A generic software platform for performance monitoring of deep-level mine systems

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ABSTRACT

Title: A generic software platform for performance monitoring of deep-level mine systems.

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Keywords: Performance monitoring, Performance indicators, Deep-level mines, Cognitive load, Software platform, Efficiency.

Systems of a deep-level mining operation are integral to the working of a mine. These systems help with water reticulation, compressed air, and energy used for mining minerals. A mine relies on these capital-intensive systems for the health and safety of employees and the mining of minerals. As the mine deepens to mine more minerals, these systems become more complex and expensive to operate and more difficult to maintain.

This leads to the need to monitor deep-level mining systems to ensure the optimal efficiency operation of these mining systems. Personnel are often responsible for several systems and projects. This can influence decision making and more informed decisions due to the amount of data that needs to be analysed. In this study, performance monitoring of deep-level mines will be investigated to develop a generic software platform for performance monitoring of various deep-level mining systems that will reduce the cognitive overload of Big data that needs to be analysed for decision making to increase a mine's profit margins.

For this study, a software platform was designed and implemented to monitor the performance of energy efficiency initiatives implemented by an ESCo. The performance of multiple systems on various deep-level mines can be monitored with ease by personnel when using the platform. By using the performance monitoring software platform, personnel are able to monitor the performance of initiatives on deep-level mining systems on a multi-level overview. Each initiative's data can be viewed in detail to improve problem identification of initiatives that are performing poorly.

By monitoring the performance of mining systems and improving the efficiency of these systems, a combined estimated cost saving of R 8.6 million per annum is achievable for the case studies that were presented. A total of 105 initiatives for deep-level mining systems' performance monitoring were configured, that enabled personnel to monitor multiple systems' performances without the need to process and analyse data. The performance monitoring

software platform enabled personnel to reduce system data analysis time between 60 and 70%.

The objectives of the study were achieved by the development of a software platform for performance monitoring that enabled ESCo and mine personnel to monitor the day-to-day performance of implemented initiatives on deep-level mining systems.

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LIST OF ABBREVIATIONS

DSM	Demand Side Management
IDM	Integrated Demand Management
ESKOM	Electricity Supply Commission
EMS	Energy Management System
KPI	Key Performance Indicator
ESCo	Energy Services Company
PLC	Programmable Logic Controller
SCADA	Supervisory Control And Data Acquisition
OPC	Open Platform Connection
ISO	International Standards Organisation
IPMVP	International Performance Measurement And Verification Protocol
DB	Database
DBMS	Database Management System
M&V	Measurement and Verification
PMSP	Performance Monitoring Software Platform
ERD	Entity Relationship Diagram

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW



Impala Platinum shaft in South Africa (Source: www.implats.co.za)

1 Introduction and Literature Review

1.1 Introduction and Background

1.1.1 Preamble

South African mining operations face many challenges due to increased competition from other countries. This has placed South African mines in a financial crisis. During the past decade there has been a decline in South African mining production which is a large contributor to the global production of precious metals. Mining operations also face increased financial challenges due to increasing operational costs to extract ore, causing a decline in profit margins of the mining companies. [1].

South Africa's mineral deposits are still considered the leading source of precious metals in the world. Although South Africa has many mineral deposits, challenges emerge in deep-level mines due to the depletion of easily accessible mineral resources [1]. Mines become deeper each year due to the depletion of minerals and resources to mine [2], [3]. Extracting minerals at deeper levels involves expanding mining systems to make the extraction possible. These systems include ventilation as well as compressed air and water systems, as illustrated in Figure 1 below [4], [5]. The expansion of these systems requires more electricity, which is a system on its own. The feasibility of a mine and its operations is dependent on the efficiency of these systems.

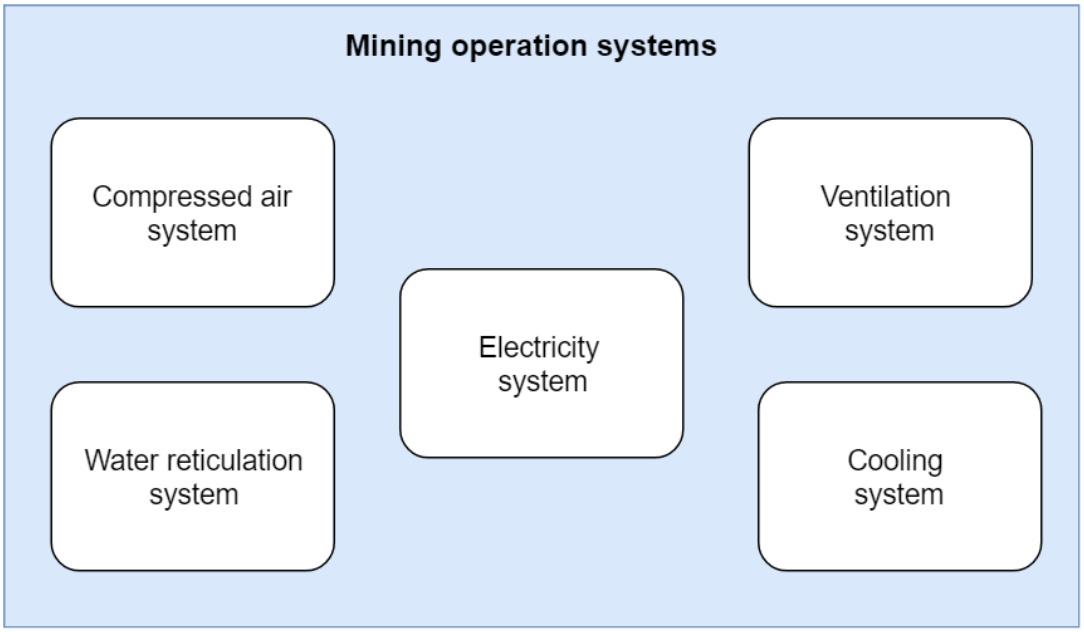


Figure 1: Mining operation systems overview [5]

1.1.2 Deep-level mines

An overview of the typical mining operational systems found on a mine is shown in Figure 2. The main systems that can be found on deep-level mines can be grouped into compressed air systems, which include all compressed air operations, and water systems which include water reticulation, ventilation, and the cooling system of a mine. These systems are required to operate the equipment as well as enable safe underground conditions for mining operations for the extraction of minerals [5].

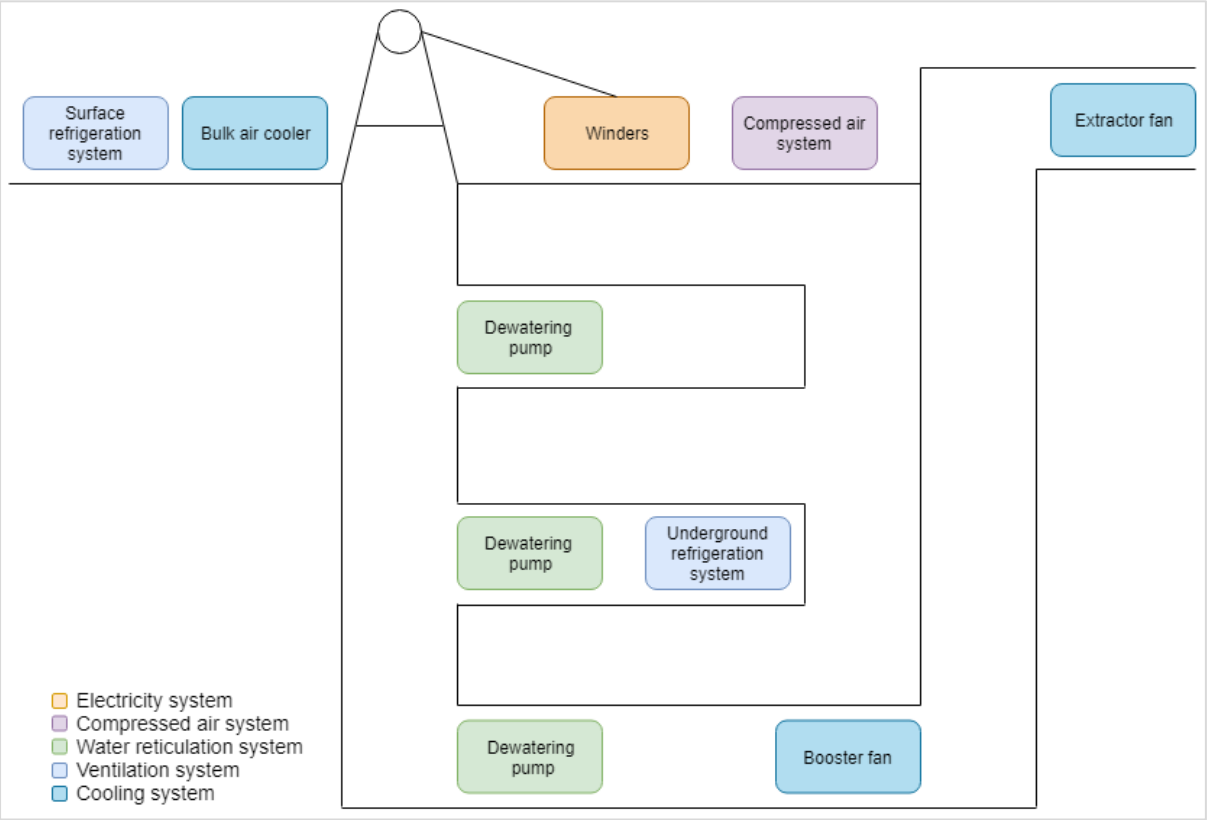


Figure 2: Overview of deep-level mining systems [5]

These systems on a mine must be maintained throughout the mine's lifetime in order to operate as efficiently as possible. Deep-level mines have increased problems with systems due to ageing infrastructure which result in increased power usage in [2], [6], [7].

Compressed air systems

Compressed air is considered a utility, particularly in the industrial sector. It is the most used utility on deep-level mines, accounting for 21% of the total electricity used by mines [2], [3], [4]. Not only is compressed air the most used resource on a deep-level mine, it is also the most expensive system to acquire and maintain [3].

Compressed air is used for production purposes mainly as a utility to power tools used for drilling into rock face [2]. In South African mines, the air is widely used in production during the extraction of mineral ore [3], [8]. Compressed air is commonly used in the industry, mainly because compressed air is easy to produce and distribute from point to point, making it easier to handle and distribute between air supply and the end-user [9].

Figure 3 shows the typical compressed air network on a mine. It usually comprises of a compressor house with compressors and a network of pipes, valves, and controllers that supply the compressed air to underground operations [2], [7].

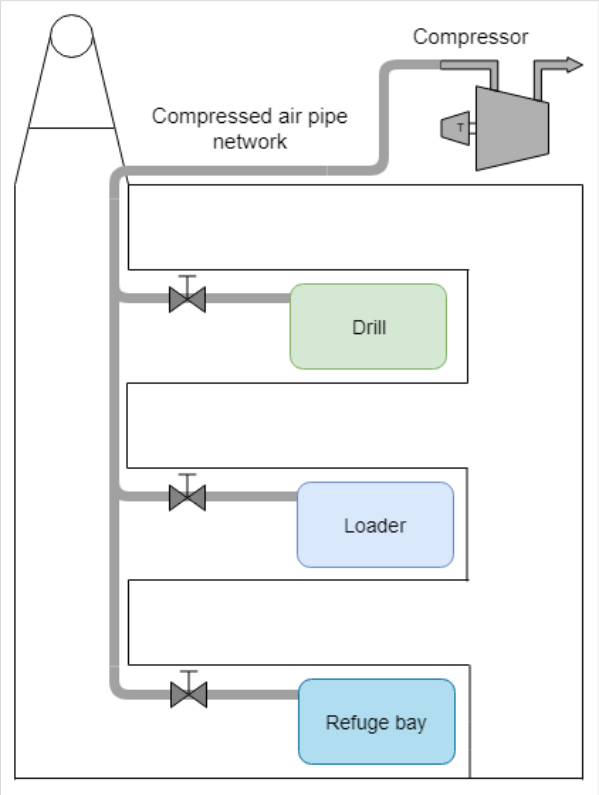


Figure 3: Deep-level mine compressed air system layout [10]**,** [8]

From the compressor house, housing multiple compressors, there exists a complex network of pipes through which the air is distributed and supplied to the consumer or end-user of the compressed air. These end-users in a deep-level mine are usually surface workshops, drills, hoppers, loaders, and refuse bays inside the mine [8], [11], [12]. The compressed air used for mining operations is usually generated by compressors that are particularly energy-intensive [3].

This is one of the most expensive methods of distributing energy or a utility, and as a result, it is an expensive asset on a mine to operate and maintain [3], [8]. Energy consumption of these systems varies depending on the time of day due to mining schedules, where different flow

and pressure is required throughout the day [11]. Compressed air is a vital component in the operation of a mine and has a direct correlation with the production on a deep-level mine [7], [12]. The cost, operation, and maintenance are important aspects affecting the operational cost of mining.

Due to a weak economy and increased production to make operations more profitable, a compressed air system is expensive to operate and maintain. There is a need to optimise the operation of compressed air in a mine and reduce the costs of these systems [7], [9].

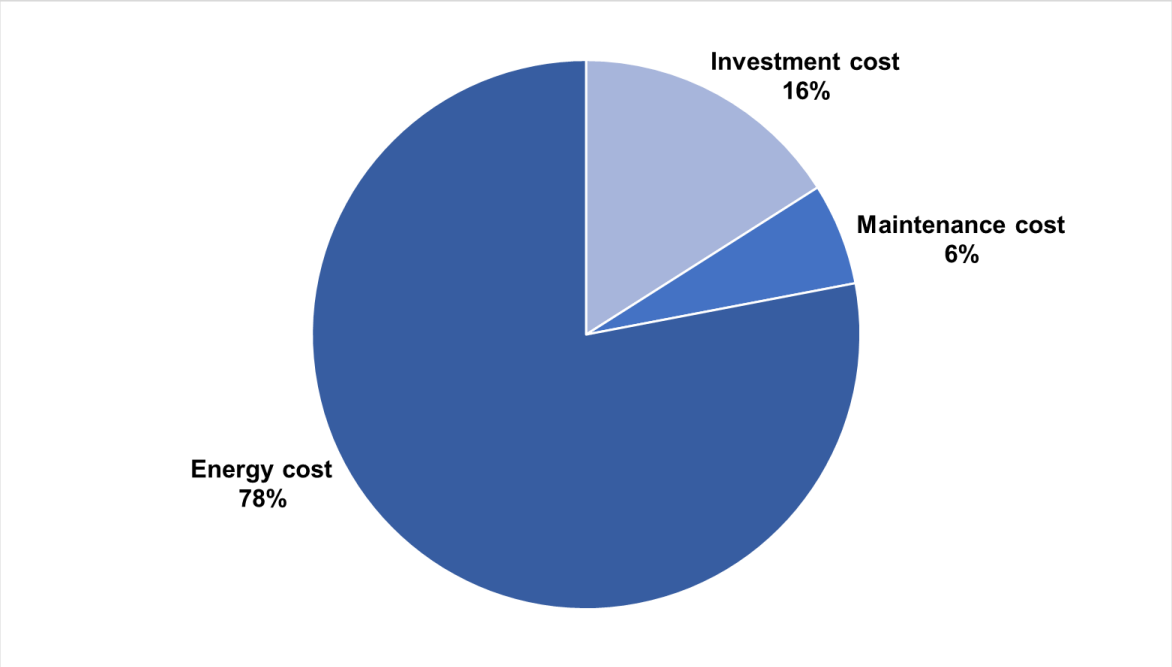


Figure 4: The life cycle cost of a compressed air system [9]**,** [13]

As seen in Figure 4 above, the cost of a typical compressed air network can be split into three main expenditures, where the energy used by the system throughout its lifetime contributes the largest portion of the costs related to this vital system on deep-level mines [7], [9].

Water reticulation systems

Deep-level mines in South Africa use water for various systems underground, including dust suppression and cleaning after blasting, drilling, and ventilation. The water that is utilised by a mine is recycled in an attempt to save water in a country with limited water resources such as South Africa [14].

When mining underground there are many challenges encountered that need solutions. One of the big challenges of mining deep underground is the rising temperatures the deeper the mine goes. Virgin rock temperatures can increase by as much as 12 ºC per vertical kilometre, meaning temperatures deep underground can reach 60 ºC at a depth of 4 km [4], [14], [15].

In order to ensure these deep-level mines are safe to work in, mine ventilation and cooling systems are necessary to cool the mine down to an acceptable legal required temperature of 27.5 ºC wet bulb or below [4], [15].

Cooling and water reticulation systems are used to cool the mine down to legal safe working conditions by supplying underground operations with cold water and air. This water is also used during drilling and cleaning periods [15]. To prevent the flooding of mining levels underground, a dewatering system is used to pump excess water out of underground areas. After the water is used for cooling, drilling, and cleaning, the water is moved to hot water dams that are used to store the water that needs to be pumped back to the surface to avoid flooding [14].

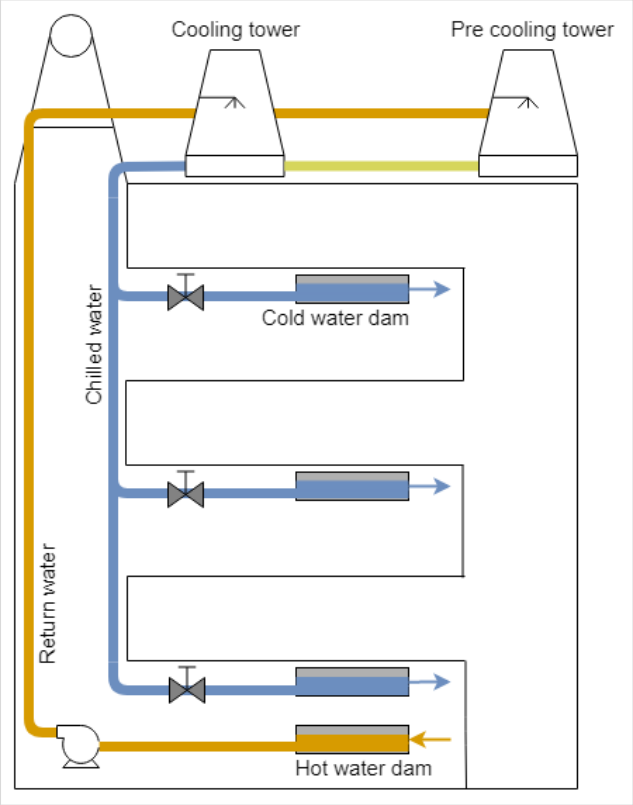


Figure 5: Deep-level mine water reticulation system layout [16], [17]

In Figure 5 above, the typical layout of a deep-level mine water reticulation system is illustrated. Water is cooled and sent down to working areas for cooling, drilling, and cleaning. During mining operations, the water gets heated in these processes and is pumped back to the surface where the water is re-cooled to be recirculated [14]. A typical deep-level mine in South Africa has pumps that circulate water throughout the mine using a complex network of pipes and dams. The water systems that are used in the mining sector include dewatering and cooling. The configuration of a semi closed-loop water reticulation system that is typically found on deep-level mines is illustrated in Figure 6.

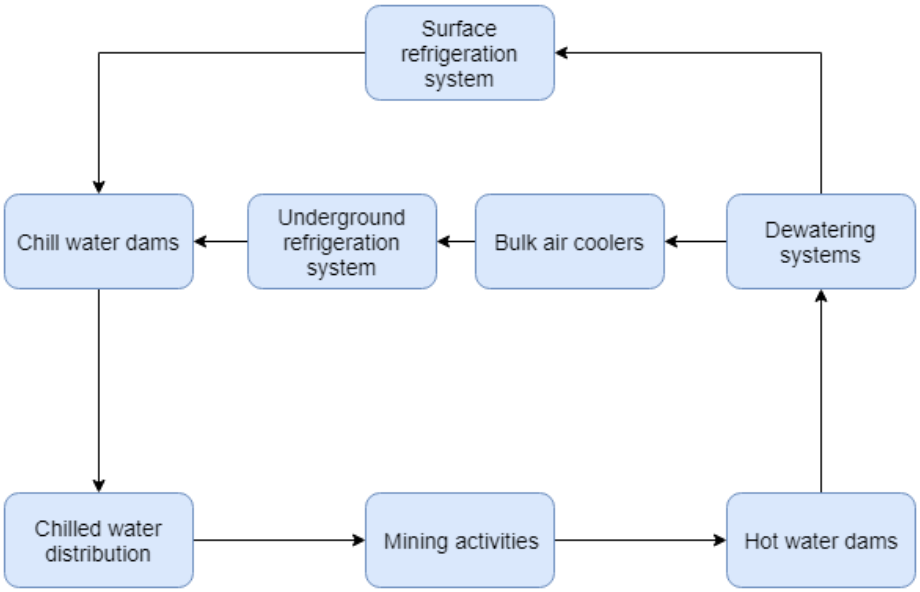


Figure 6: Mine water reticulation system overview [4]**,** [16]

Deep-level mines use a dewatering system to ensure that the levels on the mine do not flood. A cascading system of pump stations and dams are situated on several levels within the mine to dewater the mine in order to prevent flooding and to circulate water for different operations [18].

Refrigeration systems are used as part of the cooling systems found on deep-level mines. A refrigeration system's functionality is to supply cool air to ventilation systems and to supply cold water to mining operations. Refrigeration and dewatering systems operate in a semi-closed loop configuration, as illustrated in Figure 6.

The heated water that is pumped out of the mine from dewatering systems is recycled and cooled down by surface pre-cooling towers and then cooled to chilled water temperatures required for cooling and ventilation by the refrigeration systems before being pumped to chilled water holding dams [14], [18].

Water systems are crucial for the operation of mines, supplying many critical systems such as refrigeration, cooling, and energy recovery systems with water. Other water systems such as dewatering pumps are also key to ensure the operations in the mine are workable and safe for miners [19]. Water systems include cooling dams and water reticulation which is a key part of cooling in deep-level mines. In order to adhere to health and safety regulations, the mine must be kept below the set temperatures for personnel and miners [19], [20]. The temperature of a deep-level mine has a direct impact on the productivity of a mine [4], [15].

1.1.3 Electricity consumption on deep-level mines

The electricity demand in South Africa has increased year-on-year as a result of population and economic growth as well as Eskom's financial problems [21]. Due to this economic growth, the demand and feasibility for mining companies to keep mining resulted in the need for the mines to expand their operations. This expansion leads to the mines in South Africa becoming deeper to keep up with the demand for minerals [2], [22]. To reach these minerals at deeper levels, the systems used for mining operations have increased operating costs to keep up with production. New infrastructure is installed to compensate for new deeper levels within the mine. The ageing infrastructure of the existing systems used for production and mining becomes neglected, resulting in poor performance and energy usage [2].

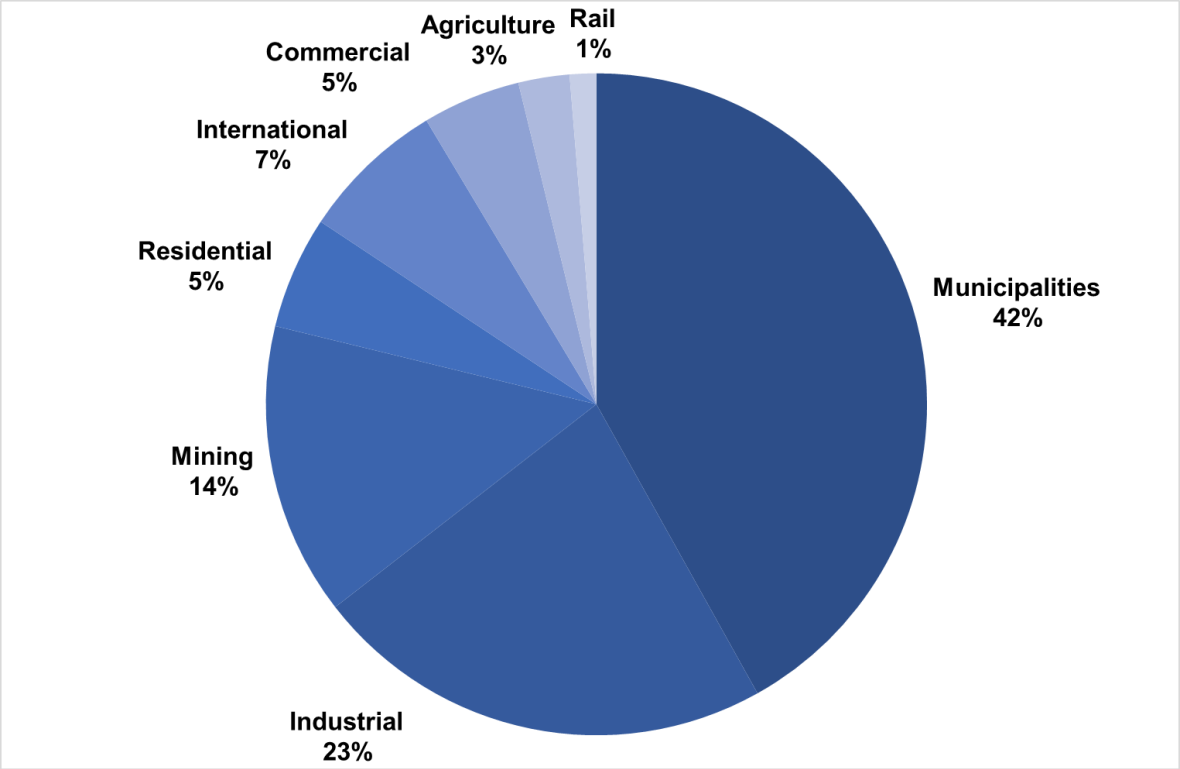


Figure 7: Eskom sales distribution for 2017 [23]

According to Eskom, the mining sector consumes 14% of electricity in South Africa, as illustrated in Figure 7 above [23]. With rising costs of electricity usage, mines are forced to optimise systems such as compressed air and water reticulation systems to minimise electricity consumption due to leaks, poor performance, or systems that are not efficient. As shown in Figure 8, some studies indicate that 21% of energy usage on a mine is used by compressed air systems alone [8], [21], [23].

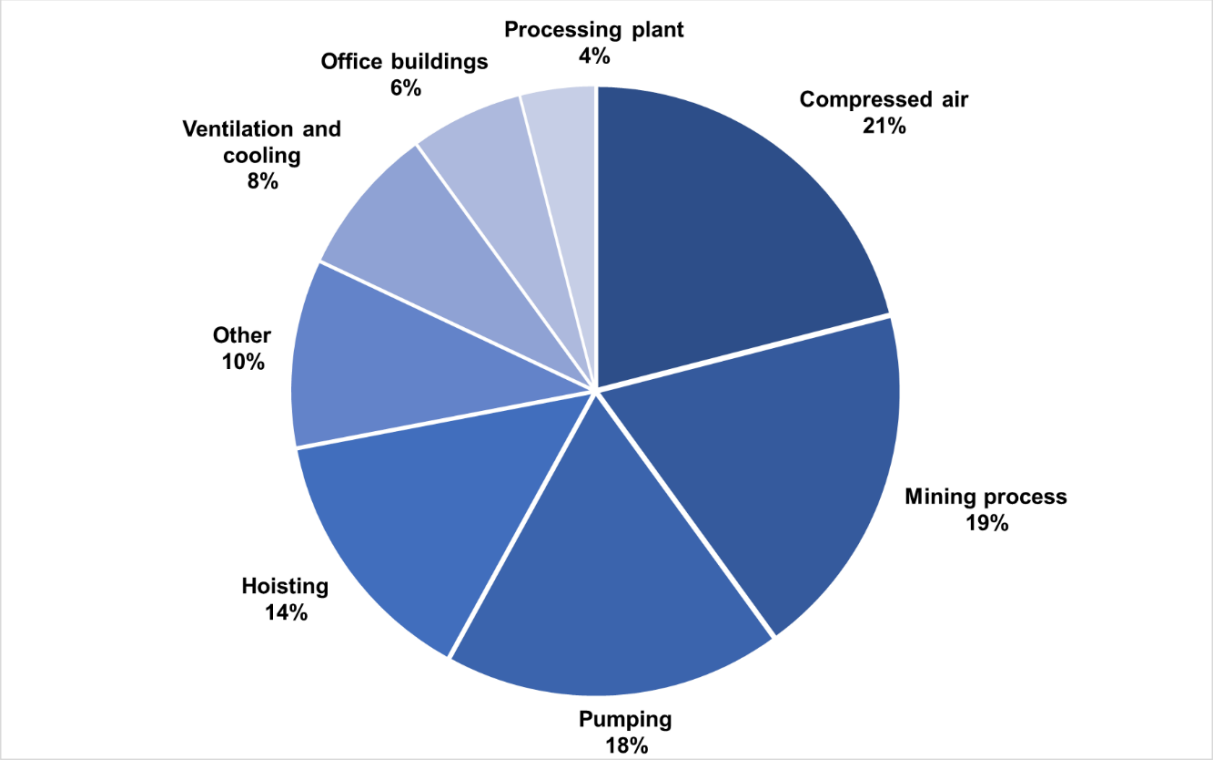


Figure 8: Deep-level mine systems energy consumption [4]

With electricity demand rising due to economic growth in South Africa, Eskom needs to invest in new operations to expand the generation capacity. Eskom does experience generation capacity problems, especially during peak demand periods [23], [24], [25], which drastically impacts the cost of electricity to force reduced electricity usage during peak periods, forcing operations to conserve energy to ensure stable operation of the national grid [2], [23].This rise in electricity costs impacts a mine's operational cost and affects the profit margins of a mine and the companies [2], [22].

1.1.4 Performance monitoring on deep-level mines

There are existing initiatives to save on electricity costs of operations, such as DSM (Demand-Side-Management) which reduces peak demand consumption [4], [25], [7]. Since 2015 a new model called IDM (Integrated Demand Management)has been implemented to replace DSM. This helps Eskom as well as the client to reduce maximum demand, which results in lower electricity usage and costs [10], [11].

Performance monitoring is necessary to optimise the systems and operations on the mine to help with cost and energy usage savings. Large energy consumers need a platform or system to monitor their energy-intensive system performances continuously [1], [10], [27].

Performance monitoring supports the requirements of ISO (International Standards Organisation) 50001 standard for energy management and aids in decision making on operations, helping with energy awareness and energy-efficient decisions in alignment with the ISO 50001 standard [13], [28].

In order to monitor these systems, the performance data of these deep-level mining systems needs to be processed and analysed. However, with large mines with complex systems, large quantities of data exist.

1.1.5 Software platforms

The increased demand to analyse and process large quantities of data is an important aspect of the Industry 4.0 movement. Big data is a term that is used to characterise large amounts of data often used in Industry 4.0, and enables software systems to effectively transform large quantities of data into usable information that can be interpreted and quantified [29].

There are many ways to present data and information. Information is processed data, but traditional methods of presenting raw data as useful information require more input from a consumer perspective. Traditional methods typically require a person to analyse the data, do calculations, and present the data and information in a useable and sensible manner. A software platform gives an automated way to present data and information that makes it easier to analyse and make decisions regarding information [30].

Using a software platform, deep-level mine system data can be better analysed to draw conclusions on the data. The software will make it possible for mine personnel to monitor and analyse the performance of deep-level mine systems. This can help prevent system failures, assist with energy-saving initiatives, and aid in overall decision-making for the management of the mine.

When industrial systems are installed, measuring devices are simultaneously installed to monitor and control these systems. The data from these measuring devices are stored in a database. These measuring and controlling devices include measuring and metering equipment, a PLC (Programmable Logic Controller), SCADA (Supervisory Control And Data Acquisition) systems, and an OPC (Open Platform Connection), as illustrated in Figure 9 below [10], [30].

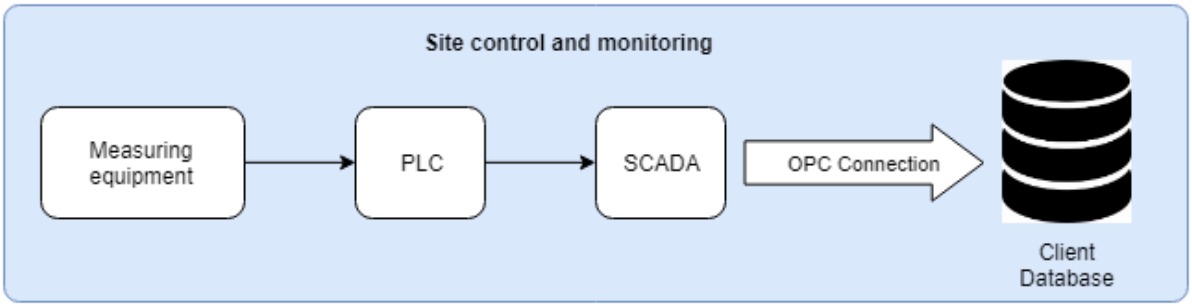


Figure 9: Data source flow [24]

In Figure 9, the flow of data from system components is illustrated. A large amount of data that is obtained from the measuring equipment is then stored in a database where the data of the systems can be used for data analysis.

Software platforms make it possible to access, view and analyse large amounts of data of deep-level mining systems, reducing the time spent on data analysis. Software platforms for Big data access play an important role in the development of the fourth industrial revolution known as Industry 4.0 [31].

1.2 Literature review

1.2.1 Preamble

This chapter contains a literature review on the performance monitoring in deep-level mines to gain insight into the typical problems that occur within the systems mentioned in Section 1.1. Existing solutions that address the monitoring of systems are investigated, and shortcomings that can be identified from the literature are highlighted. An investigation of why Big data is considered a crucial element in Industry 4.0 is done, as well as the challenges thereof.

1.2.2 Deep-level mining systems

South African mines are experiencing financial challenges due to a struggling economy, and as such the mines are seeking opportunities to improve operations for cost-saving so as to improve the profitability to keeping mining operations open. Deep-level mines rely on the electricity supply from Eskom to operate and run crucial systems to extract minerals [4], [17].

In 2018 South Africa's mining industry accounted for an estimated 18% of the total energy consumed in the country [8], [21], [23]. In the South Africa mining industry, the most energy-intensive mines are gold mines at around 47% of total energy consumed by mines, followed

by platinum mines at 33% of total usage. The remaining mines only account for an estimated 20% consumption of total energy by the industry [2], [8].

There are several systems on a typical deep-level mine, as discussed in Section 1.1.2, that make the extraction of minerals possible. These systems include compressed air, water reticulation systems, ventilation, and cooling systems. In Figure 8, the breakdown of a typical deep-level mine's operational systems energy consumption is illustrated. Mines want to reduce electricity usage on energy-intensive systems for cost-saving on electricity bills [10].

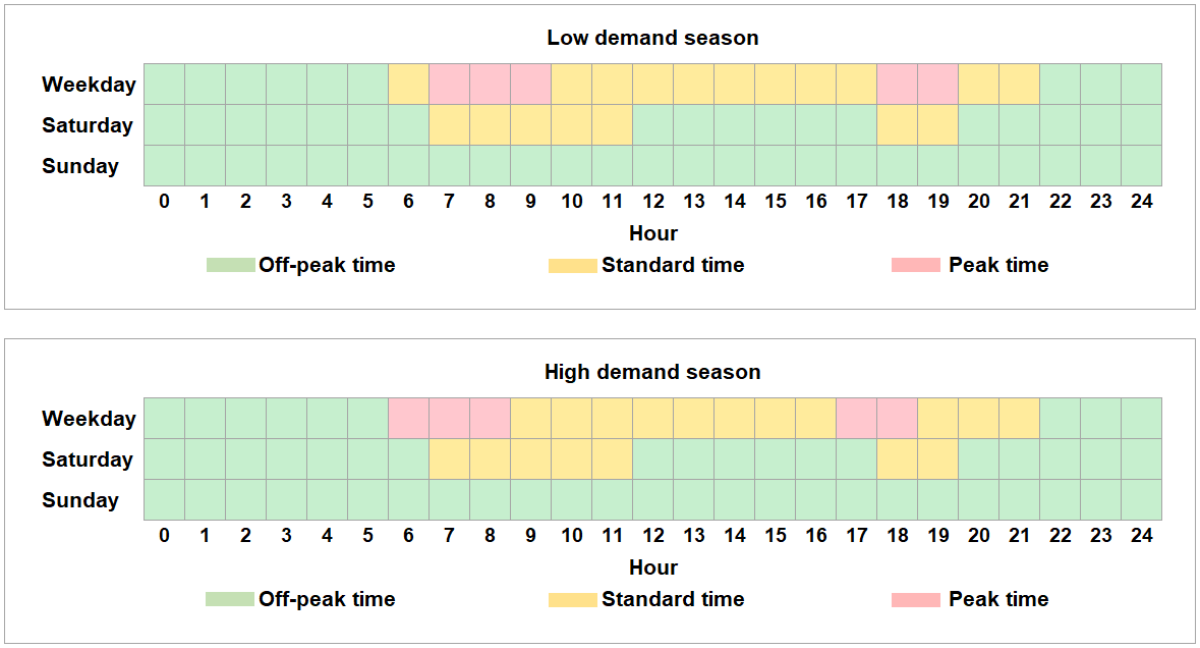


Figure 10: Eskom's Megaflex Time-Of-Use structure [10]

Eskom implements a time-of-use structure for tariffs. This tariff structure, as seen in Figure 10, implements time tariffs for certain periods during a 24-hour period. There are two structures used, one for the low demand season and one for the high demand season. These structures implement different electricity tariffs for three different periods during a day [10].

Peak demand times have the highest electricity tariff and off-peak times when the electricity demand is low have the lowest electricity tariff. This time-of-use tariff forces big energy users in the industrial sector to shift their electricity demand to the standard or off-peak periods to reduce electricity costs, which help reduce peak-time power usage when the national grid is under stress [10], [17]. The time-of-use tariffs force industries such as the mining sector to schedule mining operations to reduce peak electricity tariffs of mining systems.

The extraction of minerals from deep-level mines is dependent upon systems that make it possible for mine personnel to work in underground conditions that are safe for humans as well as use tools to mine the minerals.

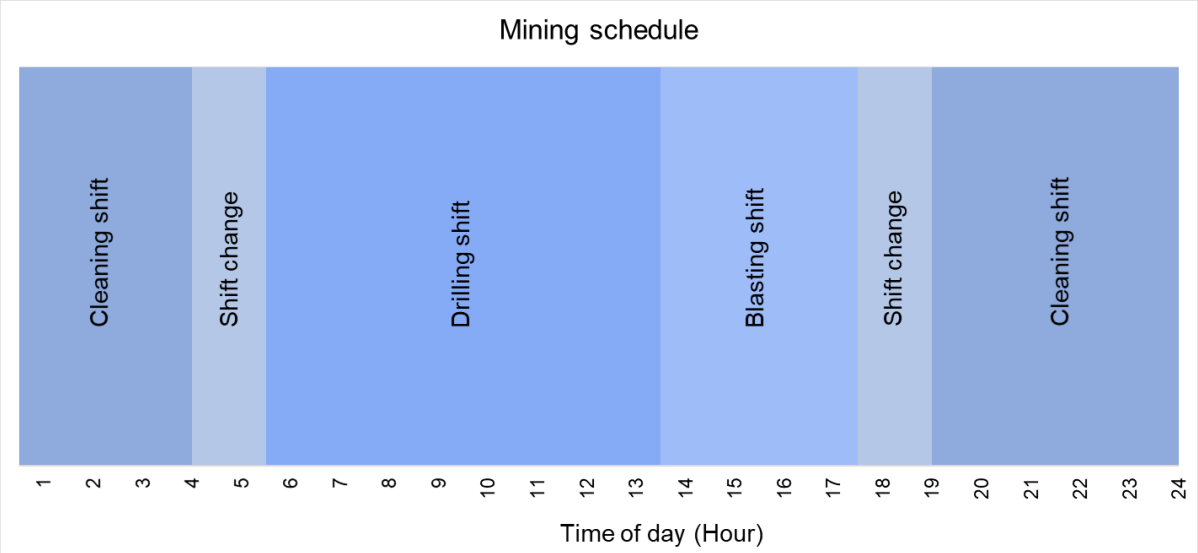


Figure 11: Typical mining schedule [20], [32]

The typical mine has a schedule for production, as shown in Figure 11. This schedule includes drilling, blasting, and cleaning phases [32]. Each phase is necessary in order to extract the minerals before processing. Each shift for production requires specific utilities and resources. This creates a demand for certain amounts of compressed air, cooling ventilation, and dewatering pumping requirements [32].

During the drilling and cleaning shifts, more compressed air and water reticulation utilities are required to operate the equipment. The mine has a specific schedule to carefully plan the use of energy-intensive systems' resources to avoid Eskom peak-energy periods. From Figure 11 it can be seen that the blasting shift is scheduled during the peak period to save on energy costs and reduce the strain on Eskom's national grid during this time [20], [32].

It is well known that compressors are one of the most expensive utilities and resource in industrial operations [33]. Improved efficiency of these systems is, therefore, crucial as it is one of the fastest-growing expenditures [12]. Compressed air demand of deep-level mines depends on the mineral that is being extracted and the demand for the resource, as well as the resources available for production. A typical deep-level underground mine has schedules for drilling, blasting, cleaning, and personnel shift changes [11].

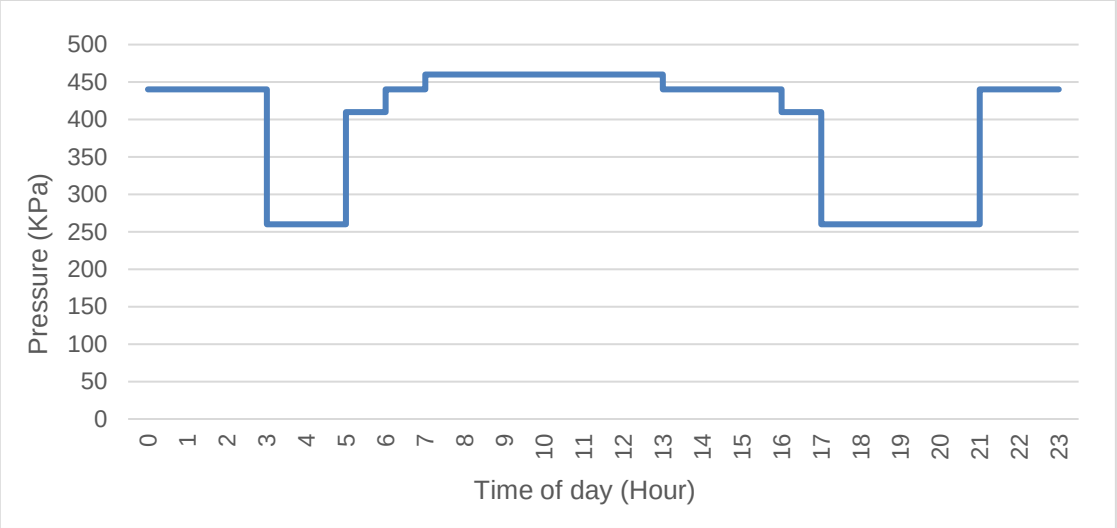


Figure 12: Typical Deep-level mine compressed air demand schedule [10], [11]

As seen in Figure 12, a typical deep-level mine has a certain demand for compressed air. Personnel working shifts usually start from 03:00 in the morning. The changeover of personnel can take some time because the deep underground level stopes where drilling and blasting occur need to be reached before the shift can start. The highest demand for compressed air is during drilling shifts during the day shift, while no air is required during the blasting shift [11].

As described in Section 1.1.2, water systems are crucial for the operation of a deep level mine. Although water reticulation systems are not as energy-intensive as compressed air systems, there is a need to monitor the performance of water systems. During the different shifts of a mining schedule, as described, there is a different demand for water in during each shift of the day [14], [20].

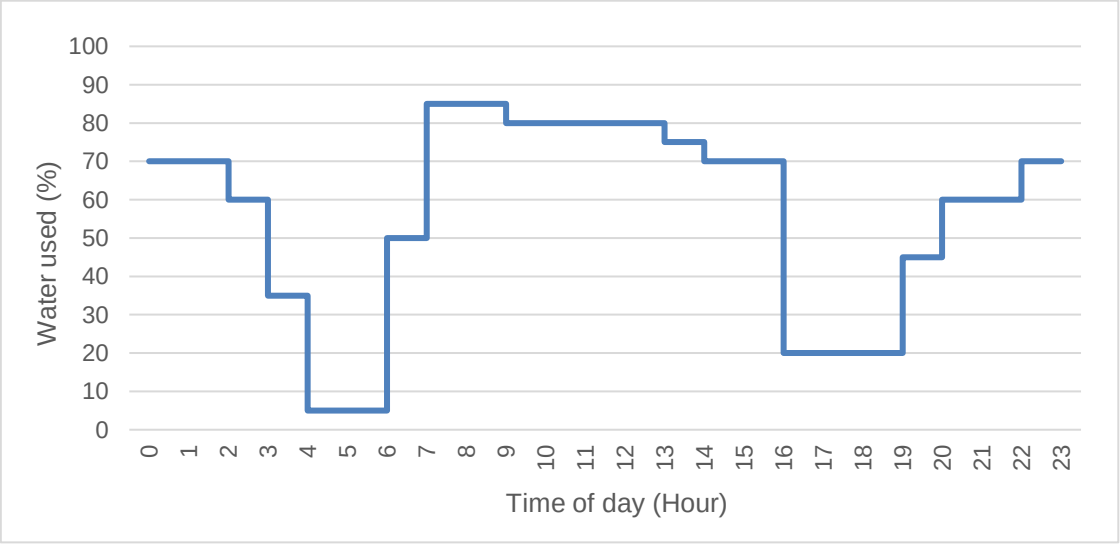


Figure 13: Typical Deep-level mine water demand schedule [20]

In Figure 13 the water requirement during the day can be seen. Water demand during drilling correlates with the mining schedule where there is a high demand for water, used by cooling, ventilation, and dewatering. During the mining shift changes, almost no water is used by the reticulation system [14], [20]. Water-intensive operation shifts are scheduled to fall outside the expensive Eskom tariff and peak periods.

The Eskom tariffs and time-of-use periods impact how mines schedule the drilling and blasting shifts. During peak periods blasting is done in the stopes. This is due to the low compressed air and water demand needed for blasting, resulting in the compressors and pumps using less energy and thus saving on the mines electricity bill [6], [11].

Most mines in South Africa have compressed air and water reticulation systems that oversupply for the actual demand that exists for the end-user [7]. In many cases, the tools used underground in the mining sector, such as pneumatic drills, have very low efficiency, causing oversizing of compressed air systems [8], [34]. Limited maintenance on compressors, pumps, pipes, and valves in the compressed air and water reticulation networks impact the efficiency and demand [8], [12], [20].

1.2.3 Performance monitoring on deep-level mines

The PDCA (Plan-Do-Check-Act) cycle is only used as a guideline to help meet the requirements and objectives set for the performance of systems [13].

Mining operational systems need to be monitored in order to minimise cost implications. This is done by monitoring the performance of individual compressors and the actual utilisation of air to what the demand for air is. By using historical data, performance indicators can be developed that will indicate the nominal usage of air during different operational shifts and during seasonal changes and condonable or disregarded days of poor production. The actual usage and performance can be compared against historical data to easily identify problems linked to production, maintenance, and poor utilisation of resources.

The performance of a system can be divided into many different aspects. The energy used by the system can be monitored. From the energy data of a system, many conclusions on the performance can be made. When a system is performing poorly, the system will typically use more energy than usual. This can indicate leaks, energy loss or maintenance problems on the system.

Performance monitoring standards and methods help monitor the progress of projects and help derive key performance indicators for a specific system and set performance indicators for the performance quantification of a project or system [35].

1.2.3.1 Standards for performance monitoring

To aid performance monitoring on systems and projects, standards and guidelines such as the International Performance Measurement and Verification Protocol (IPMVP) and the ISO (International Standard Organisation) 50001 standard have been developed [36], [37]. When the performance of systems and on-going projects adhere to these standards, industry acceptable methods and approaches are used when evaluating the performance of projects [38].

The IPMVP provides best practice techniques for ESCO's to verify the performance of energy-related projects and systems. IPMVP enables an ESCo to determine energy savings for the project and modified systems to improve performance. It is used by professionals that seek to verify the benefit of modifications made to projects and systems [39].

The ISO introduced the ISO 50001 Standard for Energy Management in 2011. This standard implements the use of a continues life cycle for EMS (Energy Management Systems) to ensure continuous improvement [40], [43].

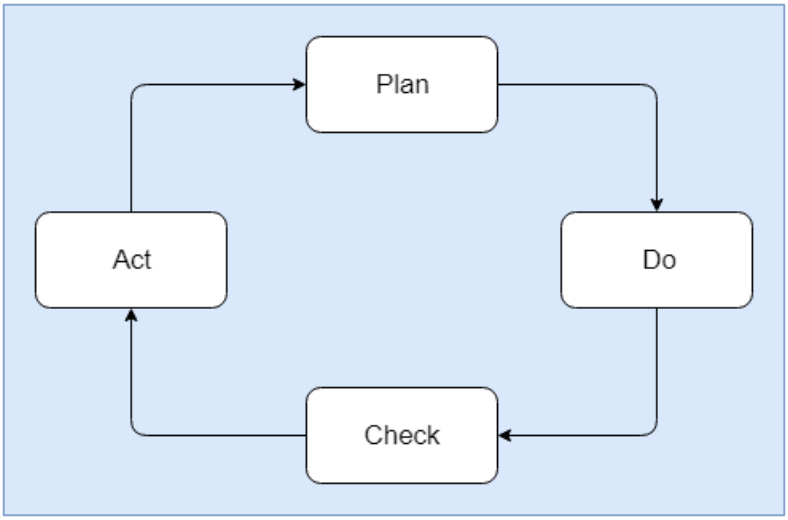


Figure 14: ISO 50001 Standard continuous improvement cycle [13]

In Figure 14, the continuous improvement life cycle of the ISO 50001 standard is illustrated. This life cycle of continuous improvement uses a Plan-Do-Check-Act cycle to ensure the improvement of EMS [13]. Most existing monitoring platforms make use of this life cycle to ensure the continuous improvement of projects and operations.

This standard help to continuously improve the performance of systems by using the steps in the cycle. Each step in the cycle has several processes and steps that serve as a framework to continuously improve systems.

These steps are:

- **Plan:** Develop an energy-saving strategy by benchmarking, reviewing energy usage, and identifying performance indicators such as baselines. After the savings strategy is developed, objectives and targets for the systems must be set [41], [42].
- **Do:** Implement the energy-saving strategy using the identified performance indicators [13].
- **Check:** After implementation, the systems must be measured and verified. The performance of implemented plans must be evaluated, measured, monitored, and verified. Further checking involves identifying characteristics of performance against objectives that were set during the planning and development of an energy-saving strategy and reporting the performance outcomes [38], [41], [42].
- **Act:** Act refers to the process of any actions that are taken to continuously improve the performance of systems of the implemented savings strategy. The actions that can be taken to ensure continuous improvement involve reviewing the plans and strategies with management [13], [41], [42].

The ISO 50001 standard is based on the PDCA (Plan, Do, Check, Act) cycle. The performance of a system or project can be measured for the long-term as well as short term goals on a project [35]. For successful systems and projects, the correct tools are needed to develop a sustainable strategy [5], [10]. Consulting expertise, management of people and resources, software platforms, and the correct hardware to gather data are an integral part of a sustainable platform for a successful project [35], [38].

These standards and protocols enable ESCO's to achieve goals that are set to improve systems. These standards incorporate the use of baselines and proposed operations to enable sustainable cost and energy savings.

1.2.3.2 Baselines for performance monitoring

The performance of a system can be determined by comparing the actual usage of a resource or quantity with a defined baseline. The baseline is determined by nominal usage or historical measurements in certain periods before the modification of systems [25], [39]. Baselines are usually determined by the historical data of measurements during different seasonal periods, weekday and weekend periods, or any condonable actions such as suspension of work periods caused by workforce strikes and maintenance [25], [35].

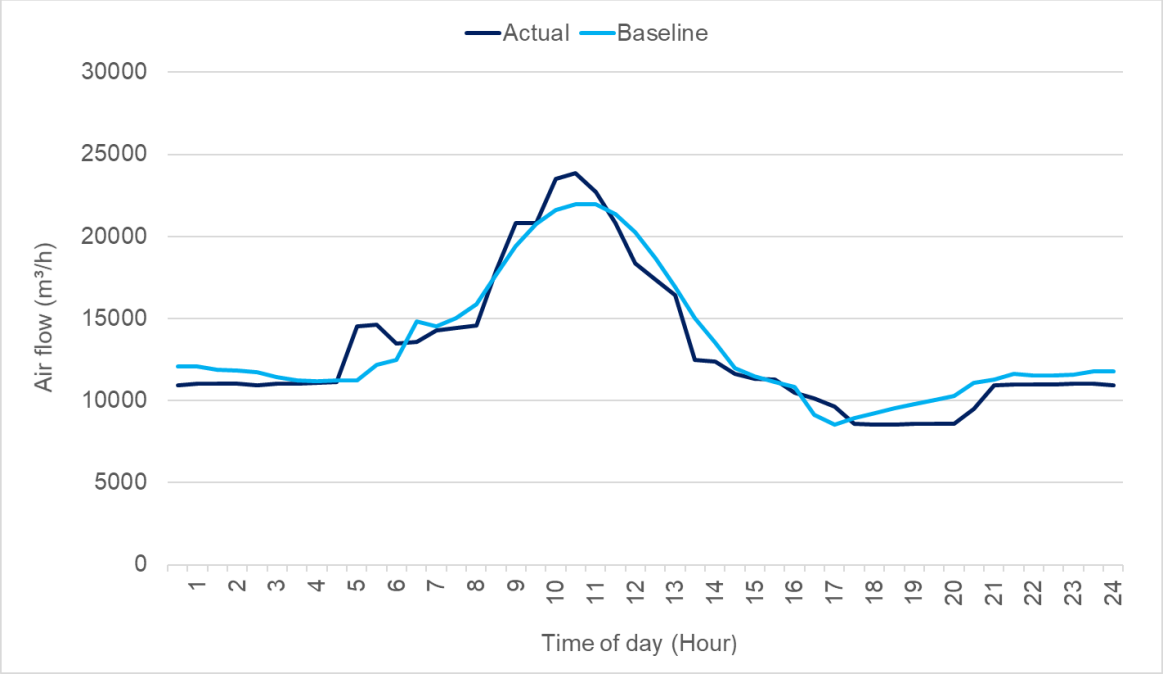


Figure 15: Baseline vs actual compressed air demand [25]

In Figure 15, a baseline versus the actual usage of a certain parameter is illustrated. As shown in the example, the baseline is the nominal usage for a certain parameter; in this case, airflow. By comparing the actual parameter to the baseline, abnormalities can be identified when the data shows a deviation in nominal parameter values [30]. The performance of a system or project can be measured by comparing the actual data to the baseline [3]. The less the actual parameter values deviate from the calculated baseline, the better the system is performing than expected.

The performance of systems or projects can be quantified to energy and cost-saving, which is standardised by IPMVP protocol and the ISO 50001 standard in equation 1 [3].

$$Saving = Projected\ baseline\ use - Actual\ usage \quad (1)$$

The savings can be quantified for resource savings as well as cost-saving by using the energy that is saved from resources to estimate the cost implication using energy tariffs [43]. The development of a baseline is an on-going process, changing as seasons, unforeseen circumstances, and performance adjustments occur [39].

1.2.3.3 Proposed profiles for performance monitoring

Proposed profiles can be used to show an optimal or better profile of the resource utilisation to follow in order to save energy and run the system more efficiently. During blasting shifts on the mine, certain resources such as compressed air and water flow can be reduced, which can result in cost savings [30].

By monitoring the performance of system parameters, patterns in resource usage can be identified [35]. These patterns can be observed to see if a resource can be cut back to the minimum required during specific shifts.

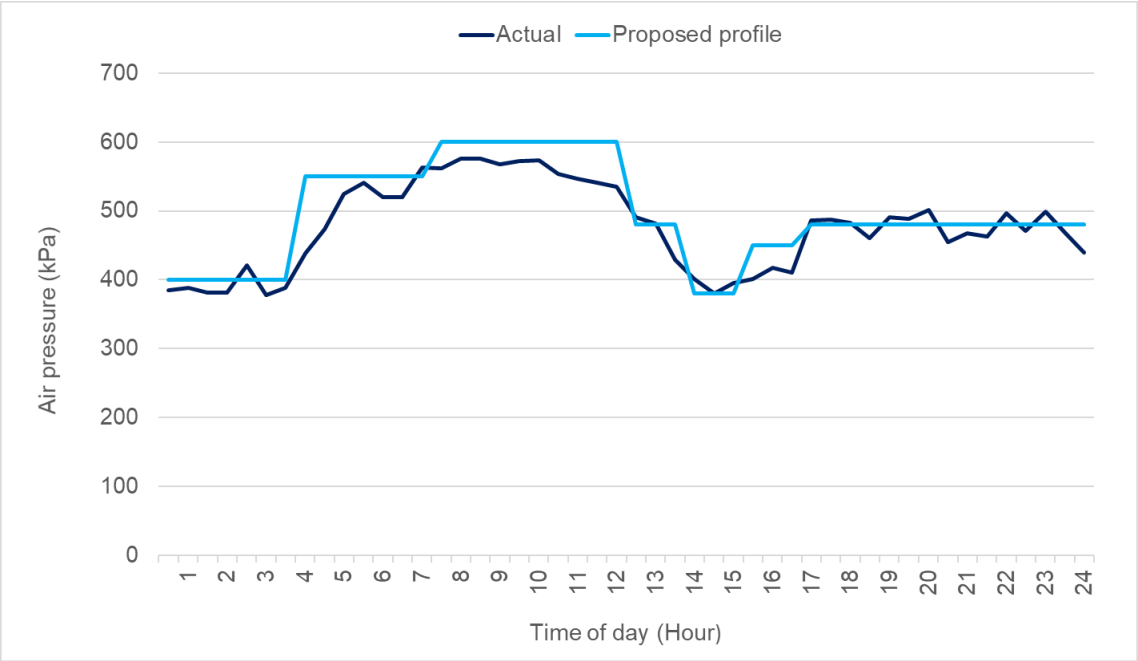


Figure 16: Proposed profile vs actual compressed air demand [30]

In Figure 16, a compressed air pressure profile of a mine shaft main valve is illustrated. By using historical data and minimum requirements, a proposed profile is advised to which the compressed air can be optimally used [20]. This monitoring can be useful to reduce the cost of mining operations and to reduce resources when there is no demand, saving energy according to the ISO 50001 standard.

According to Kim *et al.* [35], the basic requirements of a performance monitoring system is to have a platform that uses a database with relatable business information regarding the project or system that needs to be monitored [3], [25]. A performance baseline should be used to compare to the relatable data to quantify the performance of the system. The result in performance difference between actual data and the baseline is then quantified to cost savings, indicating the financial impact that improvements on systems will have [3], [25], [35]. Software platforms can be used to evaluate the data of deep-level mining systems in order to aid the monitoring of performance.

1.2.4 Software platform environment

1.2.4.1 Platform development in a software environment

According to Van der Bank [44], there are many methodologies that can be used for software development. For traditional software development of new features and platforms, the waterfall methodology is typically used. This methodology is a sequential process of steps that are followed to ensure thorough planning and execution in order to produce a successful product [44]–[46] This methodology is often referred to as the systems engineering life cycle which comprise iterative steps and processes that provide a simple method for designing an effective system [45]–[47].

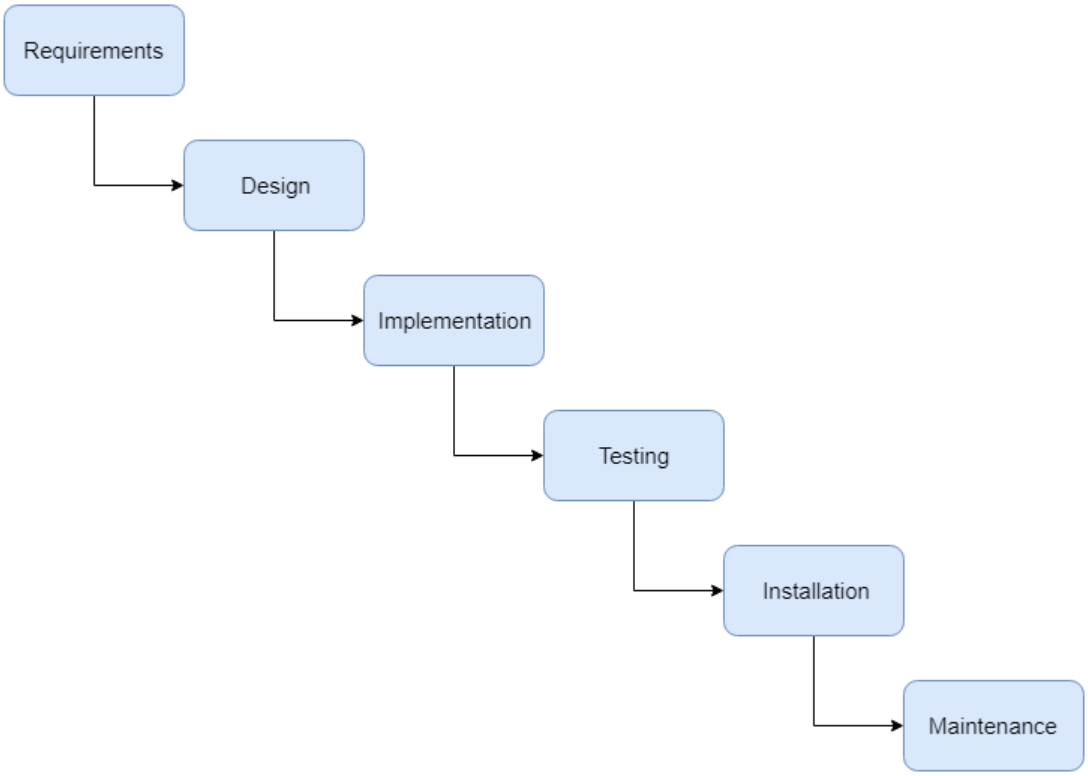


Figure 17: Basic waterfall methodology for software platforms [45]

In Figure 17, the waterfall methodology that is most commonly used for software development is illustrated [45]. A software platform is always started by establishing the requirements that the platform must conform to [44], [48]. After the requirements are set, the design of the platform can be completed and implemented in the applicable software environment as set by the requirements [44], [47].

Each step is crucial for the successful delivery of a platform. After most platforms or products are successfully tested to adhere to the requirements after installation, the software platform moves into an ongoing maintenance phase.

This phase includes the addition of new features as well as new technology changes for software environments and logic code errors resulting in code bugs [49].

To provide a quality product the steps of the waterfall methodology's steps can be reiterated. This reiteration usually happens when design changes occur or new features are added to a platform referred to as the extended waterfall methodology [45].

1.2.4.2 Software application environments

In Section 1.1.5 a brief overview of Big data and Industry 4.0 was introduced. In order to develop a software platform that will be accessible to many stakeholders, top management, and employees, a platform that is easily accessible to all is necessary.

Platforms that are typically used for data access include [5], [48] :

- Client-server applications
- Desktop applications
- Web-based applications
- Mobile applications

Client server-side applications are installed on a client-server, where software that runs on a client computer makes requests to a remote server. These requests collect data from the internal network where data is stored in databases. Desktop applications are installed on a personal computer that will make use of remote network connections to databases to access data. Web-based applications are installed on remote servers, where the application can be used by any authorised user from any remote location with network connection [48].

The disadvantages of client-server side and desktop applications are the availability on remote locations, software distribution, and software maintenance of the platform. Software installed on various devices on remote locations makes the distribution of software updates for critical bug fixes, new feature updates, and compatibility maintenance of the software difficult and challenging to the software distributor [10], [48].

However, web-based applications that are installed on remote servers means that the application can be used on any device with an internet connection [47]. The advantage of web-based software applications and platforms over desktop or client server-side platforms is the management of software. Software updates that include bug fixes, new features, and compatibility maintenance are only in one location. The ease of software distribution and ease of access to authorised users are additional advantages [48], [50].

However, web-based platforms do have their drawbacks. The platform performance and flexibility are limited to the browsers used. Web-based platforms do not have direct access to the data and need to be transferred from a client-side server or database.
The data needs to be transferred before it can be processed and displayed to a user. Web applications also require an active internet connection in order to be able to display the relevant data [5], [48].

Disadvantages of all the mentioned platforms are the dependability of network connections and the dependability on the data stored in databases that can only be accessed by network connections [51]. The different users of a software platform cannot be centralised in one location and thus the different aspects of each platform play an important role in deciding which platform to use [10].

1.2.4.3 Data and information

With the wide use of the internet and internet-based technologies that are being used in the Industry 4.0 movement, a web-based platform would be a sensible platform to ensure the ease of future developments [50]. For a software platform that is used for the Industry 4.0 movement, data access and storage for Big data is needed.

Big data is defined as high volume, high velocity, and a high variety of data and information that can improve decision making and industrial automation [51]–[53]. Big data has had a large influence on how organisations value data for use in a business [52]. Data is essential for the improvement of society by using data to better understand how everything around us works [51]. This is why Big data is an essential component of Industry 4.0. However, in order to make this data useful to an organisation or company, the data needs to be stored, processed, structured, and analysed [31], [51].

According to Coda et al. [29], there are collaborations between groups of different companies that characterise Big data that are entities for the Industry 4.0 movement.

According to Coda et al., there are three types of companies [29], [54] :

- Companies using data for optimisation tools
- Companies that use data as their business
- Companies that are data-driven for competitiveness

Type 1: Companies using data for optimisation tools

Companies using data for optimisation tools use Big data for analysis to improve the performance of the main functions of a system and are the basis of Industry 4.0 [29], [54]. The

data analysis of processes and system performance is used to modify and alter processes and parameters of systems to increase performance and increase the profitability of a company and its operations [29], [53].

These companies collect, manage, and analyse data for its own purposes and interests and may even develop software platforms for data management and analysis [29].

Type 2: Companies that use data as their business

Companies that use data as their business do not focus on the data for the processing of their systems, but instead have interest in other companies that need a service that Type 1 companies do for themselves [29], [54].

Unlike companies that use data for optimisation and their own gain for the profitability of systems and operations, companies that are data-driven for business are only concerned with data and the analysis of the data. Other companies tend to outsource these data-driven companies for their services. Data processing is the main focus of data-driven companies [29].

These companies are not the basis of Industry 4.0 but are essential for the existence of the movement, providing service of Big data processing and analysis to other companies in need of this service [29]. These companies have platforms designed to handle Big data, with a secure and stable connection between the service and the client [54]. These companies usually provide low-cost data management and data analysis software platforms for customers.

Type 3: Companies that are data-driven for competitiveness

Competitive data-driven companies focus on the flow of data, drawing conclusions and predictions on data in order to develop new business models. These companies develop their business model for products and services based on data [29], [54].

These companies develop their services and products according to data from the client's needs, ensuring the client is satisfied, giving the company strategic leverage on other companies with the same services and products [54].

Big data is changing the way we perceive technology in this new era where Industry 4.0 is a growing movement [53]. This classification of company types describes how companies utilise Big data, as well as the advantages these companies can obtain from data [54]. Most companies fail to utilise the potential of Big data as well as the management of data that can help optimise operations, products, and services to generate more profit [54], [55].

1.2.4.4 Data acquisition

Big data is a fundamental aspect of data analytics and has become an integral part of the Industry 4.0 movement. With the majority of industrial systems that are being automated, the demand in data analysis and acquisition has increased. Specialised equipment, as described in Section 1.1.5, is used to automate and log data in these operations and the equipment that is used.

As discussed in Section 1.1.5, the flow of data from measuring devices and equipment is stored on a client database. The data from measuring equipment is transmitted to a SCADA. SCADA's are commonly used in industrial settings to control and observe industrial equipment. The SCADA is seen as a central data storage unit that controls and logs data for various system components used in industrial sites such as deep-level mines.

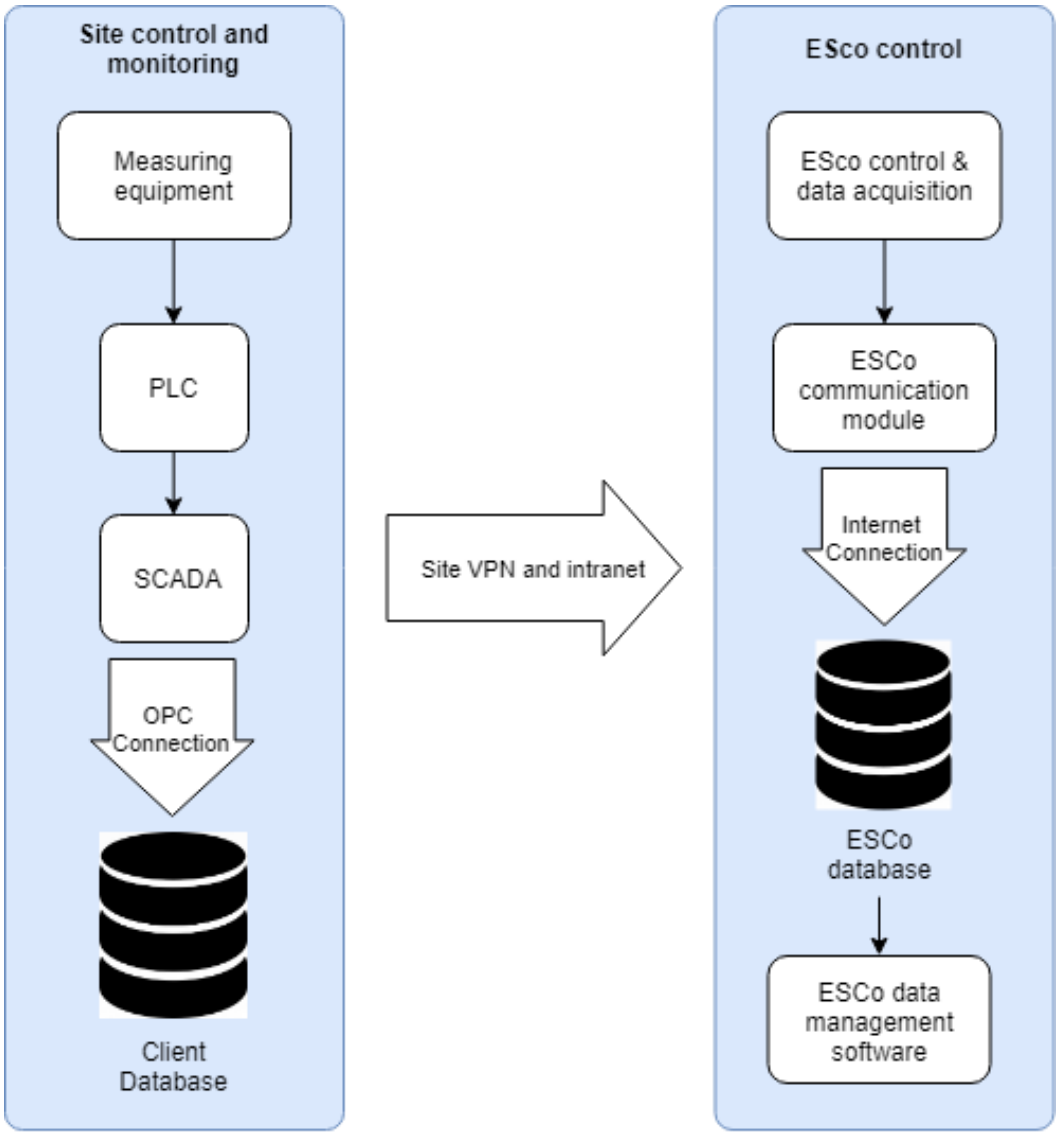


Figure 18: Data flow from site to an ESCo [10]

The data flow from measuring equipment on a typical mine to gather data is shown in Figure 18. This data is then transmitted from the client database to ESCo databases where the data can be processed and used by software applications [5], [10]. The ESCo databases and software are hosted on a web server where the data is accessible for use by the ESCo to process and evaluate.

Large organisations such as mining companies usually consist of many deep-level mines with multiple operations on each mine. Each mine will have its own SCADA system or even multiple SCADA's on one mine operation to monitor and control all the mine's operations. Data storage is used to centralise the data acquired by the SCADA. An OPC connection makes the transmission of data from SCADA's to databases where data can be acquired. The SCADA data is translated into formats that are easier for data processing and stored in the database. From this database, other connections to external software can be made where the data can be used for analysis and visualisation [5], [56].

1.2.4.5 Software maintenance

Software maintenance plays an important role in the development of any software platform. Maintenance is defined as modifying the capability of a software product [49]. In the previous section, the waterfall methodology for the software development process is described and illustrated in Figure 17. This development process ends in a maintenance phase, where the platform is maintained for the duration of its life cycle.

The maintenance of the software can be due to modification because of functionality requirement changes or flaws that may be encountered during certain conditions that were not expected during the implementation phase [44], [49]. With new technologies being developed and with more stable versions of software, there is a need for software maintenance to ensure that a software platform is bug-free and compatible with newer technologies. Without proper maintenance, a software platform can lead to a build-up of technical debt [44], [48].

The term technical debt is used by Van der Bank to describe the resources required to improve a poor quality platform from previous development to a software platform that is of acceptable quality and performance [44]. Poor quality software is usually found in prototypes where most resources are spent on the product functionality prototype due to time constraints [44]. In most cases, the management and stakeholders of a software product are only interested in functionality and short time deadlines, making the proper implementation of software difficult to realise [44], [48], [49].

Velmurugan et al. developed a software maintenance model considering validation and reliability based on the waterfall model [49]. The application that is implemented should be able to log logic errors and system failures. This enables the developer of the software to analyse and correct faulty and poor-quality code during both the testing and maintenance phases, as in Figure 17. This can also exploit vulnerabilities that may result in security breaches to be identified [49].

Software maintainability for software applications and platforms are a crucial part in the software development phase and have a large impact on a business due to downtime, faulty operations, and security threats caused by poor-quality code during the initial development phases. Strategic and effective planning and development should compromise between quality and development time to produce a software platform or application that minimises technical debt in an acceptable development time.

1.2.4.6 Scalability

Scalability and validation are two main problems that arise when software platforms are designed for processing and analysing Big data. Scalability is a known problem when working with Big data and has always been an issue in software development as large quantities of data had to be analysed [44] Data structures are an effective tool to make a system more scalable by using structures to organise data to make the search for information easier [57]. Data structures are described later in this chapter.

Big data applications may get data from multiple sources making the organisation of the data difficult. Processing this data is then complicated, as is the analysis and conclusion of this data [52]. Data volume can increase during unexpected peak periods where more data needs to be analysed [58]. This means that a developed system must be scalable enough to be able to handle the amount of data on demand without compromising the performance of the platform [59].

High-quality data is essential with large amounts of data where the data needs to be accurate and consistent. Scalability is key for the development of a platform that ensures that this can be realised.

1.2.5 Effective software platform design

1.2.5.1 User interface

The user interface of a software platform is vital to relay given information correctly to a user. The user interface can impact the efficiency of information transferred, the analysis of information, as well as decisions that are made from the conclusion that is drawn for the given information on the user interface [44], [48]. This makes the design of the user interface an important element of the software platform design.

According to Schneiderman et al., there are eight principles for effective user interface design.

The eight principles are [60]:

1. Consistency: Consistency entails many aspects which include the use of consistent terms, menus, help screens, dialogues, colours, font, layouts.
2. Usability: The software platform should be usable by different types of users, making the application user-friendly by adding features like shortcuts, explanations, and user guides.
3. Informative feedback: For every action that takes place, feedback to the action should be given to confirm to the user that the action was performed. This is usually done through visual feedback.
4. Closure dialogues: Informative feedback of the completion of an action or certain tasks should be given as feedback for the user, giving the user a sense of relief and accomplishment.
5. Error prevention: This entails preventing the user from doing certain actions without specific rights. Simple error-checking and visual limitations of certain activities can be disabled on the user interface.
6. Action reversal: Actions should be made reversible to enable the user to correct any mistakes made during the use of the software platform.
7. Sense of control: Make the user feel as if they are in complete control of all actions on the interface, giving the user the satisfaction of being in control.
8. Short-term memory load reduction: The human mind has a limitation on working memory; only a certain amount of information can be processed at a time. This means that a user interface should not contain too much information that will cause the working memory to overload.

These principles can be applied to any interactive system, whether software related or not [60]. These principles are often not implemented in industry and are often neglected during the development phases of a software platform [60]. Most developed platforms rather use the familiarity of existing software to make training and adapting to software easier for new users. Aspects such as colours, layout, and basic functionality of the user interface tend to stay the same when developing software similar to other platforms [48], [60].

Human system integration is used in systems engineering to ensure the incorporation of human factors like training, usability, consistency, and readability when developing a system that will have human interactions [46]. The cognitive load of an individual user is impacted by the consideration of a user's perspective of the user interface [46]. Easy displayed and presented data has an impact on the amount of stress that is applied to the working memory of an individual [46], [61].

1.2.5.2 Cognitive load

Cognitive load refers to the total mental effort that is needed by a person to perform a specific task [61]. Cognitive load theory is defined as, and can be classified into, different memories, each with their own purpose [61].

Working memory, referring to the temporary information that is used for processing during decision making and reasoning, can easily be overloaded by large amounts of information that needs to be processed in order to make conclusions and assumptions [48], [61].

Long-term working memory refers to previously organised information that is transferred from the long-term memory that can be used for processing during decision making, reasoning, and behaviour. Long-term memory is helpful when previous information defining specific details of current information in the working memory can aid in decision making. Long-term memory information can be recalled to working memory [61].

If the information that is stored in long-term memory cannot be recalled, the human memory turns to problem-solving using cognitive processing. This can cause strain on the working memory when information is not presented in a structured and easily understandable format [48], [61].

Decision-making of large amounts of data that needs to be processed can cause a high level of mental effort and cognitive processing that can lead to a cognitive overload of the working memory [62]. Not only can information impact decision making, but the workload and task difficulty are also factors that can influence the process [61].

From software platforms implementing cognitive load-reducing techniques, such as colours and reduced and simpler information presentation, it was found that there is a significant reduction in pupil size and arousal which directly affects pupillary responsiveness and mental strain [63].

By using cognitive load reducing and software user interface design techniques such as using colours and keywords to associate certain elements as well as information structures, the strain on working memory can be reduced [61], [63]. By lowering the interactivity of information elements, new information does not need to be learned or processed because the simple interaction has already been stored into the long-term memory. This means that information can be processed with minimal effort [61]. Simpler interfaces and interactivity to complete a task will also give the user of a software platform a more positive user experience in cognitive intensive tasks [64].

Easy navigation is part of the interactivity that a software platform can implement in order to increase user satisfaction. Finding information on an interface is also a cognitively demanding task. It involves the processing of information, decision making, and cognitive learning when navigating [62]. Improved user interface design and the significant effect on cognitive tasks and analysis is highlighted by the existing interaction research of humans and computers [62].

Data and information structures can be used to make the navigation of information easier. Structures are used to effectively and efficiently navigate to different sets of data information. They are an important aspect when designing and implementing software platforms [62].

1.2.5.3 Data structures

Data can be used to analyse, interpret, predict, and make any informed decision. Data is a source that can be used to understand and make sense of the world around us. However, in order to make data sensible and easy to use, it needs to be organised and structured. Data structures are used to organise data in order to make it usable to analyse. Data structures can be in the form of lists, tables, or tree structures to organise data in a sensible manner and to make the search for data more efficient [65].

With the existence of programming languages, data structures can be implemented to make data organisation possible. The basic data structures that exist are arrays, linked lists, stacks, queues, and tree structures [57], [66]. Each data structure has many variants, each with its own advantages and disadvantages, depending on how they are used [66].

The linked list provides a linear structure of objects that are connected to each other. While the linked list provides more structure and flexibility than arrays, stacks, and queues, it lacks the capability to represent objects with hierarchy. This becomes an issue when working with the organisation of big structures that are not limited to a one-dimensional structure [67].

Tree structures are a good representation of hierarchical order, as illustrated in Figure 19, which represents a typical tree structure. Tree structures are mainly used in computer science to organise data, but are also a representation of the natural order of things. Family and evolutional trees are examples of trees that represent natural order. This makes tree structures a good representation of business hierarchy, organising the business structure to make sense of order in large companies [57], [65].

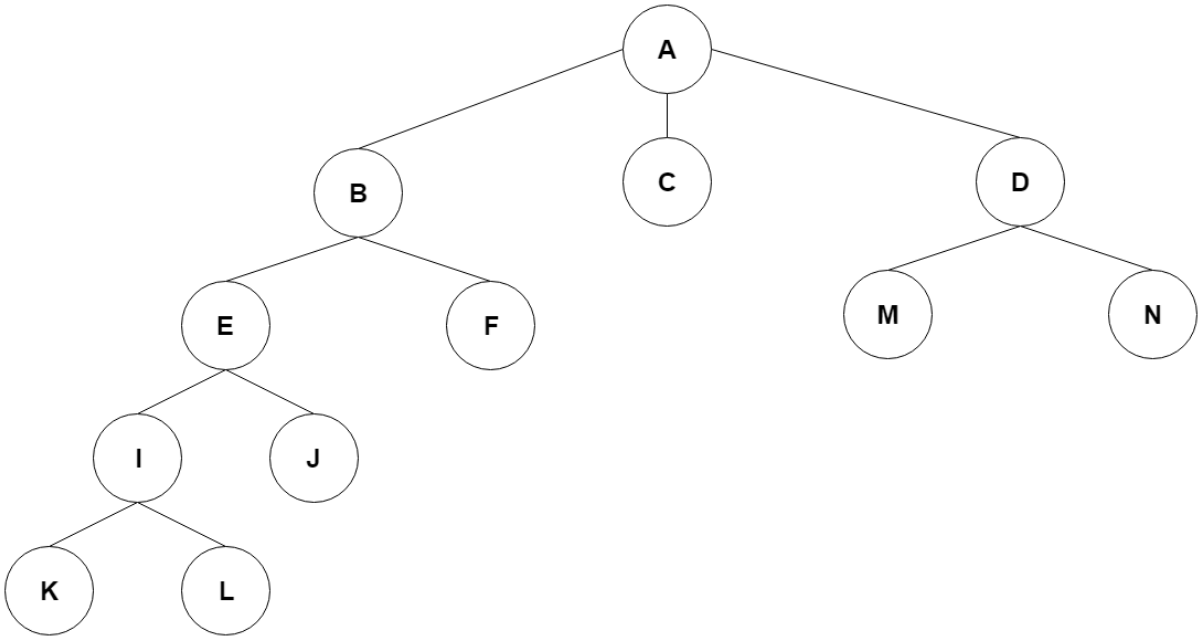


Figure 19: Hierarchal tree structure [57]

A tree structure is what the name implies: a tree with branches or subtrees connecting relevant objects and information. The tree structure comprises of nodes, where the root of the tree is the top node or parent node. Nodes that have a relation to the parent node are called a child node. A node can have many child nodes with the child node having children of its own. Child nodes with the same parent node are siblings. A node with no child nodes is called a leaf and is usually where a certain branch of a tree ends.

The ancestors of a node are the path of nodes that leads from the top node or root of the tree to the specific node. Nodes are defined by the order or level in the tree with the top node being at level 0, where the level of a node is the length of the path from the root or parent node plus one.

In Figure 19, a tree with a top node A has children B, C, and D at level 1 of the tree; node B at level 1 has children E and F at level 2; where node F, M and N are leaf nodes of the tree, illustrating the assembly of a tree data structure [57], [66]. A detailed illustration of the tree node classification is shown in Figure 20 and Table 1.

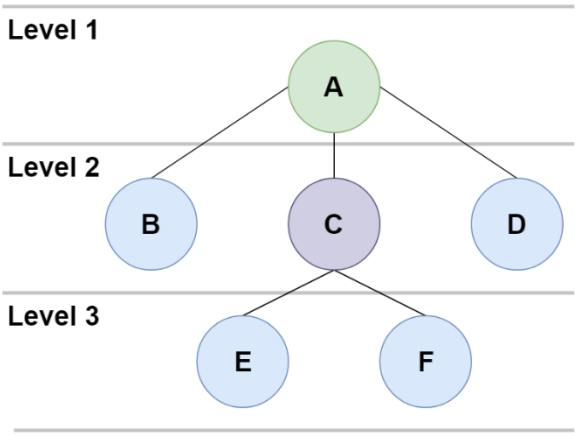


Figure 20: Detailed node classification illustration

Table 1: Node relationships in tree structures

Root	A
Parent	A, C
Child	B, C, D, E, F
Leaf	B, D, E, F
Sibling	B, C, D and E, F

There are many types of tree data structures, ordered and unordered, that are used in computer science. The most common forms of these trees are binary trees, k-d trees, and heaps. The trees are all similar to the hierarchal structure that is described above. Each node can be given a key or ID that act as identification of the node that can be used during search and connection links between nodes [57], [65].

Trees can be used to organise the operations and plants of each facility within an organisation to make the data processing and information search on a software platform easier and faster, giving a better performance and user experience.

1.2.6 Existing solutions for performance monitoring

There are many existing systems for monitoring the performance of systems and operations. Each design is implemented with specific functionality to cater to specific needs. In order to evaluate functionality that the developed generic platform needs, existing platforms that have similar functionality need to be evaluated. Existing web-based solutions will be investigated, as the generic platform must be integrated into an ESCo web-based software environment.

DSM energy monitoring platform [10]

Goosen developed a system that can monitor DSM and IDM projects on mine compressed air systems during the life span of the project. This platform was only capable of monitoring the energy management of compressed air systems' electricity usage and only allows users to monitor and evaluate the performance of compressed air energy data.

Energy data from SCADA's are transferred to an ESCo database where the data is processed. The performance of each system is calculated using time-of-use tariffs as supplied by Eskom to calculate the amount of savings according to a performance profile of the energy usage against a baseline.

Projects can be configured by defining the type of savings that is applied for each project. This platform is very useful in the monitoring of projects when the main focus is to make the system as efficient as possible in order to save money. This system was specifically designed for DSM projects where the goal of a project is to maximise energy savings and reduce the load that Eskom needs to supply to the national grid [10].

Web-based condition monitoring platform [5], [48]

Van Blerk developed a web-based online platform that uses Big data to monitor the condition of industrial equipment to identify problematic equipment [5]. The platform gives the up-to-date status of the conditions of equipment by analysing parameters such as temperature, vibrations and the energy consumed by specific equipment. If the condition of a component or equipment becomes critical and/or at warning levels, users are notified by email and SMS systems.

Multiple data parameters are gathered from SCADA's from the equipment and transferred to an ESCo relational database where the data is organised and processed to calculate and monitor the status of the equipment. The platform is designed to help industrial operations to schedule maintenance and downtime to ensure that an operation's downtime is minimised, avoiding cost implications [5], [48]. This software platform can be seen as a preventative tool to help with cost-saving and planning.

Web-based energy information report platform [40]

Prinsloo developed a web-based energy information reporting system that is capable of collecting and maintaining energy data and creating reports for stakeholders. These reports are useful when evaluating the energy management of operations and can help the decision-making process [40].

The platform gathers a wide range of energy and production-related data from multiple sources and is transferred to a central ESCo database where the data is stored and processed. The data is compiled into one data set used to report the correct data to the relevant stakeholders and clients.

An early-warning performance monitoring system [35]

This performance monitoring platform was developed to be used to objectively monitor and track the performance of projects. The monitoring is used to detect poor performance early into a project to prevent failure [35].

This platform makes use of performance indicators described by various standards that help determine the performance of projects from available data. Key performance indicators and baselines are used to build a framework for quantitive performance monitoring of projects. The platform provides guidance on data collected from projects to help stakeholders make informed decisions on a project.

Summary of platforms

All of the mentioned platforms and systems gather data for the purpose of analysing it in order to report on the operational status of systems and the management of projects. All of the mentioned platforms address the need for data monitoring for the purpose of improving operations to increase cost-saving and feasibility of industrial operations.

Software platforms were categorised according to specific criteria in order to satisfy the need for a generic scalable software platform for performance monitoring.

The criteria for a generic performance monitoring software platform are:

- Generic data usage
- Data and system scalability
- Performance indicator implementation
- Using data for performance monitoring

Table 2 is a summary of the functionality of the platforms found from the literature that addresses important criteria as mentioned above for a generic scalable performance monitoring software platform.

Table 2: Existing monitoring systems

Platform	Focus area	Generic data	Level of scalability	Performance monitoring	Performance indicators
DSM Energy monitoring [10]	Energy monitoring	No	High	Yes	Yes
Web-based condition monitoring [48]	Condition monitoring	Yes	High	Yes	Yes
Web-based energy information reporting [40]	Energy reporting	No	Low	No	Yes
Data analysis interface [30]	Energy management	No	Medium	Yes	No
Home PV monitoring system [68]	Performance monitoring	No	Low	Yes	No
An early-warning monitoring system [35]	Performance monitoring	No	Medium	Yes	Yes
Monitoring system for energy awareness [28]	Performance monitoring	No	Low	Yes	Yes

There are many performance monitoring platforms that can be used to monitor performance. These platforms are not capable of presenting any deep-level mining systems using performance indicators such as baselines and proposed profile operations.

The early warning monitoring system is a perfect platform to monitor the performance of projects to prevent performance issues using performance indicators. Although the early-warning monitoring system is used for preventing and predicting the poor performance of projects, the platform lacks the capability to enable personnel to view and evaluate the detail data and status of improvements of multiple systems from any location.

The DSM energy monitoring platform has the closest resemblance to the performance monitoring platform that needs to be designed and developed for deep-level mining systems. Although the platform monitors the performance of energy systems and energy-related data, the platform lacks the capability to monitor the performance of other data and systems that are found on deep-level mines.

The condition-monitoring platform is capable of analysing many different types of data to predict the condition of industrial equipment. It has a generic data consolidation approach that is needed to monitor the different systems that deep-level mines comprised of.

DSM energy monitoring and the condition-monitoring platforms decreased cognitive load, which aids in quick and more informative decision making, giving a high overview of multiple projects to a user. All of these systems implement components that are needed to achieve performance monitoring of different deep-level mining systems and can enable informative performance and information on the progress of projects.

1.3 Need for the study

From the literature in Sections 1.1 and 1.2, the need for the study arises.

There is a need:

- To move to Industry 4.0 by using Big data to improve the efficiency of industrial operations.
- For performance monitoring of any deep-level mining system, to enable the evaluation of systems and projects' performance during their lifetime.
- To decrease mining operational costs by analysing Big data using Industry 4.0 technologies.
- To decrease mine system evaluation time and performance monitoring system setup time.
- To identify potential risks and problems by analysing large quantities of data.
- To roll-up Big data and system performance for a high-level view of the performance of systems for users.
- For a generic and scalable platform that can handle Big data for various deep-level mining systems.
- For a platform with a user-friendly interface that can be easily maintained during the software platform's lifetime.

1.4 Objectives of the study

The aim of this study is to create a platform that will enable ESCo and mine personnel to make informed decisions on deep-level mine systems. The use of the platform must reduce operating costs and improve the overall efficiency of these systems, while still maintaining desirable performance. The software platform has to be generic and scalable.

It must be suitable for use on different types of Big data for performance monitoring of deep-level mining systems.

The objectives of the study are:

Software platform objectives

- To create a software platform that can be used to monitor the performance of implemented, maintenance, and performance assessment initiatives by ESCo and mine personnel.
- To create a platform that is capable of using large quantities of data to give a simplified overview of multiple systems and projects.
- To reduce the cognitive load of platform users.

Data, information and scalability objectives

- To create a scalable platform that can be used for multiple deep-level mine systems.
- To reduce data analysis and performance monitoring time of deep-level mining systems.
- To reduce project time for the evaluation and monitoring of mining system projects.
- To enable personnel to make informed decisions on the efficiency of mining systems.

1.5 Summary

Deep-level mines have many energy-intensive systems that need to be monitored. These systems are responsible for a large portion of the electricity and energy consumed by mines. This makes it a critical part of a mine's ability to extract minerals. Monitoring and the evaluation of system performance aid in decision making in order to minimise potential risks and problems that may have a financial impact on projects [55], [69].

Big data is an essential component of Industry 4.0, but in order to make this data useful to an organisation or company, the data needs to be stored, processed, structured, and analysed [31], [51]. Processing and analysing large amounts of data can cause a strain on working memory, resulting in cognitive overload. Software platforms can be used to process and analyse Big data to present an easy high-level overview of data that can be monitored.

There are many existing software platforms that monitor the performance or data of industrial systems, but they are mostly focused on the gathering or the processing of this data. Most existing software platforms are only reliant or compatible with data for specific equipment or operations. To efficiently monitor the performance of underground mining systems, the efficiency of these systems is quantified to comply with the ISO 50001 standard and IPMVP protocol [25].

By monitoring systems and projects, missed opportunities can be identified by analysing data where systems are operated inefficiently or advising on optimal resource usage that can lead to cost and energy saving [28].

In Chapter 2 a generic software platform for performance monitoring of deep-level mine systems will be designed and implemented by using the knowledge gained in the literature review.

CHAPTER 2

METHODOLOGY



Anglo American mine (Source: www.angloamericanplatinum.com)

2 Methodology

2.1 Preamble

This chapter is an overview of the design process that was followed for the design and implementation of the platform that was developed to address the problem that was identified in Chapter 1 Section 1.3.

The term platform is used to describe the software solution that was developed to enable personnel to easily monitor the performance of their projects on deep-level mines. The literature discussed in Chapter 1 will be used to set the requirements for the platform and will affect the design and implementation.

The generic software platform for performance monitoring will be implemented on an existing ESCo web-based platform. By using the knowledge gained from existing platforms, a platform will be developed by using an extended waterfall methodology, as discussed in Section 1.2.4. By using a structured approach, the implementation of a generic software platform for performance monitoring can be successful.

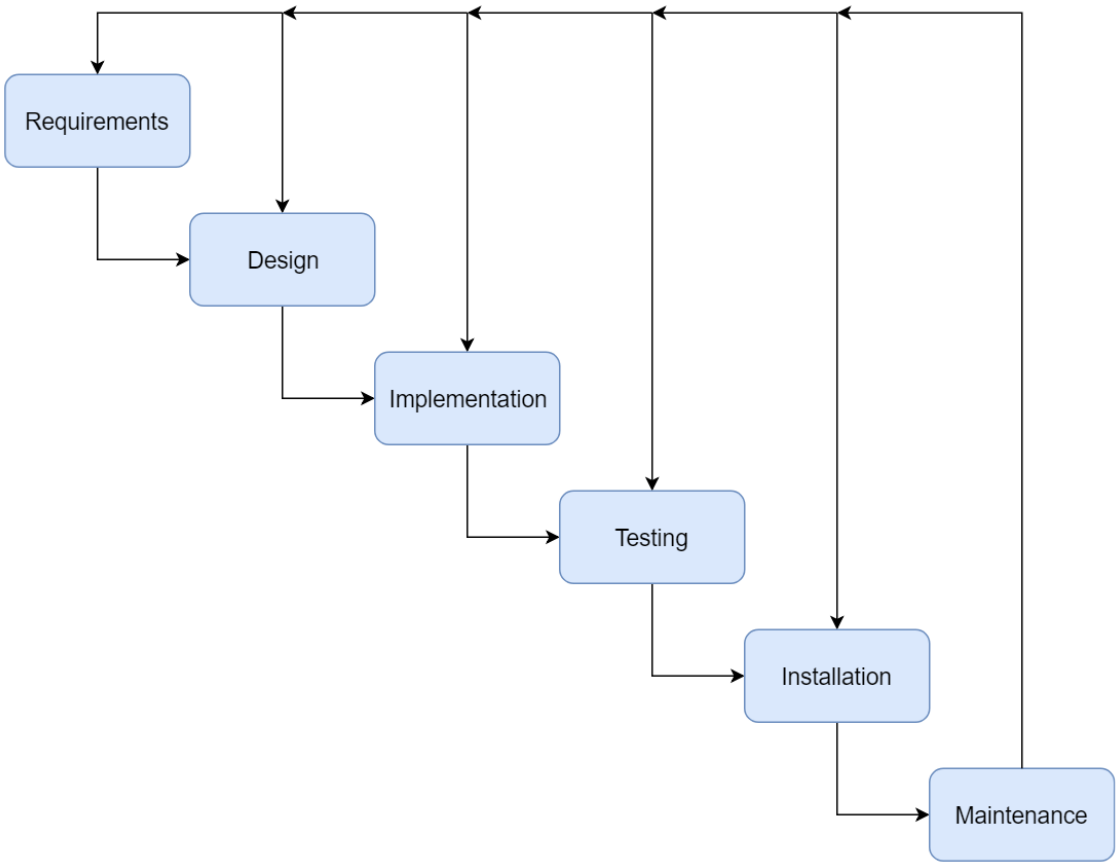


Figure 21: Extended waterfall methodology [45]

By altering and adding to the existing waterfall methodology, a continuous development strategy for the software platform can be developed that will ensure a quality product that addresses the objectives that are set in Section 1.4 [45]. Figure 21 illustrates an extended methodology that enables a continuous development strategy to ensure a quality platform that can be maintained as requirements for the platform change.

Throughout this chapter, the extended waterfall methodology will be used to set requirements, design, develop, implement, and maintain a generic software platform for performance monitoring of deep-level mining systems, and will be referred to as the PMSP (Performance Monitoring Software Platform).

2.2 Requirements

Based on the objectives set out in Section 1.4, the design requirements and specifications of the platform are as follow:

User interface

A user interface enables personnel to monitor the performance of deep-level mine systems. The user interface should give the user a simplified overview of multiple initiatives and systems, which reduces the time spent analysing data to make an informed decision and allows the user to easily identify potential problems affecting these systems.

Data and information

The platform requires that the data from these systems must be processed and stored in order to be used by the PMSP. The existing ESCo platform makes use of a relational database to store information used for user access control, platform configuration, organisational structures, data access, and mining system-specific data.

To monitor the performance of deep-level mining systems, the Big data of these systems need to be analysed and processed in order for personnel to interpret the data. Mining system data must be collected, processed, and stored in the ESCo database where it can be easily used by an ESCo in-house developed platform.

Scalability

The generic platform must be able to process and display the data of multiple different mining systems. An organisation may have multiple systems and efficiency initiatives that need to be monitored. Thus, an organisation may have multiple levels with multiple systems that are

organised in the business structure. This business structure must be easy to navigate for the PMSP user. This entails an operational system as well as an organisational overview of systems and initiatives.

Integration

The implementation of the generic software platform should make use of existing infrastructure and resources in order to minimise the unnecessary use of time and resources. The generic platform must make use of the ESCo's relational database and data structures. The platform must make use of available data from the ESCo to process, analyse, and displaying the performance on mining systems using the existing web-based platform.

2.3 Design

2.3.1 Integration with the existing ESCo web-based platform

The existing ESCo platform consists of a relational database for a web-based EMS (Energy Management System.) Data is sent from various sources such as SCADA's and historical databases on-site to the ESCo's Big data database where a large amount of data is stored before the data is processed, structured, organised, and finally stored in the ESCo's relational DB (database), as discussed in the literature in Section 1.2.4. This relational database gives easy access to data for applications and platforms used by the company. In the figure below the ESCo's data flow is illustrated.

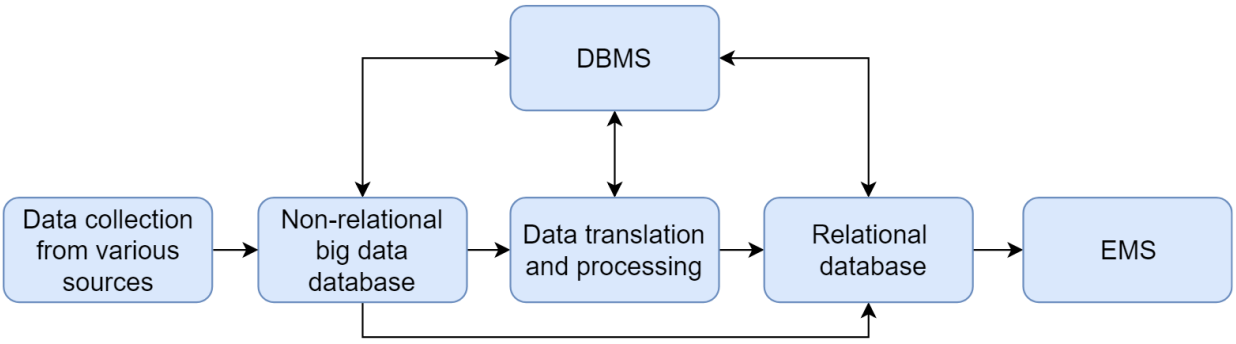


Figure 22: ESCo data flow [30]

As seen in Figure 22, the data flows from external sources to the EMS and the DBMS (Database Management System.) Data gets processed after it is received in the Big data non-relational database. From there the data can be used for configuration in the DBMS and data analysis in the EMS.

To make data monitoring possible there are three phases, namely data collection, data processing, and data visualisation, as illustrated in Figure 23.

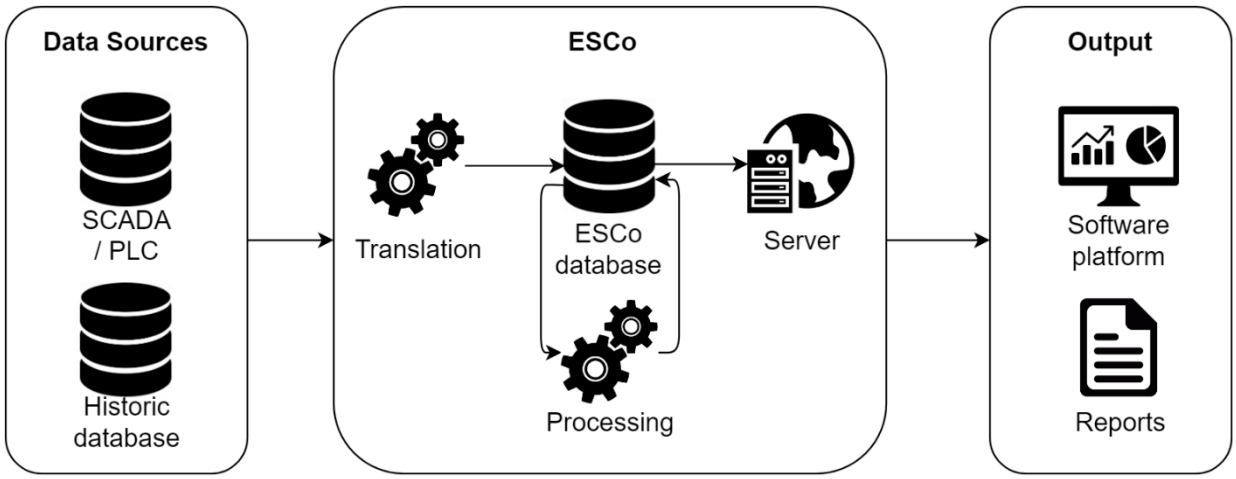


Figure 23: System diagram of existing ESCo infrastructure

Phase one makes use of data-collecting platforms developed by the ESCo as well as outsourced software to collect data from various sources such as SCADAs, PLCs, and historian databases. The process of data collection by the ESCo is illustrated in Figure 18. The data that is collected is stored in a Big data non-relational database where the data is easily accessible for processing.

Phase two involves processing large amounts of data to be used by the EMS software itself. Data that is collected from various sources have different formatting and representation of data in many different data file formats. An in-house developed software platform translates and processes the data to make it useable to the EMS. The processed data is stored in a non-relational database before the data is passed through to the EMS relational database in data tables.

Phase three is where the processed data can be used to monitor, calculate resources, and manage Big data. This data is then used to monitor systems, initiatives, and performance of deep-level mining systems. The PMSP will be implemented in the EMS and ESCo's DBMS.

The design and implementation of a generic software platform will consider both the EMS and the ESCo's DBMS. The EMS platform will be expanded to be able to analyse and monitor the performance of several different mining systems.

2.3.2 Functional design

2.3.2.1 Integration

The developed PMSP (Performance Monitoring Software Platform) will be integrated into an existing ESCo EMS platform which enables the platform to reduce implementation time as well as to utilise existing ESCo resources. In Figure 22 above, the data flow of the ESCo is illustrated. The platform will be designed to be implemented in existing infrastructure, as shown in Figure 23 above.

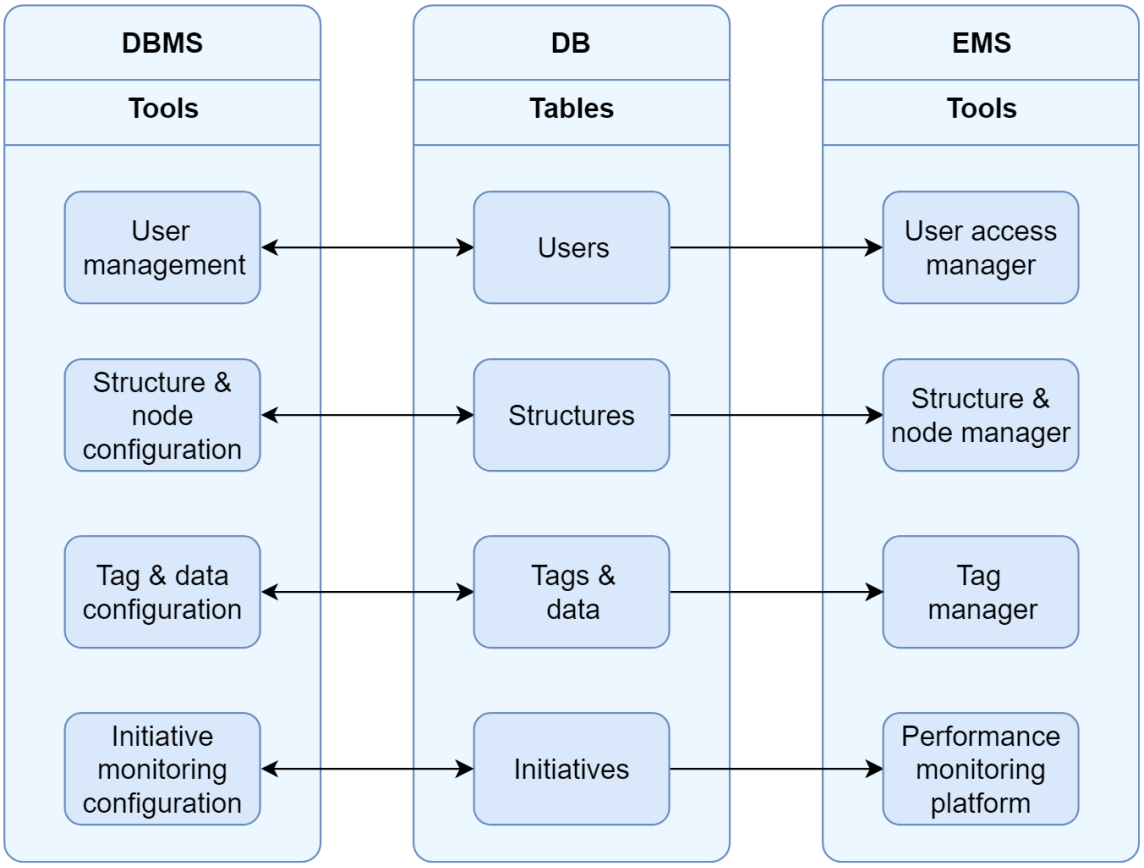


Figure 24: Integration with ESCo infrastructure

The platform will be using existing infrastructure for database management, EMS, as well as the configuration software platform or DBMS for the EMS.

As shown in Figure 24 above, the performance monitoring platform will be integrated into the current ESCo infrastructure by utilising the DBMS and DB to enable performance monitoring in the EMS software platform.

2.3.2.2 Data flow

To enable the performance monitoring of deep-level mining systems the data is gathered as shown in Figure 18 and discussed in Section 1.2.4.4. The platform will be implemented by using the Type 1 and Type 2 Big data company models discussed in Section 1.2.4.3 in the literature. Data will be gathered, processed, and analysed to improve performance.

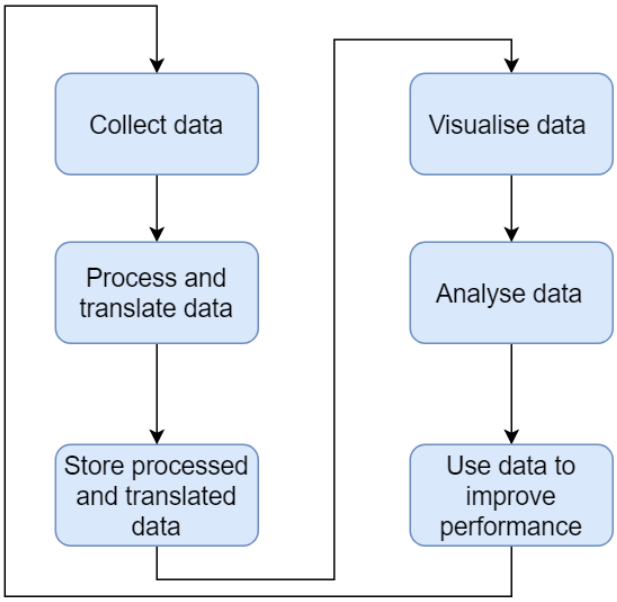


Figure 25: Basic data flow for performance monitoring platform

As shown in Figure 25, the data flow of the PMSP will enable the continuous monitoring of performance by continuously collecting, processing, and analysing data with the aim of improving performance. For each step in the data flow, the data is verified for continuity, consistency, and data loss. The most important steps in the data flow that will enable performance monitoring are processing and visualising the data. Key performance indicators will be calculated by using the data of the specific mining system.

Performance monitoring will be made easier by using performance indicators as discussed in Section 1.2.3. Performance baselines and proposed profiles are used to calculate performance indicators that can help in decision making and easy analysis of system-specific data. A mining system or project will be referred to as an initiative. An initiative's performance is monitored by linking system or project data, performance indication profiles, and calculated performance indicators.

2.3.2.3 Performance monitoring

Performance monitoring will enable personnel to improve the efficiency of an on-going project, newly implemented projects as well as possible new initiatives to optimise systems and mining operations. The process of enabling a user to monitor and view data of initiatives in shown in Figure 26 below.

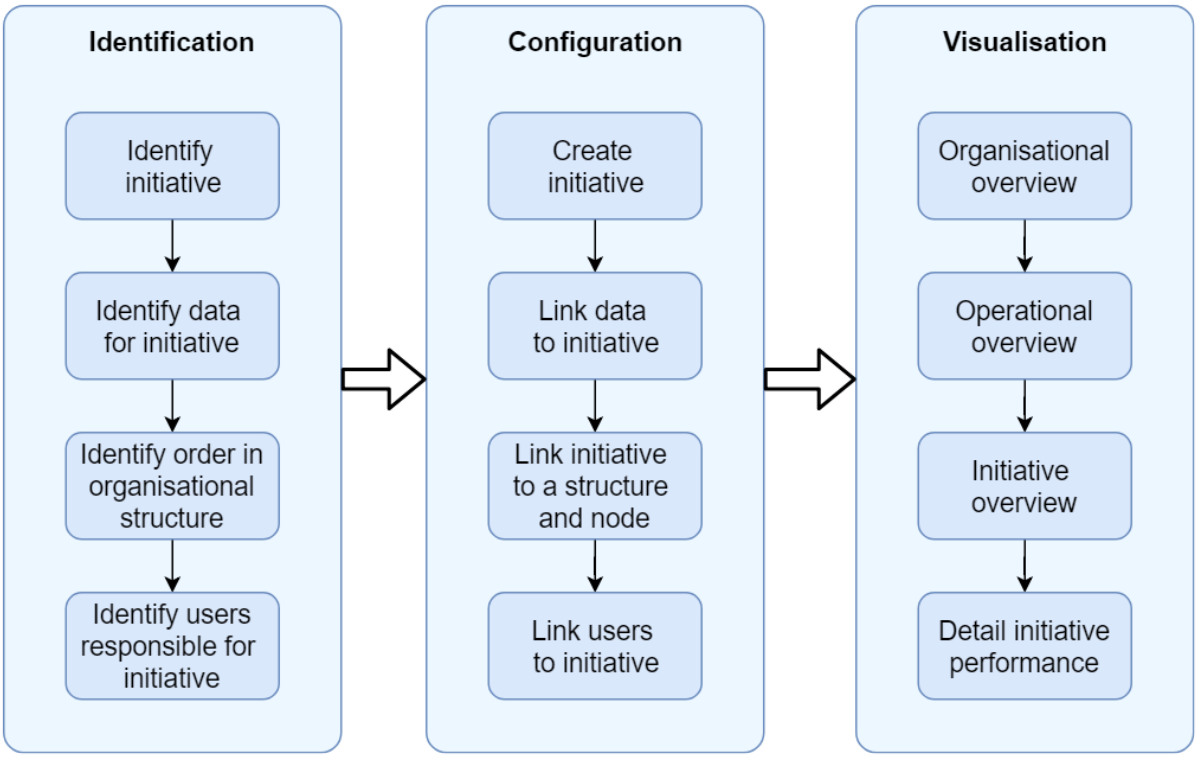


Figure 26: Performance monitoring initiative inception

To monitor the performance of a deep-level mining system or any on-going projects, an initiative with data first needs to be identified. Once the identification of responsible persons and the organisational structure of the initiative are identified, an initiative can be created and configured. The configuration process is the most important part of the PMSP. This is because important information such as data tags, initiative properties, and the performance indicators are set for the initiative.

A configuration tool will be implemented in the DBMS as a user interface that will enable the creation of an initiative. This initiative is used to monitor the performance of a project or system that is being optimised. This user interface will enable engineers to easily set up a structured performance monitoring initiative, with performance indicators, performance targets as well as the physical tags that need to be monitored. The procedure to configure an initiative for performance monitoring is made as simple as possible to reduce the implementation and structure setup time for an engineer.

Each step for configuration is essential for the PMSP to calculate, process, and visualise the performance of deep-level mining systems. The configuration of an initiative that will enable a user to monitor an initiative's performance is shown in Figure 27 below.

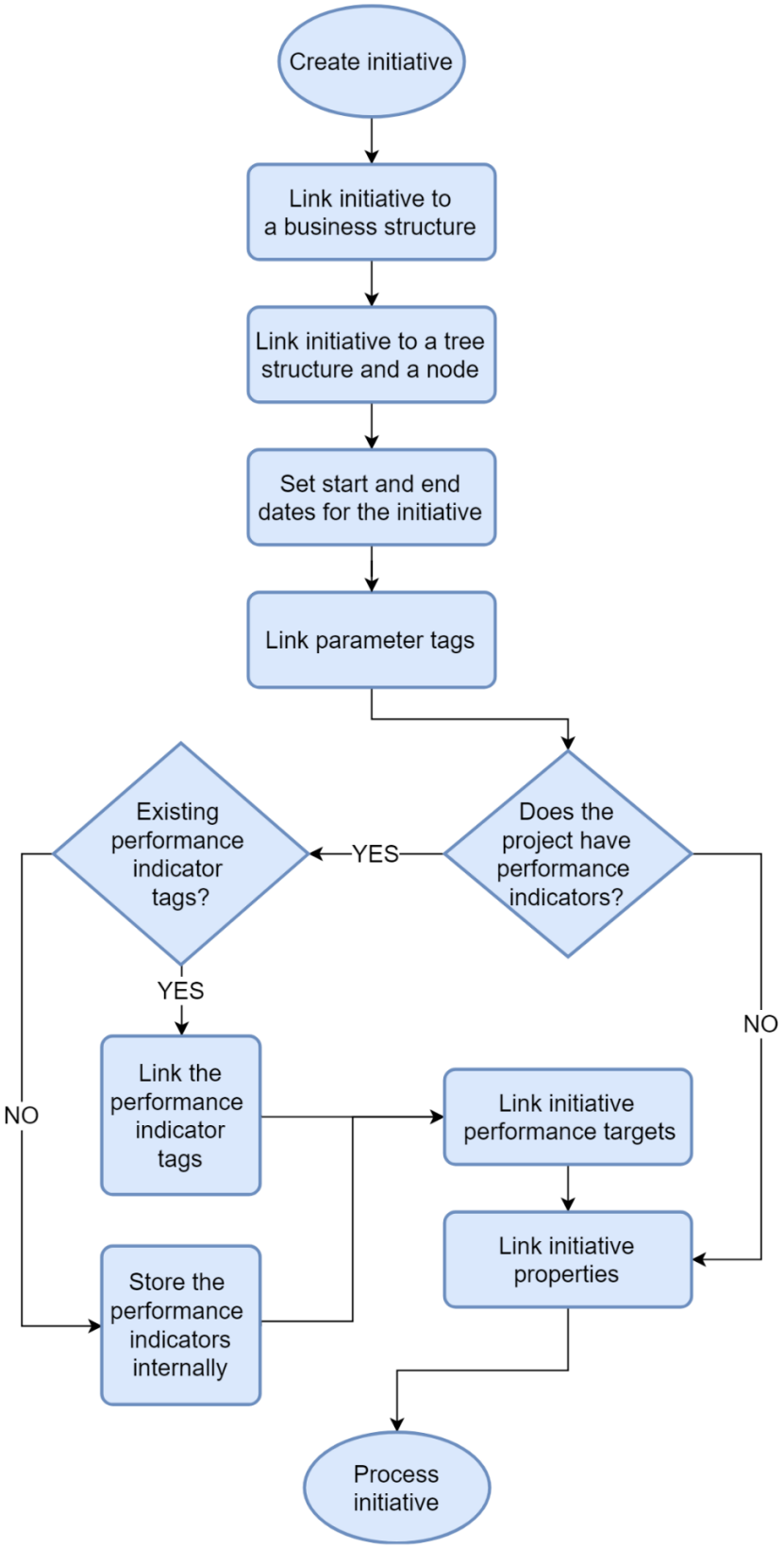


Figure 27: Performance monitoring Initiative configuration

The most important step in the configuration is the development of the performance indicators that will be used to measure the performance of the system using data. The performance indicators are developed using the IPMVP protocol and ISO standards discussed in Section 1.2.3.1. Each performance indicator needs to be approved before it can be used to measure the performance of initiatives. The process of performance indicator development is shown in Figure 28 below.

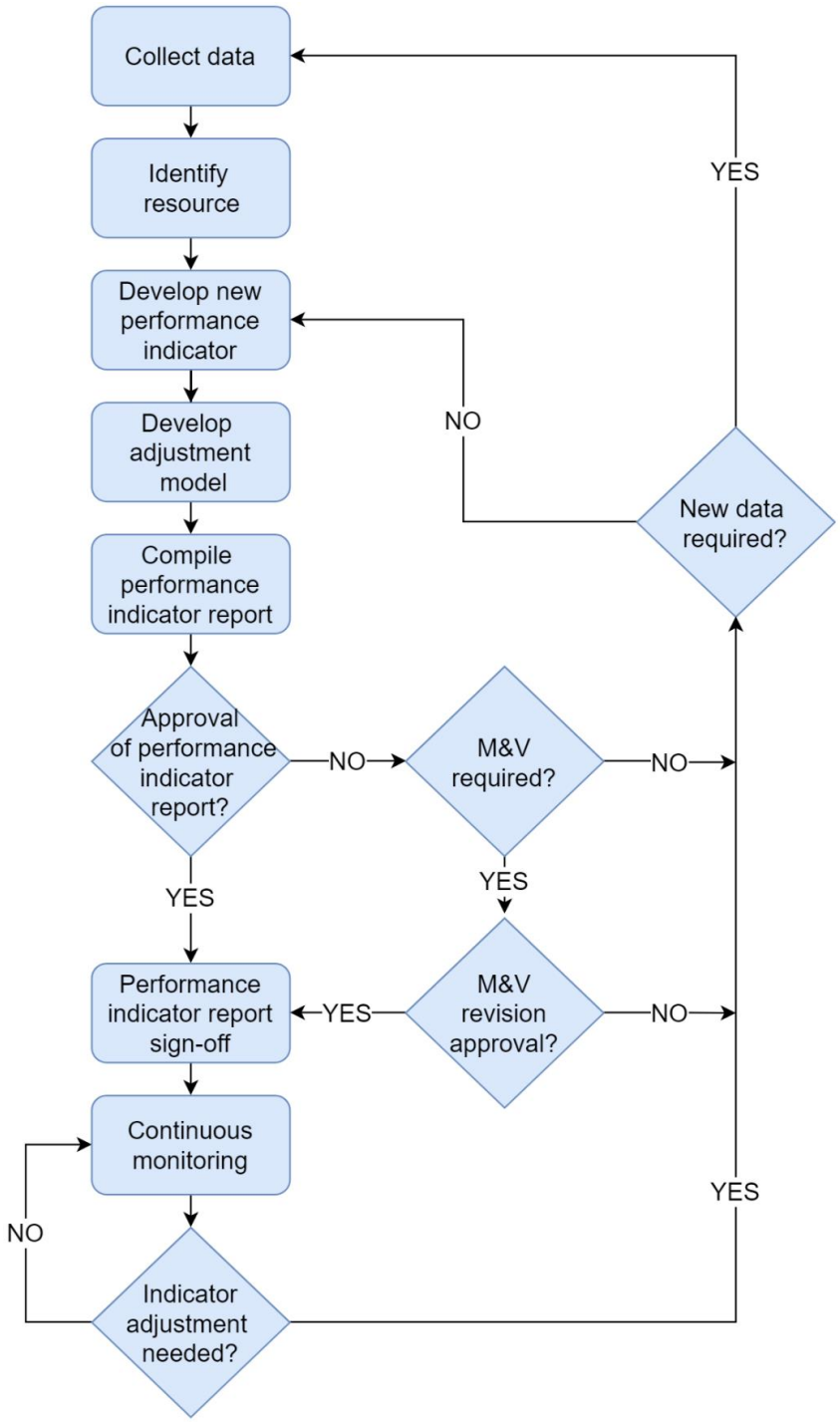


Figure 28: Performance indicator development process

After performance indicators are developed for the initiative, certain properties can be used to describe the initiative, namely the type of initiative, initiative phase or stage, performance scaling, type of savings applicable, and performance indicator sources. Targets for the desired performance of a certain resource for the initiative can be configured that will enable personnel to easily analyse the status of the performance.

After an initiative is configured with tags, properties, targets, and performance indicators, the initiative will be processed to calculate and give visual feedback on the data of an initiative on the PMSP.

Performance calculation

The performance of a project will be determined by comparing the actual resource with performance indicators for the resource.

In Figure 29, the process of performance calculation is illustrated. The performance of an initiative that is configured for the EMS is determined by the actual data of the system that is being monitored versus performance indicators using the Formula 1 in Section 1.2.3.

Each initiative processes the data in order to calculate the performance according to the initiative properties that can be set. The properties that can be set for performance monitoring on various systems are:

Table 3: Initiative performance properties

Property	Description
Performance type	Determines whether an initiative is focused on cost, energy, or resource performance.
Performance event exclusion	Determines the exclusions of performance on calendar dates, such as weekends and public holidays.
Performance indicator source	Performance indicators can be a manual input or a linked tag to the initiative. The source must be indicated.
Stage	This describes the performance stage of the initiative, which can indicate reasoning for poor or good performance.

Each configured initiative is processed with the linked data, performance indicators and properties to make it possible for a user to easily monitor the performance of active, maintenance, and performance assessment initiatives.

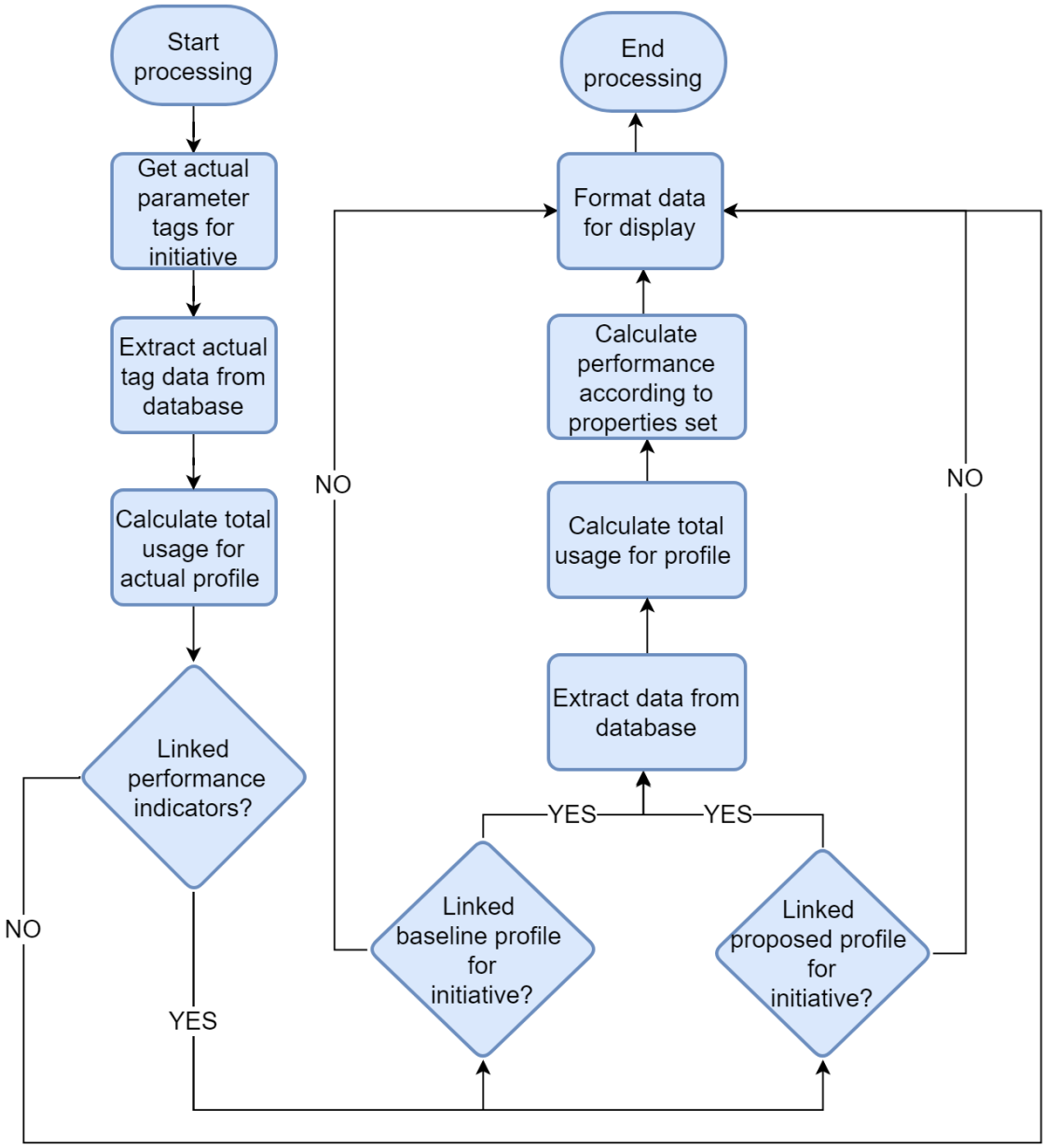


Figure 29: Performance calculation process

The functionality that is illustrated in the functional design will be used in the detail design as well as the implementation of the platform.

2.3.3 Detail design

During the design phase for a web-based platform, there are many important aspects to consider for the design in order to conform to the requirements that are set. There are, however, only two aspects that are important for the PMSP to be implemented for the given platform that addresses the need for performance monitoring since the platform will be implemented on an existing ESCo web-based platform, namely data management and user interface.

2.3.3.1 User interface design

By using the user interface design principles described in Section 1.2.5.1, a user interface that will reduce cognitive load by making use of effective user-friendly visualisation of performance monitoring on a scalable multilevel view will be designed.

A user interface with good interactivity will allow for better navigation leading to a more satisfactory cognitive load-reducing interface for users, reducing the amount of information displayed at any one time [44], [48].

Performance overview

A simplified performance overview user interface that will help reduce time, cognitive load, and improve decision making is needed. To reduce the cognitive load on users, the user interface must be designed to draw the user's attention and focus on important aspects such as the performance status of an initiative. The performance status of each initiative will be represented by an element with various colours representing the status [25].

Table 4: Performance status

Colour	Performance status	Detailed description
	No data	No data for performance monitoring is available.
	Condonable	The performance is marked as condonable because of data loss or condonable actions.
	Poor	The performance is below the performance indicators and targets indicating poor performance.
	Within 10%	The performance is within an acceptable range of baselines and proposed performance.
	Good	The performance is above the performance indicators and targets indicating good performance.

As seen in Table 4 above, the performance of an initiative will be indicated by coloured elements. Each colour represents a status of how good or poor the performance of an initiative is. This allows users to immediately identify problematic initiatives, where the initiative can be viewed in more detail.

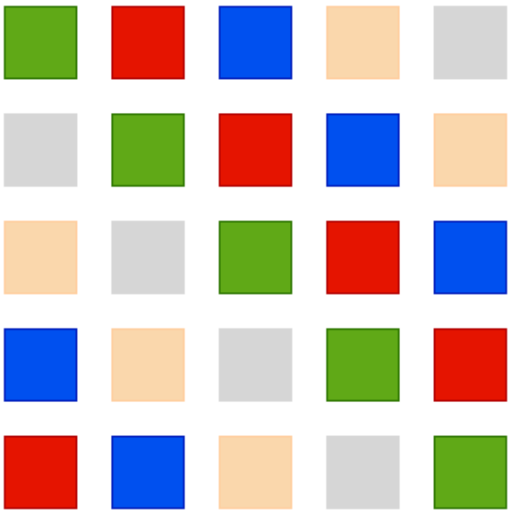


Figure 30: High-level initiative status overview grid concept

A high-level overview of these systems is needed in order to enable personnel to view multiple initiatives on a single business unit as well as several business units on a single multi-level overview of an organisation. As illustrated in Figure 30, grids can be used to represent a calendar overview of several states, from multiple initiatives as well as multiple days or instances of an initiative. Grids will be used for high-level overviews and will be separated into daily as well as monthly overviews.

These grids will be structured and organised according to the business structure and organisation to which the initiative belongs.

Structures

Data structures are used to organise data and information. Collected data is only beneficial if the data can be analysed into useful information. Collected data can be analysed with greater ease by representing the data in an organised structure [25], [48], [65].

A mining organisation has many business units, each with sub-units or levels of operation that make up the hierarchal structure of a company. As shown in Figure 31 below, a company can consist of many business units. Each business unit has separate systems and is seen as an individual entity.

A hierarchical business structure is used to manage and organise finances, data, and information in companies. These structures were discussed in Section 1.2.5.3, where the importance of using data structures in software is crucial. A hierarchical data structure that represents the organisational business structure of a mining company will be used to organise and sort data, conforming to a logical structure to represent the performance of a deep-level mine's systems.

A user will be able to link a performance monitoring initiative (as described above) to nodes in the tree structure that represents the company structure. A visual interface for creating these structures was implemented by the ESCo, which will enable fast and easy tree structure management for performance monitoring initiatives. Each node in the business structure tree will be linked to a parent node, and child nodes will be linked to a specific parent node. The organisation or business structure will be seen as the top node with each level of nodes organised by the order of importance. The management and design of these trees are described in the detail database design below.

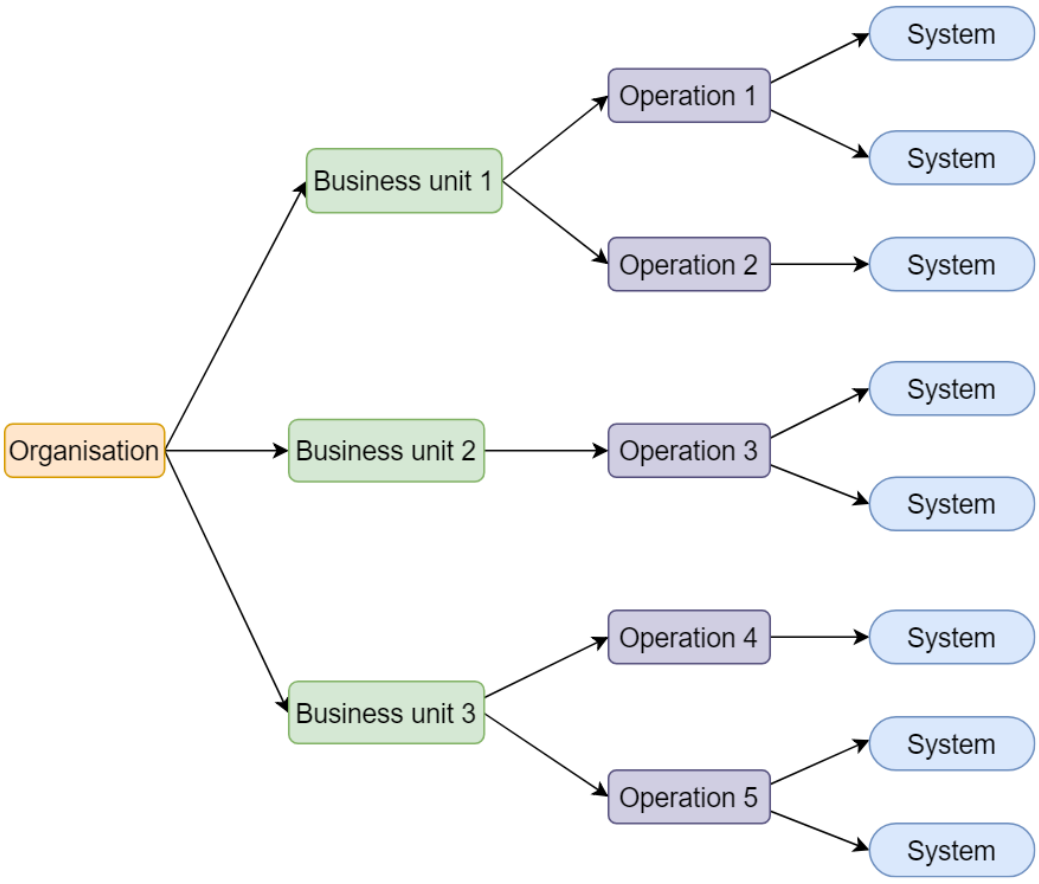


Figure 31: Hierarchical business structure

The structure can be used to monitor the performance of systems, individual components as well as resource consumption, where each initiative can be linked to the appropriate node on the business tree structure of the organisation.

2.3.3.2 Database design

Data management is an important aspect of software platform design when a large amount of data is used by the platform. Data management for structures, users, initiatives, and data sampling will be needed to enable performance monitoring. The full database design can be found in appendix A.

Data management

As discussed in Section 1.2.4.4, data from mining sites are stored in a non-relational Big data database. This data is then processed into data organised by the setup of tags into a relational database for use by the platform. ERDs (Entity Relational Diagrams) are used to illustrate the relationship between the database tables, and will be used to show the relationships of data for the platform.

Tags are organised and categorised by the value type, units, source, and tag types, as seen in Figure 32 below.

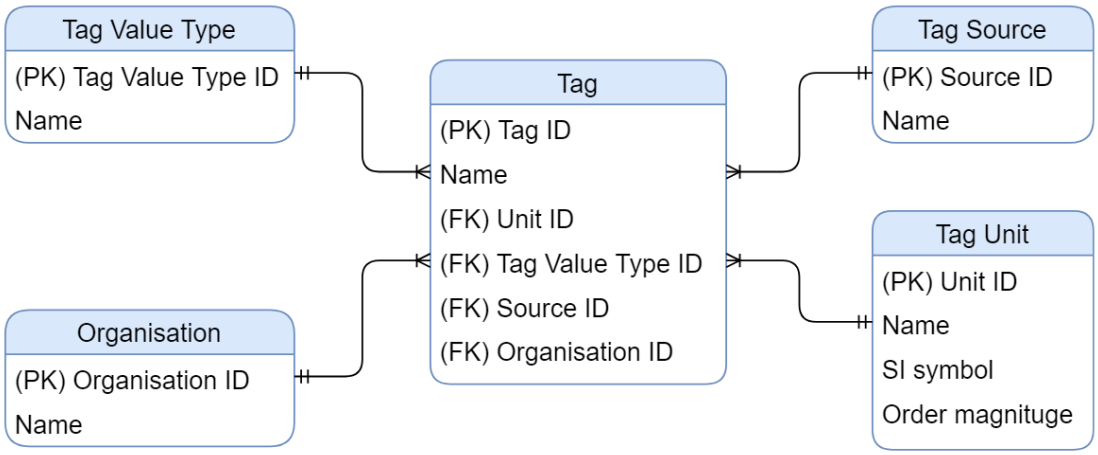


Figure 32: Tag configuration ERD

Data received from a site is usually stored as tags which are used to identify the data. These tags contain metadata such as a description of the tag, value types, units, and the data source. Relational databases are not typically used for Big data applications. This is why data is processed to reduce the sample rate of data by aggregating sampled data. The sampled data is stored in the relational database that is linked to a tag, as seen in Figure 33.

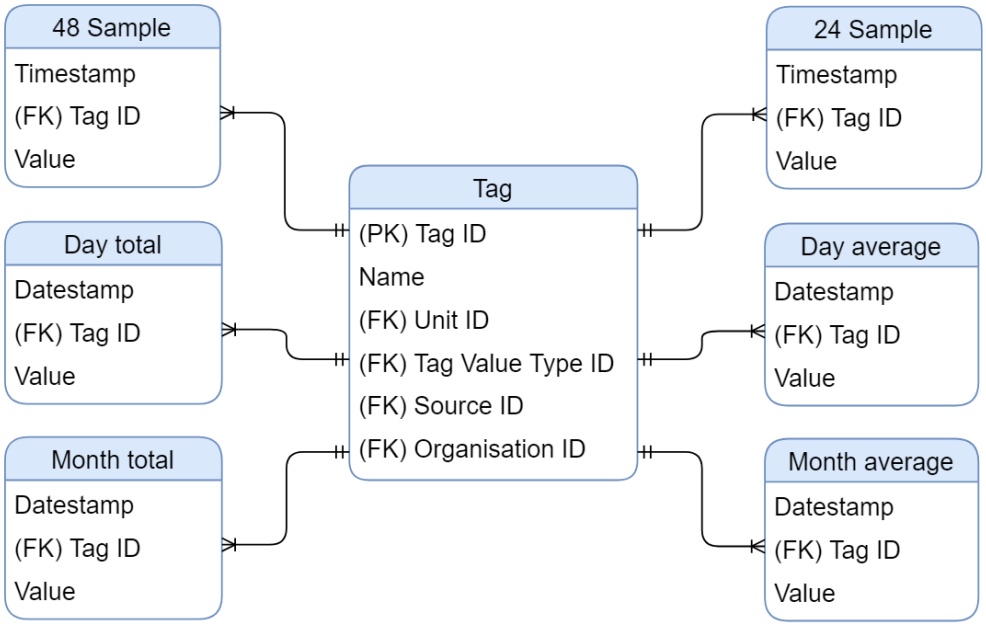


Figure 33: Data tables used to store processed data

The tag data is aggregated to 48 and 24 sample data for each day. The data is also aggregated to *day total* and *monthly total* data. An example of the tables that are used to store the aggregated data is shown in Figure 33. This aggregation is done to reduce the amount of data without losing critical data that can be used for good data analyses.

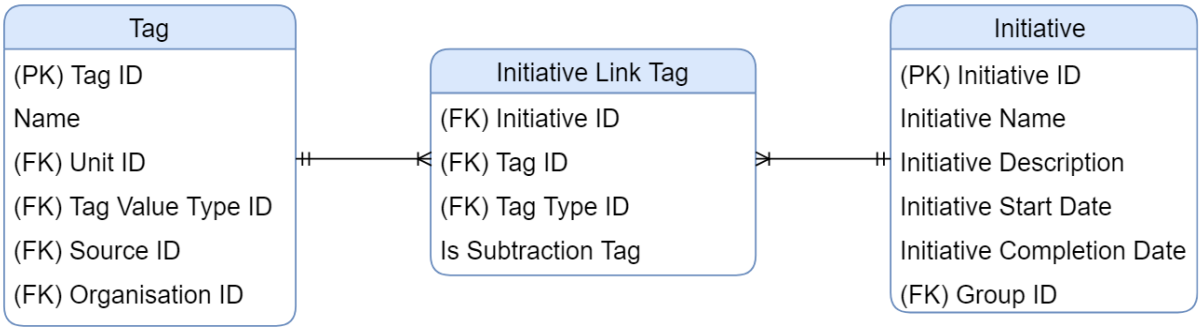


Figure 34: Tag link to initiative ERD

The data tag can then be linked to initiatives, structures, and organisations, as seen in Figure 34. This allows for organised data that is easily accessible for use by the PMSP.

Initiatives

Initiatives will be used to configure data, structures, and properties for performance monitoring of deep-level mining systems. An initiative will enable a user to configure a name, description, and a start date. Once the basic details of a project are set, a user can configure the performance indicators and targets and then link the tags to an initiative that will be used to calculate the performance. Each aspect of an initiative will have a database table that contains properties, tags, and performance indicators.

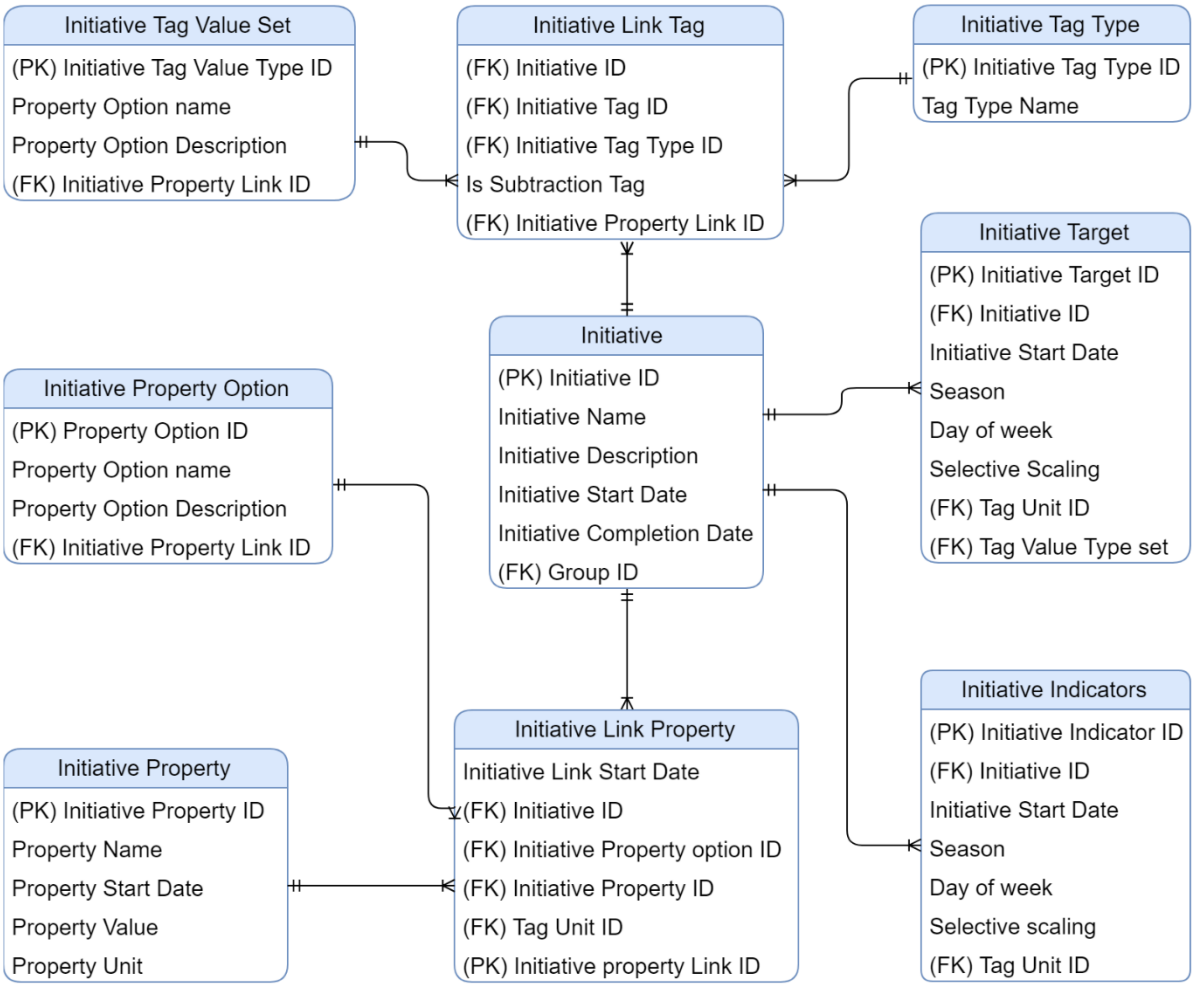


Figure 35: Initiative ERD

In Figure 35, the ERD of an initiative is shown. There is a relation between an initiative and its properties that determine how the performance will be calculated as well as how the data will be presented to a user for monitoring.

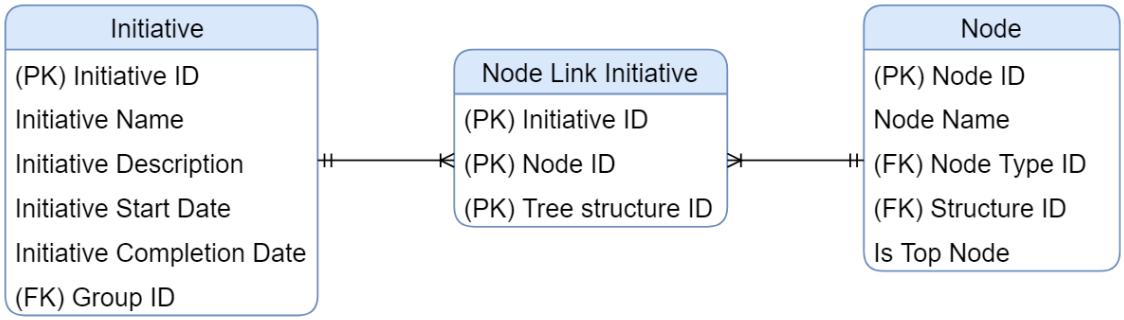


Figure 36: Initiative link to nodes ERD

To organise the initiatives, tree structures are used. The ERD of the link between an initiative and the node of a tree structure is shown in Figure 36. Once an initiative is configured for performance monitoring, the initiative can be linked to a tree structure and nodes.

Structures

Structures and tree structures will be used to organise data, initiatives for performance monitoring, and navigation on the PMSP. As described in the section above, a hierarchical business structure will be used to organise data on the platform.

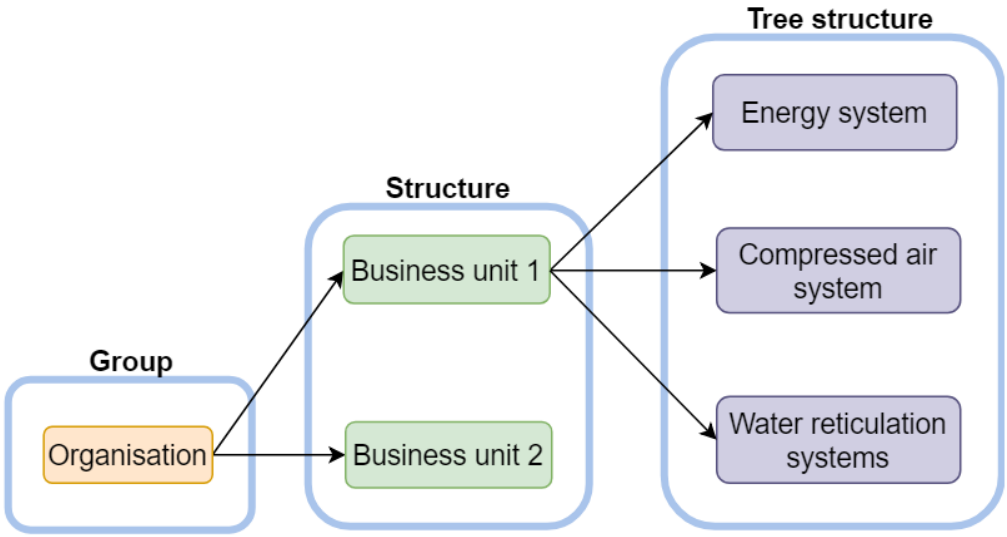


Figure 37: Structure configuration

Structures will be created that represent a business unit or business structure of an organisation. Tree structures are then created to represent the structure of many different systems that can be used to organise the different types of systems on which initiatives are used for performance monitoring as shown in Figure 37.

Each tree structure will consist of a top tree node or root node with many child nodes linked to this root node. These tree structures are used to represent the structure of operations, systems, and components.

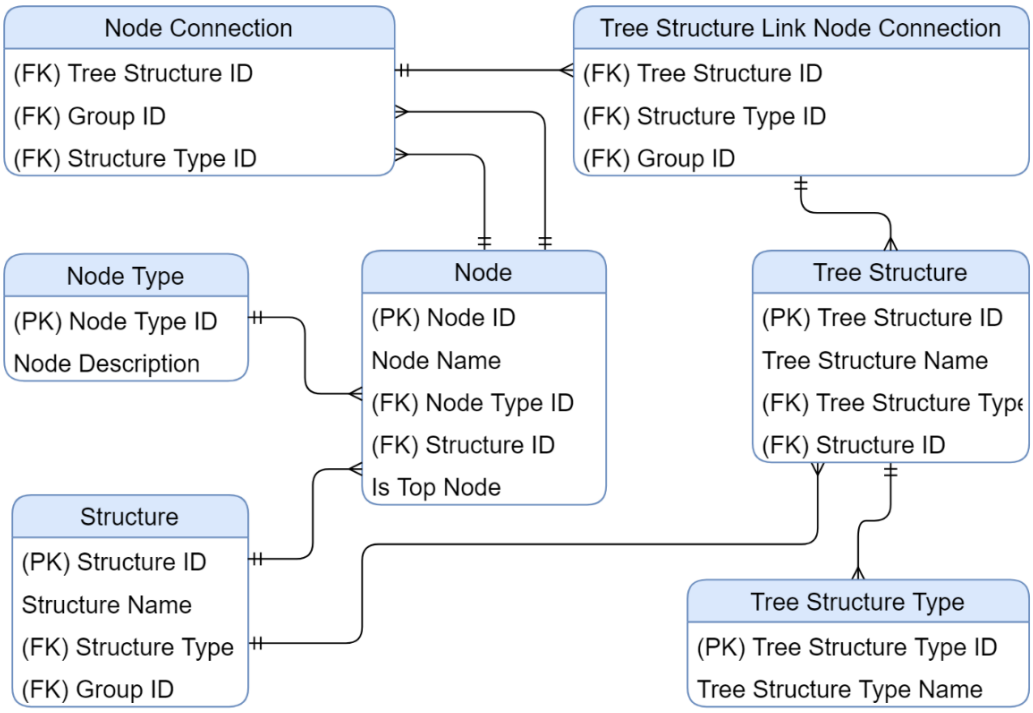


Figure 38: Structure ERD

In Figure 38, the database ERD design for the structures is shown. Each node has a link with a parent, child, or root node, and each node belongs to a specific business structure and is linked to a tree structure.

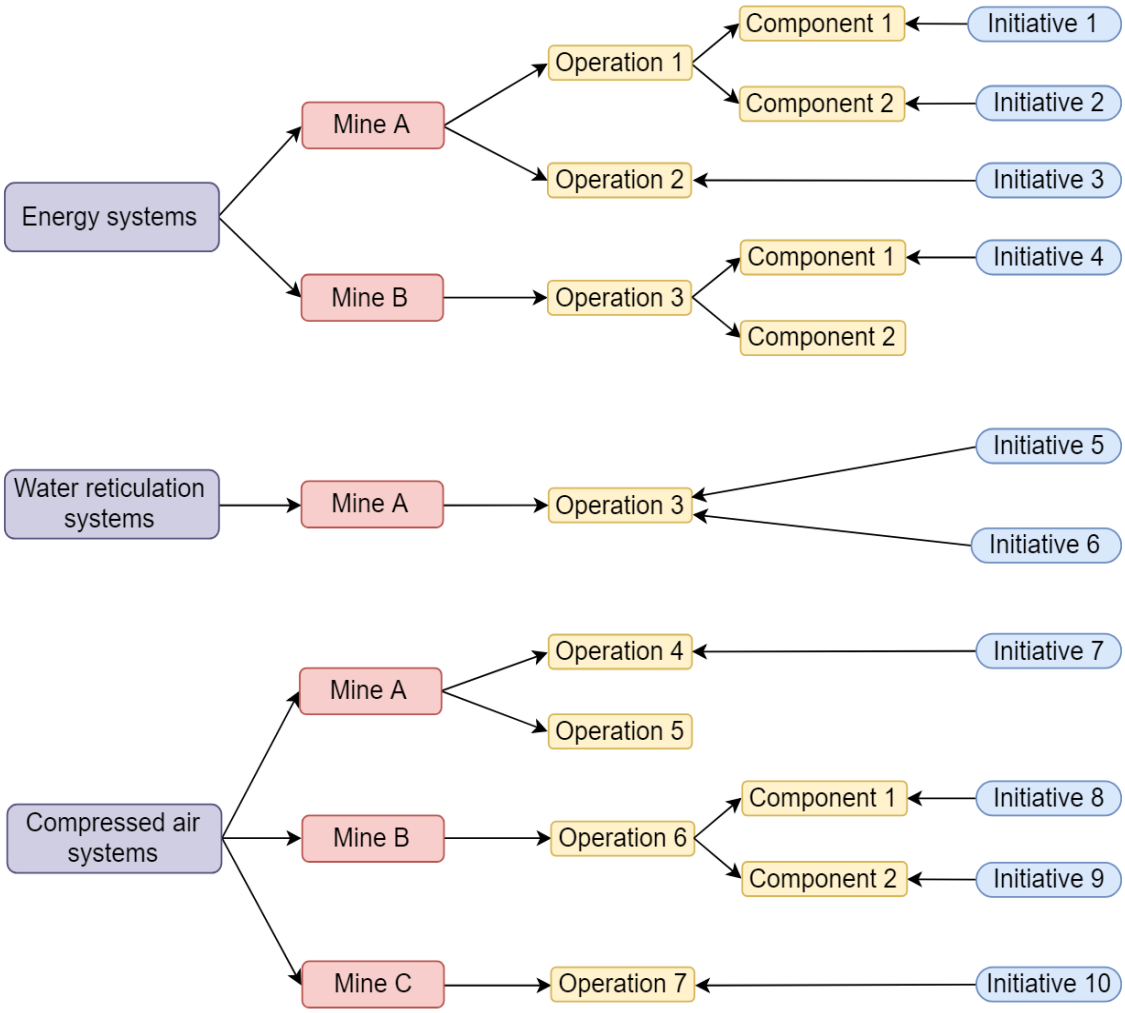


Figure 39: Tree structure configuration

These node connections define the relationship that nodes have in a tree structure. As shown in Figure 39, initiatives can be linked to different levels on the tree structure once the business structure and tree structure connections have been defined.

The detailed design presents the necessary information that can be used to implement a generic software platform for performance monitoring on an existing ESCo web-based platform. The next step in the methodology is to implement the designed platform.

2.4 Implementation and verification

The next step in the extended waterfall methodology is to implement the designed platform according to the requirements that are set. After revised requirements and design, the platform can be implemented. Using literature for user interface design, effective data structuring, and data utilisation for Big data companies, an effective software platform can be implemented using the design and requirements. The platform is implemented using effective user interface principles as outlined in the literature.

As discussed in the literature in section 1.2.4 and the design in section 2.3.1, the PMSP will be implemented on an existing ESCo web-based platform. The PMSP will be utilising the current ESCo relational database, software structures, and standards. To enable engineers to monitor the performance of deep-level mining systems and projects, the PMSP will be divided into two tools, namely a configuration tool and a viewer tool. The configuration tool will be implemented on the ESCo's DBMS and the viewer will be implemented on the EMS.

All design and visual elements of the platform are set by the ESCo's platform. The DBMS platform makes use of a blue and white colour scheme while the EMS makes use of a yellow and blue colour scheme.

2.4.1 Performance monitoring configuration

To enable a user to create a performance monitoring initiative that can be viewed on the ESCo's EMS, a configuration tool will be used to set up an initiative that would determine the performance of deep-level mining systems. The configuration tool for performance monitoring initiatives was implemented on the ESCo's DBMS as performance monitoring initiatives.

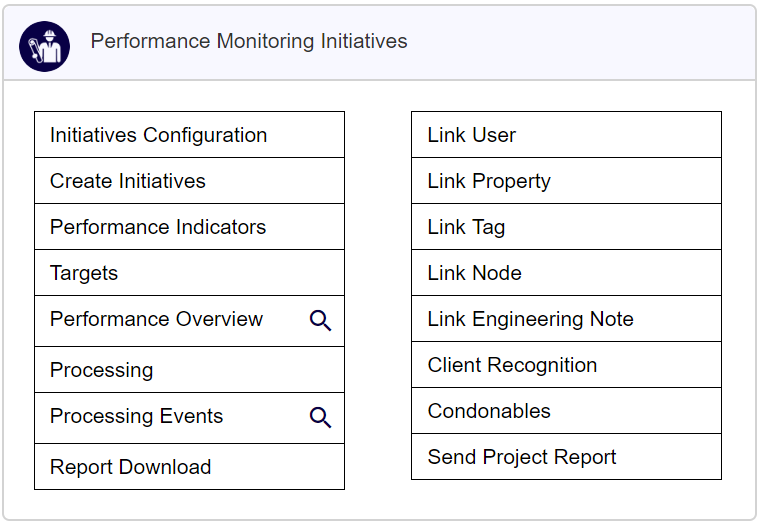


Figure 40: Configuration tool menu in ESCo's DBMS

In Figure 40, the menus for performance monitoring initiatives are shown. The functionality of the configuration tool is split into several different menus that are used for the configuration of initiatives, linking initiatives to structures and users as well as properties, performance indicators, and targets.

Initiatives are created and can be set up in the configuration menu. As seen in Figure 41, all the details of a performance monitoring initiative such as initiative name, baselines profiles, proposed profiles, targets, properties, and tags can be configured.

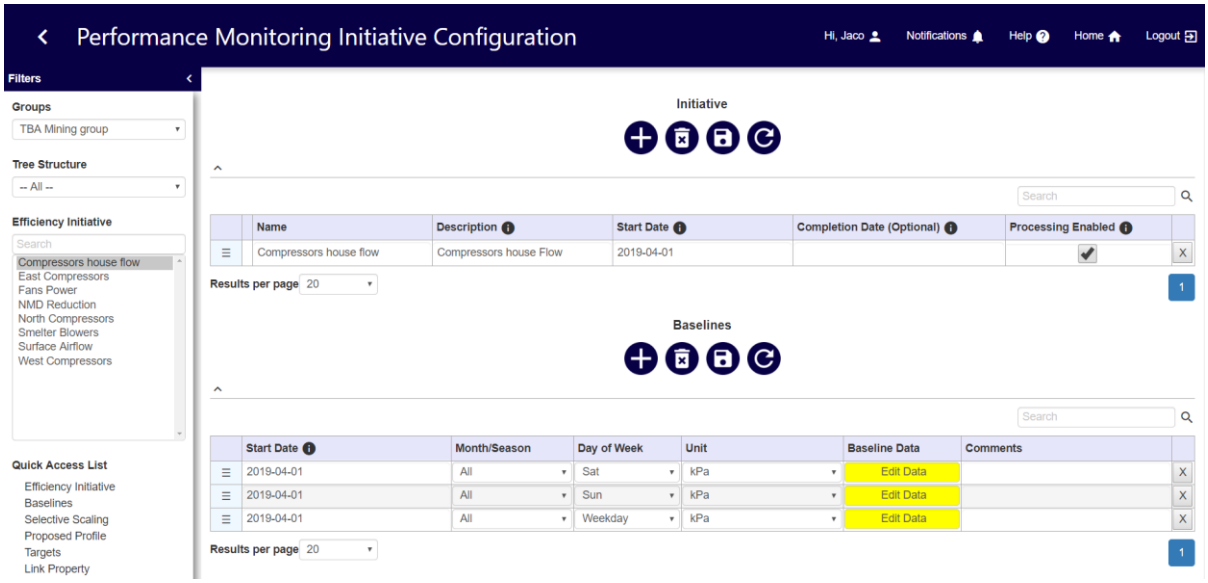


Figure 41: Initiative configuration

For each initiative, performance indicators can be configured, as seen in Figure 42, as a day total, half-hourly or hourly sample data by either manual data input or linking indicator data tags.

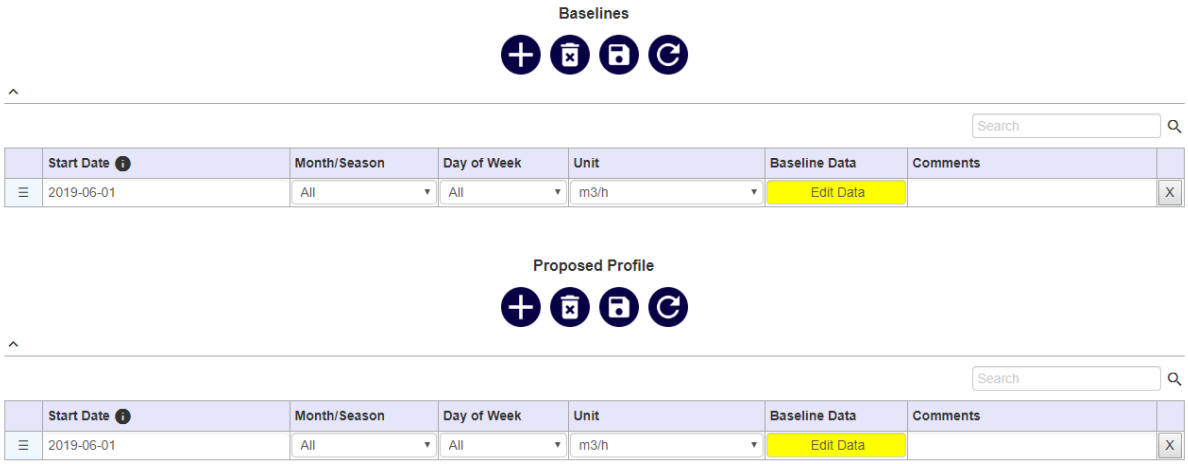


Figure 42: Performance indicator configuration

These performance indicators can be specified for a specific period, seasons, weekdays, and units, with baseline and proposed profiles that can be specified as daily, hourly, or half-hourly values to compare the actual data against, as seen in Figure 43.

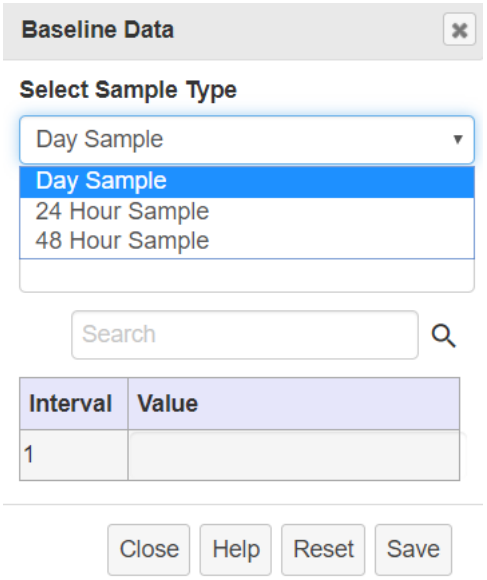


Figure 43: Baseline and proposed profile data input

As discussed in the design, an initiative's performance will be calculated and determined by using properties that will be configured. Figure 44 shows how properties can be linked to an initiative.

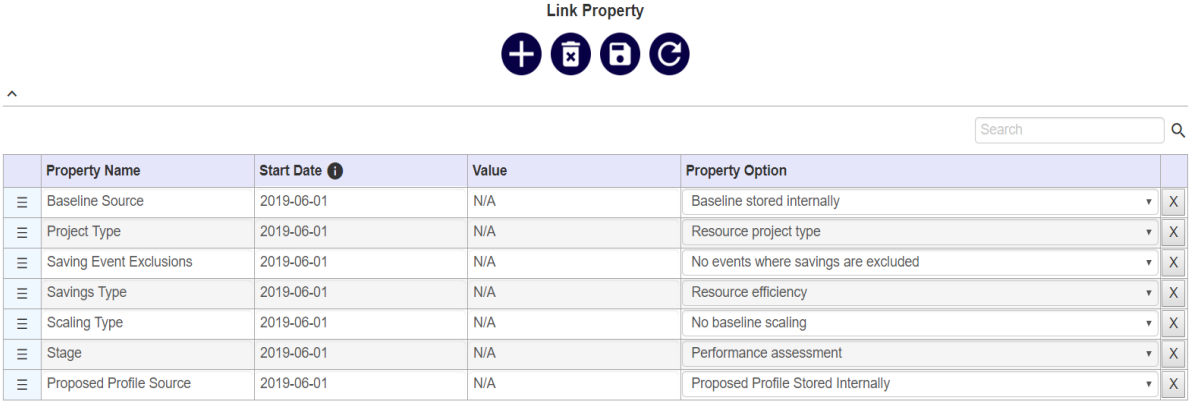


Figure 44: Initiative property configuration

Finally, tags can be linked to an initiative. There are many types of tags, namely actual, baseline, proposed, and tariff tags when cost-saving needs to be calculated. Actual tags are used to link actual tag data that is received from sites and processing. As mentioned above, performance indicators such as baselines and proposed profiles can also be linked as tags.

During the processing of an initiative, the performance data such as cost- and resource-saving are calculated and stored as tag data. Condonable days, due to data loss or incorrect values, are also stored in a data tag.

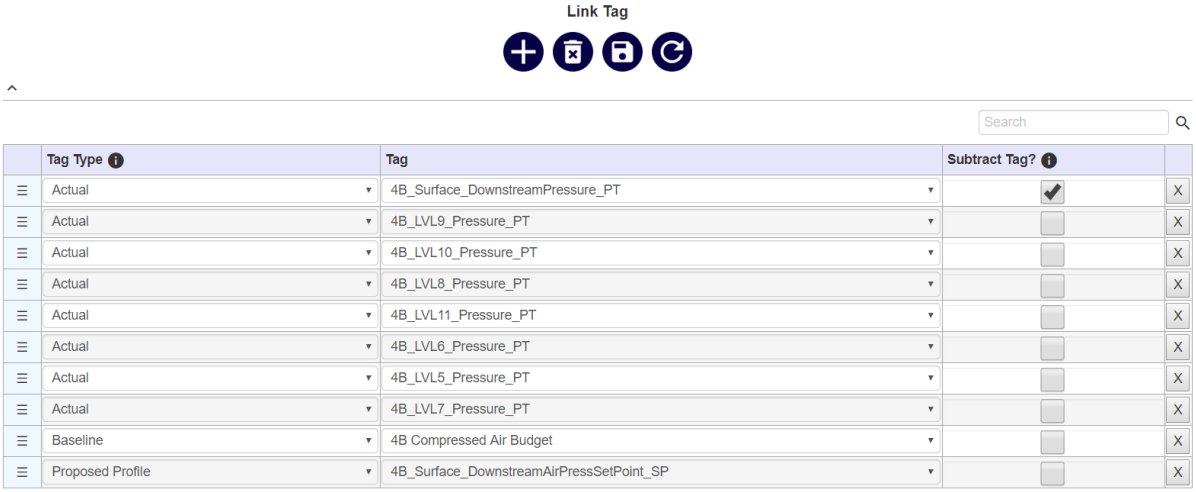


Figure 45: Initiative tag configuration

As shown in Figure 45, the actual, baseline, and proposed profile tags can be configured to add or subtract values from the total of each. Once the initiative is configured, it can be linked to a business structure and tree structure and nodes that can be configured using the DBMS.

Structures

To configure the business structures that will be used to organise the performance monitoring initiatives, the ESCo's DBMS node builder tool will be used to configure structures, tree structures and nodes.

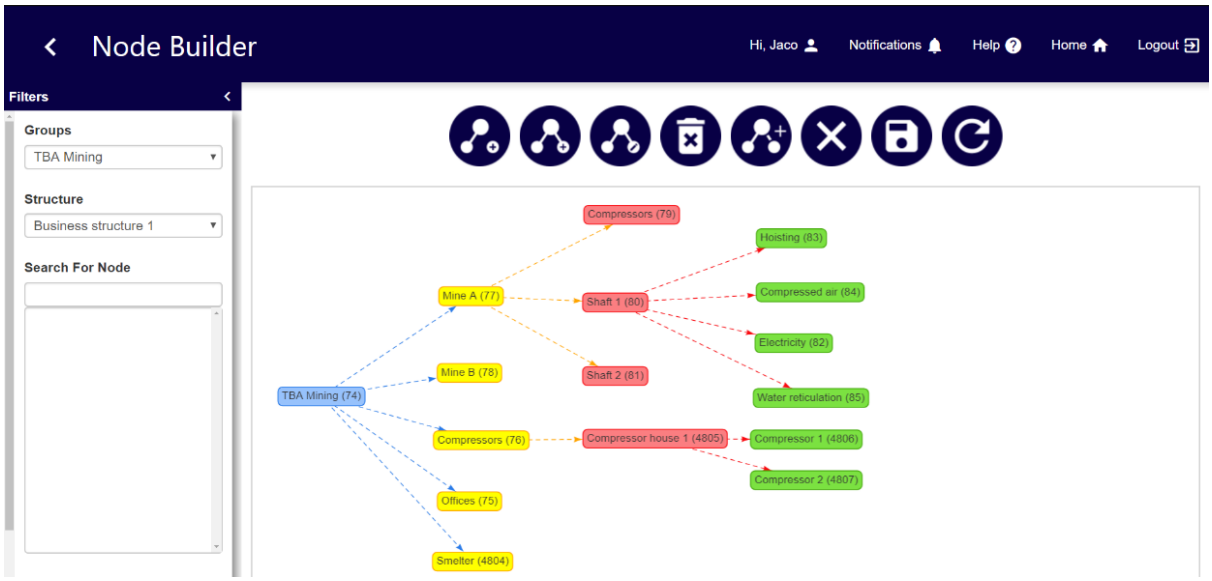


Figure 46: Node builder tool

A tree structure can be linked to a business structure. These tree structures are used to organise deep-level mining systems such as compressed air, water, and energy.

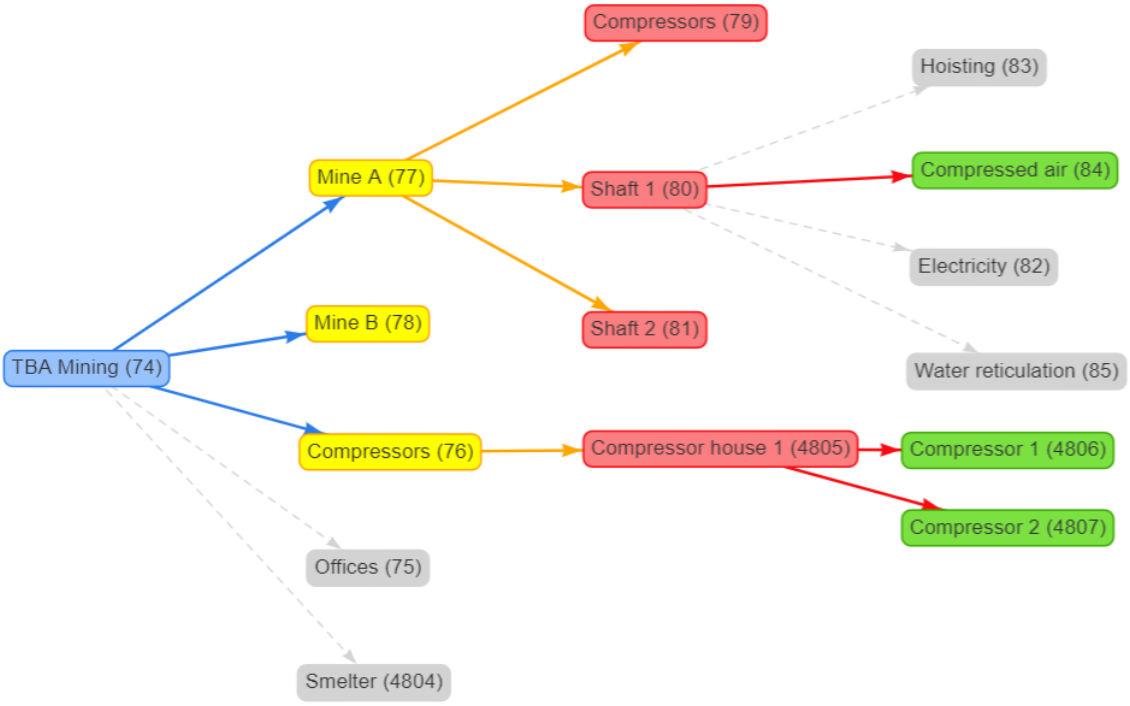


Figure 47: Tree structure node linking

Figure 47 is an example of how nodes in a hierarchical structure can be linked to a tree structure. Initiatives that are relevant to a tree structure can then be linked to the specific nodes. In this specific example it can be seen that the coloured nodes are linked to the tree structure and the grey nodes are unlinked.

After the performance monitoring initiatives are configured and linked to users and tree structures, the initiatives will automatically process, after which the data and performance can be viewed in the PMSP that was implemented in the ESCo's EMS.

2.4.2 Performance monitoring software platform

The configuration of the PMSP is done in the ESCo's DBMS. In the DBMS the performance initiatives, users, structures, and reporting in configured and processed. After processing, the PMSP will use the processed data to give a visual representation of the data and calculated performance of each initiative on many different levels of an organisation. Detailed data and performance, as well as overviews of the performance, can be viewed daily and monthly.

For a high-level performance overview of initiatives, the performance can be monitored on organisational, operational, and system levels, as configured in the DBMS for the organisation and relevant tree structures.



Figure 48: Organisational level navigation

The navigation of the organisational level is shown in Figure 48 above. This tree navigation allows business structure-relevant initiatives to be viewed, helping reduce cognitive load by allowing the user to quickly view an overview performance of each level.

These high-level overviews will indicate the performance by using cognitive load-reducing techniques by using effective user interface design principles as described in Section 1.2.5.1. The performance status per day and month will be indicated by using performance status indications as described in Section 2.3.3.1.

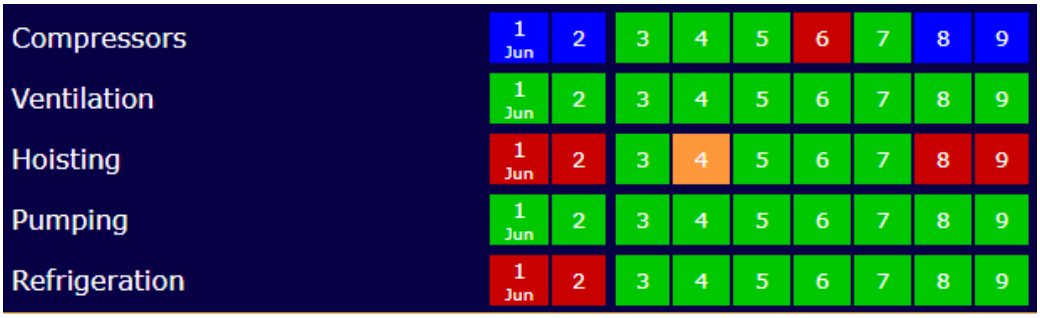


Figure 49: Daily performance overview

Figure 49 and Figure 52 show an example of how the high-level overview can indicate the performance status of several initiatives for days and months.

The data that is linked to an initiative that is used to calculate the performance is visualised in a graph. This allows the analysis of data and helps with identification of performance problems.

For further in-depth analysis of data, the raw data can be viewed in detail, as shown in Figure 50 and 51. Each tag that is linked to an initiative can be viewed as hourly or half-hourly data.

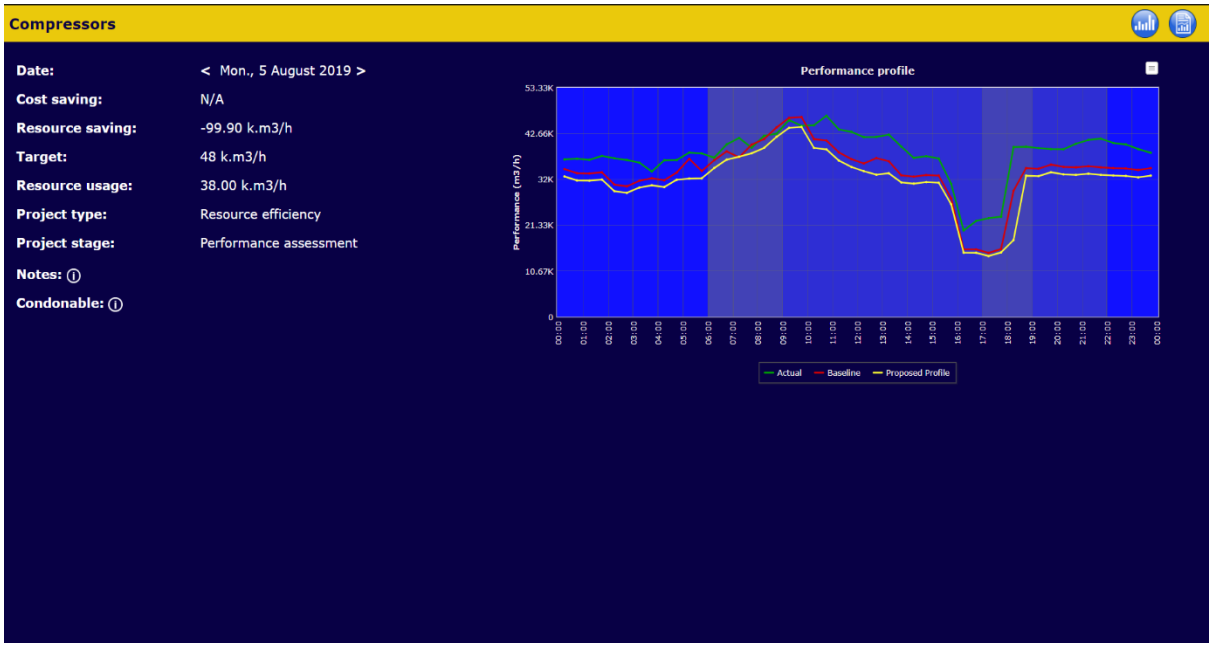


Figure 50: Daily detail performance overview

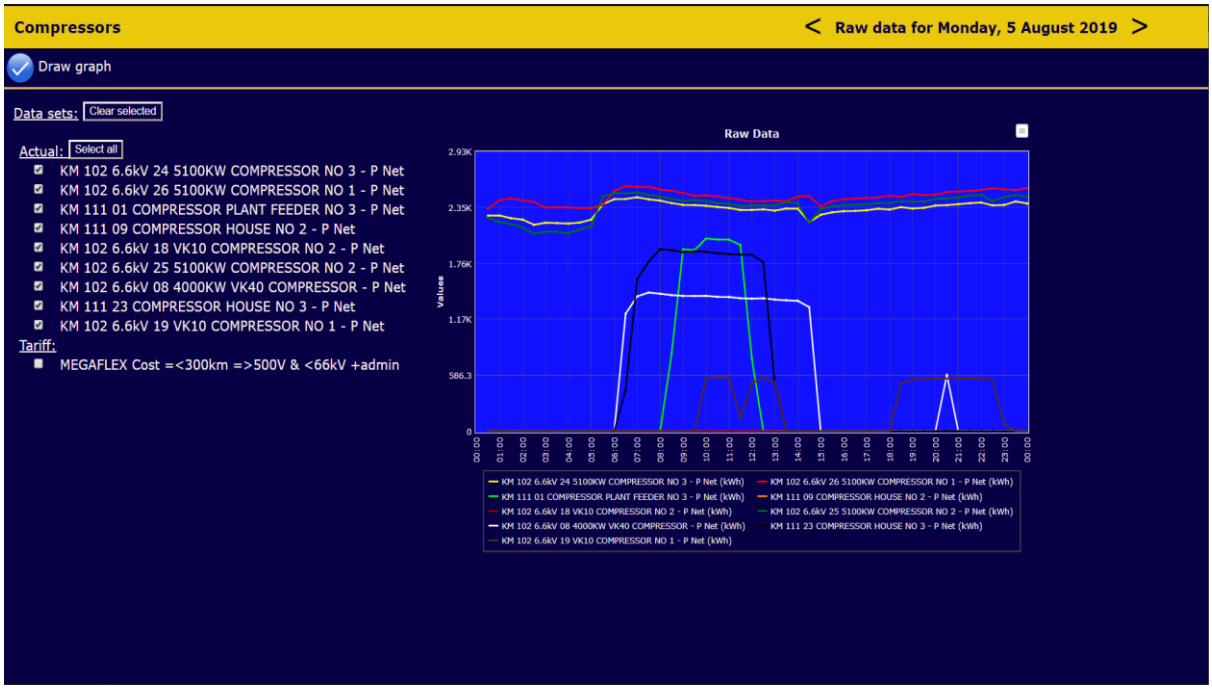


Figure 51: Detail raw data for an initiative



Figure 52: Monthly performance overview

As previously discussed, the high-level overview and detail overview views will be available to view on the PMSP. This monthly overview can show summaries of the performance of initiatives throughout a financial year, as seen in Figure 52 and Figure 53.

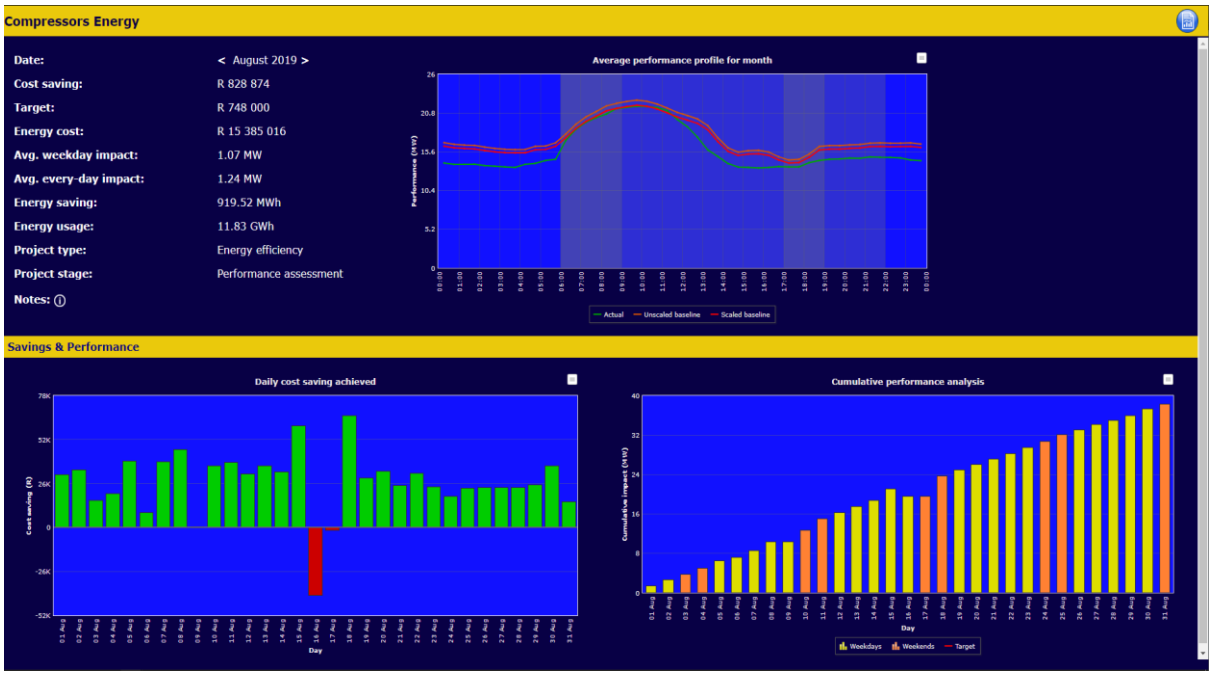


Figure 53: Monthly detail performance overview

In Figure 53, the daily performance of the example monthly view can be seen. The daily performance can help indicate problems and missed opportunities. The view also allows personnel to see the cumulative performance for the month to date.

After the implementation of the configuration and viewer tool for the PMSP, the software platform can be moved into the final stage of the software life-cycle, namely the maintenance phase. The maintenance phase will largely involve new features that the end user requires and thus is not in the scope of the usability of this platform.

2.5 Summary

The extended waterfall methodology was used to create the PMSP (Performance Monitoring Software Platform) for the performance monitoring of initiatives on deep-level mining systems. The first step is to set the requirements for the PMSP. From the literature, the requirements for the software platform were defined. The requirements were set due to the needs that were derived from the literature. These requirements were based on the literature of software platform design, deep-level mining systems, and performance monitoring to aid in achieving the objectives set in Section 1.4

The PMSP was designed with the requirements that were set, and was implemented using existing infrastructure and techniques. The PMSP integrates with the existing ESCO's DBMS and EMS platforms, utilising the existing functionality and infrastructure. The PMSP consists of two tools, namely the DBMS configuration tool and the EMS viewer tool. Data, initiatives, structures, and user control is configured in the DBMS and viewed in the EMS.

The PMSP was designed to allow personnel to create performance monitoring initiatives. This enables them to monitor deep-level mining systems in a user-friendly platform that reduces the time that is needed to analyse, structure, and calculate the performance.

The developed and implemented PMSP objectives in Section 1.4 are verified in the implementation of the platform in Section 2.4.

CHAPTER 3

RESULTS AND DISCUSSION



Sibanye Stillwater Smelter (Source: www.sibanyestillwater.com)

3 Results

3.1 Preamble

This chapter presents the results of the implemented performance monitoring software platform (PMSP.) The aim of the PMSP is to address the objectives and needs in Sections 1.3 and 1.4 for a generic performance monitoring platform.

Three case studies will be used to validate that the PMSP meets the objectives for a generic performance monitoring software platform. The software platform is validated by relevant results relating to the objectives of the study for the performance monitoring of deep-level mining systems.

3.2 Case studies

Three case studies were approached with the methodology described in Chapter 2 using the continuous improvement model. This model ensures the continuous improvement of energy management on systems. The principles of the ISO standards and IPMVP protocol will be implemented on the performance monitoring of deep-level mining systems. Performance of mining systems that can have potential energy cost savings are set up on the PMSP to be monitored.

The three mining systems that will be monitored are electricity, compressed air, and water initiatives for a mining organisation that can have potential cost savings. For the generic software platform, three different deep-level mining systems' performance will be monitored and implemented using the PDCA (Plan, Do, Check, Act) principle for continuous improvement on these initiatives.



Figure 54: Organisational structure for case studies

An organisational structure, as shown in Figure 54, was created with the business structural layout of the mining organisation. This structure, as described in section 1.2.5.3, will be used to organise the initiatives on the specific nodes of the business structure. This structure allows the performance monitoring of mines, individual shafts, and operations on a high level as well as comprehensive levels of detail.

For the organisational structure, three tree structures were created that will represent the structures of electricity, compressed air, and water systems. The created initiatives will then be linked to these tree structures where each systems' specific initiatives can be viewed.

Case study 1: Electricity

Deep-level mines use a large amount of electricity for the mining of minerals underground. The ore that is extracted must be processed to a finished platinum product. Smelters are used to process the ore that is extracted to a finished product. An energy-savings initiative was identified to operate the converters and blowers more efficiently to reduce electricity usage for the smelter.

Furnace molten matte sulfides are blown in a converter to the white metal stage and then later cast in moulds. Each converter contains multiple tuyeres, which are nozzles used to force air into the converter. The air that is forced through these tuyeres is supplied by blowers which use compressed air [70]. Each blower has its own motor that is responsible for creating air for blasting. These blower's motors consume a great quantity of electricity to operate, and thus the focus of this initiative is on the electricity consumption of the blowers.

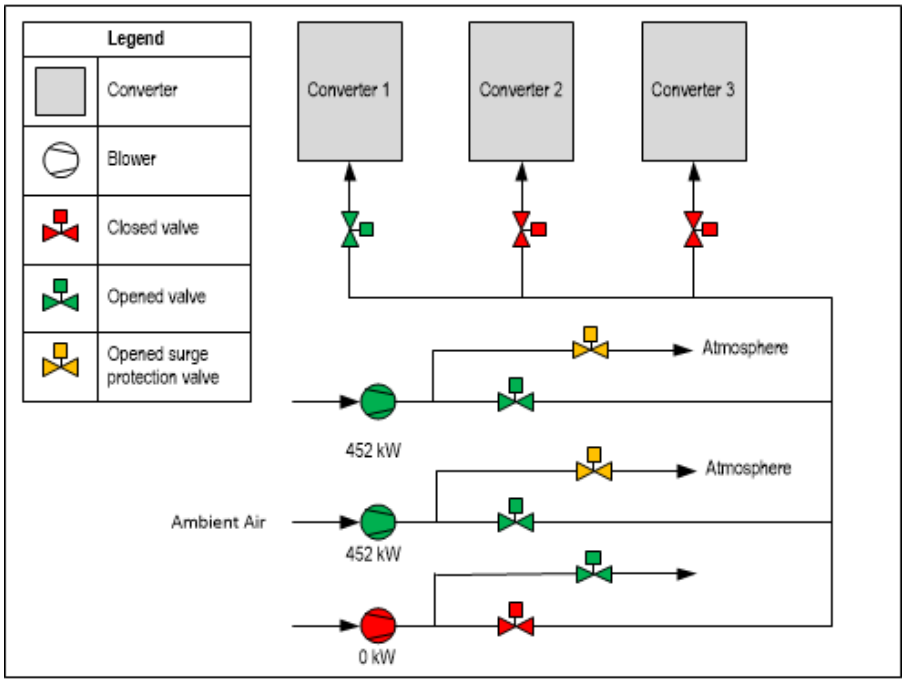


Figure 55: Schematic system layout one converter blowing

Three blowers are installed to supply air to the three converters, as illustrated in Figure 55. Under normal operation, two blowers are utilised to supply air to the converters. One converter is utilised 51% of the time and two converters simultaneously for only 9% of the time while two blowers are running. This means two blowers are running for 40% of the time while no converters are utilised. The utilisation percentages are displayed in Table 5 below.

Table 5: Converter utilisation

Current Operation: Two Blowers Continuously active		
1	Two Converters Blowing % Time	9%
2	One Converter Blowing % Time	51%
3	Zero Converters Blowing % Time	40%

The utilisation percentages in the table were calculated from the past 12 months' trend data captured on the smelter plant's SCADA system. In Figure 55, the typical operational conditions under normal operation when two blowers are running and one converter is blowing is shown.

For the optimised use of the blowers for the converters, only one blower is needed per converter. This means that the blowers can be operated according to the number of converters that are in stack. If the blowers are operated efficiently, the power usage of the blower can be drastically reduced by up to 50%.



Figure 56: Blowers power consumption initiative overview

An initiative was created using the PMSP, as seen in Figure 56, to monitor the performance and utilisation of the blower motor's power usage by using the PDCA principle. Figure 56 shows the annual performance of the created initiative on the PMSP. The power tags of the blower motors were linked with a baseline that was determined from the past 12 months of historical usage data. A proposed profile was also linked that was created with an optimised proposed power usage of the blowers according to the number of converters in stack.

The baseline was created with a historic normalised power usage of the blowers used for the converters. This baseline was developed and approved as described in Figure 28. For this specific initiative, an Eskom Megaflex tariff tag was linked, which is used to calculate the cost-saving using the performance of the actual power versus the baseline performance indicator.

The initiative was implemented on the PMSP with the approved baseline performance indicator.

Date:	< Mon., 1 July 2019 >
Cost saving:	R 15 808
Target:	R 13 500
Energy cost:	R 14 428
Average impact:	453.47 kW
Energy saving:	10.88 MWh
Energy usage:	10.05 MWh
Project type:	Energy efficiency
Project stage:	Performance assessment
Notes: ⓘ	
Condonable: ⓘ	

Figure 57: Daily performance summary of the blower motors electricity

Figure 57 shows the summary of the performance for the blower motor's electricity usage. The performance of the blower motor's initiative is determined on the cost-saving of electricity used. For the initiative, a cost target of R 13 500 for weekdays and a target of R 5 500 during weekend periods is set to determine if the performance is good or bad. The performance for this specific day indicates an average energy impact of 453 kW of power used to operate the blower. The power of the blowers was reduced by almost 50% by operating the blowers optimal to the number of converters in stack.

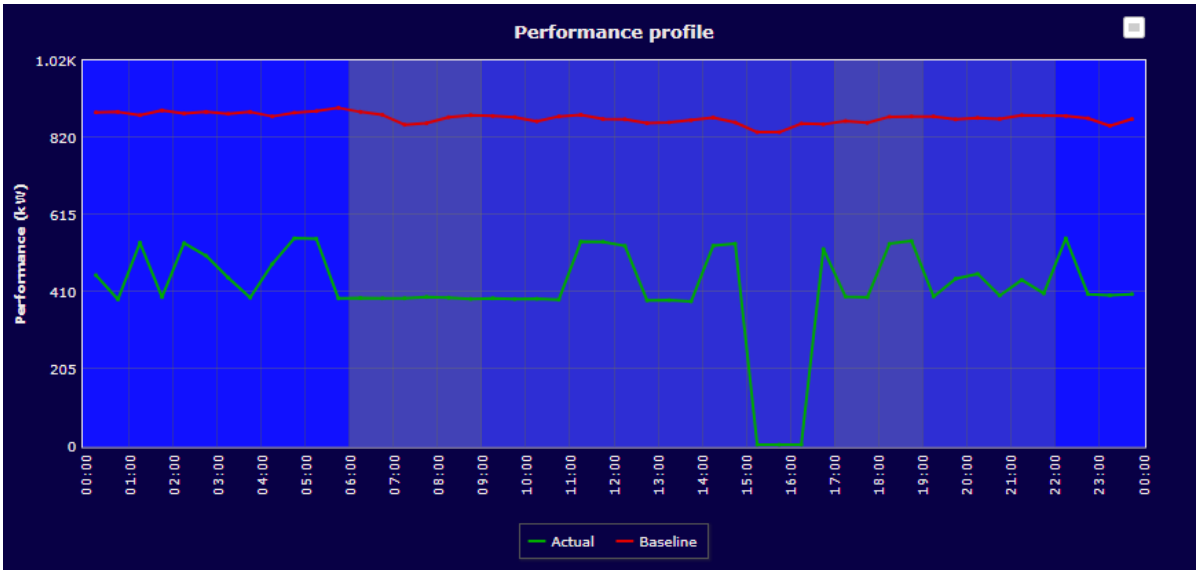


Figure 58: Daily electricity initiative performance profile graph

The actual power data, developed baseline, and tariffs used for the performance summary are visualised in Figure 58, where detail electricity usage of the blowers is plotted. From the actual power usage of the blowers, it can be seen where all the blowers were stopped while no converters were in stack. This was only done one time during the day, although there were more opportunities to save on electricity during peak time of use times, indicated by a highlighted plot background, when no converters were in stack.

After two weeks of performance assessment on the initiative, a proposed profile was developed for the operation of the blowers for the converters. This performance indicator was developed to show the optimal performance operation of the blowers and to show the cost-saving opportunities that were missed due to poor blower control by control room operators, as shown in Figure 59.

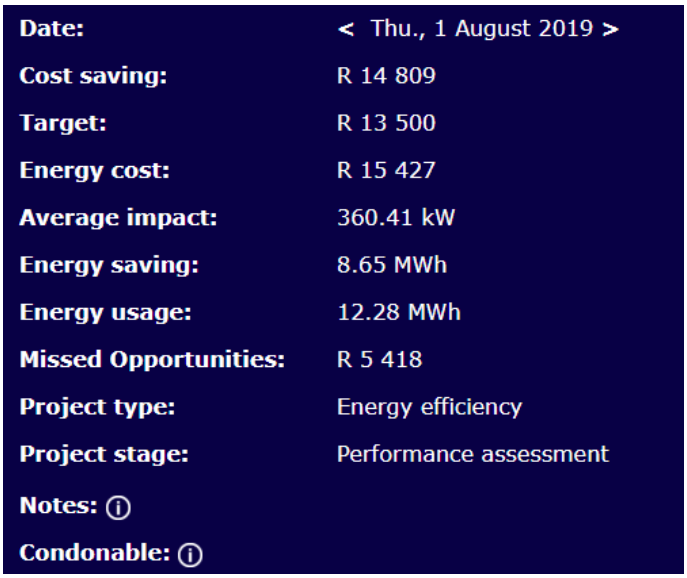


Figure 59: Daily performance after the proposed performance indicator implementation

The daily performance summary of the blowers' initiative will display the savings lost because of missed opportunities. The missed opportunities that are determined by the proposed profile versus the actual profile will only be displayed if there are missed opportunities.

In Figure 60, the implementation of the proposed profile can be seen. This proposed profile helps identify the poor operation of the blower motors or can show where the motors should have been operational but did not run, which can cause trips and converter blowing pressure problems.

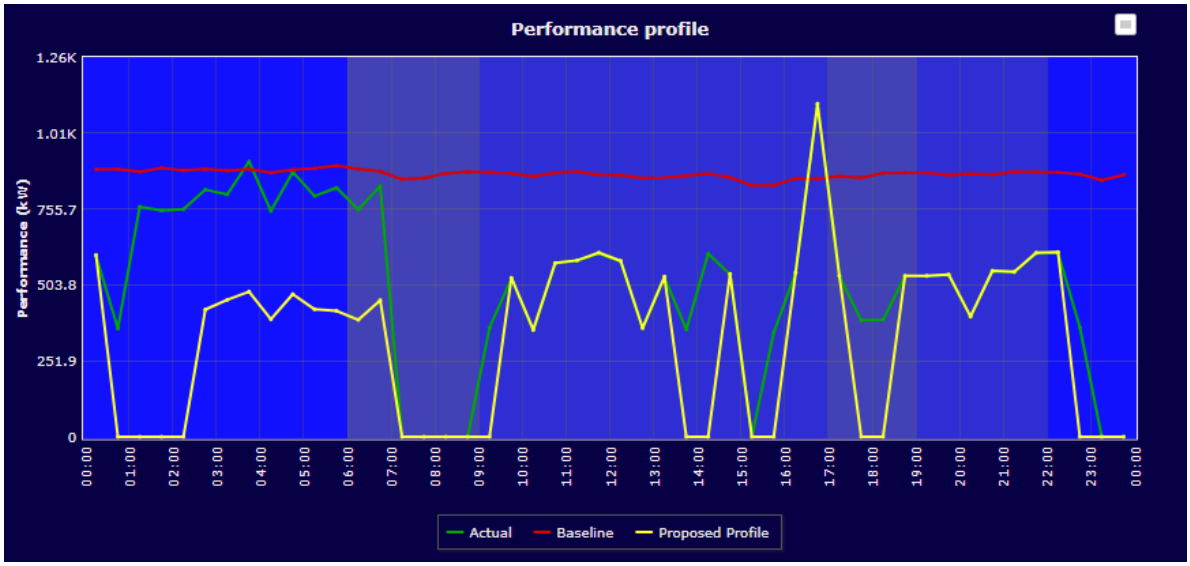


Figure 60: Daily electricity initiative performance profile graph all performance indicators

A detailed view of the tags can be monitored, as seen in Figure 61. This allows personnel to see which blowers were running during the day, helping develop a more optimal operation of the blower to avoid converter and blower trips as well as to minimise peak electricity hours' power usage.

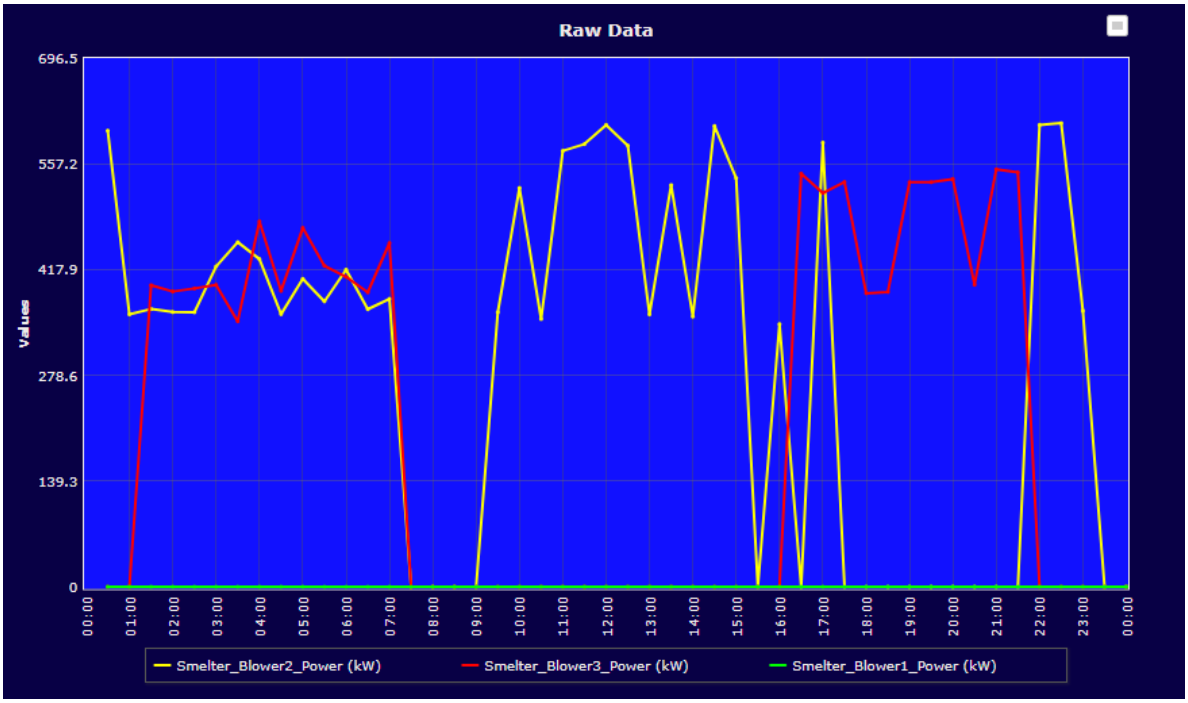


Figure 61: Detailed tag profile display for the blower motors

The preliminary results proved there is reduced power usage resulting in cost savings by only operating one converter blower and one converter at a given time.

An average cost saving of R 300 000 in winter months and R 180 000 can be achieved with optimal control. The estimated annual cost saving of R 2.1 million will be possible without any required project capital.

Case study 2: Compressed air

Deep-level mines utilise compressed air as a resource for equipment and tools for extracting ore as well as safety purposes such as refuge bays underground. Compressed air is an expensive resource, offering the potential for energy efficiency initiatives for cost-saving.



Figure 62: Compressed air implemented performance initiatives

Initiatives were configured to monitor the surface as well as the underground compressed air pressure and flow of each shaft. These initiatives, as shown in Figure 62, are used to monitor the performance of each shaft's compressed air usage performance. This allows engineers to carefully monitor the pressure and flow of each shaft on a high-level overview as well as detail performance data of each underground level.

The specific case study is on the compressed air ring system of a deep-level platinum mine. An opportunity was discovered where the compressed air pressure setpoints can be lowered, which will result in running fewer compressors on the compressed air ring, reducing electricity costs on compressed air production [10], [11].

Using the mining schedules indicated in the literature in Section 1.2.2, a new compressed air pressure demand control philosophy was developed. The new pressure setpoints were set in order to reduce the pressure of the shaft's compressed air to a minimum required pressure during inactive or low compressed air usage times [11].

Table 6: SCADA PLC profiles before and after changes

BEFORE CHANGE				AFTER CHANGE			
On-time	Off time	Value	Peak	On-time	Off time	Value	Peak
Profile 1: Week Days				Profile 1: Week Days			
12:00:01 AM	05:00:00 AM	600	FALSE	12:00:01 AM	03:00:00 AM	600	FALSE
05:00:01 AM	05:30:00 AM	600	TRUE	04:00:01 AM	05:30:00 AM	440	FALSE
05:30:01 AM	04:00:00 PM	600	TRUE	05:30:01 AM	02:30:00 PM	600	TRUE
04:00:01 PM	05:50:00 PM	500	FALSE	02:30:01 PM	06:00:00 PM	440	FALSE
05:50:01 PM	08:00:00 PM	520	TRUE	06:00:01 PM	08:00:00 PM	520	FALSE
08:00:01 PM	12:00:00 AM	600	TRUE	08:00:01 PM	12:00:00 PM	600	TRUE
Profile 2: Weekend				Profile 2: Weekend			
12:00:00 AM	02:00:00 AM	560	TRUE	12:00:00 AM	02:00:00 AM	560	FALSE
02:00:01 AM	04:30:00 AM	500	TRUE	02:00:01 AM	05:30:00 AM	440	FALSE
04:30:01 AM	05:30:00 AM	500	FALSE	05:30:01 AM	04:30:00 PM	600	TRUE
05:30:01 AM	04:30:00 PM	600	TRUE	04:30:01 PM	12:00:00 AM	520	FALSE
04:30:01 PM	12:00:00 AM	520	TRUE				
Profile 3: Sunday				Profile 3: Sunday			
12:00:00 AM	06:00:00 AM	520	FALSE	12:00:00 AM	04:00:00 AM	520	FALSE
06:00:01 PM	08:30:00 PM	440	FALSE	04:00:01 PM	08:30:00 PM	440	FALSE
08:30:01 PM	12:00:00 PM	600	FALSE	08:30:01 PM	12:00:00 PM	600	FALSE

Table 6 lists the shaft downstream pressure set points before and after changes. The value column displays the pressure setpoints of the bypass valve in KPa and the peak column shows the main compressed air valve open or closed status. A false value indicates that the main valve is closed and that the compressed air pressure of the shaft will be controlled by the bypass valve to the pressure set point as seen in the table.

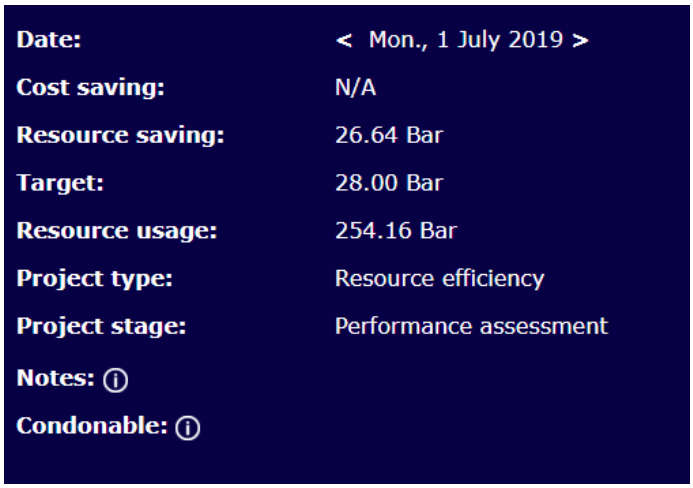


Figure 63: Shaft 1 pressure initiative performance summary

In Figure 63 and Figure 64, the setpoints that were set were monitored using the PMSP. A baseline of historical data was determined using the process of the performance indicator design process described in Section 2.3.2.3. After the new compressed air surface pressure set-points were set, a proposed profile was added to the initiative that represents the new set-points.



Figure 64: Shaft 1 daily pressure initiative performance profile graph

By monitoring the performance of the pressure measurement of the downstream pressure after the valves, it can be seen that the pressure is not controlled completely according to the set-points. After the identification of the pressure not controlled at peak energy-usage time from 17:00 to 19:00, queries were made and it was found that the main valve was switched into manual mode, resulting in the valve not closing and the bypass valve not regulating the pressure for the shaft. This resulted in the need for an extra compressor to be started in order to supply the required pressure that was not necessary. This affected the energy saving on the compressors and could have been avoided.

Not only was the pressure of the compressed air monitored, but the airflow of the shaft as well. An initiative was set up to monitor the performance of the underground levels on the shaft. All active underground levels using compressed air were monitored to gain deeper insight into the use of air during the day by each level. This initiative also monitors the total airflow of the shaft. This can be helpful to determine if there are compressed air leaks, problems, or increased production on certain levels of a mine. Increased compressed airflow can be directly correlated to production increases due to the increased use of tools and equipment utilising compressed air [11], [71].

As seen in Figure 62, an initiative was configured for the specific shafts underground airflow. A compressed airflow tag for all active underground levels was linked with the correct properties for the resource savings calculations.

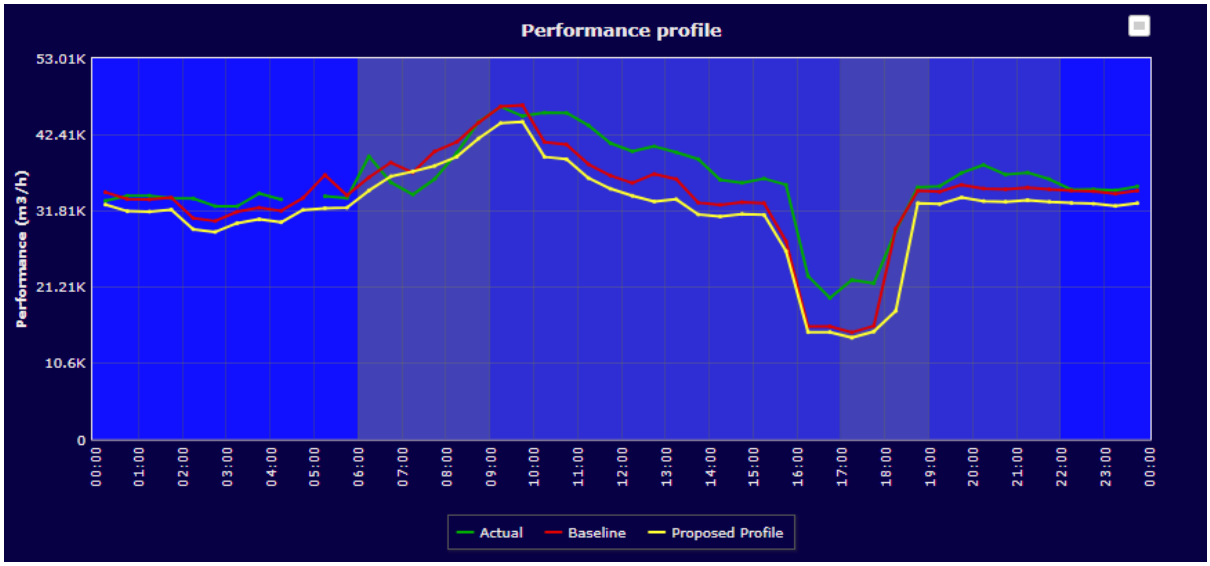


Figure 65: Compressed air-flow performance profile graph

The total airflow expected for the shaft was used as a baseline for the performance monitoring of the airflow and a proposed profile was developed that shows a more optimal airflow that may result in cost savings on compressor electricity. As seen in Figure 65, the daily airflow performance can be monitored and evaluated.

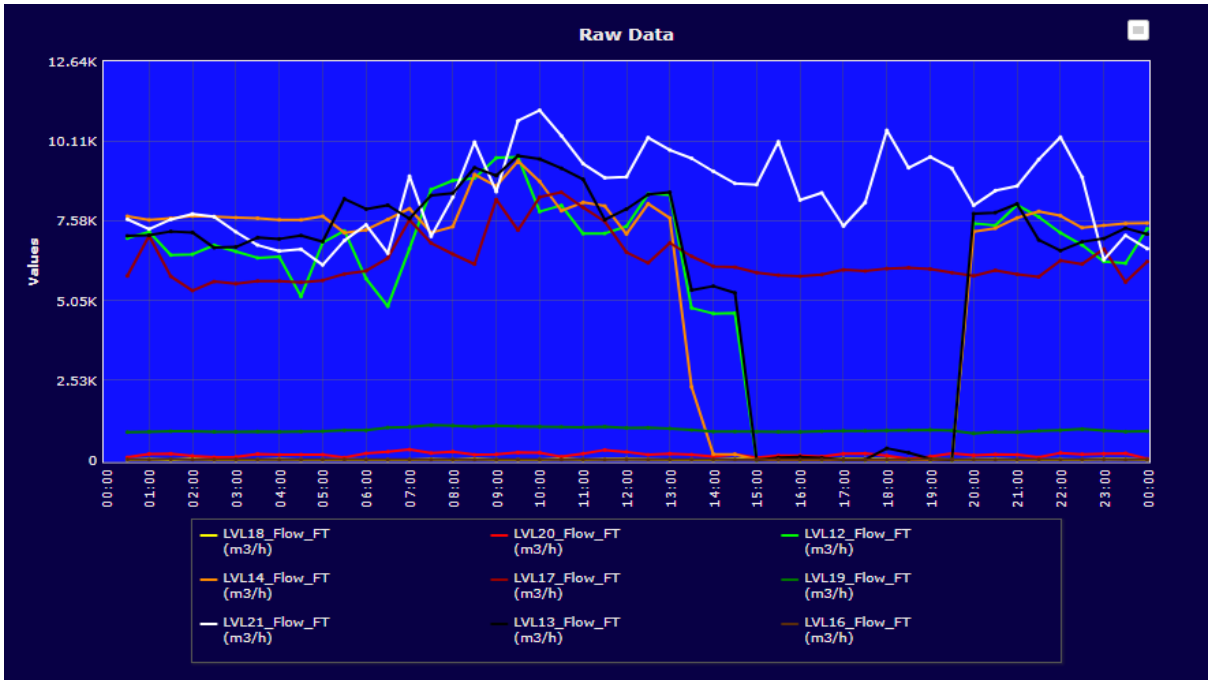


Figure 66: Raw data tag graph for the airflow of a shaft

By viewing the raw data tags as seen in Figure 66, problem levels can be identified. Levels using more air during inactive periods can be due to leaks on the compressed air network, indicating possible opportunities to fix problems that may have cost implications.

In the example shown in Figure 66, it can be seen that levels 17 and 21 have airflow during blasting shift when no compressed air is needed. It was later discovered that the compressed air shut-off valve for these levels was not closing properly. This was reported to mine personnel after which the valves were fixed, and the valves subsequently operated correctly as they should.

By monitoring the compressed air pressure and airflow on a high as well as detailed level, the compressed air systems can be optimised for energy efficiency and used to detect possible leaks in pipes and valves that lead to the discovery of new initiatives that can lead to cost savings for a mine.

By monitoring the energy usage of the compressors, a performance monitoring initiative for energy cost-saving was configured to quantify the compressor optimisation. By linking the applicable Eskom electricity tariff and a developed baseline, the cost saving of compressed air initiatives can be monitored, as seen in Figure 67.

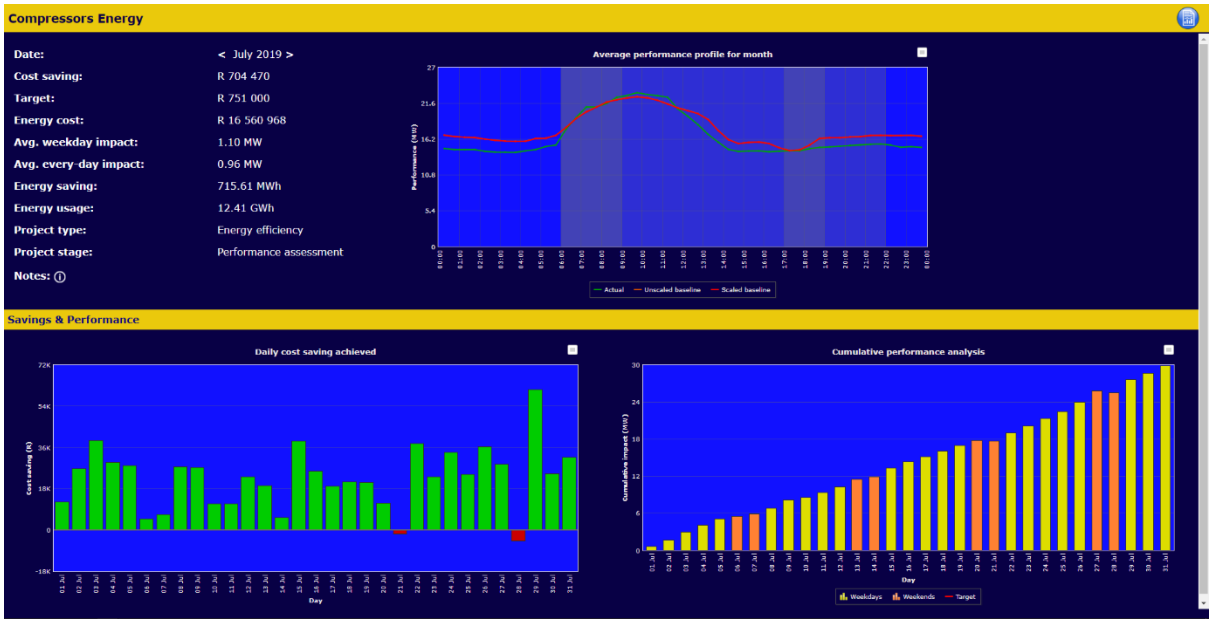


Figure 67: Monthly compressor energy savings

As less pressure and flow is required during specific times of the day, large energy-consuming compressors can be stopped and smaller, more energy-intensive compressors can be used to supply compressed air. This means less energy is used to supply shafts with compressed air and results in cost savings.

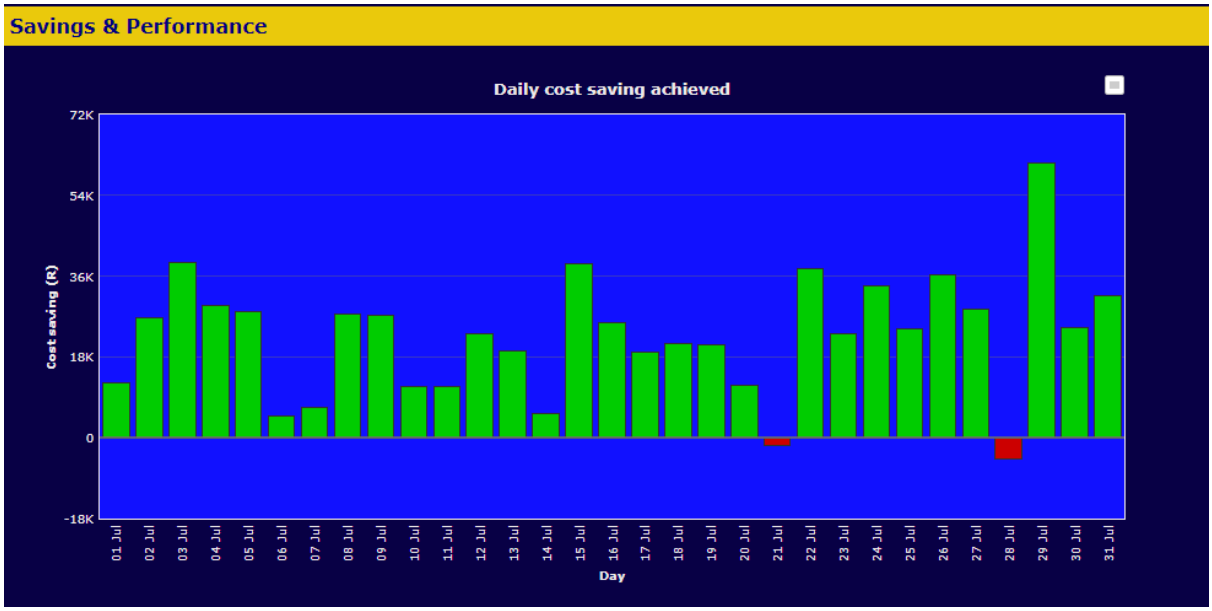


Figure 68: Daily cost savings achieved

In Figure 67 and Figure 68, it can be seen by optimising compressed air networks that supply compressed air to shafts and many other operations, energy and operational costs are improved. For this specific compressed air network, an average of R 22 700 per day, R 700 000 per month, and an estimated R 6.5 million per annum can be saved on compressed air production.

Case study 3: Water

Deep-level mines utilise water for many different systems on the surface as well as underground, as discussed in the literature. In order to save water on mines due to water scarcity in South Africa, water is recycled. Service water that is supplied from the surface to cascading underground dams is recycled and pumped back from hot water dams to surface dams, where water is filtered and cooled before being sent back underground. Not all the water that is used for underground operations can be recovered and recycled.

An initiative was created that monitors the amount of water that is being used by a shaft. The focus of the initiative is to reduce water wastage by closing the underground level's water supply during inactive periods. By reducing water wastage during inactive periods, water costs of the shaft can be reduced. Not only can water cost be reduced, but the cost of energy required to pump water from and to surface and underground dams will be reduced as well. This results in reduced energy cost by switching off the pumps during peak tariff hours.

As with the previous case studies, an initiative was configured on the PMSP to monitor the water that is being used by each underground level. The performance that will be monitored

with this initiative is the amount of water being used during inactive periods such as Sundays and blasting shifts. This initiative was implemented using the PDCA principle to ensure continuous development.

By following the methods on creating performance indicators for initiatives, a water usage baseline and proposed profile was developed to measure the performance of the initiative. Tags of each underground level water flow were linked to the initiative. The baseline was created using the surface flow of water that is sent underground. The performance of the total underground levels is then measured against the baseline to determine the water that is being saved.

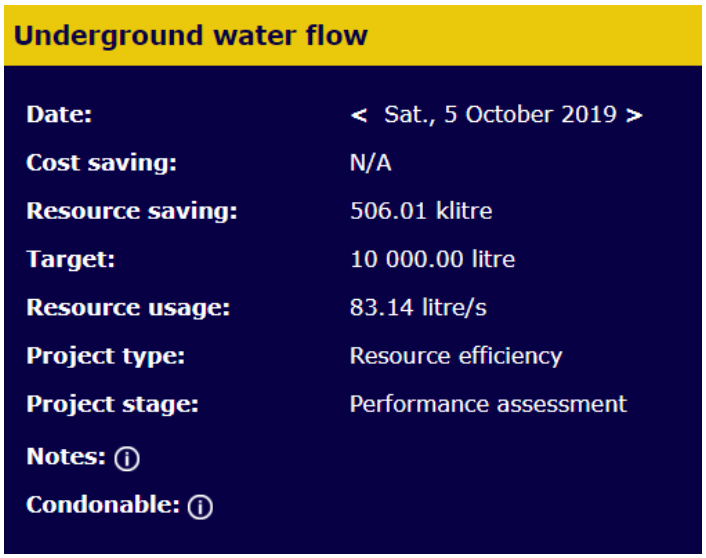


Figure 69: Saturday performance before implementation

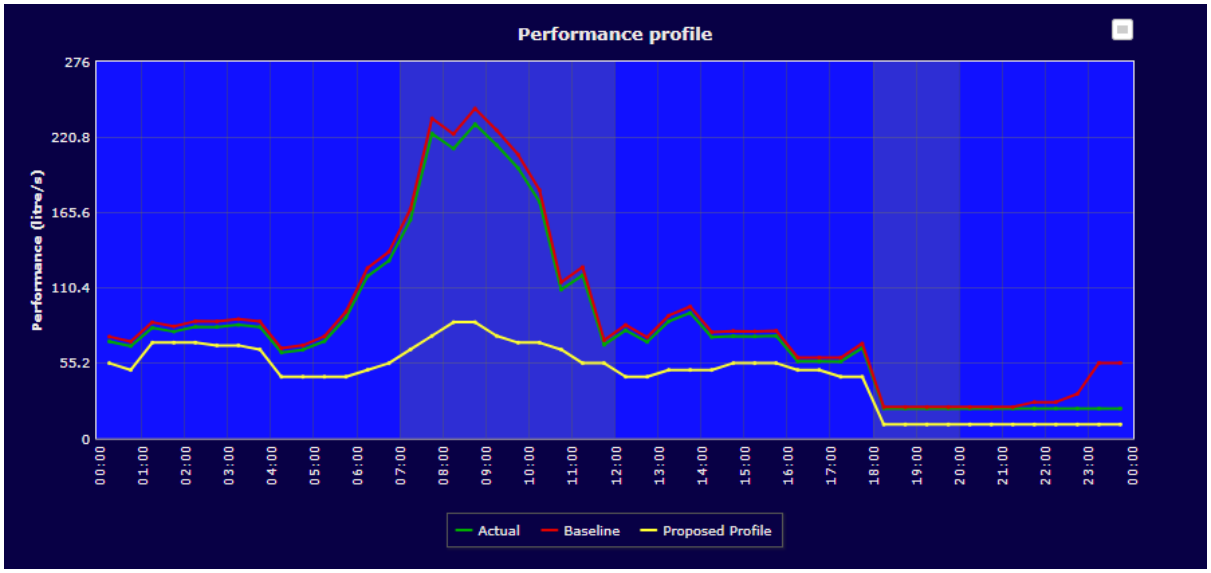


Figure 70: Saturday performance water profile before implementation

The objective of the initiative is to reduce water usage and wastage during weekend periods. Each level has a water valve that can be controlled according to a SCADA schedule. As seen in Figure 69 and Figure 70, the performance profile and water usage are shown before implementation. The goal is to reduce the weekend water usage to half of the current usage.

For the implementation of the initiative, each level will be controlled to restrict water to a minimum on a Sunday and to reduce the amount of water wasted on Saturday's. After the last shift on a Saturday, water is reduced to only supply minimal drinking water to underground workers. The water usage should be according to the proposed profile that was created.

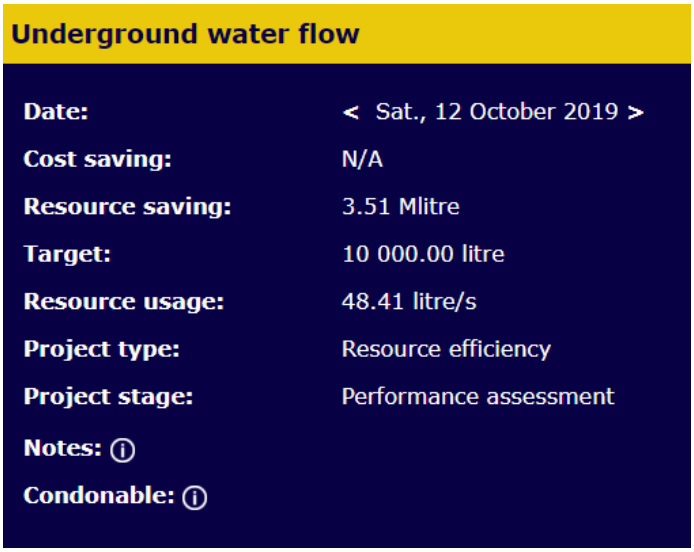


Figure 71: Saturday performance after implementation

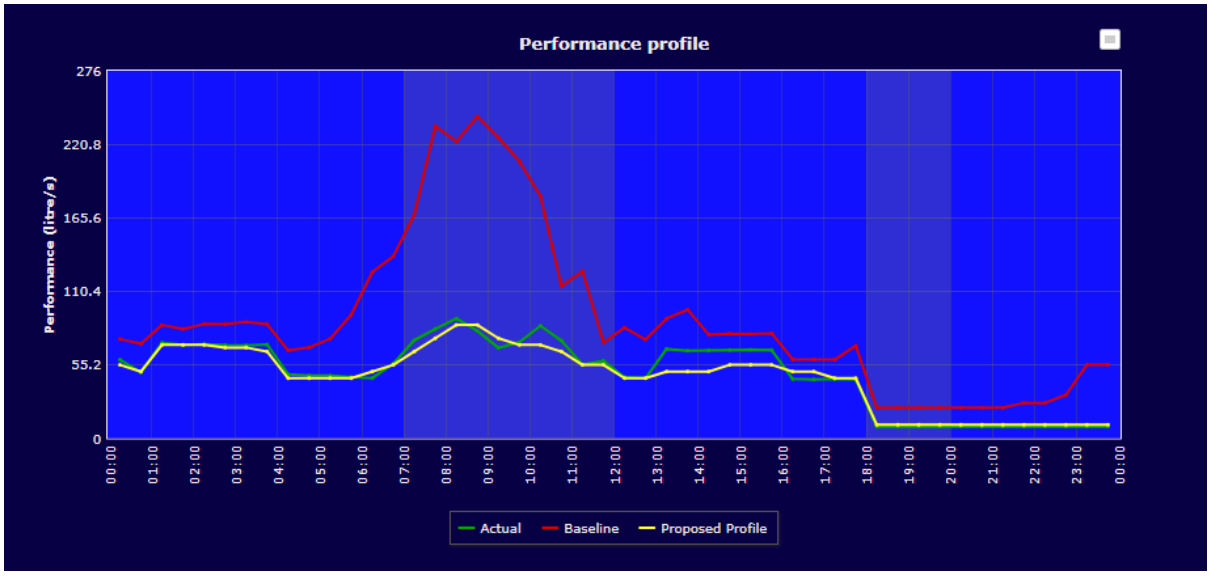


Figure 72: Saturday performance water profile after implementation

After the implementation of underground water valve control during weekends, the average usage on a Saturday was reduced by almost 42%, as seen in the performance summary shown in Figure 71. In Figure 72 it can be seen that the water flow was drastically reduced, and is controlled according to the proposed water flow that is expected.

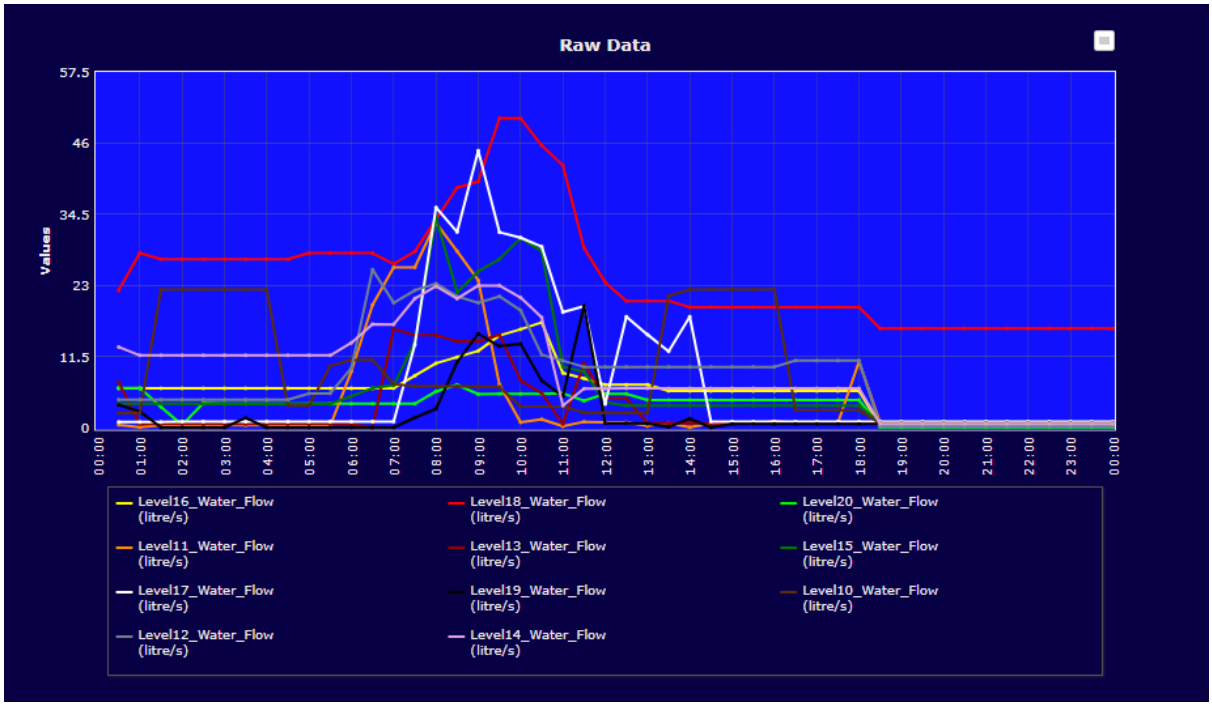


Figure 73: Saturday water flow detailed tag data

By monitoring each level as in Figure 73, possible water leaks as well as faulty valves can be identified by observing the flow of each level. From the detail tag data shown in Figure 73, it can be seen that the water valve on level 18 does not close completely. This can be due to faulty calibration, incorrect control, or a faulty valve. After investigation it was discovered that the valve is faulty and needs to be replaced.

By reducing the water that is used underground, the energy required to pump water is reduced. This is due to the amount of water that is pumped back to the surface to be recycled. Not only is energy consumption reduced for the water reticulation system, but water consumption as well.

Summary

From the three case studies that are presented, it can be seen that the generic PMSP is able to monitor the performance of many different deep-level mining systems with various types of data. The three case studies presented the monitoring of electricity, compressed air flow and pressure as well as the water flow of mining systems at shafts and a smelter.

3.3 Validation

This section aims to validate the objectives that were set in Section 1.4 A survey was conducted from 12 ESCo users of the platform to gather information on the user interface, platform usability, scalability, time management, and decision-making improvements by using the PMSP (Performance Monitoring Software Platform.)

3.3.1 Software platform and user interface

Objectives:

- To create a software platform that can be used to monitor the performance of implemented, maintenance, and performance assessment project for engineers and the mine personnel.
- To create a platform that is capable of using large quantities of data to give a simplified overview of multiple systems and projects.
- To reduce the cognitive load of platform users.

In Section 2.4 the designed platform was implemented to conform to the requirements that were set for the PMSP. These requirements were set according to the needs and objectives that need to be addressed for the platform to enable performance monitoring.

Through implementation, a software platform was created that enabled users to create initiatives that can be configured with specific deep-level mining system data tags, performance indicators, and performance monitoring properties for the type of monitoring that is required.

Once an initiative for a deep-level mining system was created, the performance can be monitored on the ESCo's in-house energy management system (EMS). By using the performance monitoring that was implemented on the EMS, the performance of multiple deep-level mining systems' initiatives of many different organisations could be monitored on a simple overview.

The cognitive load on users is reduced by the implemented multi-level organisational navigation using tree structures to organise initiatives on business structures as discussed and illustrated in Figure 54. Using tree structure navigation, the performance of initiatives on many different levels of an organisation can be monitored. As described in the design of the platform, colours are used to indicate the status of the performance to help reduce the load on the working memory of a user. The colour indication of the performance reduces cognitive

load by drawing the user's attention to initiatives with good or poor performance. This reduces the mental effort for analysing the status of initiatives and on which initiatives attention is needed to improve performance.

Multiple initiatives were created by personnel using the platform for performance monitoring. The number of initiatives that were created using the platform are shown in the tables below and illustrated in Figure 79.

Table 7: Data summary for operations of an organisation

Organisation	
Parameter	**Count**
Operations	3
Systems	13
Initiatives	105
Data tags	315
Data points	15120

Table 8: Data summary per systems initiatives

Average per system	
Parameter	**Count**
Initiatives	8.1
Data tags	24.2
Data points	3486.2

In Table 7 and Table 8, a summary of the energy systems' performance monitoring parameters per day are shown to indicate that the scalability and overview colour indication can simplify the visualisation of large amounts of data that reduces cognitive load. The figures that are shown in the summary table indicate the amount of data that can be rolled-up to condense Big data that needs to be organised and monitored by a single user.

3.3.2 Data and information

Objectives:

- To enable personnel to make informed decisions on the efficiency of mining systems.
- To reduce the cognitive load of platform users.
- To reduced data analysis and performance monitoring time of deep-level mining systems.

As seen in the implementation of the PMSP in Section 2.4.1, initiatives can be configured to monitor certain data of any deep-level mining system. By configuring an initiative for performance monitoring, the time spent structuring, analysing, and visualising data is significantly reduced.

From the literature in Section 1.2.6, it was found that there are existing platforms that allow the monitoring of energy systems. These platforms do address some of the needs to improve the time spent on structuring, analysing and visualising data. However, these platforms only allow the monitoring of energy-related data and are not generic enough to incorporate the monitoring of many different systems that may be found on deep-level mines.

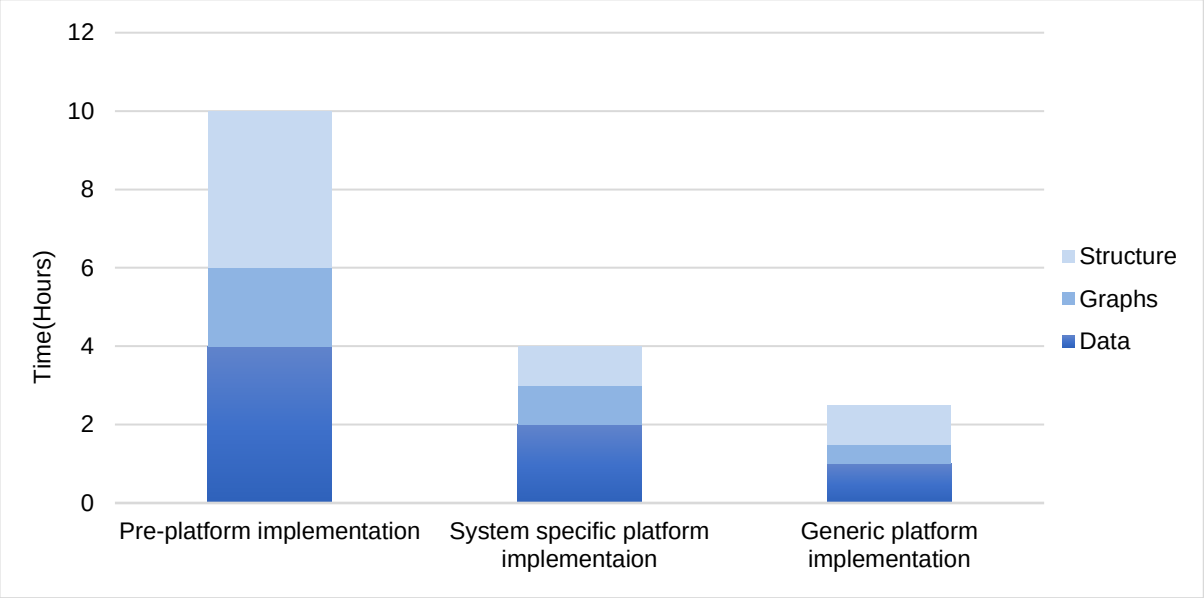


Figure 74: Average time spent per system

In Figure 74, the average time spent to structure, analyse, and visualise data is shown. This is the average time spent to monitor the performance of a deep-level mining system.

On average, personnel and users spent 10 hours to collect, structure, and analyse data. This structuring involves sorting data to make it easier to be used for analysis. Once the data is structured and sorted, the data can be used for analysis. The analysis usually consists of graphing data in order to visualise the data. With the visualisation of the data, problems and trends can be identified.

With the system-specific implementation of the platform, data collection and structuring were improved. Data were graphed and visualised on the platform. After generic data implementation of the platform, it can be seen that data structuring and analysis time was

reduced to 3 hours, which results in a 70% workforce resource-saving, allowing personnel to view detail as well as high-level overviews of data to help with decision making.

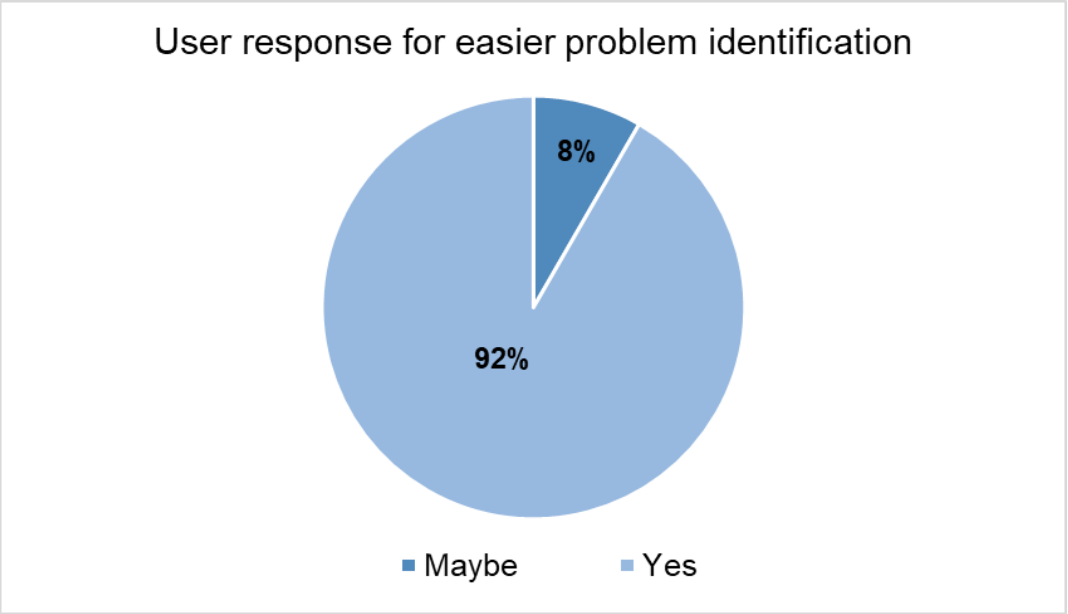


Figure 75: Big data analysis by PMSP users

These average hours spent to monitor the performance are verified by the survey from users of the PMSP. From the survey, shown in Figure 74, it was seen that the time spent to monitor the performance of a deep-level mine system was reduced, which also helps with the monitoring of multiple systems.

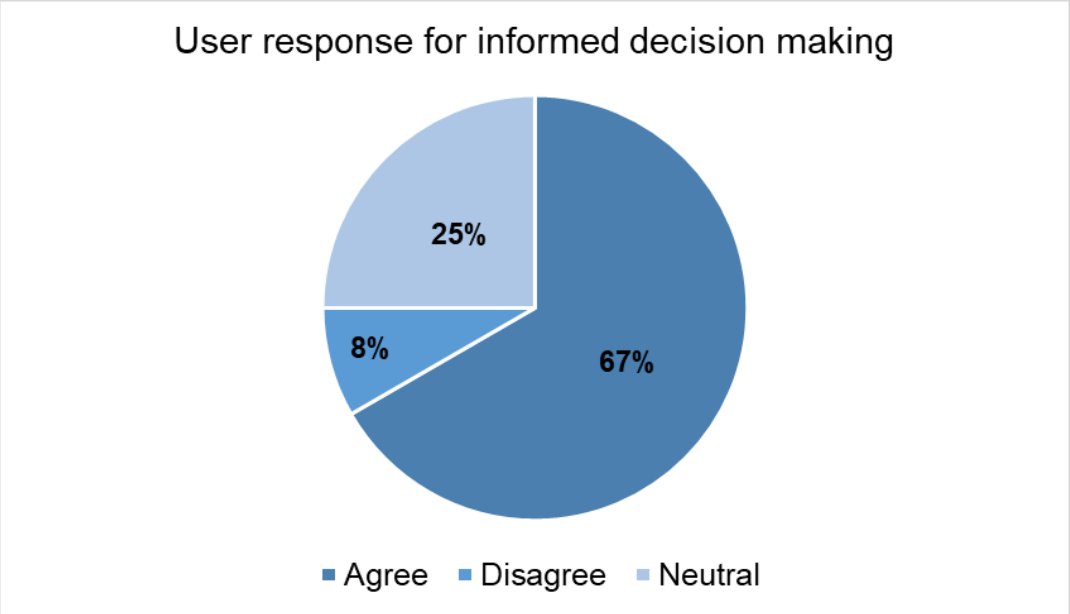


Figure 76: PMSP cognitive load reduced decision-making survey results

Figure 75 shows the responses from users of the PMSP. 92% of users agree that the PMSP helps to easily analyse and monitor the performance data of deep-level mining systems. This is due to the high-level overviews of the platforms that allow easy and quick access to information which can help in decision making.

From the survey results, as seen in Figure 76, users agree that the PMSP help with the decision making by presenting a cognitive reducing high-level performance overview of the initiatives. In order for engineers to make an informed decision of these monitored initiatives, the data must be reliable and accurate.

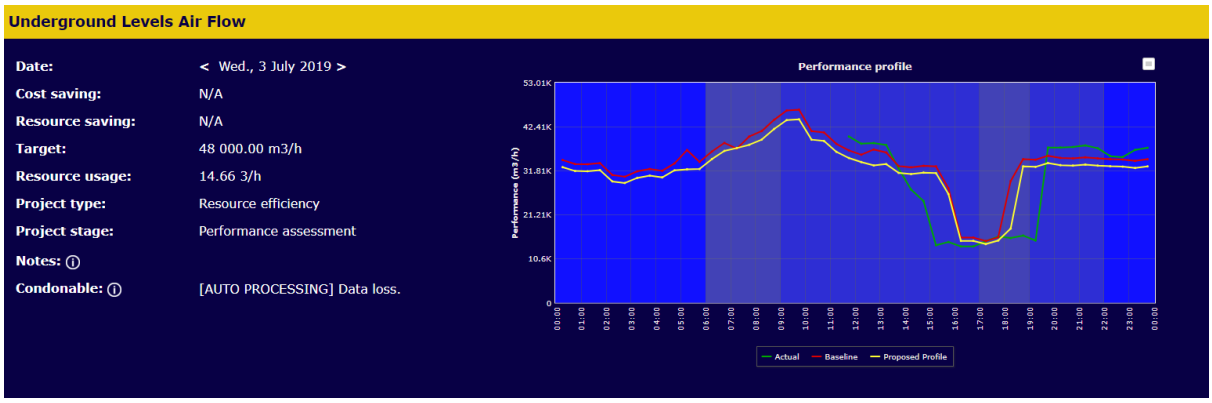


Figure 77: Detail performance profile overview with data-loss from site

The PMSP checks the continuity of data to prevent personnel from making decisions on data that is not accurate and does not indicate the correct performance of the system or initiative.

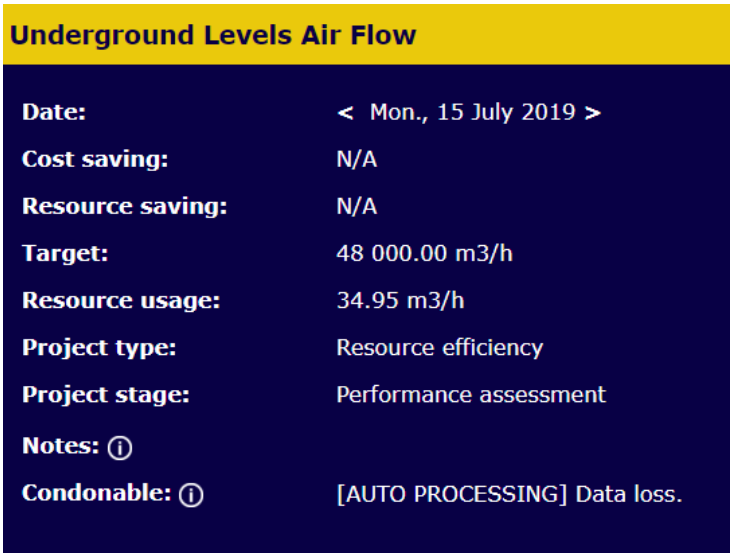


Figure 78: PMSP data verification

As can be seen in Figure 77 and Figure 78, the data that is verified for the performance of an initiative where the actual data, that has data loss, can be seen.

Due to the data loss, the PMSP automatically marks the day as a condonable day and is not considered for the total and monthly performance of an initiative. Because of the data loss from the site data, no resource savings or performance is calculated. If the missing data can be collected, the data can be manually uploaded to the PMSP using the DBMS, and the initiative can be reprocessed for the specific missing data period.

3.3.3 Scalability

Objectives:

- To create a platform that is capable of using large quantities of data to give a simplified overview of multiple systems and projects.
- To create a scalable platform that can be used for multiple deep-level mine systems**.**
- To enable personnel to make informed decisions on the efficiency of mining systems.

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The implemented PMSP was designed to provide a high-level overview of several initiatives that can be viewed by engineers, managers, and mine personnel. As discussed in the literature and implemented in the design of the PMSP, a scalable tree structure can be created that is able to represent the business structure of a mining organisation.

Figure 79 illustrates a high-level overview of many initiatives. In this example, a total of 105 initiatives were configured to monitor the performance of many systems on several shafts of

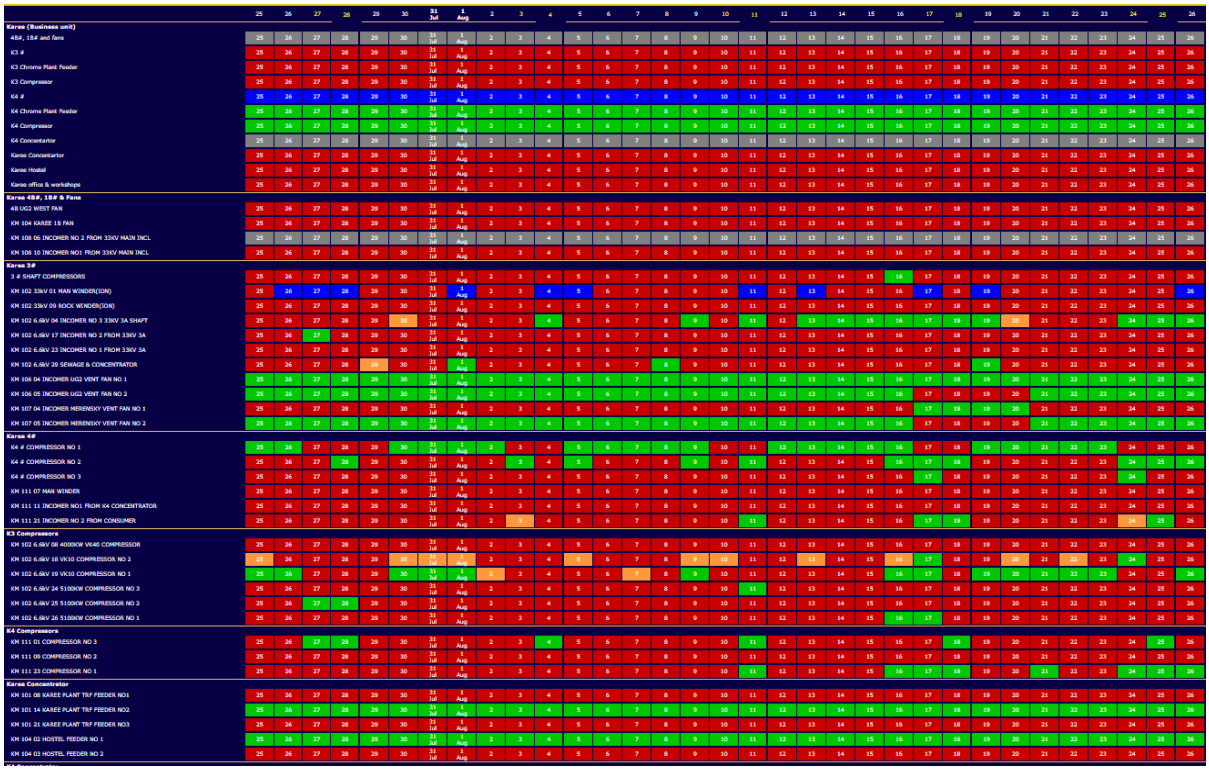


Figure 79: High-level scalable overview of deep-level mine initiatives

the mining organisation. As seen in Figure 79, initiatives can be linked to the nodes in these trees that represent the business structure which helps organise initiatives on lower detailed levels. Figure 79 illustrates the high-level overview of all the initiatives that are linked to nodes that are child nodes to the root node.

The root node is seen as the top of the organisation, where child node initiatives can be viewed by selecting the node which will load only the relevant child node initiatives of the selected node, as seen in Figure 80.



Figure 80: High-level overview of shaft specific initiatives

This scalability allows the roll-up of Big data from the bottom of the business tree structure to the top level of the organisation, where the performance of individual business units of the organisation can be viewed.

From the survey that was conducted on the PMSP, it was discovered that users prefered to analyse simple Big data tags on the PMSP compared to other platforms. The survey respondents were asked to list the software platforms used by engineers at the ESCo to analyse data of deep-level mining systems.

From the responses, indicated in Figure 81, it can be seen that all of the respondents have made use of industry-leading software, such as Microsoft Excel, for quick and easy analysis of data. Some respondents have made use of code-based software platforms such as scripts and database management software to analyse large amounts of data, requiring a certain amount of technical skill to make use of the capabilities of these platforms.

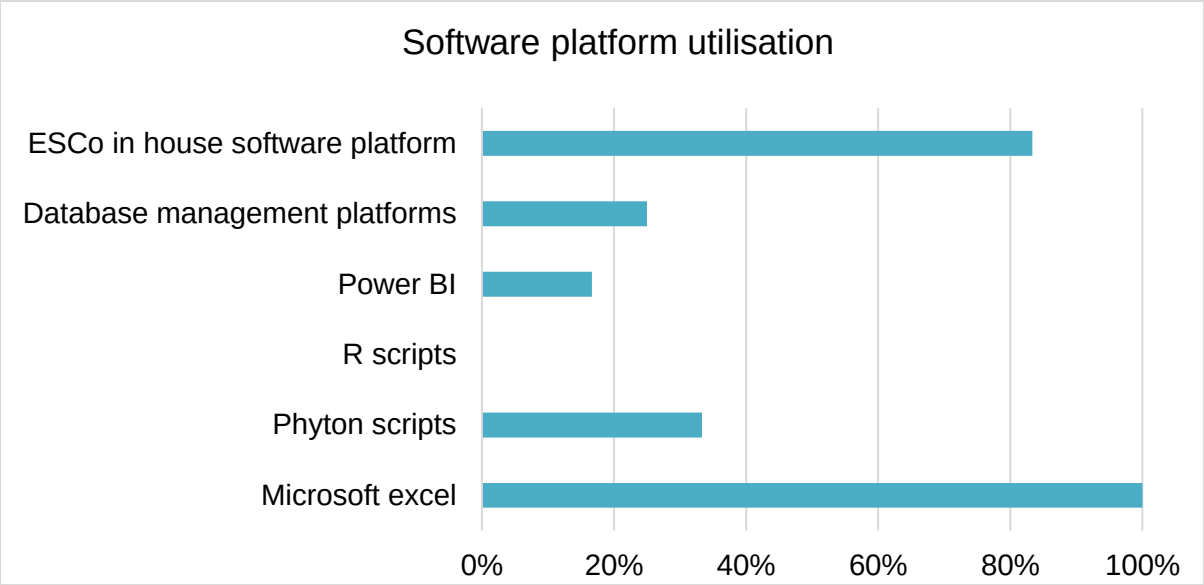


Figure 81: Survey software platforms used form data analysis

Although all of the respondents used Microsoft Excel to analyse data, 83.3% of the respondents also used the PMSP to analyse deep-level mining systems. The PMSP allows for fast access to large amounts of data that is already processed and displayed in an easily accessible manner to make easy and fast informed decisions on initiatives.

Figure 82 shows that 75% of users of the PMSP have the need to analyse and make informed decisions on a regular basis based on a large amount of data from mining systems. Although all users make use of mainstream software to analyse data, the survey concluded that the PMSP is used to analyse large amounts of data, helping personnel with mining system problem identification.

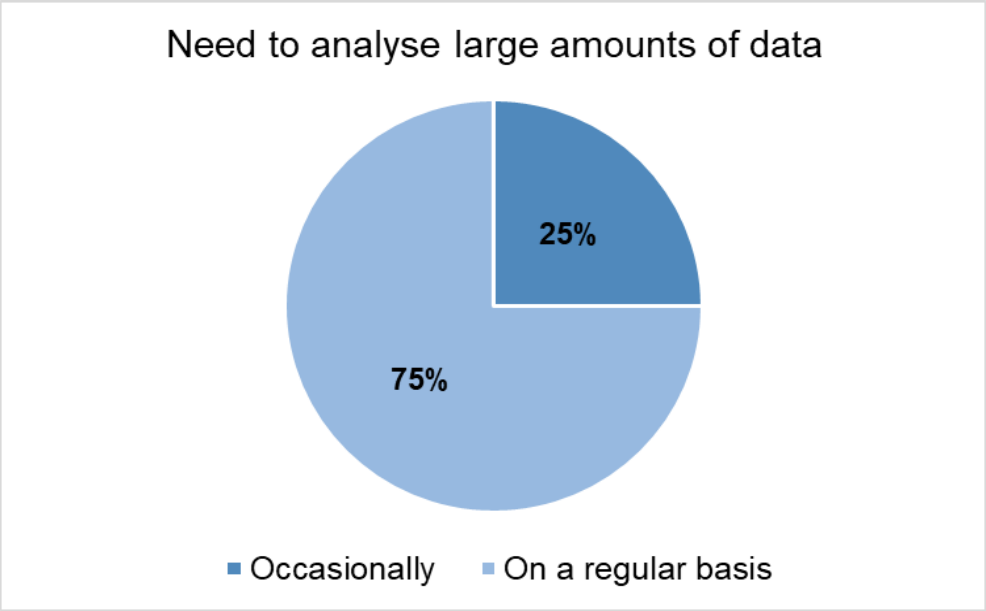


Figure 82: Response on data analysis

Users were asked if the PMSP presented a high-level overview of multiple initiatives and if the data of initiatives makes monitoring the performance of initiatives and mining systems easier, helping to reduce the cognitive load on the user of the platform by using a simple interface to display the performance of an initiative.

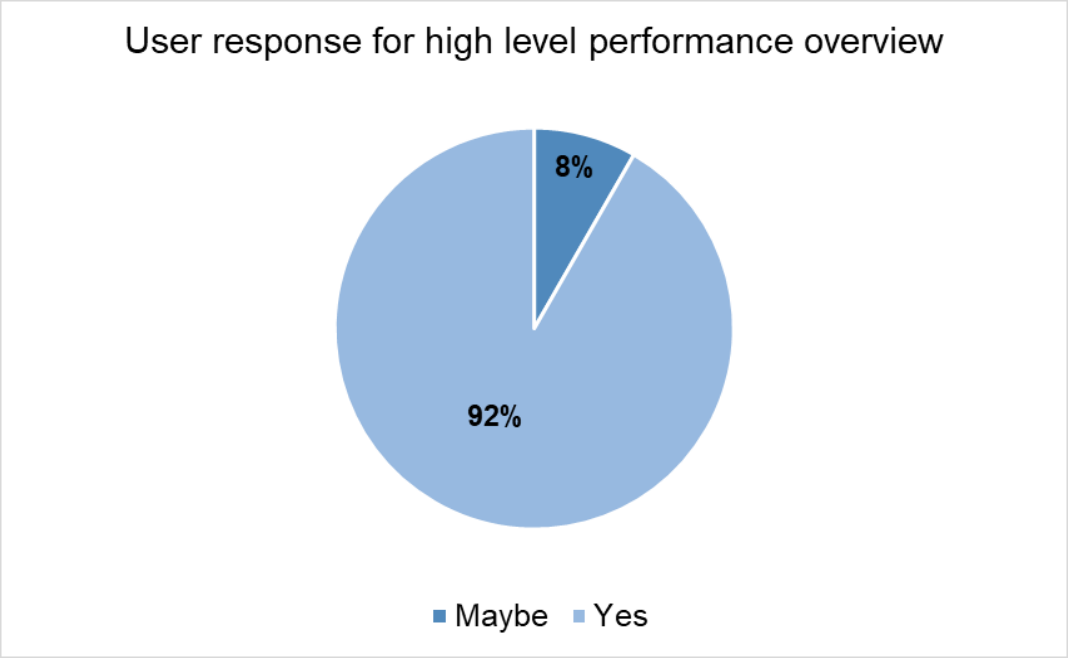


Figure 83: PMSP scalability and high-level overview survey responses

From the survey that was conducted, it was found that the PMSP helped present a high-level performance overview that is scalable to many deep-level mining systems of an organisation. This helps reduce the strain on working memory by reducing the cognitive load while using the platform to monitor multiple initiatives.

3.4 Summary

From the case studies that were implemented on the generic performance monitoring software platform, it can be seen that the platform is capable of presenting the performance of multiple types of data deep-level mining system initiatives on many different levels of an organisational structure.

By monitoring the performance of deep-level mining systems, energy efficiency and operational costs of a mining organisation can be improved. This cost-saving on operational systems such as compressed air helps with the profitability of a mine. From the case studies presented, simple deep-level mining systems can be monitored and operated more efficiently that can result in cost savings of R 8.6 million per annum.

The PMSP can be used to monitor the performance of many different deep-level mining systems by giving a platform-user a cognitive load-reduced user interface that will help a user to make a quick decision on the status of initiatives, whereupon an initiative can be viewed in detail to identify possible problems on a deep-level mining system.

All the study objectives were achieved by the implementation of the PMSP (Performance Monitoring Software Platform) and is validated by personnel using the platform to monitor the performance of deep-level mining systems.

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS



Anglo American Platinum Tumela mine (Source: www.angloamericanplatinum.com)

4 Conclusion and recommendations

4.1 Conclusion

The main objective of the study was to create a software platform that will enable engineers to monitor the performance of multiple different deep-level mining systems for a mining organisation. The generic software platform for the performance monitoring of deep-level mining systems originated from the need to monitor the resources and resource savings' initiatives that are implemented by an ESCo to help save mining organisations on electricity costs to improve profit margins.

Deep-level mines have many energy-intensive systems of which the performance needs to be monitored in order to improve the efficiency of these systems. Monitoring and evaluation of performance aids in decision making to minimise potential risks and problems that may have a financial impact. As Peter Drucker said, "If you cannot measure it, you cannot manage it" [35]. This is important for the continuous improvement of the efficiency of deep-level mines.

Most systems on a deep-level mine have measurement equipment that collects data that is used for the control and management of mining systems. The data of the measurement equipment is stored and can be used for various applications. The data is stored in a central database where it can be obtained for analysis. Large amounts of data are stored for these systems and are not easily processed and analysed.

Many platforms exist that are capable of using these large amounts of data. The existing systems utilise the data to present some form of monitoring that helps engineers and management to make decisions regarding the performance of mines. Not all of the existing platforms are able to use all the types of data that are received from mining sites. Most platforms only present the data received from mines in a reporting format on high-level organisational levels.

A generic software platform was created on an ESCo's in-house web-based EMS platform that was designed and implemented to address the needs and objectives of the study. The main objective of the study was to create a platform that can monitor the performance of most deep-level mining systems by using large amounts of data to analyse and calculate the performance of systems according to actual tag data and performance indicators calculated by engineers. The platform will reduce the time spent analysing, structuring, and evaluating data to enable an engineer to make informed decisions on initiatives.

Deep-level mining system tag data can be used to monitor the performance of a system and can be configured as an initiative using the ESCo's database management platform and be monitored on the EMS. By using the ISO 50001 standard and IPMVP protocol, initiatives were created with baselines and proposed usage profiles that are used to determine the performance and status of an initiative. Once an initiative has been configured and linked to a tree structure representing an organisational structure, the performance status can be viewed on the ESCO's EMS platform.

The platform presents a simplified overview of large amounts of data which will enable quick data analysis and decision making in order for engineers to identify problems as well as improve deep-level mining systems. Multiple different deep-level mining systems can be created and linked to different levels of a mining organisation. This helps with the organisation and easy navigation of initiatives by platform users to make the platform more user-friendly. Not only do data tree structures help with the organisation of data, initiatives, and organisational structure representation, but they help to reduce the cognitive strain on a user by presenting data in a high-level organised view.

From the case studies that were presented, it was seen that the PMSP was a generic platform that can be used to monitor the performance of many different types of deep-level mining systems, each with its own unique set of unique data and properties that define how the performance of an ESCo initiative is determined. By using the performance monitoring platform, engineers were able to monitor the day-to-day performance of implemented initiatives for cost-saving and helped identify critical as well as potential problems that may affect the performance of the specific mining system.

By monitoring the performance of mining systems and improving the efficiency of these systems, a combined estimated cost saving of R 8.6 million per annum is achievable for the case studies presented. A total of more 105 initiatives for deep-level mining systems' performance monitoring were configured. The performance monitoring software platform enabled personnel to reduce system data analysis time by 70%.

The generic software platform for the performance monitoring of deep-level mining systems achieved all of the objectives that were set for the study. The platform helped engineers monitor the performance of many different systems to improve the efficiency of these systems to improve the profit margins for the mining industry in South Africa. The generic platform proves that software platforms can be used in Industry 4.0 by using large amounts of data that define systems to determine the performance of a system, identify problems, and improve efficiency.

4.2 Recommendations for future work

With the Industry 4.0 movement, data and information are an important aspect that can help with the monitoring of complex systems. Currently, the system is able to monitor the performance of many different types of mining systems, each with its own unique data. The PMSP can, however, not be configured for initiatives to supply more information on initiatives that can help identify problems.

The platform can be expanded to accommodate more types of tags for initiatives that can be used for different types of performance indicators. Currently only baselines and proposed profiles can be linked to an initiative to compare the actual tag data to.

A pro-active warning system can be added to the initiatives to notify engineers and relevant personnel that resource usage is above or below a threshold as described and implemented by van Blerk on a condition monitoring system [48]. This can warn engineers that there is a critical problem on a system.

Currently the system allows the generation of daily and monthly performance reports for each system which is used to communicate the performance to clients and personnel. The reports are generated according to a template and cannot be altered. For future features, customisable reports for deep-level mining systems can be implemented to allow engineers to set what data, as well as how the data is presented, to be configured. The platform can also be configured to send these generated reports automatically to engineers and the client.

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Appendix A: Complete database design



Appendix B: Survey information

Survey details	
Population	26
Sample size	12
Respondents qualifications	Engineering
Average respondents years experience in engineering	3
Survey administration	Electronic online forms

Number	**Question**
1	How often do you need to analyse large amounts of data?
2	Do you monitor the performance of on-going projects, initiatives or systems?
3	Which software platforms do you normally use when analysing data?
4	Have you used the efficiency initiatives platform?
5	Have you configured an initiative on the platform?
6	Have you used the platform to monitor the performance of initiatives?
7	Does the performance monitoring platform present a high-level overview of multiple initiatives, making monitoring of multiple initiatives easier?
8	Does the platform make it easier to identify problems and make informed decisions on problems?
9	It is easier to analyse data of initiatives by using the performance monitoring platform compared to other platforms?
10	It is easier to make fast informed decision of initiatives by using the performance monitoring platform compared to other platforms?
11	By using these platforms, what is the average time spent in hours per initiative to: 1. Using other platforms - Structure and visualise large amounts of data? - Daily, monthly and yearly performance analysis of an initiative to make an informed decision? 2. Efficiency initiatives platform - Structure and visualise large amounts of data? - Daily, monthly and yearly performance analysis of an initiative to make an informed decision?