qualifications are. If someone needs a Firewatch you know how many you have on site at that moment and where they are.

A third participant placed emphasis on the Lock-Out-Tag-Out (LOTO) times. This activity is where the Operations department's Local Operators will go to each relevant panel and lock it in the desired position and place tags that clearly indicate the position of the equipment which allows all staff to know what work is and is not allowed, on that panel. The LOTO process is critical for safety of people and plant and always on the critical path. The participant shared that accurate LOTO times will not be known until the first performance but keeping notes to accurately reflect future outages is a key evolution. Another participant shared a similar view saying that "Operations take as long as they do". Therefore, doing time and motion studies with the aim of (a) ensuring the durations are well known and can be programmed accurately into a schedule and (b) finding ways to reduce the LOTO times as part of the evolution, would bring immense value.

Further suggestions included only scheduling to 80% of your craft resources which allows for a 20% emergent work cushion. This proposal should be considered in the context that most plants are not resource loading and resource levelling their schedules. In cases where loading and levelling are well established, there is less needed to schedule to 80%.

One participant said that lots of things do not get adequately planned, and when you get to the execution you realize you left out something important, preventing you from working on the necessary the component. For example, an incorrect isolation or forgetting about scaffolding to get to the valve. Correcting scaffolding or an isolation may take a few hours to rectify. Forgetting to order a component can be disastrous. If the component needed to be ordered, it could take days or longer and if this activity is on the critical path, it is an unacceptable waste of resources and outage lateness. Reflecting on these issues, especially the scaffold, seems unthinkable for a nuclear plant, yet

happens often enough. Not having adequate skills is a major contributing factor. To overcome this, robust planning tools are essential. Tools that prompt job or activity requirements to the requisite degree. If job planning is done, all electronically, algorithms can be built to create prompts or checks and balances, thereby reducing or eliminating the need to rely on memory or manual systems. In the context of a shortage of suitably qualified people, systems can protect against failure.

Two participants emphasized the requirement for Outage project leaders to have tabletop exercises to discuss work scope, possible delays, and actual staging of work beforehand. These tabletops can be done as frequently as required and adjusted from informal to formal, depending on the agenda. These tabletops are useful and efficient ways of getting work or issues clarified or moving quickly and should be kept as informal as possible, yet never losing the actions and due dates to be taken. It has become commonplace for some to insist on formal minutes of meetings, which takes too much time for an engineer or outage worker, who are very technically orientated and generally don't have any administrative support. Simple emails or action registers with short descriptive actions and due dates are sufficient underpinned with a strong culture of accountability.

4.9.2.2 Question 8 Analysis – Sufficient skilled resources

The need for sufficient, skilled resources was highlighted seven times with good examples. One participant highlighted the need for sufficient personnel to prevent testing from causing delays. He provided the example of having two MOV/AOV diagnostic test assessors; one per shift, saying it will prevent delays in reading the tests so that the work orders can be closed promptly, and the schedule maintained. Another participant suggested that dedicated resources for all critical and sub-critical activities. These suggestions are completely rational, yet not always done. Instead, there is one person pushed to work maximum hours, quickly gets fatigued and human error creeps in. This was reinforced by another participant who shared his concern about rework with examples being poor maintenance, lack of maintenance, and even leaving out a gasket so that when doing requalification of the component, it fails.

Another participant recognized the need to employ experienced and knowledgeable planners and schedulers who can develop a logical and detailed overall plan which avoids conflicting actions. Planners and schedulers of this nature are abundant in industry and the imperative is on the NPP to recruit the best and retain them to ensure institutional memory is retained.

One participant emphasized that the common need is "having a skilled workforce in the organization. People that know what is needed and have an ability to drive and achieve it". Sometimes companies appoint people who are not ready for the role, lacking technical or managerial competence (or both) and don't support them once appointed or they do not do enough to retain and appreciate those who have the competence, with disastrous consequences.

The next participant echoed similar views emphasizing the need for having the right people on site. He went on to offer a solution saying that NPPs need to identify upfront where they have a deficit in

skills, local or international. For example, Koeberg has a big issue with support for polar crane maintenance. Koeberg is having big delays and response to repairs. Person A and Person B whom we know are really experts in their field both left Koeberg about the same time and Koeberg now needs to mitigate by having the OEM to support. KNPS needs to do a risk analysis before outage and decide if they need the OEM. The OEM is very expensive, and KNPS needs to evaluate its risk, and decide if it is beneficial to have the OEM on standby at a certain cost in case of a breakdown versus not having the OEM. It is also far more sustainable to retain the people who left.

Most technical nuclear workers such as the valve technicians can be considered scarce skills and require attracting, retaining and continuous training. In 2020 and 2021, in the South African context particularly where Eskom finds itself cash strapped and with a workforce having low morale, this is particularly relevant. Many skilled artisans and technicians from KNPS are making their way to perceived greener pastures, i.e., BNPP, OL3, HPC and elsewhere. Other countries such as Egypt, Turkey and the UK have nuclear new build programs that attract skilled nuclear workers drawing them away from South Africa or from each other. With new nuclear plants being built in these countries, the competition for scarce resources will continue. Organizations like Eskom need to adapt to retain its people and enhance its pipeline for these resources.

4.9.2.3 Question 8 Analysis – Risk management and contingency planning

This method was mentioned six times. Participants mentioned the need to plan for contingencies, having good or adequate risk management and contingency plans. One advised to assume that a percentage of work will be delayed. Another shared experience that he always tells people to anticipate what could go wrong because from his experience people only look at what is happening on current shift whereas they should be looking at the at the bigger picture and get a helicopter view. He explained that the maintenance support team generally looks at the first week of the outage and sets up scaffolding accordingly. They think they have bought themselves seven days to make adjustments for the next week. They often do not plan for contingency scaffolding in case of emergent work and sometimes are forced to delay some planned work to use its scaffolding for the emergent or more urgent work.

Risk management and contingency planning success is underpinned by a culture of risk management and having experienced, capable personnel. It cannot be a haphazard activity to tick a box. The people delivering inputs into the process need to know the work well. They need to know nuclear outages to analyze the risks and as a team put in place contingency plans. Contingency plans in themselves need to undergo a cost benefit analysis. To be successful at-risk management and contingency planning, having enough skilled resources is a necessity. Risk management is closely related to effective planning and scheduling and should be treated as such.

4.9.2.4 *Question 8 Analysis – Effective Execution to the Schedule*

Effective execution was mentioned four times. The first advice emphasized the need to schedule the outage properly and follow the schedule as it is scheduled. The participant explained, “do not try to jump ahead of the schedule because all the work will be tied in a process that ensures all work is performed and when completed opens up the next activity.” He added that all work orders had to be walked down by all disciplines and documented which sets you up for effective execution.

Another participant highlighted the importance of an adequate execution strategy for bulk work in the maintenance shops. These workshops become rather busy during an outage and there can be no bottlenecks. Part of the execution strategy includes protecting the critical path and sub critical paths resolutely by having a team looking at upcoming activities and ensuring those activities are ready to be executed and directing resources accordingly. Another method was to timeously complete the paperwork and update the various systems/tools, e.g., SAP and Primavera to ensure execution is tracked in real time and focus is placed where it is needed most.

For the most part, workers will follow the schedule. The real delays come from work taking longer than planned due to an incorrect pre-estimation, lack of skill or tools and equipment failure. Staging of the workshops to avoid bottlenecks and staging the other work areas can make a significant difference. Having spare tools, equipment and spare parts fall into a different section of best practice but as indicated before they are all interrelated. The theme of effective planning and scheduling which includes risk management stands out as the most important success factor to avoid delayed outages.

4.9.2.5 *Question 8 Analysis – Effective Scope Control*

Scope control was mentioned thrice as an effective means to avoid outage delays. Scope creep or growth occurs when there is an inadequate system for change management. One participant elaborated saying one needs to minimize scope growth and investigate means/justifications to postpone repairs if possible. The risk for delaying repairs is somewhat uncertain at times. It is easier and risk averse to do the repair as soon as possible, to avoid a trip during the typical 18-month fuel cycle. Engineering departments are traditionally risk averse and prefer repairs to take place at the earliest. However, having sufficient trend data from the system itself as well as similar issues at other plants can help inform risk-based decisions and delay repairs. Due to the safety risks associated with nuclear and even the perceptions to be managed, nuclear engineering departments are and should be more conservative than other types of power plants.

4.9.2.6 *Question 8 Analysis – Spares Management*

Spares management was mentioned by two participants. The proactive approach is crucial. In addition to warehouse inventory levels and reorder points, one participant advised to do proper spares check before the outage. The other went on to explain the requirement to have the available

spares to fix those components that breakdown. In effect there are spares required for the outage maintenance but also spares required if some equipment, systems or even tools break down during or immediately before or after the outage. Therefore, it is necessary to look at OE and history from one's own station as well as other similar plants and use that OE to do a risk assessment and order contingency spares. The secondary, yet important reactive approach if some spares were not provisioned for, would be to have a good relationship with suppliers and utilize the emergency purchase process and wait until the spares arrive. With international suppliers, this may add significant time to the outage and should be avoided.

4.9.2.7 Question 8 Analysis – Benchmark Other Plants

One participant emphasized benchmarking with two good examples. One example was to do benchmarking visits to high-performing plants during their outages. The other method was to second workers to high performing plants for outage support. Both these methods are used in the industry. However, with the Covid-19 pandemic and associated travel restrictions, the option to conduct benchmarking or secondment physically is less viable, substantially riskier, and more expensive.

For refuelling outages including standard maintenance, there is a clear argument to be made that sending people to other plants has a low ROI. However, if the outage involved a major modification such a steam generator replacement that occurs on average once in 40 to 60 years, the modification often cannot happen without exposing key people to these benchmarking exercises. NPPs need to carefully select the right people for these assignments, ensure the outputs will be used, ensure the person/s delegated are retained after the benchmarking is complete and there is knowledge transfer to the rest of the outage organization to maintain the institutional memory. It cannot be where one or more people are sent, they acquire profound knowledge and experience and within months of their return, they resign. More needs to be done to tighten these employment contracts.

Covid-19 has expedited and intensified the use of online meetings and collaboration. This is an exciting opportunity to find ways to do benchmarking virtually, using online tools. Many more people can participate, and knowledge transfer is far reaching. However, arranging and participating in these online meetings can be very time consuming and it is not the same as witnessing activities yourself. Besides, some plants prohibit cameras. On the other hand, people who could not participate even in the online meeting, can watch the recording later, like webinars. This brings a value of sharing knowledge that cannot be accomplished by sending one or a few individuals. A balanced approach needs to be sought. One thing is certain is that the benchmarking in whatever format is absolutely required and online collaboration is the future. A further study of the value of benchmarking and its ROI is required. Coupled with a structured approach to do online benchmarking, NPPs can improve performance significantly at a significantly reduced cost.

4.9.2.8 *Question 8 Analysis – Practice Drop and Swap*

One participant recommended drop and swap. This is essentially when you remove equipment, replace it with a spare, which saves a lot of time, and maintain the removed equipment in the workshop. At the next outage, you do the same by using the equipment removed last time. Further research is required to know for which components or systems this has economic value and for which it does not. The author expected this method to be more prominent in the interviews and could be a topic of further investigation.

4.9.2.9 *Question 8 Analysis – Optimize Use of Equipment (Polar Cranes, etc.)*

One participant reported that from experience at KNPS, he was aware that optimizing the use of the polar crane availability can save as much as 24 hours per outage. One full day just by planning the efficient use of the polar crane is a significant saving that costs just about nothing, only effective and efficient planning. It's a 3% (1/35 days) saving on outage duration. Investigating to what extent this is practiced or not, presents an opportunity for further study.

4.9.2.10 *Question 8 Analysis – Effective Contractor Oversight*

One participant reported the need for good oversight of the contract workforce, ensuring they have the right standards. Contractors work for various customers and customers have varying standards of quality, safety, culture, etc. Usually, NPPs have the highest standards, and this comes at a cost. For various reasons such as gaps in knowledge, understanding, complacency, cost frugality, etc., contractors don't always adhere to the highest standards. Therefore, apart from working with them on improving to reach the quality standards expected by NPPs, there is a clear requirement for effective contractor oversight in all phases of the outage, especially the planning and execution. This oversight helps significantly to reduce errors and improves people and plant safety. Practical methods to help identify contractors include specific uniforms. Some plants in the US, even place stickers on hardhats and badges to identify new to nuclear workers. Elsewhere in the literature review, reference is made to partnering with your contractors. This partnering will make them adopt the nuclear safety culture and other good practices as their own. In-turn, it will result in a reduction of incidents and consequent delays.

4.9.2.11 *Question 8 Analysis – Effective Walkdowns*

One participant said to make sure all work orders are walked down by all disciplines and documented. Multiple walkdowns are normal practice with every job, online and offline and may be the reason why others did not mention it as a means for mitigating delayed outages. Multiple walkdowns for the same job allows the team to think through the various planning and execution stages. It also helps with arranging staging.

4.9.2.12 *Question 8 Analysis – Pre-outage Readiness Assessments*

One participant mentioned readiness assessments. This was somewhat surprising in that it allows for significantly better planning. However, it could also be because it is such a well-practiced method, it did not require special mention. From experience, these assessments require a standard checklist which helps one set up successfully. These assessments take on various forms. Sometimes they are done by the outage department itself. The outside-in assessments are the most beneficial. In some cases, other parts of the organization observe and challenge readiness whilst at other times, outside organizations like other NPPs and Contractors are invited to challenge outage readiness. When conducted with properly, these challenges bring immense value.

4.9.2.13 *Question 8 Analysis – Open, Transparent Communication Trust Environment*

One participant emphasized an open, transparent communication and trust environment. He said this allows people to share information freely and importantly ask for help when required. They don't sit with a problem until it becomes a bigger problem because the environment and culture allow sharing and trust. One example that has resonated with the author throughout his career is if someone drops a foreign object like a nut or similar into a system in error, he should feel completely at ease to inform his supervisor knowing there will not be negative repercussions. Knowing about the foreign object at time of the error is far less expensive and damaging than starting up that system with the foreign object inside. Similar examples are available for the planning phases of outages where sharing information earlier allows more time to adapt and address the challenges at hand, always less expensive too.

4.9.2.14 *Question 8 Analysis – Effective Processes*

The participant repeated the advice from Question 7 where he explained his most common reasons for outage lateness and offered a solution. This was discussed in 4.8.2.10 and not repeated here.

4.9.2.15 *Question 8 Analysis – Conclusion*

Participants shared the experiences and knowledge on the best methods to avoid outage delays. Their experiences are all valuable and personal based on their career experiences. Even though each one ranked the methods, there was no common theme or inference that could be made from the ranking. What was evident was that the following practices were most mentioned.

1. Effective Scheduling and Planning
2. Sufficient Skilled Resources
3. Risk Management / Contingency Planning
4. Effective Execution to Schedule
5. Effective Scope Control

A commonality is evident between question 7 that dealt with causes for outage delays and this question 8, that deals with ways to mitigate outage delays. Once again, there was no mention of a lack of using technology such as tablets and phablets. This may be because they have become too used to having paper-based work orders and accepted it as the status quo. However, using tablets or phablets should be investigated further. There are numerous opportunities to mitigate delays and optimize outages. Interestingly, incentives were not mentioned as a tool for mitigating outage delays. Finally, there is sufficient cause to study each topic in depth to better understand each and help the NPP improve performance.

4.10 INTERVIEW QUESTION 9

What are the main benefits to optimizing outages? (Establishes how different stakeholders perceive benefits and may show competing objectives.). Why do we want to, or should we optimize outages?

4.10.1 Question 9 Answers

Five key themes emerged in the responses about the main benefits of optimization with the results displayed below in Figure 4.5 below.

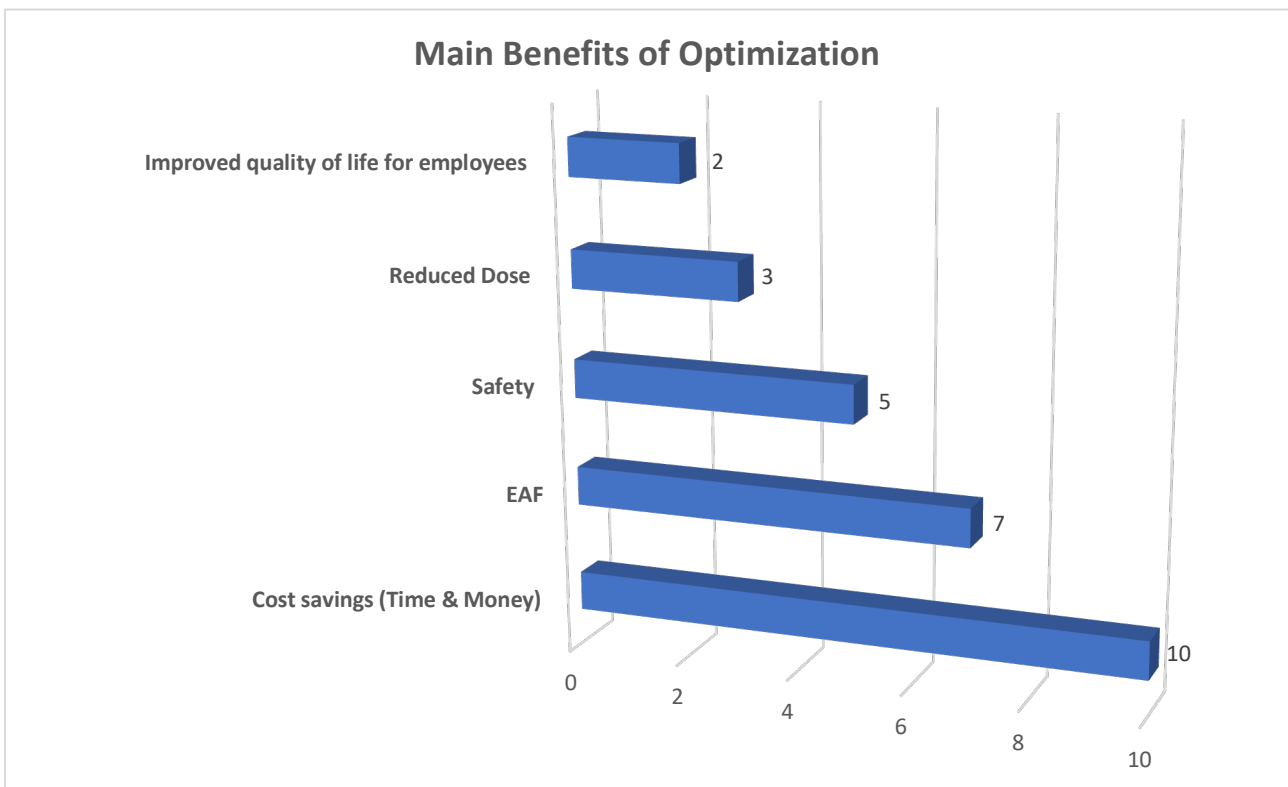


Figure 4.5: Main Benefits of Outage Optimization

Participants reported in various ways that cost savings in the form of time and money was the most prominent benefit or goal of outage optimization. They deduced that shorter outages meant more revenue from generating plant, less manpower costs for outage staff and even reduced insurance

costs. One participant said that in the Western industry (USA) it's all about the money. That is why the West often criticizes Europe and France who have a 70% to 80% EAF vs 90% in the USA. Noting however, that France largely runs on load following and if load is low, electricity production goes down.

Another participant insightfully said that it depends, explaining that if it is a for shareholders then it is to maximize revenue and profit. However, for KNPS as a state-owned utility and with current circumstances it is satisfying the demand of the country's energy needs (eliminating or reducing load shedding). He also said that in South Africa, a dependable supply of electricity is favorable for foreign direct investment and that right now, South Africa is in big need for optimization because of the unreliability of coal plants.

Safety was the next driver. Participants said that you want to have all safety systems operable to deal with the core, which are most effective when online, not whist in the spent fuel pool (SPF). They added that shorter outage durations and less work implies less accumulated radiation dose and that less work means less opportunities for injuries to occur.

One participant explained that shorter outages provide employees with a higher quality of living. Normally, personnel work about 72 hours/week during an outage. The longer this goes on, the more risk to emotional and physical health. As attention spans decline due to emotional stress/burnout, the risk of injury/accident goes up. Additionally, shorter outages allow for more work to be done online, equalizing the workload across the year. This allows for better planning and scheduling of work items. This, in turn, allows employees to work consistently and more even paced, reducing stress. Quality of life emerged as a distinct and important need.

4.10.2 Question 9 Analysis

Shorter outages that are well managed directly translate into cost savings and a better EAF. A better EAF also means less load shedding. Optimized outages come at a cost but if done properly, benefits far outweigh those costs. Thereafter, nuclear safety, industrial safety and dose that is ALARA are clear safety drivers that translate into cost savings. The emphasis on better quality of life for employees is not often seen as a direct benefit for the company but the rationale by some of the interviews is sound. There is room for an analytical model for outage optimization that covers not only the hard metrics in terms of time and cost but rather to build into this model variables such as the financial value of lower dose, happier (less stressed employees), reduced safety incidents, and so on.

4.11 INTERVIEW QUESTION 10

What are the most effective ways to optimize/reduce outage durations (not avoiding delays but rather optimizing from acceptable planned standards/durations)? Can you rank them from what is most effective to least effective? Provide at least 3 to 5.

4.11.1 Question 10 Answers

The participants provided varied responses and they were grouped as per the graph xx below. Some participants provided 3-5 responses and others less. They ranked their individual responses but there was no clear pattern of ranking between participants.

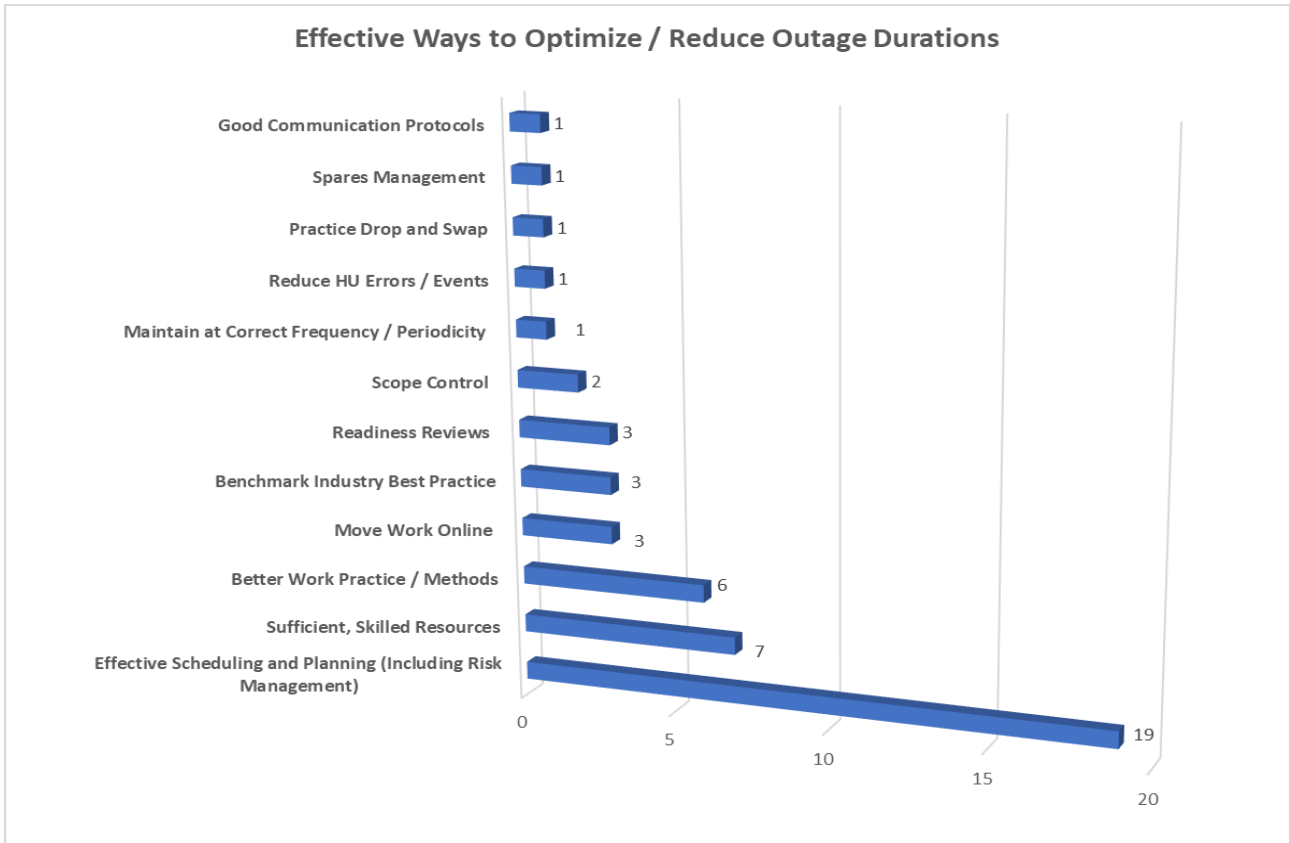


Figure 4.6: Effective Ways to Optimize / Reduce Outage Durations

It is evident that effective scheduling and planning, including risk and contingency planning is viewed as the most effective way to optimize or shorten outage duration. Some practical methods from participants included:

1. Organize work into windows, based upon clearance boundaries. Maximize the amount of work that can be done inside a single clearance. E.g.: Maximize the EDG work when it must have any maintenance done.
2. Detail levelling of resources across the organization with qualified and experienced people.
3. Schedule to 80% because emergent work is going to happen so building a cushion is a key defense.
4. Realistic timelines. Providing accurate job times and ensuring they fit into the outage is key. A big error that occurs often is that the work is "shortened" to fit into an outage window by someone who is not a technical expert (for example a scheduler). This can cause outage delays.

5. Plan smarter and work smarter. I asked this participant to provide one or two examples of smarter meant to him and he replied with: He said first they need to ask themselves, how KNPS could work smarter and plan smarter. He thought KNPS could plan better. They should ask what else could go wrong and have contingencies in place if something goes wrong. Another way of working smarter is to have swop outs (drop and swap). Instead of opening, testing, and repairing a valve, rather have swop outs to replace the valve. Replace vs repair is often quicker. You can also increase productivity on back shifts. Nights shifts are often very slow vs day shifts, he said.
6. Cut down on duration, for example optimize all work in a specific location and at more or less the same time, and optimize support required in that area. Don't go back two weeks later to do work in the same room. Avoid duplication.

The need for sufficiently skilled was ranked second and better work practice or methods was third. Some items may have been mentioned in Question 8 but here some pragmatic better work practices that are worth considering:

1. Give artisans or discipline / job supervisors the ability to do more. E.g., "when artisan works on a valve and needs a block and tackle for rigging and lifting, he can do this himself. Instead, it is typically given to the support function that adds resources and often causes delays. Another example is allowing the artisan or job supervisor to do the radiological survey when valve is open. At Koeberg we have to phone RP to do the survey. They should rather let the artisan and his assistant do this". Another example is sometimes there are different requirements from Maintenance compared with Engineering. For example, Maintenance needs to do visual inspection and Engineering requires someone qualified on ASME to do VT 3 inspection. They send two resources, often at different times but the higher qualified person could add 15 minutes to the task and do both whilst at that component.
2. Implement new / innovative methods of performing activities.
3. Challenge the norm while staying within the rules.
4. Change the rules of acceptance.
5. Perform more continuous improvement programs/initiatives.

4.11.2 Question 10 Analysis

Upfront planning, scheduling, risk management and contingency planning remains the most effective way to reduce outage durations. It provides the reasonable luxury of time, typically 18 months between outages but typically starts 24 months in advance. This planning needs to be done with skilled resources and the execution of the outage too. NPPs need to evaluate its Human Capital in relation to the work at hand. What skills and people will they require going forward and what needs to be done to retain them.

Finding new, innovative ways of conducting any aspect of outage management is crucial and exciting. Even though nuclear workers are trained to be conservative in their decision making, it is innovation that moves us forward.

Apart from time and cost savings, there are a number of other benefits already discussed, that in the end translates to savings for the company. As one participant aptly said in this question, "if outages are too long, people get tired or fatigued and leads to mistakes. In nuclear especially, you want to avoid that."

This question about optimizing outages was similar to the Question 8, seeking methods to avoid outage delays. The answers were mostly similar. This is useful as it reinforces the practices to be further studied as means to optimize outages.

4.12 INTERVIEW QUESTION 11

At your plant or previous plants, what are/were the constraints or inhibitors to implement shorter outage durations?

4.12.1 Question 11 Answers

The participants provided 19 varied responses shown in Figure 4.7 below.

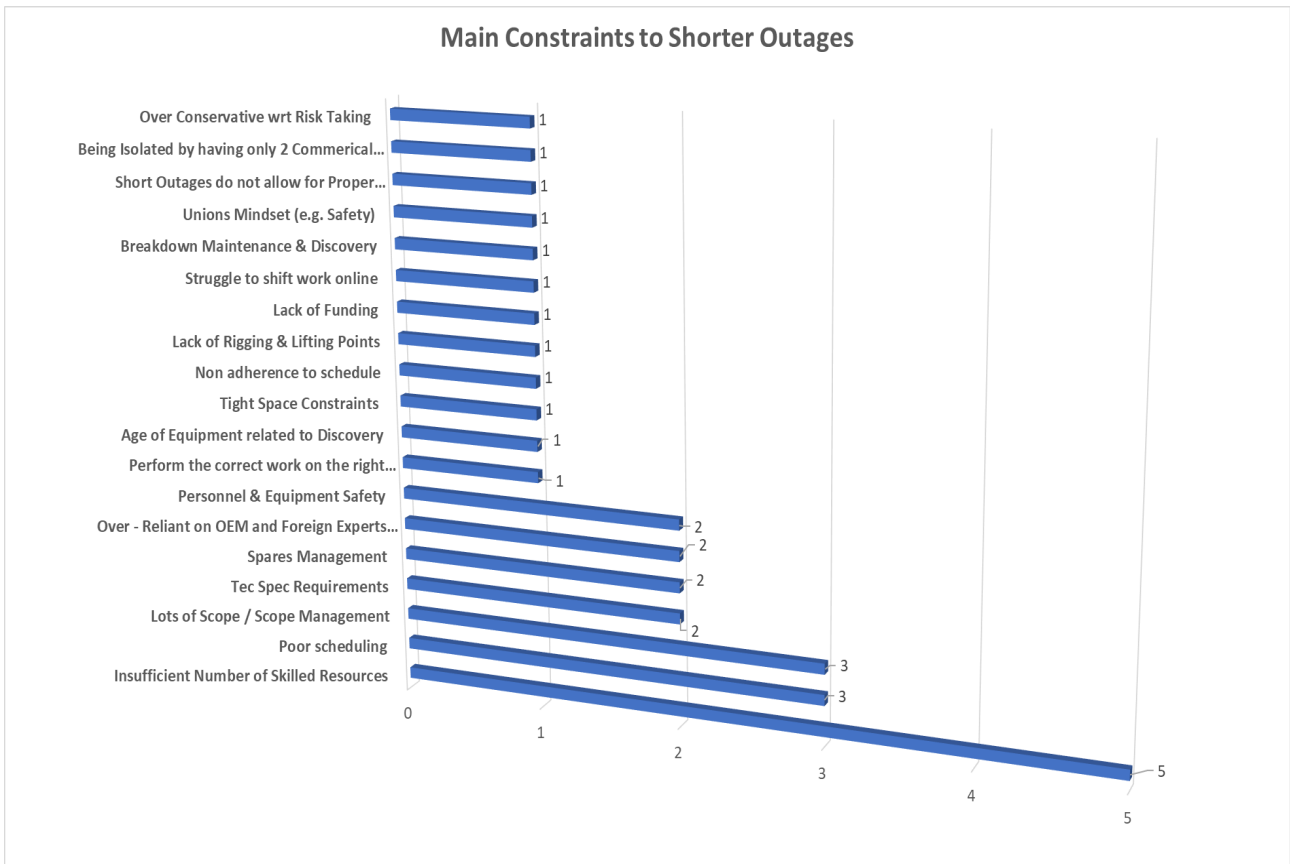


Figure 4.7: Main Constraints to Shorter Outages

Some of the interview discussions centered around skills scarcity and that there were typically shortages of engineers to read MOV/AOV traces and insufficient civil engineers to review/approve rigging and scaffold designs and plans. Another interview emphasized scarce resources included technicians or craft to perform maintenance, for example, the SGs are specialized, and the resource pool is limited, so getting more resources was not always easy and added to that was a shortage of skilled supervisors. Competition globally, for specialized technicians or engineers from various equipment OEMS like Fischer, German Schneider for pumps and valves was very apparent. There was also an over reliance on the OEM and foreign experts to influence decisions.

Poor scheduling was another key constraint to shorter outages. Participants said it led to inefficiencies. An example of an activity that is easily controllable but not practically done includes when a specific task qualification is needed for the work and the only person with that qualification is on a day off or the opposite shift. Another example is the ineffective management of system windows and protected trains. One participant said that at his old plant, “outages were never done on time. My plant was built in the 1960’s and we always had a bunch of mod work. We also were not very concerned about cost as we were government funded. Our outage group also was very accepting of work, some of which should have been done online.” This last example demonstrates a culture not conducive to continuous improvement, nor optimization.

Scope management remains an Achilles heel of many project organizations, nuclear outages included. The participants said the constraints were accepting new works into the outage scope after scope freeze (increased scope growth), the PM scope was very huge and significant and often the mandatory scope emanating from the OHS Act, Pressure Vessel Regs, ISI, etc. increased over time. For example, at KNPS one needed to consider the age of the SGs that needed regular plugging of tubes or other remedial actions. This had become necessary scope and reduced the opportunity for scope optimization.

The remaining factors shown in Figure 4.7 are all real examples of constraints that can easily be remedied if NPPs know what the constraints are and have the right leadership to effect change.

4.12.2 Question 11 Analysis

A lack of skilled resources has shown to be a common theme in questions 7, 8 and 10 thus far. It has shown to be a prominent constraint and a source of opportunity for outage optimization. The view on a scarcity of qualified technicians is supported by the author’s own experience in 2021 as project manager to recruit and qualify technicians for BNPP.

Poor scheduling and scope management were the next biggest constraints. Tech spec constraints and spares management featured as well. Good spares management is easy to achieve with qualified people and good systems to manage inventory. Nuclear plants generally have good systems in the form of SAP. Therefore, spares management as a cause for poor outage durations can be eliminated by having the right leader and support staff managing spares.

4.13 INTERVIEW QUESTION 12

In your view what are the 5 things NPP Outage Organizations or their Leaders (CNO, VPs or Senior Managers) need to do to ensure Outages run on time or are optimized? **The emphasis here is what Senior Leadership needs to drive...**

4.13.1 Question 12 Answers

The participants advocated seven key aspects they believed the senior leadership need to be involved with or sponsor, shown in Figure 4.8 below

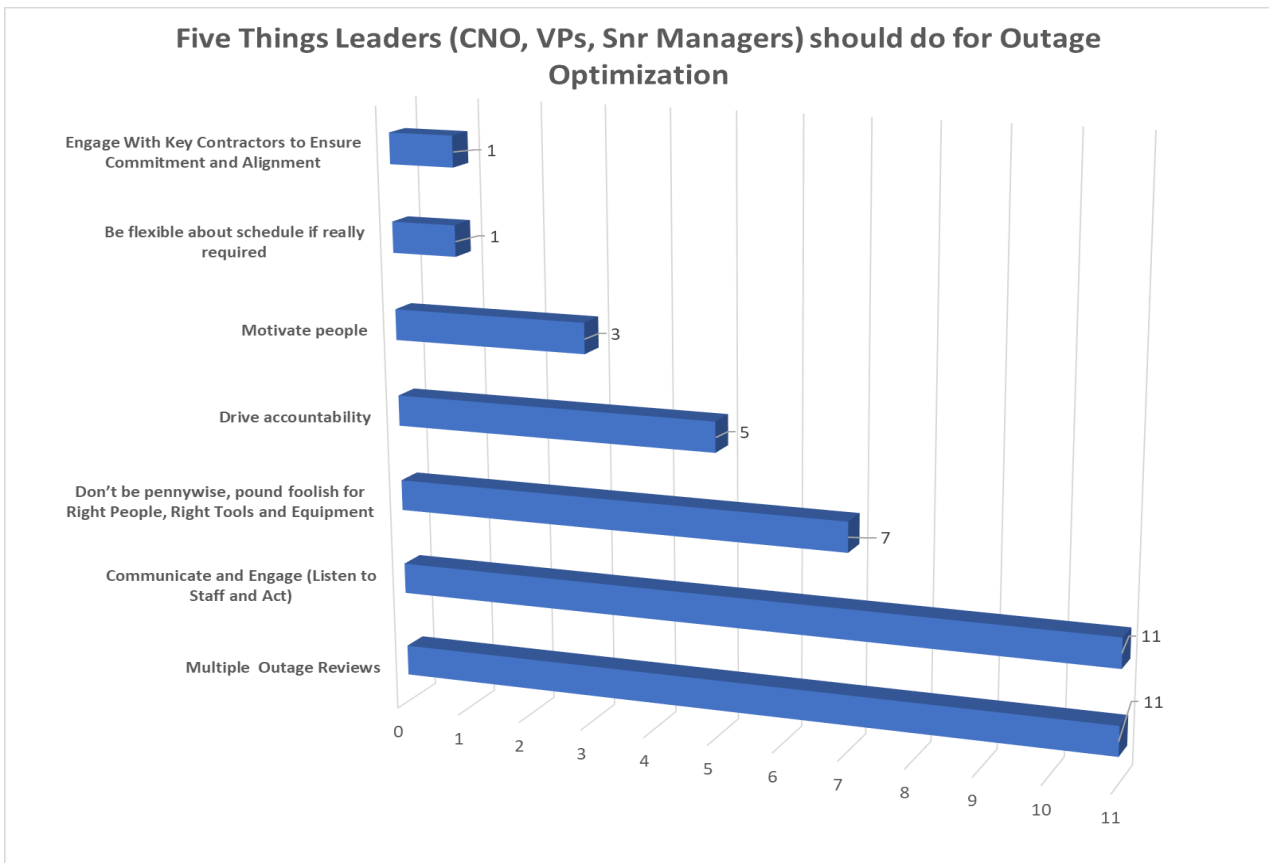


Figure 4.8: Things Leaders (CNO, VPs and Senior Managers) should do to Optimize Outages

The two main themes the participants advocated for was for senior leadership involvement with multiple outage reviews and communicating and engaging with staff and acting upon any support required. This was followed by the need not be too focused on saving money on getting the right people, tools, and equipment, at the expense of success. The fourth aspect was for leaders to drive accountability. Motivating people ranked fifth. Finally, allowing flexibility in the schedule and engaging with key contractors were also seen as priorities.

4.13.2 Question 12 Analysis

The multiple outage reviews are a good means to assess outage readiness. The value of getting senior management involved is useful as long as they sponsor and do not interfere and try to control the sessions or use it in a punitive manner. Their presence and support for the challenge reviews allows them a few advantages including:

- Communicating and engaging staff as per the second leadership requirement in Figure 4.8
- Show support for staff and motivate them
- Understand their organizations strengths and weaknesses
- Obtain insights on what to improve

Not being pennywise pound foolish ranked third and focused on securing the right people, tools, and equipment. None of the participants discussed incentives, higher salaries, or bonuses in this question nor in any of the other questions. Incentives are usually a standard motivation mechanism for outages. This may be a topic for further investigation.

4.14 INTERVIEW QUESTION 13

Are you aware of any outage optimization programs in your current plant or previous plants and can you name the top 1 to 3 in terms of what durations/time it could save? Are plants actively managing optimization or are they just taking it as it comes?

4.14.1 Question 13 Answers

Participants reported a number of optimization programs. Figure 4.9 shows PM optimization programs which includes challenging the technical specifications featured highest. This was followed by programs to upskill staff. External outage reviews ranked third with the remaining programs showing some efforts of optimization.

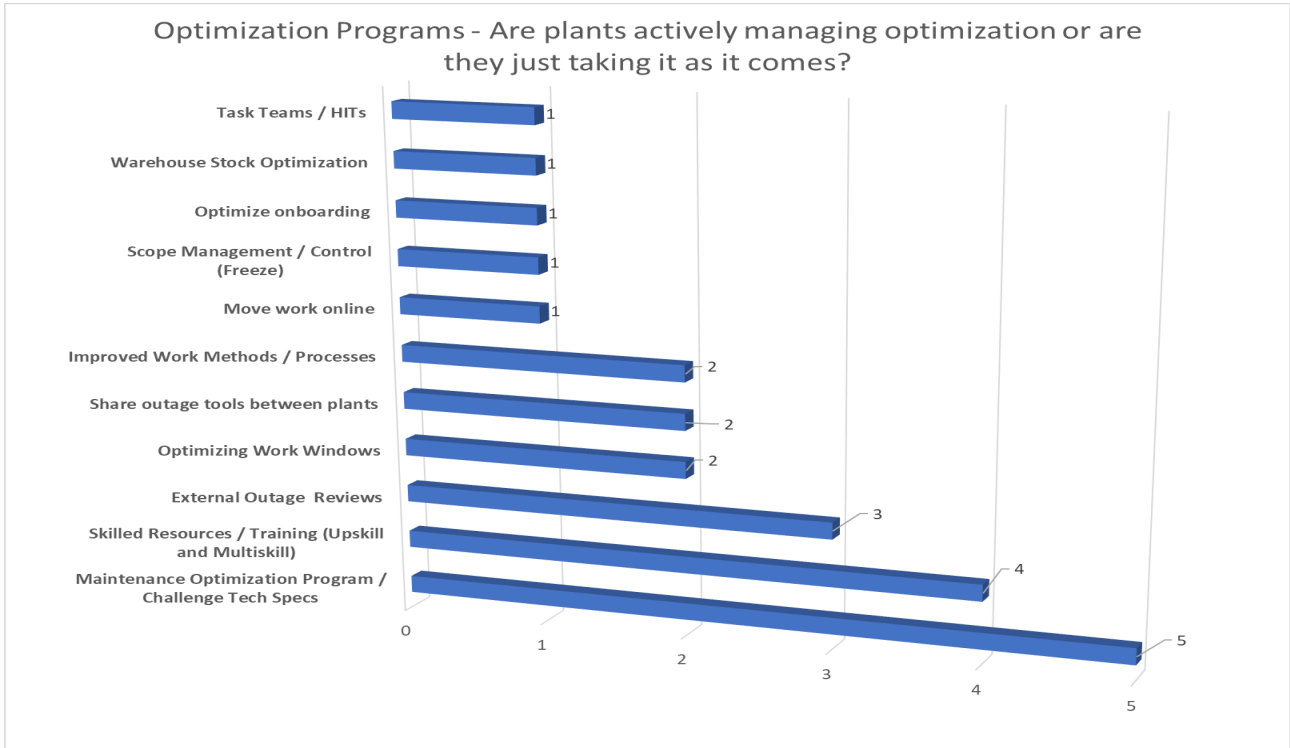


Figure 4.9: Optimization Programs – Are plants actively managing optimization or are they just taking it as it comes

4.14.2 Question 13 Analysis

PM optimization programs, moving work online, optimizing work windows, and scope management are usual parts of the repertoire at most plants. They are primary functions of the resident Engineering and Outage departments. Programs that go above and beyond this require special resolve by management and allocation of additional resources. Upskilling and especially multi-skilling staff are very relevant examples. Internal outage reviews are standard practice, but external outage reviews are complimentary, smart ways to learn from other plants and obtain an outside-in perspective. These reviews can be done using online media and do not require a physical presence by the external reviewers, albeit that the physical presence does provide some additional insight. Optimizing the sharing of tools between stations can be a source of cost saving but needs to be managed accurately as it can also be a source of delay. Stock optimization was shown in previous questions to be a necessity given how frequently timing of spare parts has been mentioned. The inventory management process is an easy one to undertake if there is management support and the warehouse and station has the right skillset.

4.15 INTERVIEW QUESTION 14

What other advice or feedback would you give to NPP leaders wrt outage optimization? One or more bits of advice that you feel strongly about.

4.15.1 Question 14 Answers

The answers to this question have been filtered to remove responses already dealt with adequately in previous questions. The final advice about optimization specifically for NPP leaders are listed below.

1. Ensure Maintenance, Engineering, Operations are all involved in the optimization program. This will ensure the items scheduled for outage are actually, for the outage and help shift as much work online as possible, safely.
2. Don't micro-manage. This invariably reduces the initiative that Line personnel are willing to take to optimize work. Allow Discipline/Area leaders to lead. One said, "I hate it when the VP or PM walks thru a space, sees someone sitting down, and then explodes in the OCC about how Electrical Maintenance isn't working. Inform the leader and then allow them to address it. There may even be a good reason they were in the shop. i.e., on standby after being given their 30-minute heads-up to support Mechanical maintenance by de-termining a motor".
3. Put the right people in place with the right motivation and energy. Often, organizations are poorly set up to deal with outages and outage work activities.
4. Some managers don't really respect the skills that people have because there are some people who are very skilled in specific activities and are not appointed where they add the most value. An example is one skilled MMIS Technician who should be either in Maintenance or Engineering, but he works in PSC only because he wanted a foot in the door. Another example is the very qualified NDT Phased Array Inspections Technician whose skills we should use better"
5. Most importantly, if there is not a good resource pool for the money we offer, it will result, most likely, with numerous errors and mistakes causing outage delays. The old adage, "you get what you pay for" is pertinent.
6. Listen to the people doing the work and give them an opportunity to execute their ideas, within reason that is. More often the success lies in the obvious suggestions.
7. Don't Americanize it. Just making people work longer hours with less resources is not the answer. We have the opportunity to think differently, from schedules, to work hours, to every aspect of how we conduct ourselves, don't get stuck with "This is how we always do it". From an American.
8. I believe that mutual respect and true teamwork are going to play a bigger role during outages here at this NPP than anyone has ever previously experienced. The pressure that most Americans are used to, has a tendency to shorten tempers and occasionally erupt into anger and frustration. This will be very damaging if it occurs in this multicultural environment, and we all must take extra efforts to ensure that we act with dignity and professionalism at all times.
9. The processes with the Procurement department will cost us dearly.

4.15.2 Question 14 Analysis

There were nine key points. The first point reminds NPP leaders and managers to consult broadly, specifically about the PM Optimization Program. This is not an only-Engineering exercise as most organizations execute it.

The next four points are all about people, i.e., avoiding micro-managing, appointing the right people in the right roles, motivating, and trusting people to be their best. Part of this is carefully listening to people and supporting them for success. There is also a stark reminder that NPPs need to proactively find a balance between hiring the cheapest resources and the resultant potential for errors and consequent delays and costs.

The comments from an American to not Americanize as well as to think differently are profound. Create your own authentic culture that takes the best from everywhere, including from yourself. The same person provided an example of the necessity to enhance mutual respect, teamwork, dignity, and professionalism. Outage managers will need to work within the continuum between ask nicely and tell or instruct as well as manage expectations. Clear reporting lines of authority with the space and culture that allows for a questioning attitude will facilitate this.

Finally, and profoundly, the need for state-owned organizations to implement proactive procurement, fast and efficiently. Outages are often delayed because of spare parts inventory levels that were mismanaged in the warehouse, slow procurement processes for goods and services and the procurement department not understanding the needs of a NPP because it is filled with staff from organizations whose needs do not revolve around nuclear safety and maximizing the EAF.

Often it is said that organizations should not only communicate top down but should listen to its people and allow for communication flow upwards and laterally. This dissertation and points of advice are from people actively involved in outages throughout their careers. The advice is worth considering and implementing and should be considered as the words spoken from the bottom-up and from the side. This information comes across as pragmatic and can provide NPP leaders and managers with a competitive edge and form the basis of future constructive engagement.

4.16 INTERVIEW QUESTION 15

Do you have any other feedback, ideas, suggestions, and comments?

4.16.1 Question 15 Answers

Six of the 12 participants did not have any further comments. The other six participants additional comments are shown below.

1. Work the schedule as scheduled, this will ensure the plant does not enter into an unwanted condition and slow down the outage.

2. "Levelization is so little understood, and its impact is crucial. Folks think we have 80 people here every day of the week, and its 40 per shift, we are levelized. NOT EVEN CLOSE. You need to know your skills sets and leadership are levelized down to the smallest detail."
3. Outage performance is a team sport, and everyone has to be engaged and proper communication is key.
4. Outages is a team sport. This requires complete alignment from all. Celebrate successes and seek to understand challenges as they arise. Operational experience is important to a successful outage.
5. Important that organizations know their equipment reliability and SPVs. Current 561 SPVs.
6. Ensure proper training is given to employees who have to use tools in place, e.g., SAP and Primavera, as it is intended to be used, not butchered to what individuals think it should do. Do benchmarking to utilities where these tools are being used and are actually interfacing, not only looking at utilities for their INPO status or plant designs.

4.16.2 Question 15 Analysis

The first comment reminds of the importance of following the schedule in a sequenced manner or the path as designed and agreed to avoid deviation and errors. Of course, changing the schedule if required is allowed but only using the change control process. This keeps everyone focused on the same objectives and more importantly safeguards the people and the plant.

The second comment is valid in that the author's own observations both at Eskom and elsewhere, was that very few people understand resource levelling properly and therefore don't apply it properly or at all. If done effectively, it helps achieve an accurate schedule that is more trustworthy, accurate, reliable, timely and achievable. It holds potential for immense accuracy and comfort in determining the true outage duration. One of the participants with at least 26 outages to his name stated: "Operations activities tend to take as long as they do. When plans are put together, it is often an aspirational plan. E.g., Mode durations/windows and often those windows are exceeded. An outage organization has very little control over Operations". If resource loading and levelling was used, Operations activities would be loaded and levelled, and the participant would not make a comment like this.

The third and fourth comments were similar but came from different participants. They emphasized that outages are a team sport, and that communication, engagement and alignment are key. One participant added the importance of celebrating successes. This is implicit in any organizational success but if they felt the need to emphasize this, the advice should be heeded.

The fifth comment was critical advice, knowing the Single Point Vulnerabilities (SPVs). What the participant did not emphasize was the importance of having plans and contingency plans to mitigate and reduce the SPVs. These SPVs are not well known to any employees. They typically reside in a report that does not get due attention. To be effective at managing SPVs, employees need to know

what they are and be working towards reducing or mitigating them. They should be visible and an important facet in performance contracts of all employees.

The sixth comment emphasized the need to provide proper training on outage tools such as SAP and Primavera as they were intended to be used and not allow “butchering” to what individuals think they should do. Its again implicit that this should happen, and one cannot imagine that organizations do not do this. Yet, it happens and must be because of issues like appointing the wrong people, poor leadership, bad culture and even remuneration practices that encourage people to serve their self-interest rather than organizational interests. The same interview emphasizes the benchmarking of organizations where these tools are being used and not only utilities for their INPO status or plant designs. The message is clear, that benchmarking outage management tools are as important as INPO status or design engineering. This point presents an opportunity for further investigate to what extent NPPs do in fact benchmark outage management tools compared with resources spent and benefits gained from other benchmarking efforts. After-all, it is effective and short outages that reduce the cost of operating and that has immediate benefits for the bottom line.

In conclusion, Question 15 was meant to cover any items the participants did not already discuss or reinforce certain practices or ideas that could improve outage durations. Four key themes were emphasized:

1. Proper planning, scheduling, and executing to the schedule
2. Having enough suitably qualified resources which includes continuous training
3. Teamwork and motivation of employees
4. Knowing the SPVs and working to reduce and mitigate them.

Effective planning, scheduling and execution as well as having enough of the right resources have been key success factors throughout the interview analysis. NPP management and leadership should objectively evaluate these specific factors to determine probability of success.

4.17 SUMMARY OF INTERVIEWS ANALYSIS

This interviews and analyses thereof presented exceptionally useful and pragmatic information and practices that the NPP organization could use immediately. Questions 5 and 6 on outage durations showed that even nuclear outage professionals with an average of 30 years nuclear experience each and having participated in about 30 outages each have different paradigms of what best outage durations are and should be. Their estimations were on average 62% longer than top performing NPPs. Therefore, if their paradigms transcend the NPP, it indicates that the NPP has to create a new image of what good looks like. Otherwise, the organization will not be cohesive and not be working towards best in class.

Question 7 analyzed the most common reasons for outage delays. There were 13 reasons discussed by the participants and the following featured most prominently:

1. Inefficient scheduling/planning

2. Discovery / Emergent Work
3. Availability of replacement parts
4. Lack of the right resources
5. Expanded scope, human performance errors and rework all had an equal mention

They are consistent with those reasons mentioned in the literature review. In the case of the literature review, the sources did not rank the reasons. However, this dissertation does. Importantly, this question and interview answers sets the scene for both questions 8 and 10.

Questions 8 and 10 discuss the most effective ways to mitigate delays and optimize outages. The questions are similar in nature and help reinforce the answers to each. If the answers were substantially different, this would be cause for further investigation. However, the answers were similar and effectively reported the most effective optimization practices as:

1. Effective Scheduling and Planning, including Risk Management and Contingency Planning
2. Sufficient Skilled Resources
3. Risk Management / Contingency Planning
4. Effective Execution to Schedule
5. Effective Scope Control
6. Better Work Practices

Question 11 assessed major constraints or challenges to shorter outages and also supported the answers in Questions 8 and 10. There were 19 constraints reported and the three major constraints were ranked:

1. Insufficient number of skilled resources
2. Poor scheduling
3. Ineffective scope management

Questions 13, 14 and 15 were intended to extract information from participants that may or may not corroborate previous answers. In all cases the answers in these questions provided useful information and context to outage delays and opportunities for optimizations. Of note, there were no trends based on nationality (USA vs SA). The interview data set the stage to better understand the existing thinking in the NPP and will help the willing organization to craft a better culture, with better people, systems and work methods that drive top tiered outage performance.