Optimising gold ore transportation systems for electricity cost savings

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Abstract

Title: Optimising gold ore transportation systems for electricity cost savings

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Keywords: Gold ore transportation system, rock winders, DSM, electrical cost savings

Electricity is an essential but limited resource in South Africa. Limited supply capacity and growing demand cause electricity prices to increase rapidly, therefore, reducing electricity consumption. Costs are critical within the mining sector. Demand-side management (DSM) is an appealing and effective initiative to reduce electricity consumption and costs. Various DSM initiatives have already been implemented on isolated components within gold ore transportation systems. Implementing such initiatives on multiple gold ore transportation systems in an integrated ore distribution network has, however, not yet been analysed, despite the large cost-saving potential.

A gold-processing plant is usually supplied from multiple mineshafts and waste rock dumps within an ore distribution network. Implementing DSM on a gold ore transportation system can influence the ore distribution channels and the gold plant operation. This study focused on implementing a DSM initiative on an integrated ore distribution network without negatively influencing production. Electrical load management was recognised as the primary opportunity to deliver feasible cost savings.

In-depth investigations were conducted on several mining processes, which can be categorised as mining, ore transportation and gold-processing. Within the ore transportation system, rock winders are identified as the largest electricity consumers, which is the component that has to be optimised. Although load management potential may exist, it may not be feasible for practical reasons. Simulations were developed to fully quantify the effect of implementing load management on rock winders at multiple shafts and the effect on the system as a whole.
This study was implemented on two complex gold ore transportation systems as case studies. Peak period load shifting of 3.1 MW and 1 MW, respectively, were achieved on average for a single test week. This is equivalent to a total electricity cost saving of R1.1 million and R380 000 per annum, respectively. If the results of this study are extrapolated to the rest of the mining sector, the potential cost savings could amount to R37 million per annum.

Large electricity cost savings were achieved without affecting the overall production negatively. Furthermore, implementing load management on an ore transportation system improved the monitoring and control of the ore supply. This creates electrical load management opportunities on gold-processing plants due to improved production planning capability.
Acknowledgements

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Abbreviations

BMR        Blair multi-rope
CPI        Consumer price index
DSM        Demand-side management
EAF        Energy availability factor
ODN        Ore distribution network
OTS        Ore transportation system
SCADA      Supervisory control and database acquisition
TOU        Time-of-use
UCLF       Unplanned capacity loss factor
VSD        Variable speed drive

Nomenclature

Symbols

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<td>cent per kilowatt-hour</td>
</tr>
<tr>
<td>h</td>
<td>hour</td>
</tr>
<tr>
<td>kg</td>
<td>kilogram</td>
</tr>
<tr>
<td>kW</td>
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Chapter 1

Introduction

“The secret of getting ahead is getting started” – Mark Twain
1.1 Background

1.1.1 Preamble

Electricity is an essential but restricted resource in South Africa. Limited generation capacity, poor management and the growing demand for electricity cause electricity prices to increase rapidly. Eskom, a state-owned utility, dominates the generation of electricity in South Africa. Eskom’s generation division has an installed capacity of 41.99 GW, in 2014, which supplies 95% of South Africa’s electricity [1]. The high electricity demand causes Eskom to implement curtailment measures to be able to supply consumers fully.

1.1.2 South African electricity supply versus electricity demand

Eskom was established in 1923 as the Electricity Supply Commission. A rapid increase in electricity demand in South Africa was met with an additional 31 000 MW of new generation capacity from 1970 to 1990. Eskom had surplus electricity supply from 1991 to 2005. During these years, little was invested in new electricity generation facilities [2].

Post-2005, the electricity demand grew close to the electricity supply capacity due to a 50% increase in electricity demand from 1994 to 2005 [3]. In 2007, the national electricity demand exceeded the maximum power generation capacity, which led to national load-shedding [4].

The electricity shortage led Eskom to implement a drastic capacity expansion programme. In the past decade, Eskom only managed to add 6 137 MW of the targeted 17 384 MW supply capacity for 2018. Figure 1-1 shows the year-to-year capacity increase during the last decade as part of the capacity expansion initiative [5].

![Figure 1-1: Eskom's year-to-year capacity expansion](image-url)
Owing to unplanned maintenance, breakdowns and overdue capacity expansion, Eskom cannot operate at full capacity. Ideally, a power utility requires a reserve margin, emergency generation capacity, of 15–20% to ensure system stability during maintenance and unplanned outages [6]. Due to a lack of expanding generation capabilities and maintenance on power plants, Eskom’s reserve margin was under 10% at times during the peak demand periods. Table 1-1 illustrates South African electricity production and usage [6].

Table 1-1: South African electricity production and usage

<table>
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<th>Year</th>
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<th>Installed capacity (GW)</th>
<th>Operational capacity (GW)</th>
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<td>2008</td>
<td>38.6</td>
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<td>40.2</td>
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According to data collected by The World Bank, electricity consumption in South Africa has increased by 22% over the last decade [3]. However, a maintenance backlog has caused a decrease in generation availability. Figure 1-2 illustrates Eskom’s average year-to-year unplanned capacity loss factor (UCLF) versus the energy availability factor (EAF) [5].

Figure 1-2: Eskom electricity generation constraints
It is evident from Figure 1-2 that the electricity available to satisfy the consumers’ demand in South Africa has been decreasing rapidly. By acknowledging the condition of the EAF, it can be derived that Eskom was only capable of supplying an average 77% of its installed capacity during September 2014. From the rapidly growing electricity consumption, delayed generation capacity expansion and the weak EAF it is evident that the Eskom power grid is overloaded and insubstantial.

1.1.3 Introduction to DSM initiatives
As stated in the previous section, Eskom’s reserve margin is depleting at a tremendous rate, which means that the surplus capacity under which Eskom operated in the early 2000s has diminished. To delay the demand from surpassing the supply capacity, the consumer’s power profile must be adjusted as the electricity demand in South Africa reaches peaks during certain time periods of the day. Figure 1-3 illustrates the typical demand profile of summer and winter days during 2014 [5].

![Figure 1-3: Typical South African electricity demand profile](image)

During a typical winter weekday, the electricity demand increases between 06:00–10:00 and again between 17:00–20:00. To encourage consumers to adjust their load profile, Eskom implemented a time-of-use (TOU) pricing tariff structure. The structure is used to encourage electrical load management by increasing electricity prices during peak periods and lowering prices during off-peak periods.

Demand-side management (DSM) is an initiative launched by Eskom to promote optimal electricity usage. The purpose of DSM is to limit the need for further generation capacity expansion by managing electricity demand [7]. Furthermore, DSM initiatives ensure a stable
power grid to ensure constant electricity supply to consumers\(^1\). DSM projects focus on different TOU structures used by industrial electricity consumers.

DSM also refers to load shape-altering events and reduced energy consumption [8], [9]. Application of DSM is commonly divided into load management and energy efficiency projects. Figure 1-4 illustrates the classic forms of DSM initiative.

![Figure 1-4: DSM intervention structure](image)

**Load management**

Load management is based on reducing electricity consumption during the high peak periods. By maximising off-peak period utilisation, as determined by the Eskom TOU tariff structure, large cost savings can be achieved by the consumer. Furthermore, power utilities can benefit immensely by relieving pressure on the electrical grid during the peak periods. Load management consists of multiple strategies that will be discussed in the sections that follow:

**Valley filling**

Valley filling is a form of load management that is implemented commonly. This involves intensifying electricity use during off-peak periods. By increasing electricity usage during these periods, the average electricity cost of the consumer decreases [10].

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Load shifting
Load shifting involves shifting loads from the peak demand periods to the off-peak periods. The total energy consumption of a system is not impacted, thus the initiative can be seen as energy neutral [9].

Peak clipping
Peak clipping assists power utilities by reducing loads during the peak periods, which results in a reduction of total energy consumption. This form of load management focuses only on the peak periods of a typical day [10]. Peak clipping is known to be a combination of load management and energy efficiency initiatives, as peak demand and the total daily power consumption are reduced.

Energy efficiency
Energy efficiency allows consumers to maintain the same operational service while using less energy. It promises attractive benefits for the consumer in the form of cumulative electrical cost savings, which are linked to increasing electricity costs [10].

DSM in the form of energy efficiency and load management offers the opportunity for reduced electricity costs and consumption for industrial consumers, thus enabling power utilities to operate more efficiently, which in turn creates large potential for reducing greenhouse gas emissions [11], [12].

1.2 Gold ore transportation

1.2.1 Overview of gold mining and processing
Mining refers to various actions dedicated to recover gold-bearing minerals from their originating locations. The technique required to recover the gold is mainly determined based by the source of gold-bearing minerals, i.e. underground mining or surface mining (open-pit mining).

Worldwide, South Africa is one of the largest gold producers with some of the deepest mines. Gold mines in South Africa account for nearly one-third of the world’s found gold reserves [13]. South Africa is estimated to have 6 000 tonnes of gold reserves and produced 156 tonnes in 2014. The majority of gold produced in South Africa originates from deep-level mining, which can reach depths up to approximately 4 000 m [14]. Figure 1-5 illustrates a typical gold-processing line.
In underground mining, large deposits of ore are mined through various tunnels and shafts that are sunk into the earth’s crust. When the underground minerals are reached, holes are drilled into the deposits for blasting. Blasted rock is gathered and moved to a haulage point by means of an ore pass system, from where it is hoisted to surface.

Underground mining commonly produces two types of material, namely, reef and waste rock. Reef consists of a much higher head grade than waste rock. The head grade of ore refers to the gold content per rock mass mined. This property of reef makes it the preferred mineral to recover owing to its economic potential [15].

Waste rock is the term used for material mined with little or no economic value at present [16]. Despite the low economic value of waste rock, it must be mined to reach the gold-bearing reef. Reef and waste rock are both hoisted to surface where each deposit is stored separately. Waste rock is stockpiled on a surface waste dump. Reef is typically stored in surface silos before it is transported to a processing plant to be treated and refined.

1.2.2 Gold ore transportation system

During the gold reef extraction process, multiple components are used to transport, classify, crush and haul the ore from underground to surface. When gold-bearing minerals are blasted from the earth’s crust, they are gathered and then transported from underground to reach the gold ore processing plant eventually. This method of underground transport is known as tramming, which includes conveyors and underground trains or trucks.

The blasted ore is then sent to crushers that pulverise the rock into smaller rocks. Reef and waste rocks are processed separately. This crushed rock is then loaded and hauled to surface by means of rock winders. People and equipment are transported from surface to underground, and vice versa, by means of man winders.
Transportation equipment is essential to link various processes in a gold production line. The transportation equipment varies according to the specific nature and conditions along the production line. Material transportation systems comprise multiple components including:

- Winders
- Trams
- Conveyors
- Crushers
- Ore passes

Table 1-2 summarises the operational power consumption of the most commonly used electric transport equipment [17]. Winders are identified as the largest energy-intensive equipment used within an ore transportation system.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Typical rated power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winders [18]</td>
<td>2 600–4 600</td>
</tr>
<tr>
<td>Crushers [19]</td>
<td>200–600</td>
</tr>
<tr>
<td>Conveyor belts</td>
<td>15–160</td>
</tr>
</tbody>
</table>

Surface silos are typically used to store reef. Waste rock is dumped in stockpiles, better known as waste dumps. The reef is then distributed to a gold plant for further processing. Such an ore transportation system forms part of an ore distribution network, which may include multiple ore transportation systems.

Figure 1-6 illustrates a typical deep-level mining layout, as well as the typical components included in an ore transportation system. The key components are indicated by red lines.
1.2.3 Gold ore distribution network

A gold-processing plant is commonly supplied with gold ore from multiple mineshafts and waste dumps. Figure 1-7 shows a typical gold ore distribution network. Each mine has unique mining operations and production schedules. The purpose of an ore distribution network is to transport the gold ore from each mine included in the ore distribution network to a gold plant. In some cases, conveyors, road or railway transportation is used to distribute the ore.
Waste produced far exceeds the quantity of valuable materials [16]. Although waste rock is referred to as “waste”, it contains a certain grade of ore. At the time of production, waste may be considered to have a too low economic value to recover and process. However, in some cases waste rock is processed due to improved extraction technology or an emerging gold market [16], [21].

Transporting gold ore from each mine, and in some instances waste rock from waste dumps as well, causes a time delay in a typical ore distribution network. Each mineshaft produces a distinctive amount of ore per day. The key priority of each mine and the integrated ore distribution network is to ensure a constant ore supply to the gold plant.

Section 1.2.2 and 1.2.3 form a basic understanding of the process on which this study is based.
1.3 Problem statement

Constrained generation capacity accompanied with vast growth in energy demand caused high electricity tariff increases in order to expand generation capacity [22]. Figure 1-8 shows the rate with which electricity prices increased over the last 10 years with forecasted figures for the near future.

As seen in Figure 1-8, the electricity price in South Africa keeps increasing at a much higher rate than the consumer price index (CPI) [23]. The increase in cost of electricity was constant prior to the electricity shortage experienced during late 2007 and early 2008. Electricity prices in South Africa have increased immensely since 2008 with an average yearly increase of 20.3%. Forecasts determine that a yearly average electricity price increase of at least 8% can be expected from 2015 [23].

Rising electricity prices have different effects on certain industries, which can leave them vulnerable and unprofitable. The level of vulnerability of industries to rising electricity prices depends on their electricity requirements as an input to production. Mining as a whole is one of the sectors most reliant on electricity as an input to production. Gold mines are classified as the most vulnerable to electricity price increases due to the electricity intensity of deep-level mining operations as opposed to other types of mining firms [24], [25].

Gold mining contributes up to 47% of the total electricity consumption within the South African mining sector. This is due to an increase in cost intensity of deep-level mining operations and activities [24]. During the same period in which electricity prices increased...
drastically, overall gold mining operation expenditure increased with decreasing gold ore head grades as illustrated in Figure 1-9 [26], [27].

![Figure 1-9: Ore grades and operating costs of South African gold producers](image)

Considering the rate of electricity price increases, the electricity intensity of a typical gold mine and the decreasing gold ore head grade, electrical cost management plays a crucial role in the gold mining sector. In the South African mining industry, DSM has proven to be a dynamic electricity cost relief initiative with an acceptable return on investment rate [28], [29].

The lowering head grade of gold ore causes mines’ energy requirements to expand. This is due to the need to mine deeper and to process more ore to produce a tonne of gold. In some cases, mines do not have capital available to expand mining operation for increased production, which can lead to closure [30].

Apart from the large amount of capital required to expand mining operations, over the last decade, the cash-operational cost per kilogram gold produced increased fourfold [26]. This is due to the decrease in ore head grade and the rise of mining operational costs (Figure 1-9). Thus, it is beneficial to implement electricity cost-saving initiatives on energy-intensive equipment to reduce operational costs.

**DSM on gold ore transportation systems**

DSM initiatives are widely implemented on various components within ore transportation systems in the South African mining industry. DSM interventions are most commonly implemented on rock winders and underground crushers for optimal electricity management [13], [18]. However, the effect of implementing load management on multiple
ore transportation systems in an integrated ore distribution network has not yet been analysed in available literature.

Ore production is a key priority at any mine and the primary indicator of a mine’s performance [15]. As production is determined to be the principal indicator of a mine’s operation, implementing cost-saving initiatives on the ore transportation systems is seen as a risk if production is compromised.

Furthermore, implementing load management on the ore transportation systems may disrupt the ore distribution and gold-processing operations.

### 1.4 Research objectives

The objective of this study is to investigate, analyse and implement electrical cost-saving measures on gold ore transportation systems on South African gold mines. As discussed in Section 1.2.2, the winders included in an ore transportation system are identified as the largest energy-intensive component.

The focus is on establishing DSM opportunities that are relevant to rock winders in a gold ore transportation system to decrease operational electricity costs. Furthermore, the impact of implementing load management on rock winders included in gold ore transportation systems in integrated ore distribution networks is analysed. Thereby, answering that the overall production targets are maintained during the implementation of an integrated cost-saving initiative. This is necessary to ensure sustainable cost savings.

The study objectives are summarised as:

- Investigate and analyse rock winder operation and cost.
- Investigate potential DSM initiatives relevant to rock winder systems.
- Investigate integrated ore distribution network operations and operational constraints.
- Simulate and analyse operational feasibility of implementing DSM initiatives on rock winder systems.
- Implement cost-saving interventions on rock winders of multiple ore transportation systems in single ore distribution networks.
1.5 Study scope

Delayed capacity expansion and overdue maintenance on Eskom’s generation units caused electricity shortages in South Africa, especially during peak demand periods. Therefore, South African electricity prices have rocketed during the last decade.

Gold mines are recognised as one of South Africa’s largest electricity consumers with energy-intensive operations. Considering the electricity price increases and large operational costs, electrical cost-saving methods are necessary. Cost savings can be realised on various electrical components in South African gold mining, which include underground pumps, compressed air, fridge plants and rock winders.

This study will focus on optimising rock winders in gold ore transportation systems on several mines in a common ore distribution network. Implementing control strategies on a man winder would cause too much of a logistical problem, due to the unpredictable use as mine personnel are transported for many reasons, such as shift changes, inspections and emergencies [31].

The core purpose of this study is to realise maximum electricity cost savings for a mining group while adhering to the integrated constraints and production targets of an ore transportation system.

1.6 Overview of dissertation

Chapter 1 provides general background information and adequate relevance for the study, which includes the motivation, objectives and the scope for the study.

Chapter 2 investigates the electricity consumption and operational parameters of rock winders in gold ore transportation systems. Through reviewing literature to understand all aspects of rock winders, further load management opportunities are investigated. The current operation strategies are discussed and the shortcomings of current operations are evaluated.

Chapter 3 focuses on developing and implementing a generic investigation methodology for the integration of an electricity cost-saving intervention on ore transportation systems.

Chapter 4 focuses on developing a generic optimisation model for multiple ore transportation systems. In-depth simulation techniques are developed to determine the operational feasibility of achieving integrated electrical cost savings. The optimisation model is verified and the sustainability of such a cost-saving strategy is discussed.
Chapter 5 focuses on implementing the newly developed integrated cost-saving strategy on rock winders in ore transportation systems. The strategy is implemented on two integrated gold ore distribution networks – each containing several ore transportation systems. The results are compared to the optimised methodology results and ultimately verified.

Chapter 6 includes a conclusive discussion of the dissertation. The key objectives and results are reviewed and further recommendations to expand the study are discussed.
Chapter 2

Electricity cost-saving measures in gold ore transportation systems

“If you can’t explain it simply, you don’t understand it well enough” – Albert Einstein
2.1 Introduction

In Chapter 1, the typical operation of an ore transportation system was discussed and the integrated operation of multiple ore transportation systems in a typical ore distribution network was elaborated on. Furthermore, the interconnection between an ore transportation system, ore distribution network and a gold plant was discussed.

Man and rock winders were identified as the largest electricity consumers within an ore transportation system. Rock winders was identified as the key component for implementing DSM cost-saving interventions. Man winders were excluded from the scope of study, due to their diverse operational scheduling and essential function of transporting people.

Chapter 2 provides sufficient literature of rock winder design, layout, operation and electricity consumption. This will help reinforce the principles used for operating and controlling the rock winders. Furthermore, the typical operation of a gold plant is discussed to comprehend the integrated requirements of an ore transportation system.

Several studies of DSM electricity cost initiatives in the mining sector, both internationally and nationally, are included in this chapter. It is determined whether similar projects and methods can be applied to the ore transportation systems.

2.2 Rock winder systems and their electrical consumption

2.2.1 Preamble

The South African mining consumed 14.1% of all electricity generated during the 2013/14 financial year [1]. As discussed in Chapter 1, gold mining is identified as one of the largest energy-intensive divisions, consuming 47% of all electricity supplied to the mining industry [24].

The largest and most prominent energy-consuming equipment on a typical gold mine are [32]:

- Hoisting (16% of total electricity usage)
- Compressors (15% of total electricity usage)
- Refrigeration (15% of total electricity usage)
- Pumping (14% of total electricity usage)
- Processing plants (13% of total electricity usage)
Acknowledging the large energy requirements of a typical hoisting system further motivates the study of implementing potential DSM initiatives to achieve electricity cost savings. The energy requirement is known to increase on mines where the mining operations expand with increasing hoisting depths.

2.2.2 Winder types and configuration

Skip hoisting is one of the most common methods of vertical material transport in underground deep-level mines. Rock winders form an integral part of the ore transportation system, as they are responsible for the vertical transportation of mined material. The following components form part of the basic winder system and need to be defined to understand the winding process [13], [33], [34]:

- **Skip (conveyance)** – The payload container that is filled with ore or waste rock. Two skips are used in a typical winder system to work as counterweights.
- **Winder cable** – The key purpose of the winder cable is to connect the skip to the winder. The cable is wound and unwound to transport the skip from surface to various mining levels and vice versa.
- **Winder motor** – Electric motor used to drive the winding operations.
- **Winder** – A drum used to wind the winder cable.
- **Sheave wheel** – Used to guide the winder cable down the shaft.
- **Shaft tower** – Used to house the sheave wheel and to support the hoists within which man, rock and material is transported.

Figure 2-1 shows a basic layout of a winder system used in deep-level mines.
Figure 2-1: Typical layout of a winder-based hoisting system

The two types of rock hoist that are most commonly used are drum hoists and friction hoists [35], [36]. A number of configuration variations exist within these winder types, where the most common configurations are known as [34]:

- Double-drum winder
- Blair multi-rope (BMR) drum winder
- Koepe (friction) winder

In this section, the winder configurations identified above will be discussed due to their popularity and wide application. A summary of the comparative analysis of the various winder types, as applied to deep-level mining, is also included.

**Double-drum winder**

As the name suggests, two separate drums are used to wind the winder cable in opposite directions. As one skip is hoisted to surface, the other skip is lowered within a single rotation. This configuration forces the two skips that are connected to counterbalance each other.
The skips can be positioned relative to the different shaft levels by clutching one or both of the drums while keeping the hoist balanced [37].

![Figure 2-2: Double-drum winder system configuration](image)

Summary of the main features included in a double-drum winder system configuration:

- Ideal for shallow depth, high payload hoisting.
- Capable of hoisting from multiple levels.
- Limited by the strength of the single rope used to carry the load.
- Expensive operating costs.
- High peak and average power demand.

**BMR drum winder**

The BMR drum winder was designed and developed to accommodate the deep mines in South Africa [38], due to the drum winder being able to extend two or more ropes. It was introduced in South Africa by Robert Blair in 1957. Until today, the BMR hoist is used almost exclusively in South Africa [13].

The BMR drum winder was developed with a two-compartment drum with a winder cable (rope) per compartment. A single skip is attached to a compartment by means of two ropes. Furthermore, a rope tension-compensating pulley is attached to the skip, which can regulate moderate rope length changes during winding. This is necessary to equally distribute the load between the two ropes during hoisting [39]. This enables the BMR drum winder to hoist heavier loads at deeper shafts [34].
A summary of main features in the BMR drum winder specifications include:

- Smaller rope diameter required due to the use of multiple ropes.
- Smaller drum diameter is required in comparison to other drum hoists.
- Due to these physical characteristics, it is regarded as the favourable winder system.

**Koepe (friction) winder**

Unlike the drum hoists, Koepe winders are most commonly mounted right above the shaft at the top of the headgear. The winder system is seldom mounted on the ground above the mineshaft. Single or multiple ropes, depending on the operation requirements of the winder system, connect the skips to each other. The haulage rope is not attached to the winder drum but passes around it [13].

The Koepe winder system uses a tail rope, which is looped in the shaft and connected to the bottom of each skip or counterweight, to reduce the unbalanced load. Furthermore, using a tail rope reduces the peak horsepower required to put the skip or counterweight in motion [34].

Figure 2-4 illustrates the typical layout of a Koepe winder system.
Therefore, the Koepe winder’s initial power consumption is approximately 30% less when compared to the drum winder for the same application [35]. However, the average power consumption remains the same. The initial power reduction effect due to the tail rope being used on the Koepe winder system is evident when compared to the power consumption of a typical drum winder system (Figure 2-5) [40].
Summary of the main features included in the Koepe winder specifications [39]:

- For the same production capacity as a drum winder, the peak power demand is lower.
- A smaller winder motor can be used due to the peak power consumption being eliminated.
- For depths up to 1 800 metres, the Koepe winder can hoist heavy loads; this number is known to rise as the number of winder cables increases.

2.2.3 Rock winder system hoisting operation

To understand and analyse the typical power consumption of a winder system, the fundamental operation of a single cycle must be defined and investigated. A single rock winder cycle can be divided into seven key segments where the speed and the power usage of winders vary. These segments are illustrated in Figure 2-6 and explained after the figure.
Interval $t_0$ and $t_1$ form part of the creep-out segment. During interval $t_0$, the loaded or unloaded skip experiences a constant acceleration from its steady-state position to the creep velocity. Once the winder reaches its creep velocity, it moves at a constant speed while the skip moves out of the station ($t_1$). A small spike is seen in the power consumption in the creep-out segment due to the torque required to overcome the initial inertia moment and friction experienced by the skip.

Interval $t_2$ is known as the initial start segment. In this interval, the skip passes out of the station from where it experiences a constant acceleration to reach its mean velocity. The skip accelerates for the up-and-down journey. During this segment, the winder motor power consumption reaches its peak and requires maximum torque to hoist the loaded skip.

During interval $t_3$, the winder motor reaches its mean velocity and the power consumption decreases. This is because the power required to hoist the skip is reduced to overcome only the friction and gravitational forces experienced by the skip.

As the skip reaches its end destination, the winder motor velocity starts to decrease ($t_4$). The mean velocity of the motor is reduced to the creep-in velocity to enter the station. During interval $t_4$, the kinetic energy (which is not absorbed by brakes, friction loss or gravity) of the skip is regenerated back into the electrical network. Note that not all winder systems are capable of regenerating energy back into the electrical grid.

Interval $t_5$ and $t_6$ form part of the creep-in segment. This is the final segment of a hoisting cycle. During interval $t_5$, the skip moves at a constant creep velocity to enter the station. As the skip reaches its end destination, the creep velocity reduces to a standstill as the skip docks into the station ($t_6$). This completes the hoisting cycle.

As the skip is locked in the designated station, the elevated skip unloads the hoisted payload as the lowered skip is loaded. Once the load and unload tasks are completed, the process is completed for the next hoisting cycle.

### 2.2.4 Winder system energy consumption

In the previous section, the typical operation of a rock winder hoisting cycle was discussed. In this section, multiple methods are discussed to determine the average power consumption of a rock winder during its hoisting cycle. It is important to note that not all winder systems have the same power consumption. These requirements differ depending on the winder type,
vertical hoist height, winder motor specifications, motor efficiency, shaft friction and the skip mass.

The preferred and most accurate method for obtaining the electrical energy consumption of a rock winder is to install power meters on the electrical feeder of the winder system. Although this method is preferred, it is time-consuming and requires capital expenditure to obtain and install these devices. Furthermore, using power meters cannot assist with forecasting measures to contribute to production planning. However, several other methods can be used to determine the average power consumption of a winder cycle.

Grimestad [35] stated that the power consumption for a deep-level mine hoisting system is estimated to be 1 kWh/tonne extracted for each 367 m of vertical hoisting distance at 100% efficiency (no mechanical or electrical losses). However, the efficiency is about 80% in practice [13].

Vosloo [13] suggested the use of fundamental physics rules to determine the average power consumption per cycle. The kinetic energy required to displace an object to a specific height is equal to the potential energy of the object at its destination [41]. To be able to apply this rule to a winder system based on its physical parameters, a few assumptions are made to simplify the energy calculations:

- The friction induced by the skip is constant for each specific winder.
- The loaded skip weight, constant for each cycle, is measured in tonne.
- South African deep-level mines always use balanced winders, thus the skip weight can be neglected.
- The winder rope weight can be neglected in a balanced winder system.

Now that the system has been simplified, the energy required to transport an object to a specific height can be calculated. Consider a mass \( m \) which must be transported a height \( h \) by a winder system. Equation 2-1 shows the gravitational potential energy law that states [41]:

\[
PE = m \times g \times h
\] (2-1)

Where:

\( PE \) – Potential energy (joule)
\( m \) – Specific object mass (kg)
As discussed, it is important to include the winder system efficiency ($\eta$) in the equation as it is a defining factor for power consumption. To convert mechanical energy (potential energy in J) to EE (electrical energy in kWh), the conversion of $1 \text{ J} = 2.78 \times 10^{-7} \text{ kWh}$ is used. Thus, Equation 2-2 is determined to be:

$$EE = \left[ \frac{m \times g \times h \times 2.78 \times 10^{-7}}{\eta} \right] \text{kWh} \quad (2-2)$$

According to Badenhorst [17], who took into account the simplifying assumptions of a winder system based on the physical parameters stated by Vosloo [13], the power required for a single hoist can be calculated by Equation 2-3:

$$P_{\text{hoist}} = \left[ \frac{(1 + ff)\frac{\text{tonnes}_{\text{payload}}}{\text{skip}} \times g \times h}{\eta \times T_{\text{cycle}}} \right] \text{ kW} \quad (2-3)$$

Where:

$ff$ – Friction factor of skip movement in shaft ($0 \leq ff \leq 0.3$)

$\frac{\text{tonnes}_{\text{payload}}}{\text{skip}}$ – Payload per hoist (tonne)

$g$ – Gravitational acceleration ($\text{m/s}^2$)

$h$ – Vertical winding depth (m)

$\eta$ – Winder motor efficiency

$T_{\text{cycle}}$ – Average cycle time (s)

The power required for a single hoist ($P_{\text{hoist}}$) can now be reformulated to calculate the amount of energy required per hoist ($E_{\text{hoist}}$) using Equation 2-4:

$$E_{\text{hoist}} = \left[ \frac{(1 + ff)\frac{\text{tonnes}_{\text{payload}}}{\text{skip}} \times g \times h}{(\eta \times 3600)} \right] \text{ kWh} \quad (2-4)$$
As the average electrical energy consumed per cycle for a specific winder is calculated, the electrical energy consumed in an hour can be calculated. This is done by multiplying the number of hoisting cycles completed within an hour with the average electrical energy consumption.

From the above rock winder power and energy consumption calculation, it is clear that the electrical power consumed by the rock winder is directly related to the amount of rock extracted. Therefore, it has a direct impact on the production of a mine as daily and monthly production targets are specified for each specific rock winder. These formulas are used in Chapter 4 to calculate potential reduced cost savings for operations.

2.2.5 Gold-processing plant operation

Efficient gold plant operations are dependent on the effective gold ore production of mines. Thus, the rock winder system’s schedules and operation are important functions in a typical gold production line. A mine’s daily production target is known as the amount of ore that needs to be transported from underground to surface within a 24-hour period.

If the daily production target of a mine is not reached, the gold plant might be at risk of losing production. On the other hand, if efficient production planning is not implemented at a gold-processing plant, there is a possibility of overloading the gold plant’s surface storage. If this happens, the backlog of ore will cause the mining operations to be suspended. Thus, accurate production planning is a necessity [42].

2.2.6 Summary of electricity consumption of a rock winder system

In this section, the operation and electricity consumption of a rock winder system were reviewed. The next step is to identify potential opportunities to achieve electricity cost savings relevant to the rock winder system of a mine. In this study, energy efficiency and load management opportunities are investigated.

2.3 DSM opportunities on South African mines

2.3.1 Preamble

As discussed in Chapter 1, DSM initiatives are widely welcomed in the South African mining sector due to increasing electricity costs and electricity shortages experienced in the country. Cost reduction initiatives have already been successfully implemented on multiple systems within mining operations such as compressed air networks, mine dewatering systems and cooling systems [6], [43], [44], [45].
In this section, various energy efficiency and load management opportunities in the mining sector are discussed to identify viable opportunities for implementation on the rock winders of an ore transportation system.

2.3.2 DSM energy efficiency opportunities

The focus of energy efficiency initiatives is on reducing or optimising energy usage. This matter is considered high priority as energy availability decreases and electricity prices increase drastically. These two factors are considered as a high risks for production-orientated industries. Energy efficiency includes a wide variety of activities, which can be classified in the following categories [46], [47]:

- **Replacement/modification** – As the name indicates, this includes replacing or modifying existing equipment or processes with high efficiency retrofits.
- **Controls** – Improving operational performance by optimal process and equipment control.
- **Observation and maintenance** – Constant monitoring of processes to identify relevant maintenance opportunities to recalibrate or repair essential equipment.
- **Benchmarking** – Using standardisation codes, such as ISO 50001, benchmarking can be implemented on existing processes.

Energy efficiency investigations most commonly implemented on the South African gold mining sector are discussed hereafter to identify the magnitude of success realised in this area. The discussion then focuses on further energy efficiency opportunities on transport equipment used in the gold mining sector.

**Energy efficiency in South African mining**

Due to the deep operations of South African mines, large energy-intensive cooling systems are required to provide and maintain safe working conditions. Van Greunen [44] successfully obtained energy efficient operation on mine cooling systems. This was accomplished by installing variable speed drives (VSD) on mine chiller evaporator and condenser water pumps to deliver variable flow control, hence reducing pump motor electricity usage.

As South African mining compressed air networks are relatively old and are not maintained adequately, inefficient distribution and use of compressed air occur. Bredenkamp [48] identified the potential reconfiguration of compressed air networks to obtain efficient operation and cost savings. The compressed air network was reconfigured in such a manner
to deliver sufficient and accurate pressure to each mine included, thus eliminating compressed air wastage. The new setup required pipe interconnections and new control valves.

Botha [49] successfully implemented multiple techniques to reduce water wastage within a deep-level mine-water reticulation circuit. These techniques included leak management, stope isolation control and supply water control. In his first case study, Botha [49] used existing control valves to adjust supply water pressure set points to selected equipment sections. This technique resulted in a 1.4 ML daily water reduction, thus realising a 9.65 MWh energy reduction on the dewatering pumps.

In another case study, Botha [49] implemented water pressure control on multiple mining levels. This required the installation of multiple new control valves. Leaks on the water reticulation piping were repaired. The implementation of these initiatives resulted in a daily 92 MW h electricity consumption reduction on the dewatering pumps.

The studies discussed show that energy efficiency is widely implemented with great success in the gold mining sector.

**Energy efficiency on ore transport equipment**

Typical gold mine transport equipment include conveyors, crushers and rock winders. These components are used for transporting process streams and can account for large electricity consumption. In this section, energy efficiency initiatives implemented on ore transportation equipment are discussed.

**Conveyor belts**

Zhang and Xia [50] stated that conveyor belt energy efficiency can be improved on four different levels, namely, performance, equipment, operation and technology. However, literature mainly focuses on the operational and equipment level of improving energy efficiency of conveyor belts.

Reducing energy consumption of a conveyor belt on an equipment level includes highly efficient equipment retrofits. The idler, belt and drive system are the main targets. Staniak and Franca tested and discussed energy-saving idlers [51]. Improving the structure and rubber compounds of a belt proved to lead to more efficient operation [52]. VSDs and energy efficient motors were recommended for efficient conveyor belts operation [53].
Zhang and Xia [50] conducted a study on improving the operational level of a conveyor system where an analytical energy model was created. Multiple parameters and constraints were identified that were used as variables in the newly developed model to achieve the best operational efficiency of a conveyor belt. Variable speed control of conveyors belts, which ensured constant material loading along the belt, was identified as the most feasible method for reducing energy consumption of a conveyor system.

**Crushers**

According to Moray et al. [54], the energy efficiency of large industrial crushers can be improved by the following adjustments:

- Operating the crusher near or at full load at all times.
- Installing efficient motors on crushers.
- Adjusting closed-side setting of the crusher to achieve greatest size reduction to improve downstream processes.

Moray et al. [54] identified opportunities to decrease the process energy intensity of a crusher plant on an asphalt plant. Based on the operational requirements of the plant, the opportunity to replace the tertiary crusher with a more efficient, higher capacity crusher was identified. The closed-side setting of the secondary crusher could be increased to reduce the primary crusher downtime. This could lead to annual cost savings of $1.5 million (R18.9 million).

Multiple energy efficiency opportunities in the mining sector were reviewed for applications to obtain energy efficient operations. Energy efficiency initiatives on rock winders could not be identified in literature. In the next section, electricity cost savings through load management is reviewed.

**2.3.3 DSM load management opportunities**

Electrical load management has been proven to be an effective peak load control measure for both the supplier and the consumer [55]. Electricity suppliers promote electrical load management in cases where (1) demand requirements surpass supply capacity or (2) lack of resources causes delays in expansion of electricity supply capacity [56].

---

2 Exchange rate as on 2015/08/10: 1$ = R12.64
As discussed in Section 1.1.2, both these factors are relevant to electricity supply in South Africa. Load management initiatives undertaken by the consumer are based on variable price structures, which include TOU energy tariffs. Barnard [57] and Cousins [58] stated that the two main reasons for applying the TOU tariff structure are:

- To be more cost reflective as each consumer has a unique load profile.
- To enable consumers to manage loads accordingly to obtain electricity cost savings.

The majority of large electricity consumers in South Africa, including mines, are billed according to Eskom’s Megaflex TOU tariff structure. This tariff structure includes seasonal and TOU-differentiated active energy charges. Peak TOU active energy charges are up to 250% (low demand season) and 600% (high demand season) more expensive than charges for the off-peak periods [58]. Therefore, strategic load management in the form of load shifting and peak clipping can provide large cost savings.

**Load management on gold ore transportation systems**

Several authors investigated ore transportation system components for load management opportunities as they contribute an average of 24% to the total electricity consumption of mines [59]. These components include crushers and rock winders, which are discussed further.

**Crushers**

Numbi, Zhang and Xia [60] developed an optimisation model for jaw crushers in deep-level mines while considering the applied TOU tariff structure. The model focused on reducing energy cost and consumption of jaw crushers by optimising switching control, while adhering to technical and operational constraints.

The model showed that savings up to 46% was achievable. It was proved that these savings increased significantly where large up- and downstream storage capacity were available. However, in practice, switching off a crusher will require installing a soft-starter system or a VSD. This requires large initial capital expenditure.

**Rock winders**

Vosloo [13] identified the rock winder as one of the largest electricity-intensive consumers in deep-level mining. A model was developed to investigate the potential for implementing
a load management initiative on a rock winder system. In this model, multiple operational constraints were identified and the impact on the gold plant was determined.

A real-time controller was implemented to schedule the winder operation optimally using the TOU tariff structure to realise electricity cost savings. The optimal control of the rock winder introduced a 3.5 MW load shift from the evening period to less expensive periods. According to the 2014/15 electricity tariffs, the cost savings of this intervention was estimated to realise R1.1 million per annum [13].

Buthelezi [18] developed a model to investigate potential load management opportunities on cascading rock winder configurations. Thereafter, a real-time control system was implemented to control the rock winder operations according to the identified operational parameters and TOU tariff structure. An average evening peak load reduction of 2.4 MW was achieved, which could lead to an approximate cost saving of R800 000 per annum according to the 2014/15 electricity tariffs.

Furthermore, the study indicated the potential of using a rock winder system for maximum demand control as the system consumes large amounts of electrical power and could be stopped and restarted with ease [18].

Badenhorst’s [17] study objective included developing an optimal hoist-scheduling programme for deep-level mines. The optimised hoisting schedule incorporated physical and operational constraints of a winder system and obtained electricity cost saving using TOU structures while still achieving hoisting targets.

Firstly, a rock winder system was modelled using a linear programming model that included physical constraints, operational constraints and an energy cost-based objective function. Secondly, a closed-loop model predictive controller was incorporated to obtain an optimal scheduling algorithm [17].

Multiple simulation results concluded that the optimal scheduling algorithm accurately scheduled minimal hoisting during the expensive peak periods and maximal hoisting during less expensive periods while still achieving hoisting targets and satisfying operational constraints [17].

From the studies that have been reviewed, it is seen that load management is a feasible and effective opportunity to obtain electricity cost savings from a rock winder system.
2.4 Identifying viable energy management solution

2.4.1 Preamble

Literature showed that multiple DSM interventions have already been implemented successfully within the South African mining industry. Load shifting and energy efficiency interventions were found to be the primary sources of electricity cost savings. In order to identify the most suitable intervention to obtain electricity cost savings on a winder system, the following criteria are used:

1. Viable electricity cost-saving potential;
2. Short payback period;
3. Minimal capital expenditure required;
4. Brownfields implementation;
5. Operational simplicity and feasibility; and
6. No negative impact on production targets.

Firstly, the potential implementation of an energy efficiency intervention on a winder system is discussed. Thereafter load management opportunities are discussed.

2.4.2 Energy efficiency

The aim of an energy efficiency initiative is to reduce electricity consumption without reducing operational service. As discussed in Section 2.2.4, the electrical energy consumption of a winder system is primarily dependent on the:

- Mass of the object hoisted
- Height of the hoist; and
- Winder motor efficiency.

Winder system design specifications include the height of the hoist and the maximum mass that can be hoisted [35], [61]. Therefore, the winder motor will be the key focus for investigating the implementation of energy efficiency DSM initiatives on a winder system. The following opportunities are commonly reflected as energy efficiency applications on electric motors [62]:

- Power factor correction;
- Effective maintenance;
- High energy efficient motor retrofits; and
- Rewinding of motors.
Although these opportunities may realise electricity cost savings, the majority of the criteria were not met. The majority of energy efficiency opportunities require large capital expenditure that necessitates large returns in order to obtain a practical payback period. Thus, energy efficiency is not a viable electricity cost-saving intervention for rock winder systems based on the criteria developed in this study.

2.4.3 Load management

The key focus of load management initiatives is embedded in operational improvements. From the literature survey it was evident that these opportunities require lower capital expenditure, which in turn results in a smaller payback period.

According to Ashok and Banerjee [63], load shifting is considered to be the best method for reducing customer peak demand period consumption, as the identified load or process is shifted or rescheduled to lower demand periods. Furthermore, load shifting initiatives are proven to be the preferred method for optimising winder system energy costs [13], [17], [18], [31].

According to Bosman [31], a major concern regarding implementing load shifting initiatives on electric energy-intensive equipment is that the equipment is frequently switched on and off for short periods. This results in cycling of electric motors, which is destructive for certain motor types. Winder motors, however, are designed to cycle as discussed in Section 2.2.3. Thus, the potential implementation of a load shifting initiative is simple and feasible.

Jordaan [64] suggested the following criteria to review load management opportunities in the form of load shifting in production-related operations:

1. *Up- and downstream buffer capacity* – Storage buffers are required to absorb disturbances caused by load shifting interventions.
2. *Uncompromised production* – Overall production volumes must be maintained.
3. *Overtake operational capacity* – The system must be able to compensate for lost production during the peak load reduction.
4. *Energy neutral* – The post-implementation energy consumption must be equal to the pre-implementation energy consumption as production volumes may not be compromised. This refers to the application where energy intensity remains constant.
The criteria as applied on ore transportation rock winding sections are discussed in more detail:

**Storage buffer capacity**
Ore is mined from where it is transported and stored in underground storage units such as ore passes. Underground storage acts as the upstream buffer for the winder system. Surface silos are used to store the hoisted ore for further distribution on surface to the gold plant. The surface silo acts as upstream buffer capacity.

**Production volumes**
The electrical cost savings obtained through load management initiatives will not amount to the value of gold produced at a gold plant. Therefore, it is fundamental to maintain production volumes for feasible load management implementation. The primary focus of the rock winder system is to hoist all the material mined within a day.

**Overtake capacity**
Winder systems generally experience multiple stoppages during the day as the production of a mine decreases over the years. Therefore, the overtake capacity of a winder system can be sufficient to hoist the mined material to surface. This needs to be proven per mine.

**Energy neutral**
The power consumption of a rock winder is directly dependent on the production volumes hoisted to surface. Thus, if the production volumes are maintained and the winder system has sufficient capacity to compensate for the lost production during peak periods, the system will be energy neutral.

**2.4.4 Summary**
Given the criteria for identifying the most suitable DSM initiative to realise electricity cost savings on an ore transportation system, it is observed that load management opportunities are favoured over energy efficiency initiatives. Table 2-1 illustrates the criteria check for both energy efficiency and load management opportunities as specified in Section 2.4.1.

<table>
<thead>
<tr>
<th>DSM intervention</th>
<th>Criteria check</th>
<th>Viable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy efficiency</td>
<td>[1], [6]</td>
<td>No</td>
</tr>
<tr>
<td>Load management</td>
<td>[1], [2], [3], [4], [5], [6]</td>
<td>Yes</td>
</tr>
</tbody>
</table>
From Table 2-1 it is evident that the decisive factors are founded on the low capital expenditure input, feasibility and ease of implementation as only moderate operational changes are required to obtain large cost savings. Also, several studies concluded that load management is feasible on isolated ore transportation systems [17], [31], [65].

2.5 Critical analyses on DSM initiatives implemented on rock winder systems

2.5.1 Preamble

Literature shows load management has been implemented on numerous rock winder systems within the South African gold mining sector. In this section, the shortcomings that have been identified within the previous studies are discussed.

2.5.2 Further study potential

As discussed in Section 1.2, a rock winder system forms part of a larger network of components in an ore transportation system. The operation of an ore transportation system influences the ore distribution and gold plant operation within an ore distribution network. Therefore, efficient winder operation is required. From the literature reviewed, it is evident that the authors focused on optimising a single mine’s winder systems and in some cases, investigating the impact of such an intervention on the gold plant operation.

Thus, the need for investigating potential implementation of load management initiatives, and the impact thereof, on multiple ore transportation systems within a single ore distribution network has been identified. As each ore transportation system is unique due to a mine’s distinctive production capabilities and targets, an investigation methodology needs to be developed. This is done to investigate and comprehend the complex operation and constraints of each ore transportation system, the ore distribution process and the gold plant operation.

DSM initiatives may be proof of effective cost-saving interventions on multiple systems within the mining industry but effective maintenance is essential for sustainable savings. Groenewald [66] and Grobbelaar [67] conveyed the importance of maintenance to sustain optimal cost savings from DSM initiatives. The authors focused on monitoring and reporting approaches for sustainable performance.
The studies that were reviewed did not address the sustainability of implementing load shifting initiatives on rock winder systems. Thus, in Section 4.5, a feasible and effective reporting structure is developed and discussed to ensure sustainability.

2.6 Conclusion

In this chapter, the basic operation, energy requirements and the effect of DSM on ore production were discussed. Multiple studies were reviewed to identify relevant DSM opportunities that could effectively reduce a rock winder’s electricity costs. Criteria were established against which the available DSM opportunities were rated.

Energy efficiency measures generally require substantial capital expenditure and effort on implementation. On the other hand, load management opportunities in the form of load shifting is identified as an easy measure to obtain cost savings. Moderate operational changes can deliver large-scale interventions.

Load shifting interventions have already been implemented on the rock winders of several single ore transportation systems. These studies were analysed and several areas of improvement were identified – these have been incorporated in this dissertation. The areas of improvement include:

- Investigating multiple rock winder systems in a single ore distribution network.
- Analysing the feasibility of implementing load management initiatives on the rock winders of several ore transportation systems and analysing the impact thereof on the integrated ore distribution network operation.
- Improving the sustainability of such cost-saving interventions.

These improvement opportunities are addressed in the study by:

- Developing a detailed investigation methodology for an integrated ore distribution network in Chapter 3.
- Developing a model to simulate the feasibility of such an integrated cost-saving intervention in Chapter 4.
- Compiling a generic report to inform relevant mine personnel on day-to-day operations to improve sustainability.
In the next chapter, a detailed investigation methodology is developed to investigate multiple ore transportation systems in an integrated ore distribution network. The methodology is used to identify the integrated operations and layout of an ore distribution network.
Chapter 3

Development of an optimised cost-saving investigation methodology

“The only source of knowledge is experience” – Albert Einstein
3.1 Introduction

Chapter 2 discussed the design, layout, operation and power consumption of a typical ore transportation system. Multiple existing DSM initiatives on South African mines were included in the literature review to identify viable DSM opportunities on rock winder systems used in ore transportation systems. A critical analysis was done to identify shortcomings in the current DSM initiatives implemented on rock winder systems.

Chapter 3 focuses on the investigation methodology for an integrated electricity cost-saving intervention. Integrated electricity cost-saving intervention refers to electricity cost-saving initiatives for multiple ore transportation systems in a larger ore distribution network.

The electricity cost-saving methodology entails a load management DSM intervention to shift load from Eskom’s peak period. Before implementing an integrated cost-saving methodology, the feasibility of the intervention needs to be analysed. This chapter provides the necessary investigation criteria to develop such a cost-saving methodology. The primary focus of this chapter include:

- Investigating integrated system layout and normal operations;
- Data acquisitioning and processing;
- Identifying integrated system constraints; and
- Proposing an integrated cost-saving strategy.

3.2 Overview of optimised investigation method

3.2.1 Identifying mining layout and criteria

Investigating multiple ore transportation systems at several mining shafts requires accurate system information and comprehensive data analyses. As discussed in Section 1.2.3, each shaft has unique operational constraints. In order to fully quantify the electricity cost-saving potential on an ore transportation system, the normal operation of the system must be determined.

This investigation methodology is developed to be generic for any ore distribution network. Figure 3-1 illustrates the proposed investigation methodology for analysing the normal operation of an ore distribution network. As discussed, an ore distribution network consists of multiple ore transportation systems and at least one gold plant.
Optimising gold ore transportation systems for electricity cost savings

A. Investigate the ore transportation systems in an ore distribution network

A typical ore distribution network supplies a single gold-processing plant from multiple mining operations. Each individual mining shaft has different ore production capabilities, targets and operations. The core function of each mineshaft is to produce ore and transport the mined rock to surface.

It is important to investigate and analyse the distinctive ore production and ore transportation system of each mining shaft included in the ore distribution network. Furthermore, the ore distribution method used to transport the ore from the known shafts to the gold plant is identified and elaborated upon. The following aspects must be investigated:

- Number of mineshafts;
- Respective ore production capabilities;
- Operation details of the ore transportation system of each shaft; and
- Ore distribution method, capacity and schedule.

B. Investigate ore transportation system’s ore handling capacity

A number of ore storage facilities are used in underground mining operations and on surface. Depending on the mine layout, the storage facilities include underground ore passes, loading bins and surface silos. Storage capacity is not only essential for effective underground operations but it is also a key factor when implementing DSM interventions such as load shifting. The following aspects need to be investigated:
C. Determine ore transportation system normal operation

Mining is a 24-hour operation that is typically divided into three eight-hour shifts. Each shift has specific tasks to complete. During each shift change there is approximately one hour during which little to no mining is conducted. This will influence the ore transportation system significantly in most cases where the system is not automatically controlled.

During weekdays, the ore production is much higher than on weekends. Each mining shift’s contribution to the daily ore production is different due to various operations that must be completed during the shift. It is important to investigate the ore production during each shift. This will determine the feasibility of an optimised ore transportation schedule.

The operation of the ore transportation system is halted approximately twice a week for roughly four hours to conduct shaft and hoist examinations. The purpose of these inspections is to determine if the shaft meets required standards. This causes a backlog in the ore extraction process that can lead to a deviation from a predetermined schedule. The following aspects are investigated in this step of the investigation methodology:

- The time and duration of mining shifts;
- Weekday and weekend tonnes extracted per shift; and
- Maintenance and inspections schedules.

D. Determine typical power consumption

The power consumption of an ore transportation system needs to be determined in order to determine potential electricity cost savings. All components included in an ore transportation system must be analysed to determine the largest electricity consumer. Within most ore transportation systems, the rock winder is identified as the largest electricity-intensive component.

If power data is accessible and accurate, an average power profile can be determined. The power data of the rock winder can typically be accessed from power meters. In some instances power meters may not be available, in which case Equation 2-4 can be used as discussed in Section 2.4.
E. Investigate gold-processing plant ore requirements

A gold plant is designed to be able to process a large amount of ore daily. As a rule, the total daily tonnes of ore mined must be transported within a limited period to satisfy the “daily call” requested by the gold plant. The daily call refers to the total production target per day. The total daily production transported to a gold plant is measured in a 24-hour period, typically from 05:00 to 05:00 the next morning.

A typical gold plant consists of multiple ore storage units, mills for grinding of ore, thickeners and downstream gold recovery units. The following aspects are investigated in this step of the investigation methodology:

- Number of ore silos;
- Ore silo capacity; and
- Milling capacity.

F. Determine tariff structure used

The key focus of this dissertation is achieving electricity cost savings by optimising the ore transportation system utilisation on multiple mining shafts. The electricity tariff structure used in a mining group should be consistent for each mining shaft included in the mining group. The optimised ore transportation utilisation is achieved by implementing a DSM initiative. Therefore, investigating the tariff structure is a crucial step in the investigation methodology to determine the cost savings.

The electricity tariff structure will ultimately determine which DSM initiative is most promising for optimal cost savings. The following need to be investigated considering the tariff structure:

- Type of tariff structure; and
- Active energy charge (c/kWh) per TOU period.

G. Investigate integrated system layout and operation

The previous steps of the investigation methodology create a good basis for understanding an integrated ore transportation layout. It is important to understand the normal operation and layout of each ore transportation system in an integrated system. In this section of the investigation methodology, all of the above information will be analysed to understand how the ore transportation systems are interlinked.
It is important to understand the interconnection between the ore transportation systems and the ore distribution network of a mining group. Both these systems directly influence the effective utilisation of the other. It is important that the system as a whole be managed to ensure adequate ore supply to the gold-processing plant.

3.2.2 Data acquisitioning and baseline calculations
The focus is on the end goal, which is to derive an optimised ore transportation schedule to determine the electrical cost-saving potential of an integrated system. This requires a power profile baseline for electrical consumption comparison. The baseline is calculated with data acquired from on-site investigations, which shows the typical power consumption of an electricity user.

A baseline contains the average daily power profile of typically three consecutive months to ensure that the impact of all possible scenarios can be considered. In most cases, the necessary baseline data can be acquired from local supervisory control and database acquisition systems (SCADAs).

In some instances, where power meter data is not available, tacho sheets can be used to determine the number of cycles completed. A tacho sheets records the speed-against-time profile of a winder system, which indicates each cycle. Once the total number of winder cycles is known, the equations discussed in Section 2.2.4 can be used to determine the power consumption of the winder system.

3.3 Investigating system characteristics

3.3.1 Ore distribution network integration investigation
In this study, the investigation methodology developed in Section 3.2 is implemented to outline the relevant aspects of the respective investigations. The focus of this section is on illustrating how the investigation methodology is implemented on a real-life ore distribution network.

To illustrate the implementation of the developed investigation methodology, a typical ore distribution network with \( n \) number of mines is investigated. A single gold-processing plant is included in the ore distribution network. The ore distribution network takes the form of rail transportation between the gold plant and each identified mine.

Figure 3-2 demonstrates the two primary focus points of the investigation methodology that was developed. The red circles highlight all the components investigated during the first
stage (ore transportation system level) of the investigation (as demonstrated in Figure 3-1). A detailed application of the first stage of the investigation methodology on a typical mine is discussed in Section 3.3.2.

![Figure 3-2: Typical ore distribution network investigation breakdown](image)

The blue blocks highlight all the components investigated during the second stage (ore distribution network level) of the investigation (as demonstrated in Figure 3-1). A detailed application of the second stage of the investigation methodology on a typical ore distribution network is discussed in Section 3.3.3.

The generic investigation methodology is implemented on each mine in the ore distribution network. The study of one mine is elaborated on in this section, including the ore transportation system of the mine and the ore distribution method from the mine to the gold plant. Thereafter, the gold plant requirements, electricity tariff structure of the system and the integrated layout and operation of the ore distribution network are investigated.

### 3.3.2 Detailed investigation of an ore transportation system

**OTS-1 investigation**

Mine-1 undertakes conventional undercut mining on the Basal and B Reefs with a mining depth of 2200 m. The shaft contributes approximately 14% of the mining group’s total production, which makes the shaft one of the largest operations of the mining group. An average of 4000 tonnes of ore is produced daily, which must be transported to surface.
Ore Transportation System 1 (OTS-1) consists of underground tramming systems, crushers and surface winders that are used to haul personnel and material to surface. Figure 3-3 shows Mine-1’s ore transportation system layout with all of its components.

Underground trams is used to transport mined rock from the stopes to the underground storage. The ore is extracted from the underground storage by crushers and reduced into smaller rock. As rock is crushed, it is loaded into rock winder skips and hoisted to surface.

The rock winder is dedicated to transporting mined rock from underground to surface. Table 3-1 shows the required characteristics of the OTS-1 rock winder.
Table 3-1: OTS-1 rock winder characteristics summary

<table>
<thead>
<tr>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winder type</td>
<td>N/A</td>
</tr>
<tr>
<td>Rated power</td>
<td>kW</td>
</tr>
<tr>
<td>Baseload</td>
<td>kW</td>
</tr>
<tr>
<td>Hoisting depth</td>
<td>Metres (m)</td>
</tr>
<tr>
<td>Skip factor</td>
<td>Tonnes (t)</td>
</tr>
<tr>
<td>Skips per hour</td>
<td>N/A</td>
</tr>
</tbody>
</table>

The ore transportation system operation schedule varies from day to day due to the dynamic underground operations. Once the mined rock is hoisted to surface, it is stored in separate ore- and waste rock silos.

The ore on surface is transported to the gold plant by means of railway transportation. A single railroad is allocated to multiple mines to transport the mined ore by train to the gold plant for further processing. Depending on the distance between the mine and the gold plant as well as train availability, a retour period in the transportation occurs. The required characteristics of the ore distribution network are listed below:

- Number of hoppers;
- Hopper payload (t); and
- Retour time (h).

**Ore handling capacity**

The ore transportation system at Mine-1 was originally designed to transport 6 600 tonnes to surface per day. As determined during the investigation period in 2013, the daily call is 4 500 tonnes of ore and there is 1 350 tonnes waste per day as well. The ore transportation system has a total underground rock storage capacity of approximately 4 150 tonnes. This includes two separate storage units: a 2 150 tonne ore pass is dedicated for ore storage; a 2 000 tonne ore pass is used to store waste rock.

An average of 5 750 tonnes of rock was transported to surface daily during the investigation in 2013. This indicates that the ore transportation system is being utilised at approximately 72% of the total capacity during an average day.
Due to the unpredictable conditions underground and the dynamic nature of daily ore production, the daily ore transported to surface may vary significantly from the average determined above. An error factor is calculated to account for deviation in the daily rock mined and transported to surface.

The ore production error factor is determined by calculating the deviation of the actual daily rock transported versus the three-month average used. This is quantified as a standard deviation in the tonnes of rock mined and transported daily. The standard deviation in tonnes of rock transported daily is quantified to be 420 tonnes (8.7%).

This indicates that the tonnes of rock transported daily can vary between 4 380 and 5 220 tonnes. In order to determine the average idle time of the ore transportation system, the upper boundary of the tonnes transported is used. The idle time of the ore transportation system is used to determine the feasibility of implementing a load shifting intervention on the system. In this case, the idle time was determined to be 21%.

The fact that the ore transportation system was not utilised at its full capacity to hoist all the mined material to surface, meant that a possibility existed to optimise the operational schedule of the system. In the case where the mined ore is stored in stockpiles on surface, unlimited storage capacity is considered. Thus, the surface storage will not be considered as a constraint. This is rarely the case since surface silos are most commonly used as surface rock storage units.

**Normal operation**

The mine’s labour priorities are divided into three main shifts, namely, a morning, afternoon and night shift. During each of these shifts, various secondary activities take place in different sectors across the underground operations. Production is the primary objective during these shifts.

It is important to investigate and analyse the impact of each shift change on the normal utilisation of the ore transportation system. Table 3-2 shows the operational shifts.

<table>
<thead>
<tr>
<th>Shift</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morning</td>
<td>05:00–13:00</td>
</tr>
<tr>
<td>Afternoon</td>
<td>13:00–21:00</td>
</tr>
<tr>
<td>Night</td>
<td>21:00–05:00</td>
</tr>
</tbody>
</table>
A gold mine’s key priority is gold ore production. The current control philosophy implemented on the ore transportation system is transporting mined rock to surface as soon as it is available. The daily rock production of one mine in the mining group could be obtained. The rock production profile is allocated to each of the mines included in the mining group.

The unique production properties and transportation requirements identified in the previous section are used to scale the typical production profile acquired to fit the production capabilities of Mine-1. Production boundaries are calculated by means of the standard deviation (as discussed in the previous section) of the typical variation in day-to-day production of Mine-1. This is done to illustrate how production at Mine-1 may vary at any instance of the day.

Figure 3-4 shows the scaled rock production for an average weekday during each shift, with the upper and lower boundaries determined by the ore handling capabilities of the ore transportation system.

![Figure 3-4: OTS-1 weekday rock production profile](image)

From Figure 3-4, three prominent periods of production can be determined. Figure 3-4 illustrates that shift changes have a large impact on daily production. During the afternoon and night shifts, the most tonnes are delivered, which must be hauled to surface. During the morning shift, the available tonnes to haul to surface is minimal. Ore production decreases over weekends.

Shaft and hoist inspections occur on two different predetermined weekdays. The purpose of these inspections is to ensure that the shaft meets the required standards to deliver safe and
effective production. Both inspections last three to four hours if no significant issues are reported.

These shaft inspections and hoist examinations cause a build-up of ore and waste rock in the underground storage that can possibly affect the daily call.

**Power consumption**

From the investigation it is evident that the rock winder is the largest energy consumer in OTS-1. It is also clear that the rock winder is a key component in an ore transportation system, owing to the unique operation of extracting ore stored underground [36]. Other components’ operations within an ore transportation system are dependent on the utilisation of rock winders.

This electricity cost-saving intervention focuses on the rock winders of an ore transportation system due to the large energy requirement to haul heavy ore loads to surface. Successfully implementing an electricity cost intervention on a rock winder will create opportunities for further cost savings on other components linked to an ore transportation system. This is due to the integrated operation of an ore transportation system, where the rock winder is identified as the key component. The up- and downstream components of a winder can be scheduled according to the winder operation.

Figure 3-5 shows the power baseline for an average weekday calculated over a three-month period. The baseline indicates that the rock winder is constantly used during the day except for during the morning and afternoon shift change. As seen in Figure 3-5, the average power consumption is low during the Eskom morning peak period due to the winder maintenance that is scheduled during this period.
Optimising gold ore transportation systems for electricity cost savings

3.3.3 Detailed investigation of an ore distribution network

Gold plant requirements

The gold plant processes reef and waste rock from various shafts in the area. The plant consists of three process lines and is one of the largest gold plants in South Africa. The gold plant consists of 12 ore silos on surface, each with a capacity of 2 000 tonnes, which indicates that the gold plant has total silo capacity of 24 000 tonnes. During normal daily operation, the silo level is controlled between 50% and 80%. The plant’s milling circuit consists of six ROM (run-of-mine) mills. The details of the mills are summarised in Table 3-3.

<table>
<thead>
<tr>
<th>Type</th>
<th>Quantity</th>
<th>Average tonnage (tph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROM mill</td>
<td>6</td>
<td>100</td>
</tr>
<tr>
<td>Total</td>
<td>6</td>
<td>600</td>
</tr>
</tbody>
</table>

Table 3-3: Gold plant milling circuit summary

With the use of rail distribution, the supply of ore to the gold plant is inconsistent because of the large retour times of the trains and the number of mines included in the ore distribution network. Each mine has a daily call to fulfil to supply the gold plant with suitable tonnes for effective processing operations.

It is important to investigate the gold plant’s processing capacity to be able to determine the limits within which the total daily ore supply from the mines are acceptable. It is essential to ensure that the gold plant will be able to process the supplied ore. The gold plant also requires a minimum ore supply from the mines to ensure continuous milling and refining operations.
Electricity tariff structure
Mine-1 is registered on the Megaflex TOU tariff structure. Refer to Appendix C for a detailed overview of the Megaflex structure.

Integrated layout
An integrated layout of Ore Distribution Network 1 (ODN-1) was compiled using all the information acquired, the investigation methodology and on-site experience. Figure 3-6 shows the integrated operation layout of ODN-1.

![ODN-1 integrated operation layout](image)

Figure 3-6: ODN-1 integrated operation layout

The total power consumption of the rock winders in each ore transportation system in an ore distribution network can be combined as the electricity cost-saving intervention is implemented on an integrated ore distribution network. Figure 3-7 shows the typical power profile of the combined ore transportation systems in an ore distribution network.
3.4 Development of an integrated cost-saving methodology

3.4.1 Preamble
An investigation methodology is used to gather the basic operation, layout and ore handling capabilities of an ore transportation system. Completing the investigation methodology assists in compiling a model for the current operation and control strategies for multiple ore transportation systems in an ore distribution network. During the investigation, it was found that no particular control for electricity cost optimisation was implemented on the ore transportation systems in the ore distribution network under investigation.

From the investigation, it was realised that each ore transportation system included in the ore distribution network had its own production targets and operation capabilities. Knowing this, an electricity cost-saving intervention must be investigated on each individual ore transportation system to obtain an integrated cost-saving in an ore distribution network.

The primary focus is on optimising the winder operation schedule for minimal utilisation during the respective Eskom peak periods in a day. Successfully implementing electricity cost-saving initiatives includes not influencing the ore production negatively. In the following section, the major generic constraints are elaborated.

3.4.2 Constraints in the current control for an ore transportation system
From the investigation methodology, it was found that each ore transportation system in an ore distribution network is allocated with an individual daily call according to its ore production capabilities. This is an ore production target that the ore transportation system
must deliver to a gold plant daily. The following points are a summary of the major constraints that were identified:

- Rock storage capacity;
- Dynamic underground operations;
- Total daily ore production;
- Ore production per shift;
- Daily call;
- Hoisting capacity; and
- No real-time monitoring.

The current control implemented on a typical ore transportation system is ore and waste extraction to meet the daily call. Power consumption and TOU are not considered in the ore extraction process. In order to be able to create effective awareness on different electricity pricing periods during a weekday, some aspects need to be addressed.

The ore production per shift varies day to day because of the dynamic underground circumstances. For instance, it may be that on a specific day the underground railway transportation failed during the afternoon shift, which means that the lost extraction time and backlog of ore need to be transported during the evening shift to meet the daily requirement. Various other technical difficulties can also influence the production at any given time.

To ensure that such an incident does not cause production loss, the rock storage underground and on surface must be monitored and controlled between acceptable limits. The surface storage must be kept above the predetermined minimum to supply the gold plant. Underground storage levels must be kept below the predetermined maximum to be able to contain the mined ore and waste rock at any instance.

Hoisting the ore and waste rock from underground to surface is, thus, an essential factor for an ore transportation system. It is important to understand and analyse the hoisting capabilities of a winder in an ore transportation system. Winder specification may vary from mine to mine, including:

- Hoisting distance;
- Skip size;
- Cycles per hour; and
- Rated power.
These aspects will be integrated in the optimisation model of an ore transportation system.

3.4.3 Proposed control strategy for achieving electrical cost savings

In the previous section, the constraints and shortcomings in the current ore transportation system control to achieving electrical cost savings were discussed. In this section, the proposed control will be discussed in detail, stating a solution to integrate an electricity cost-saving intervention on an ore distribution network.

Integration of an ore distribution network

The integrated electrical cost saving of an ore distribution network proposes that the system as a whole is analysed and optimised. Implementing a DSM intervention on an individual ore transportation system in an ore distribution network can influence the ore distribution in the network and the gold-processing plant’s operation, even more so when optimising multiple ore transportation systems in an ore distribution network. Implementing DSM interventions on multiple ore transportation systems in an ore distribution network will realise large electricity cost savings. This is only feasible if the ore production and gold plant operations are not affected negatively.

Firstly, the potential for implementing a DSM intervention in the form of load shifting on the individual ore transportation systems in an integrated ore distribution network must be determined. The level of success in the proposed strategy will also affect the integrated electricity cost saving. Thus, investigating the feasibility of such an intervention on a single ore transportation system is crucial. Figure 3-8 shows the feasibility test procedure of implementing load shifting on a rock winder in an ore transportation system.
From the investigation, it is clear that the ore transportation system operation, ore distribution network and the gold plant operation are directly dependent on the ore supply from each mine. Achieving electricity cost savings is the primary objective – the exception being that the ore supply from underground is within limits.

Once the feasibility of the ore transportation system optimisation is proven on each ore transportation system within an ore distribution network, the effect on the ore distribution network must be analysed. The total ore supplied to the gold plant must be consistent and the ore distribution network schedule must be adhered to. Figure 3-9 shows a flowchart of the feasibility investigation of the optimised ore transportation systems in the ore distribution network supplying the gold plant.
This approach makes it possible to implement an electricity cost-saving strategy on an integrated ore distribution network to achieve maximum savings.

### 3.4.4 Control strategy conclusion

Implementing a DSM load shifting intervention on a rock winder in an ore transportation system will influence a large number of elements within the ore distribution network. These elements’ constraints were identified and discussed. The identified constraints are used to create simulations (as will be seen in Chapter 4) to test the feasibility and fully quantify the effect of implementing an optimised control strategy to achieve electrical cost savings.

### 3.5 Conclusion

Chapter 3 focused on the strategy for integrating an electricity cost-saving intervention on multiple ore transportation systems in an ore distribution network. It was emphasised that investigation was important. An investigation methodology was developed for an ore distribution network. It was discussed how operational data and baselines were obtained.
In this chapter, a typical ore distribution network and ore transportation system were introduced and the investigation methodology was applied to obtain the necessary information to develop the cost-saving strategy.

The ore distribution network under investigation was analysed to identify the current control strategy of each ore transportation system and the shortcomings thereof. Finally, Chapter 3 concluded with the proposed control strategy for the integration of electricity cost-saving interventions. It is evident that the proposed control strategy has multiple variables that cause an integrated effect. Therefore, in Chapter 4 simulation methods are developed to address this.
Chapter 4

Optimisation model development and simulations

“I am easily satisfied with the very best” – Winston Churchill
4.1 Introduction

The investigation methodology developed in Chapter 3 is implemented to outline the relevant aspects of the respective investigations. After the investigation, the complex integrated network and requirements in an ore distribution network will be understood.

In this chapter, the primary focus is on developing new optimised operating schedules for all ore transportation systems in an ore distribution network to obtain integrated electricity cost savings. The impact of implementing the optimised control strategy will also be determined. As explained in Chapter 3, a detailed investigation on an ore distribution network is needed before a model can be developed.

The optimisation model is based on the control strategy proposed in Section 3.4. The relevant data and information obtained in Chapter 3 will be used to test the feasibility and the potential cost savings of the newly developed control strategy. This chapter is structured according to the following:

- Model development
- Model verification
- Optimisation outcomes

4.2 Model development

4.2.1 Review of investigation method

The optimisation model is created to serve as a generic system that can be implemented on various ore transportation systems. To start developing such a model, the following information of a typical ore distribution network is required:

- Data
- Layout

The layout of an ore distribution network is dependent on the primary operation used to transport the mined rock to the gold-processing plant. The rock distribution operation may consist of conveyor, road or rail transportation. In this study, the focus is on road and rail transportation, both consisting of certain retour delays between the mines and the gold plant included in the ore distribution network.

Chapter 3 discussed the specific data requirements. Table 4-1 summarises which data is required to develop an optimisation model for a typical ore distribution network.
Table 4-1: Summary of required ore distribution network information

<table>
<thead>
<tr>
<th>Data required</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineshafts</td>
<td>Number of mineshafts included in an ore distribution network</td>
<td>N/A</td>
</tr>
<tr>
<td>Gold plants</td>
<td>Number of gold plants included in an ore distribution network</td>
<td>N/A</td>
</tr>
<tr>
<td>Ore distribution</td>
<td>Method used to distribute gold ore to gold plants</td>
<td>N/A</td>
</tr>
<tr>
<td>Distribution limitations</td>
<td>Distribution delays and retour times per shaft</td>
<td>Time (h)</td>
</tr>
<tr>
<td>Ore handling</td>
<td>Amount of ore transported per trip</td>
<td>Capacity (t)</td>
</tr>
<tr>
<td>Gold plant rock storage</td>
<td>The total ore capacity of the gold plant silos</td>
<td>Capacity (t)</td>
</tr>
<tr>
<td>Gold plant ore requirement</td>
<td>Total daily ore processing capacity</td>
<td>Capacity (t)</td>
</tr>
</tbody>
</table>

Once the ore distribution network has been identified, the ore transportation system of each mine included in the ore distribution network must be analysed. The typical layout and operation of an ore transportation system is constant, i.e. the mined rock is gathered, stored and hauled to surface (Figure 1-6). Although the typical layout may be consistent, the daily operational schedule, ore handling capacity and equipment used may differ. Table 4-2 summarises which data is required to develop an optimisation model for a typical ore transportation system.

Table 4-2: Summary of required ore transportation system information

<table>
<thead>
<tr>
<th>Data required</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ore production capabilities</td>
<td>The amount of ore mined daily per shift</td>
<td>Capacity (t)</td>
</tr>
<tr>
<td>Ore production profile</td>
<td>The amount of ore produced during a certain time interval in a day</td>
<td>Rate (t/h)</td>
</tr>
<tr>
<td>Underground storage</td>
<td>The total capacity of the underground rock storage</td>
<td>Capacity (t)</td>
</tr>
<tr>
<td>Ore transportation system hoisting capabilities</td>
<td>The rate at which the ore is extracted from the underground rock storage</td>
<td>Rate (t/h)</td>
</tr>
<tr>
<td>Ore transportation system rock winder power usage</td>
<td>The electricity consumed by the ore transportation system</td>
<td>Power (kW)</td>
</tr>
<tr>
<td>Surface storage</td>
<td>The total capacity of the surface rock storage</td>
<td>Capacity (t)</td>
</tr>
</tbody>
</table>
Obtaining the relevant data and understanding the layout of an ore distribution network create the opportunity to develop an optimisation model for the system. Due to the complex nature of an ore distribution network, the model is developed in three different levels. Figure 4-1 shows a summary of the three levels that form the building blocks used to develop the model.

![Figure 4-1: Integrated optimisation model](image)

As illustrated in Figure 4-1, the mine layout and the ore transportation system power consumption are the first aspects that must be modelled and analysed. This is due to ore production being the key component in any mining operation. The ore distribution method is modelled in Level 2 and the gold plant operation is modelled in Level 3 to analyse the integrated effect of the potential optimisation of each ore transportation system in the ore distribution network.

### 4.2.2 Mining

As discussed, the ore transportation system is the central component of each mine included in the ore distribution network. The primary target of an ore transportation system is to extract all the rock mined on a daily basis. The rock winder is identified as the key focus for
implementing an electricity cost-saving intervention on an ore transportation system. Thus, the operating schedule of the rock winder will be optimised to realise significant cost savings.

The data necessary to develop Level 1 of the model for the mining operation of an individual mine is presented in Table 4-2. A detailed overview of the steps taken to develop Level 1 of the integrated model follows. Figure 4-2 presents Level 1 of the model with the underground rock supply, underground and surface storage buffers and the rock winder in an ore transportation system.

Figure 4-2: Level 1 of the optimisation model

**Underground rock storage**

The underground rock storage level is identified as one of the parameters according to which the ore transportation system operates. It is important to control the underground silo below its maximum level at any given time. Level measurement instrumentation is in most cases not practical in underground storage due to the rough nature of underground operations.
Two factors influence the rock level in the silo – the ore supply from the mining operations and the hoisting capabilities of the rock winder. A simple mass balance is used to determine the underground storage levels (Equation 4-1):

\[
\text{Initial level} + \text{Input} = \text{Final level} + \text{Output} \tag{4-1}
\]

Assumption: Due to a lack of measurement instrumentation on a typical underground storage unit, the initial value of the storage is assumed.

During an investigation, the normal daily ore and waste rock production capabilities of a mine must be identified. To simplify the model, the ore and waste rock production will not be analysed separately. The total production of ore and waste rock will be used to determine the rock input to the underground storage. This is possible because the key priority of an ore transportation system is to extract mined material, irrespective of it being gold ore or waste rock, from underground to surface.

In some cases, the actual ore supply rate of the mining activities is available. If this information is unavailable, the average daily ore production can be used to determine an hourly production rate. Due to the dynamic production operations of a mine, an hourly production profile is used. Table 4-3 illustrates the typical rock input parameters of the model that was developed. The typical profile used can be scaled according to daily varying tonnages for site-specific applications.

<table>
<thead>
<tr>
<th>Time (h)</th>
<th>Rock production rate (P_h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:00</td>
<td>316</td>
</tr>
<tr>
<td>01:00</td>
<td>305</td>
</tr>
<tr>
<td>02:00</td>
<td>306</td>
</tr>
<tr>
<td>03:00</td>
<td>158</td>
</tr>
<tr>
<td>04:00</td>
<td>22</td>
</tr>
<tr>
<td>05:00</td>
<td>9</td>
</tr>
<tr>
<td>06:00</td>
<td>18</td>
</tr>
<tr>
<td>07:00</td>
<td>22</td>
</tr>
<tr>
<td>08:00</td>
<td>61</td>
</tr>
<tr>
<td>09:00</td>
<td>83</td>
</tr>
<tr>
<td>10:00</td>
<td>89</td>
</tr>
<tr>
<td>11:00</td>
<td>103</td>
</tr>
<tr>
<td>12:00</td>
<td>76</td>
</tr>
<tr>
<td>13:00</td>
<td>27</td>
</tr>
<tr>
<td>14:00</td>
<td>32</td>
</tr>
<tr>
<td>15:00</td>
<td>126</td>
</tr>
</tbody>
</table>
Once the rock supply to the underground silos has been determined, the hoisting capabilities of the winder must be derived. The winder specifications are used for the optimisation model to calculate the rate at which rock is extracted from the underground storage. As mentioned in Section 3.4.2, the winder specifications are site-specific. It is essential to identify the capacity of the winder skip as well as the maximum number of cycles that can be achieved in an hour.

A predetermined maximum number of cycles is determined using site-specific requirements and winder design. The maximum cycles per hour is calculated using the loading time of the skip and the hoisting time, which is dependent on mine depth. During a single winder cycle, two skips are hauled to surface. Skip size is also site-specific. Identifying the skip and hoisting capacity makes it possible to determine the rate at which ore is extracted from underground storage (Equation 4-2):\

\[ f_h = s_c \times s_h \] (4-2)

Where:

\( f_h \) – Hoisting rate (t/h)

\( s_c \) – Skip capacity (t/skip)

\( s_h \) – Hoisting capacity (skips/h)

Furthermore, using the parameters identified in this section, the underground silo level can now be determined using daily operational information (Equation 4-3).

\[ UGS_F = P_h + UGS_I - f_h \] (4-3)
Optimising gold ore transportation systems for electricity cost savings

Where:

\( UGS_F \) – Final underground rock storage level (t)

\( UGS_I \) – Initial underground rock storage level (t)

\( P_h \) – Rock production rate (t/h)

\( f_h \) – Hoisting rate (t/h)

The underground rock storage level is determined to ensure that optimising the winder’s operational schedule does not compromise the daily production of the mine.

**Rock winder power consumption**

Section 2.2.4 discussed the energy consumption of a typical rock winder system. Equation 4-4 calculates the energy consumption of the specific rock winder under investigation.

\[
EE = \left( \frac{(s_c \times s_h \times g \times d_m \times f_{fs_c})}{3600} \right) + B_l
\]

(4-4)

Where:

\( EE \) – Rock winder energy consumption (kWh)

\( s_c \) – Skip capacity (t/skip)

\( s_h \) – Hoisting capacity (skips/h)

\( g \) – Gravitational acceleration \( (m/s^2) \)

\( d_m \) – Hoisting depth (t/h)

\( ff_{fs_c} \) – Hoisting efficiency factor

\( B_l \) – Winder baseload (kWh)

Equation 4-4 makes use of an efficiency factor that varies from site to site. The efficiency factor is used to compensate for multiple aspects that cannot be determined, which include:

- Winder motor efficiency;
- Inaccurate weighing of each skip;
- Rope tension variations;
- Friction factor on skip path; and
- General efficiency of the hoisting system.
It is impossible to determine the specific value for each of these aspects. Empirical data, which was acquired from the on-site investigation, is therefore used to determine the average efficiency factor of each skip in the specific winder system. This is done using Equation 4-5.

\[ f_{fs_c} = \frac{EE}{EE_p} \]  \hspace{1cm} (4-5)

Where:

- \( f_{fs_c} \) – Hoisting efficiency factor
- \( EE \) – Calculated rock winder energy consumption (kWh)
- \( EE_p \) – Actual rock winder energy consumption from power meter reading (kWh)

**Surface rock storage**

The rock extracted from the underground storage units is hauled directly to surface and delivered to the separate ore and waste rock surface silos. During the investigation, the daily call for mined ore and waste rock hoisted to surface is determined. According to mine personnel, the ore-to-waste ratio is considered constant from day to day. The ore-to-waste ratio is used to determine the amount of tonnes sent to the surface ore and waste rock storage. Equation 4-6 states that:

\[ R_s = \frac{f_h \times C_R}{RM} \]  \hspace{1cm} (4-6)

Where:

- \( R_s \) – Ore hoisted to surface (t/h)
- \( f_h \) – Hoisting rate (t/h)
- \( C_R \) – Average amount of ore hoisted daily (t)
- \( RM \) – Average amount of rock hoisted daily (t)

The amount of ore extracted from underground is transported to the surface ore silos directly. The surface silo level is influenced by a number of factors including tonnes extracted from underground, silo capacity and the amount of ore removed by the transportation system.

In most cases, level measurement instrumentation is not installed in the surface silos. As with underground storage, a mass balance is used to calculate the silo level as indicated in Equation 4-7.
Optimising gold ore transportation systems for electricity cost savings

\[ SS_F = SS_I + R_s - f_{ODN} \]  \hspace{1cm} (4-7)

Where:

\( SS_F \) – Final surface ore silo level (t)

\( SS_I \) – Initial surface ore silo level (t)

\( R_s \) – Ore hoisted to surface (t/h)

\( f_{ODN} \) – Ore distribution network rock extraction rate (t/retour)

The rate at which the ore distribution network extracts ore from the surface silo is discussed in Section 4.2.3. The purpose of surface storage monitoring is to ensure that the optimised winder operation schedule does not cause the ore level to deplete or to reach maximum capacity. This would disrupt the overall ore distribution network process line.

Once the waste rock is on surface, it is transported to waste dumps. No consistent monitoring or control is applied to this operation due to the low priority of waste accounting.

4.2.3 Distribution

Various methods are implemented on ore distribution networks to transport mined gold ore from each mine to a processing plant. This dissertation focuses on the primary transportation methods including road and railway transportation. Both of these methods have a specific retour time depending on the number of mines, the distance between the mines and the gold plant, and the distribution method. Figure 4-3 illustrates typical road- and railway distribution networks.

Figure 4-3: Level 2 of the optimisation model
Road distribution
Trucks are used most commonly in the form of road distribution networks. In this case, the gold plant is usually located in the vicinity of the mines. A number of trucks is commonly assigned to a specific route between a single mineshaft and the gold plant. The distance between the start and end destinations will determine the retour time. The ore distribution rate is determined by identifying the following aspects:

- Retour time;
- Truck payload capacity; and
- Number of trucks.

Once these variables are known, the rate at which the ore is transported to the gold plant can be calculated by Equation 4-8:

\[
f_{ODN} = \frac{(T_n \times T_c)}{R_t}
\]  

(4-8)

Where:

- \(f_{ODN}\) – Ore distribution network rock extraction rate (t/retour)
- \(T_n\) – Number of trucks
- \(T_c\) – Truck payload capacity (t)
- \(R_t\) – Retour time (h)

Railway distribution
Trains are most commonly used in the form of railway distribution networks. In the case of a railway distribution network, multiple trains travel from site to site until the maximum payload is reached. Trains return to the gold plant to offload the ore and return to their predetermined routes to collect ore at the mines. The ore distribution rate can be determined by identifying the following aspects:

- Retour time;
- Number of hoppers per train; and
- Hopper capacity.

Once these variables are known, the rate at which the ore is transported to the gold plant can be calculated using Equation 4-9:
Optimising gold ore transportation systems for electricity cost savings

\[ f_{ODN} = \frac{(H_n \times H_C)}{R_t} \]  

(4-9)

Where:

- \( f_{ODN} \) – Ore distribution network rock extraction rate (t/retour)
- \( H_n \) – Number of hoppers per train
- \( H_C \) – Hopper payload capacity (t)
- \( R_t \) – Retour time (h)

### 4.2.4 Gold plant

It is essential that the gold plant production capacity is not exceeded or limited during an operational day. The maximum, minimum and nominal processing capacity of the gold plant are determined to ensure that the gold plant operates within these limitations.

The nominal processing capacity of a gold plant is obtained by calculating the daily average processing operation of the mills. The gold plant operational data is available on-site and can be acquired during the site investigation.

The maximum processing capacity can be determined by combining the total milling capacity and the reserve silo level of the gold plant. This is done to determine the maximum daily amount of ore supply in which the efficient processing can occur. A gold plant strives to control the silo levels within a predetermined margin. The spare capacity of a silo is known as the margin between the maximum control level and the maximum silo capacity.

The maximum milling capacity can now be determined by Equation 4-10:

\[ GPMC_{\text{max}} = CM_N + (f_{SC} \times SS_C) \]  

(4-10)

Where:

- \( GPMC_{\text{max}} \) – Maximum milling capacity (t/d)
- \( CM_N \) – Nominal milling capacity (t/d)
- \( f_{SC} \) – Reserve silo capacity (%)
- \( SS_C \) – Surface storage capacity (t)
The minimum processing capacity of the gold plant is usually considered a specific proportion of the nominal processing capacity. This is mostly directly linked to the layout and production capabilities of the gold plant. The minimum capacity factor varies from site to site, which must be identified during the site investigation. Equation 4-11 shows how to calculate the minimum milling capacity to determine the minimum amount of ore supply required daily for efficient processing operations.

\[ GPMC_{\text{min}} = CM_N \times C_p \]  \hspace{1cm} (4-11)

Where:

- \( GPMC_{\text{min}} \) – Minimum milling capacity (t/d)
- \( CM_N \) – Nominal milling capacity (t/d)
- \( C_p \) – Minimum capacity factor (%)

The total amount of tonnes transported to the gold plant is calculated to be the forecasted ore supply from all the mines included in the ore distribution network. The forecasted ore supply of each mine was determined in Section 4.2.1. The total ore supply can now be determined by adding all the ore transportation systems in Equation 4-12.

\[ F_{\text{OS}} = f_{t_{ODN1}} + \ldots + f_{t_{ODNn}} \]  \hspace{1cm} (4-12)

Where:

- \( F_{\text{OS}} \) – Total forecasted ore supply (t/d)
- \( f_{t_{ODN1}} \) – Tonnes transported daily from Mine-1 (t/d)
- \( f_{t_{ODNn}} \) – Tonnes transported daily from Mine-n (t/d)

Using the three levels, a simplified model can be created for the simulation and optimisation of any specific ore distribution network. This approach is used to estimate the optimisation and feasibility of a potential electricity cost-saving intervention in the form of load shifting on a complex ore distribution network with multiple ore transportation systems.

### 4.3 Model verification

The verification of the developed model focuses on verifying the operational aspects of the rock winder. As discussed, the rock winder is the key component in an ore transportation...
system. The simulated power consumption according to an actual operational schedule must be accurate to obtain reliable electricity cost-saving potential.

The model verification is based on a single ore transportation system that provided the necessary information to be able to compare the optimised model to the actual data.

The simulated amount of rock extracted due to the operational schedule implemented on a rock winder must be accurate. This is important, as the key focus of an ore transportation system is on extracting the rock mined to surface on a daily basis. The amount of ore extracted influences the entire ore transportation system and the ore distribution network operation as illustrated in Section 4.2.4.

The 24-hour power profile of a rock winder was obtained from the installed power meters in the mine substation at Mine-1. The number of skips per hour during the same period than the measured power profile was acquired from the mine’s on-site SCADA. The number of skips per hour was used as an input to the model to obtain the simulated power consumption seen in Figure 4-4.

Comparing the actual power consumption with the simulated power consumption of the rock winder indicated an average error of 6% for the developed model. The 6% deviation in the rock winder power consumption was due to the efficiency variation during each cycle completed by the rock winder, as discussed in Section 4.2.1.

![Figure 4-4: Actual versus modelled rock winder power consumption](image-url)
The modelled tonnes of rock hoisted to surface for the same day as the power profile seen in Figure 4-4 was verified with actual data acquired from the mine SCADA. The tonnes of rock hoisted hourly during the day was compared with the tonnes of rock hoisted according to the model. An average hourly error of 4% was seen between the actual data and the model calculations as shown in Figure 4-5.

Figure 4-5: Actual versus modelled rock hoisted per hour

Figure 4-6 shows the cumulative hourly rock extraction profile for the actual and the simulated day. The actual profile of tonnes extracted per day served as a target for the simulated day. As can be seen from Figure 4-6, the simulated day (using the newly developed model) was within 4% accuracy of the actual day. The two profiles followed the same trend, which verified the model. Both these profiles reached the 100% production target mark.

Figure 4-6: Actual cumulative tonnes versus modelled tonnes hoisted per day
The ore distribution data gathered in the investigation phase of the study only showed the daily total amount of ore transported to the gold plant. The actual daily ore transported to the gold plant was used as a target for the modelled ore distribution network. The ore distribution in this case was by rail transportation.

The train consisted of 14 hoppers – each with a capacity of approximately 52 tonnes. The train had a minimum return period of two hours. This indicates that the ore could only be collected from the mine every two hours. This is accounted for in the model as seen in Figure 4-7.

![Figure 4-7: Actual versus modelled ore distribution network operation](image)

Figure 4-7 shows the total ore mined, extracted and transported to surface is transported to the gold plant within the 24-hour period of the daily call.

It can be seen in Figure 4-4 to Figure 4-7 that the data points from the optimisation model and the actual power profiles did not correlate completely. They were, however, within a range of 6% of each other. Numerous limitations occurred with the optimisation model that could have influenced the accuracy of the model:

- Due to the dynamic operations and unpredictable conditions in the mining sector, the model was simplified, considering only the most critical inputs.
- As discussed, the power profile obtained from the model used an iterative process to determine the efficiency factor for the energy required to hoist several payloads of rock. This procedure influenced the accuracy of the model.
As more data becomes available, the optimisation model may become more accurate. As discussed in Chapter 4, the model serves as a tool to investigate load shifting potential and electricity cost savings. Now that the model has been verified, it can be used to optimise the multiple ore transportation systems included in an ore distribution network to identify potential electricity cost savings.

### 4.4 Optimisation

The key purpose of the optimisation was minimising the total rock winder power consumption during the peak periods and, in doing so, minimising the total electricity cost of the rock winder operation. To obtain an optimised model, an iterative optimising process was used to create the most cost-effective solution, whilst considering all the constraints and variables identified in Chapter 3.

The input data was compiled for a typical weekday in a specific demand month. It would be possible to optimise each day in a typical month if enough operational data could be captured. This would yield a more accurate representation of the real rock winder operation.

In order to optimise the rock winder operation for electrical cost savings, a minimum number of cycles had to occur during Eskom peak periods. This suggested that the underground rock silo had to be at its minimum level before the peak period. On the other hand, the surface ore silo had to be at its maximum level to ensure that the gold plant did not experience production loss due to depleted surface ore stock.

The model was optimised using three different periods; these time slots were adapted from the Eskom TOU tariff structure.

<table>
<thead>
<tr>
<th>Period</th>
<th>Period description</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Off-peak</td>
<td>8 hours</td>
</tr>
<tr>
<td>2</td>
<td>Standard</td>
<td>11 hours</td>
</tr>
<tr>
<td>3</td>
<td>Peak</td>
<td>5 hours</td>
</tr>
</tbody>
</table>

The cost-saving intervention focused on minimising the winder utilisation during Period 3, which included the Eskom morning- and evening peak periods. The shaft and hoist examinations at a mine are usually conducted during the morning peak periods. Thus, the focus was on reducing winder utilisation during the evening peak period.
The objective of the optimisation was to schedule the operating time of the winder to less expensive periods of the day. This could be achieved by scheduling maximum winder operation during the off-peak and standard periods.

The optimisation of the rock winder aimed to reduce the load during the peak periods and to shift it to off-peak periods. This is not always possible due to the multiple constraints and limitations of a typical ore transportation system. Thus, the focus was to shift the peak period load to off-peak and standard periods while still ensuring overall operational constraints are within limits.

Optimisation takes place at Level 1 of the optimisation model. Level 2 and Level 3 form part of the model to determine the effect of the optimisation on the ore distribution network and gold plant operation. The integration of all three levels in an ore distribution network is important for a successful optimisation model. Figure 4-8 shows the inputs for this specific application of the optimisation on Level 1 of the model.
Level 2 and Level 3 are mostly dependent on Level 1 operations. The inputs required for Level 2 and Level 3 of the optimisation model are:

- Ore distribution schedule; and
- Gold plant milling capacity.

The outputs required from the optimisation model are:

- Optimised winder schedule;
- Winder power cost;
- Rock storage levels;
- Mined ore extraction;
- Ore distribution; and
- Gold plant ore supply.

Optimising the rock winder operational schedule to less expensive time periods during a typical weekday would reduce the specific hoisting energy cost (R/tonne), which in turn would result in more economical operation.

The investigation methodology discussed in Chapter 3 and model developed in Chapter 4 provided the necessary tools to complete the integrated optimisation of an ore distribution network. The optimisation results will be verified against real-life implementation results in the form of several case studies in Chapter 5.

### 4.5 Reporting for sustainability

Monitoring an optimised ore transportation system’s day-to-day operation will play a crucial role in the achievable electricity cost-saving potential. All the necessary information to create an informative reporting structure is available on the on-site SCADA and winder monitoring system installed on the winder.

To ensure sustainable electricity cost savings on the ore transportation systems in an ore distribution network, reports are created to inform the mine personnel of daily operations and operational shortcomings. Typical information required to monitor the operations of an ore transportation system are:

- Winder operation schedule;
- Winder energy usage distribution and cost;
- Tonnes extracted from underground;
- Cost savings; and
- Missed opportunities.

Reporting on the daily operation of multiple ore transportation systems in an ore distribution network is important for the sustainability of the effective and optimised operation of the whole ore distribution network. Furthermore, accurate reporting on the production of each ore transportation system will enable the gold plant to implement improved production planning capability. In turn, this can create further load management opportunities on the gold plant. Refer to Appendix D for an example of a typical reporting structure.

4.6 Conclusion

In Chapter 4, the proposed strategy was developed into an optimisation model. The model was verified by comparing actual operational data with the results obtained from the model. A proposed optimisation technique to achieve electricity cost savings was specified and discussed.

In Chapter 5, the newly developed model is used to optimise multiple ore transportation system with diverse daily production capabilities and constraints. The integrated effect of the optimisation is also analysed and discussed.
Chapter 5

Ore transportation optimisation, case studies and results

“Actions speaks louder than words but not nearly as often” – Mark Twain
5.1 Introduction

In this study, two different ore distribution networks were investigated, each containing multiple mineshafts with diverse ore transportation systems. Both the ore distribution networks in question belong to a single mining group. The investigation methodology developed in Chapter 3 was used to form a background to the typical operation and constraints on each of the relevant ore transportation systems.

The model developed in Chapter 4 is used to determine the feasibility of implementing a load shifting initiative on each of the ore transportation systems in the ore distribution network being investigated. After the feasibility of implementing a load shifting initiative is confirmed using the optimisation model, the actual results of the implementation of the initiative are compared and discussed. Each case study is discussed at the hand of the following:

- Background;
- Identification of load management potential for each ore transportation system;
- Results of implementation for each ore transportation system and the integrated potential savings; and
- Conclusion.

5.2 Case Study A

5.2.1 Background

Ore Distribution Network A (ODN-A) contains two mineshafts with a single ore transportation system each. The two ore transportation systems in this section are described as Ore Transportation System A1 (OTS-A1) and Ore Transportation System A2 (OTS-A2). A single on-site gold-processing plant is supplied from both OTS-A1 and OTS-A2 by means of road transportation.

Refer to Appendix A for the detailed investigation that was done on the ore transportation systems and the gold plant included in ODN-A. The investigation in Appendix A is based on the investigation methodology discussed in Chapter 3. All the required information for an accurate model is discussed in detail and is used for the optimisation of the ore transportation system.
5.2.2 Identify load management opportunities

During the investigation phase of the study, the necessary data and information are obtained and populated into the newly developed model discussed in Chapter 4. The model is used to determine the potential load management opportunities of each individual ore transportation system in ODN-A. The combined ore transportation system potential savings of an ODN is also discussed by addressing:

- The optimal power profile versus the operation baseline;
- Ore transportation system storage levels; and
- Mined ore extracted and distributed.

**OTS-A1**

Optimised power profile versus baseline

The optimised power profile and the scaled baseline of OTS-A1 is illustrated in Figure 5-1. The baseline was scaled to be energy neutral with the potential load management profile. This is because no operational load was lost but rather shifted. The optimised power profile of the rock winder in OTS-A1 was obtained by following the procedures and adhering to the constraints as set out in the model discussed in Chapter 4.

![Figure 5-1: OTS-A1 optimised rock winder power profile versus scaled baseline](image)

A typical daily production profile was scaled to fit the average daily production of the mine to determine the hourly production rate of OTS-A1. The model was used to simulate an average weekly power consumption of the rock winder in the ore transportation system, whilst satisfying all the predetermined constraints. As seen in Figure 5-1, Mine-A1 already
shifted load from its peak TOU periods, although improvement was still possible to obtain optimal load shifting.

An average evening peak load shift of 740 kW and morning peak load shift of 240 kW were proposed by the optimisation of the rock winder in OTS-A1. Although the primary focus was on the evening peak, the optimised model indicated a morning peak load reduction was possible as well. The morning peak was included in the optimisation to quantify the potential electrical cost savings of OTS-A1 fully.

As seen in Figure 5-1, the potential morning peak period savings was minimal due to the weekly schedule maintenance of the ore transportation system during that time. The potential evening peak load was shifted to the less expensive periods during the day.

The rock winder load reduction of OTS-A1 during Eskom’s peak periods presented considerable electricity cost savings. An average summer weekly saving of R3 439 was achievable. During winter months, for the same load shift opportunity, an average weekly saving of R7 187 is proposed. Refer to Appendix C to see the winter and summer electricity cost. If quantified to a year, the average electricity cost savings was approximately R300 000 per year. Table 5-1 shows the average daily potential cost savings in rands.

<table>
<thead>
<tr>
<th>TOU period</th>
<th>Tariff (R/kWh)</th>
<th>Baseline cost</th>
<th>Optimised cost</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak</td>
<td>0.7093</td>
<td>R8 897</td>
<td>R1 064</td>
<td>R7 833</td>
</tr>
<tr>
<td>Standard</td>
<td>0.4882</td>
<td>R33 610</td>
<td>R35 426</td>
<td>R-1 816</td>
</tr>
<tr>
<td>Off-peak</td>
<td>0.3097</td>
<td>R17 521</td>
<td>R20 099</td>
<td>R-2 578</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>R60 027</td>
<td>R56 588</td>
<td>R3 439</td>
</tr>
</tbody>
</table>

Average savings per week: R3 439

Ore transportation system storage levels

During the investigation of the normal operation of OTS-A1, the margin within which the hourly production might vary in an average day was determined. The production deviation was used as upper- and lower boundaries during the ore storage level monitoring of the respective ore storage units.
Assumptions: The initial underground and surface storage levels for the simulated operational mining week were required to quantify the effect of an optimised rock winder schedule on the respective storage units.

- Initial underground storage level: 30%
- Initial surface silo level: 60%

Figure 5-2 shows the underground rock storage level during a 24-hour day in which the ore transportation system was optimised. The underground storage maximum and minimum limits are indicated on the graph as 20% and 40%. The maximum and minimum limits are identified by the relevant on site team to ensure efficient operation without compromising production. It can be seen that the underground storage constraints were satisfied.

Figure 5-3 shows the surface silo level during a 24-hour day in which the ore transportation system was optimised. The surface silo maximum and minimum limits are indicated on the graph as 40% and 80%. It can be seen that the surface silo constraints were satisfied.
Optimising gold ore transportation systems for electricity cost savings

Figure 5-3: OTS-A1 surface silo storage level percentage

Figure 5-3 shows that the underground and surface storage were able to absorb the supply of mined rock with the optimised rock winder schedule of OTS-A1.

**Mined ore extraction and distribution**

Figure 5-4 shows the rate at which the mined rock was extracted from underground to surface. It was interpreted that the total amount of rock mined was hauled to surface by implementing the optimisation. It is clearly seen that the rate at which the tonnes were extracted from underground flattens during the peak periods due to the peak load reduction.

Figure 5-4: OTS-A1 cumulative production and ore distribution network transportation

Figure 5-4 indicates that the rock extracted was transported to the gold plant. The road distribution network enabled the rock to be transported constantly throughout a typical day.
As can be seen, all the rock mined during the specific day was hauled to surface and transported to the gold plant within the specified call period.

**OTS-A2**

**Optimised power profile versus baseline**

The optimised power profile and the scaled baseline of OTS-A2 are illustrated in Figure 5-5. The optimised power profile of the rock winder in OTS-A2 was obtained by following the procedures and adhering to the constraints as set out in the optimisation model.

![Figure 5-5: OTS-A2 optimised rock winder power profile versus scaled baseline](image)

A typical daily production profile was scaled to fit the average daily production of the mine to determine the hourly production rate of OTS-A2. The model was used to simulate an average weekly power consumption of the rock winder in OTS-A2, whilst satisfying all the predetermined constraints.

An average evening peak load shift of 685 kW and morning peak load shift of 403 kW were proposed by optimising the rock winder in Ore Transportation System A2 (OTS-A2). Although the primary focus was on the evening peak, the optimised model indicated that a morning peak load reduction was possible as well. Including the morning peak period in the optimisation showed a large effect on the total electricity cost savings.

The rock winder load reduction of OTS-A2 during Eskom’s peak periods showed considerable electricity cost savings. An average summer weekly saving of R4 548 was achievable as shown in Table 5-2. During winter months, for the same load shift opportunity, an average weekly saving of R8 761 is proposed. Refer to Appendix C to see the winter and
summer electricity cost. If quantified to a year, the average electricity cost savings was approximately R370 000 per year.

Table 5-2: OTS-A2 optimised cost savings per week

<table>
<thead>
<tr>
<th>TOU period</th>
<th>Tariff (R/kWh)</th>
<th>Baseline cost</th>
<th>Optimised cost</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak</td>
<td>0.7093</td>
<td>R10 997</td>
<td>R2 057</td>
<td>R8 940</td>
</tr>
<tr>
<td>Standard</td>
<td>0.4882</td>
<td>R18 822</td>
<td>R20 160</td>
<td>R-1 338</td>
</tr>
<tr>
<td>Off-peak</td>
<td>0.3097</td>
<td>R8 526</td>
<td>R11 581</td>
<td>R-3 055</td>
</tr>
<tr>
<td>Total</td>
<td>R38 345</td>
<td>R33 798</td>
<td></td>
<td>R4 548</td>
</tr>
</tbody>
</table>

Average savings per day: R4 548

Ore transportation system silo levels

During the investigation of the normal operation of OTS-A2, the margin within which the hourly production might vary in an average day was determined. The production deviation was used as upper and lower boundaries during the ore storage level monitoring of the respective ore storage units.

Assumption: The initial underground storage level for the simulated operational mining week was required to quantify the effect of optimised rock winder schedule on the storage unit.

- Initial underground storage level: 30%

Figure 5-6 shows the underground rock storage level during a 24-hour day in which the ore transportation system was optimised. The underground storage maximum and minimum limits are indicated on the graph as 20% and 40%. It is seen that the underground storage constraints were satisfied.
The surface rock storage was not investigated in this instance because the rock was stored in stockpiles on surface. The surface stockpiles had large constraint boundaries. It was found that the underground storage was able to absorb the mined rock with the optimised rock winder schedule of OTS-A2.

**Mined ore extraction and distribution**

Figure 5-7 shows the average rate at which the mined rock was extracted from underground to surface. It was interpreted that the total amount of ore mined was hauled to surface by implementing the optimisation. It is clearly seen that the rate at which the tonnes were extracted from underground flattened during the peak periods due to the peak load reduction.

![Figure 5-6: OTS-A2 underground storage level percentage](image)

![Figure 5-7: OTS-A2 cumulative production and ore distribution network transportation](image)
Optimising gold ore transportation systems for electricity cost savings

Figure 5-7 indicates that the rock extracted was transported to the gold plant. The road distribution network enabled the rock to be transported constantly throughout a typical day. It was observed that the rock mined during the specific day was hauled to surface and transported to the gold plant within the specified call period.

**ODN-A integrated optimisation results**

Figure 5-8 represents the integrated ore transportation system optimised power profile for ODN-A. A total load shift of 640 kW was seen as achievable during the morning peak with an evening peak load shift of 1 400 kW.

![Figure 5-8: ODN-A integrated optimised power profile](image)

Optimising all the ore transportation systems included in ODN-A resulted in a large load reduction during Eskom’s peak periods, which illustrated considerable electricity cost savings. An average summer weekly saving of R7 987 was achievable. During winter months, for the same load shift opportunity, an average weekly saving of R15 949 is proposed. If quantified to a year, the average electricity cost savings could add up to R670 000 per year. Table 5-3 shows the average weekly potential cost savings in rands.

<table>
<thead>
<tr>
<th>TOU period</th>
<th>Tariff (R/kWh)</th>
<th>Baseline cost</th>
<th>Optimised cost</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak</td>
<td>0.7093</td>
<td>R19 894</td>
<td>R3 121</td>
<td>R16 773</td>
</tr>
<tr>
<td>Standard</td>
<td>0.4882</td>
<td>R52 431</td>
<td>R55 585</td>
<td>R-3 154</td>
</tr>
<tr>
<td>Off-peak</td>
<td>0.3097</td>
<td>R26 047</td>
<td>R31 680</td>
<td>R-5 633</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>R98 373</td>
<td>R90 386</td>
<td>R7 987</td>
</tr>
</tbody>
</table>

Average savings per week: R7 987
Gold Plant A

As discussed in Section 4.2.3, a gold plant requires a constant ore feed from each of the ore transportation systems in the ore distribution network. The optimisation of each individual ore transportation system in a single ore distribution network can influence the gold plant operation. Although electrical cost saving may be possible on each of these ore transportation systems, it may not be feasible if the gold plant operation is compromised.

Considering the ore distribution network transportation schedule used to determine the surface silo levels for both OTS-A1 and OTA-A2, the total daily ore transported to the gold plant is also known.

![Figure 5-9: ODN-A gold plant average daily ore supply](image)

Figure 5-9 shows the daily average gold ore transported from OTS-A1 and OTS-A2 over a week. The forecasted ore supply was seen to react within the operational limits specified to satisfy the required targets. It is important to understand that all the ore mined, referred to as the forecasted ore supply, was transported to the gold plant and reacts within the gold plant operational limits.

The maximum and minimum boundaries are indicated on the graph as 1 645 tonnes and 4 291 tonnes, as where the forecasted ore supply was 3 290 tonnes. It was found that the optimisation of OTS-A1 and OTS-A2 did not have a negative impact on the gold mining and processing operations.
5.2.3 Implementation and results

In Section 5.2.2, the feasibility and maximum potential load shift opportunities on OTS-A1 and OTS-A2 were discussed. The electricity cost-saving potential of implementing load shift initiatives on these ore transportation systems was also illustrated. As OTS-A1 and OTS-A2 were both included in ODN-A, the total potential electricity savings were also discussed as integrated electricity cost savings.

During the modelling of each ore transportation system included in ODN-A, average production data and multiple assumptions were used to optimise the winder schedule to obtain electricity cost savings. To be able to compare the actual electricity cost saving achieved, the power usage of the model was scaled energy neutral to the actual results obtained. This ensured that the comparison between the optimised model and actual results reflected accurately according to the actual production of the mine.

As discussed in Chapter 4, the goal of the optimisation model was investigating the total electricity cost savings achievable in ODN-A and analysing the effect of implementing such an initiative on multiple ore transportation systems. Thus, the optimised schedule of the rock winder of each ore transportation system was not discussed in detail. However, the rock winder schedule optimisation of an individual ore transportation system was discussed in detail in two other studies [13], [18].

During the period of 26 May to 30 May 2014, a test was conducted on OTS-A1 and OTS-A2, which form part of ODN-A. During the test period, the focus was only set on weekdays. The rock winder operator of each ore transportation system in ODN-A was instructed to halt the rock winder operation between 18:00 and 20:00 provided that the normal process constraints of the extraction process were not impaired.

If the rock winder operator received instruction from management to hoist or if the normal conditional constraints were exceeded, the test was stopped for the day, whereafter the operational schedule of the ore transportation system continued as it would have done previously. The winder operators were instructed to continue operations as usual after the evening peak period. The power data for each rock winder in OTS-A1 and OTS-A2, respectively, was obtained from the power meters installed in the mine substations.

Load management results of OTS-A1

The test performed on OTS-A1 proved successful and correlated with the load shifting potential indicated through the optimisation model. Although large electricity cost savings
was achieved, perfect load shifting was not accomplished during the test week as proposed by the optimisation model because of the influence of mining dynamics and the rock winder being controlled manually.

The rock winder utilisation of OTS-A1 was minimal during the Eskom peak periods as shown in Figure 5-10. The average evening peak load shift achieved was 500 kW over the period of five weekdays.

![Figure 5-10: OTS-A1 average scaled baseline versus the actual average daily and optimised power profile (26–30 May 2014)](image)

The actual cost savings due to the optimised rock winder schedule for the week resulted in R2 610 as indicated in Table 5-4. This can be quantified to an annual saving of approximately R250 000.

<table>
<thead>
<tr>
<th>TOU period</th>
<th>Tariff (R/kWh)</th>
<th>Baseline cost</th>
<th>Optimised cost</th>
<th>Actual cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak</td>
<td>0.7093</td>
<td>R7 171</td>
<td>R858</td>
<td>R2 494</td>
</tr>
<tr>
<td>Standard</td>
<td>0.4882</td>
<td>R27 090</td>
<td>R28 554</td>
<td>R27 159</td>
</tr>
<tr>
<td>Off-peak</td>
<td>0.3097</td>
<td>R14 371</td>
<td>R16 200</td>
<td>R16 370</td>
</tr>
<tr>
<td>Total</td>
<td>R48 633</td>
<td>R45 611</td>
<td>R46 023</td>
<td></td>
</tr>
</tbody>
</table>

**Actual average savings per week during summer:** R2 610

**Load management results of OTS-A2**

Figure 5-11 shows that OTS-A2 has shown some load shifting potential during the week the test was conducted. The average evening peak load shift achieved was 400 kW over the period of five weekdays. The test performed on OTS-A2 was not optimal but illustrated
some load shifting potential during Eskom’s evening peak period. As Mine-A2 was at the end of its lifetime, the key focus was on extracting the mined rock to surface regardless of electricity cost or optimal hoisting schedules.

![Diagram showing power consumption profile](image)

Figure 5-11: OTS-A2 average scaled baseline versus the actual average daily and optimised power profile (26–30 May 2014)

The actual cost savings due to the optimised rock winder schedule for the week resulted in R975 as indicated in Table 5-5. This can be quantified to an annual saving of approximately R120 000.

<table>
<thead>
<tr>
<th>TOU period</th>
<th>Tariff (R/kWh)</th>
<th>Baseline cost</th>
<th>Optimised cost</th>
<th>Actual cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak</td>
<td>0.7093</td>
<td>R12 170</td>
<td>R2 224</td>
<td>R9 103</td>
</tr>
<tr>
<td>Standard</td>
<td>0.4882</td>
<td>R20 207</td>
<td>R21 802</td>
<td>R22 265</td>
</tr>
<tr>
<td>Off-peak</td>
<td>0.3097</td>
<td>R9 193</td>
<td>R12 524</td>
<td>R9 226</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>R41 570</strong></td>
<td><strong>R36 550</strong></td>
<td><strong>R40 595</strong></td>
<td></td>
</tr>
</tbody>
</table>

*Actual average savings per week during summer: R975*

**Integrated results**

The test concluded that OTS-A1 and OTS-A2 were capable of achieving large electrical cost savings by optimising the operational schedule of the rock winders. The integrated load reduction of ODN-A is illustrated in Figure 5-12. The average evening peak load shift achieved was 1 000 kW over the period of five weekdays.
The cost savings associated with the load shifting is summarised in Table 5-6. It is evident that peak load was shifted to the less expensive off-peak and standard periods. The weighted average cost showed cost saving of R0.05 per kWh of electrical energy consumed. This led to an average decrease of 9% in the specific hoisting energy costs of the rock hoisting sections in the ore transportation systems included in ODN-A. The combined cost savings amounted to R3 585 over the summer week. This can be quantified to an annual saving of R380 000.

Table 5-6: Electricity cost savings summary on ODN-A

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Baseline period</th>
<th>Optimisation period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak energy consumption (%)</td>
<td>14 %</td>
<td>8%</td>
</tr>
<tr>
<td>Standard energy consumption (%)</td>
<td>48 %</td>
<td>51 %</td>
</tr>
<tr>
<td>Off-peak energy consumption (%)</td>
<td>38 %</td>
<td>41 %</td>
</tr>
<tr>
<td>Average peak load reduction (MW)</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Weighted average cost (R/kWh)</td>
<td>R0.60</td>
<td>R0.55</td>
</tr>
<tr>
<td>Electrical energy consumption (kWh)</td>
<td>40 047</td>
<td>40 047</td>
</tr>
<tr>
<td>Specific hoisting energy cost (R/tonne)</td>
<td>R6.21</td>
<td>R5.64</td>
</tr>
</tbody>
</table>

Impact on Gold Plant A

During the test week, the operation of Gold Plant A was monitored to determine the effect of implementing load shifting initiatives on OTS-A1 and OTS-A2. Figure 5-13 shows the Gold Plant A production capacity versus the optimised and actual daily average tonnes delivered to the gold plant during the test week.
As discussed, during the optimisation of each ore transportation system, average production profiles and operational data were used to determine the total production of the ore transportation system for each day. This explained the deviation seen between the actual and forecasted tonnes delivered to Gold Plant A. The actual total ore supplied to the gold plant was solely dependent on the actual amount of tonnes mined.

As seen in Figure 5-13, the actual ore supply to Gold Plant A during the test week satisfied the boundary constraints. It is evident that the optimisation of OTS-A1 and OTS-A2 did not negatively affect Gold Plant A’s operations.

5.2.4 Conclusion
Implementing load shifting initiatives on OTS-A1 and OTS-A2 illustrated that the optimised rock winder schedule did not impair the gold plant’s production capabilities, whilst large cost savings was achieved. If the savings achieved during the test week was extrapolated over a year, an average ore transportation electricity cost reduction of 9% would be possible on ODN-A, which amounted to approximately R380 000.

5.3 Case Study B
5.3.1 Background
Ore Distribution Network B (ODN-B) contains five mineshafts with a single ore transportation system for each. The ore transportation systems in this section are described as Ore Transportation System B1 (OTS-B1), Ore Transportation System B2 (OTS-B2), Ore Transportation System B3 (OTS-B3), Ore Transportation System B4 (OTS-B4) and Ore
Transportation System B5 (OTS-B5). A single gold-processing plant is supplied from all the ore transportation systems by means of railway transportation.

Refer to Appendix B for the detailed investigation on the five ore transportation systems and the gold plant included in ODN-B. The investigations in Appendix B were based on the investigation methodology discussed in Chapter 3. All the required information for an accurate simulation is discussed in detail and is used for the optimisation of the ore transportation systems.

5.3.2 Identify load management opportunities

During the investigation phase of the study, the necessary data and information were obtained and populated into the model developed in Chapter 4. The model was used to determine the potential load management opportunities of each individual ore transportation system in ODN-B. The combined ore transportation system potential savings of ODN-B is also discussed by addressing:

- The optimal power profile versus the operation baseline;
- Ore transportation system storage levels; and
- Mined ore extracted and distributed.

**OTS-B1**

**Optimised power profile versus baseline**

The optimised power profile and the scaled baseline of OTS-B1 is illustrated in Figure 5-14. The baseline was scaled to be energy neutral with the potential load management profile because no operational load was lost; it was shifted.

The optimised power profile of the rock winder in OTS-B1 was obtained by following the procedures and adhering to the constraints as set out in the optimisation model. A typical daily production profile was scaled to fit the average daily production of the mine to determine the production rate of OTS-B1.

As seen in Figure 5-14, the normal operational rock winder schedule already included minimal operation during the morning peak period and the standard TOU periods. The current rock winder schedule was seen to hoist at a maximum rate during the off-peak TOU period. Additional savings was shown to be possible with the optimisation model of OTS-B1.
An average evening peak load shift of 670 kW and morning peak load shift of 168 kW were proposed by the OTS-B1 optimisation. Although the primary focus was on the evening peak, the optimised model indicated that a morning peak load reduction was possible as well. The morning peak was included in the optimisation to quantify the potential electrical cost savings that could be achieved fully.

As seen in Figure 5-14, the potential morning peak period savings was minimal due to the maintenance schedule and the previous operational schedule of the ore transportation system during the investigation. The potential evening peak load was shifted to the less expensive periods during the day.

The load reduction of OTS-B1’s rock winder during Eskom’s peak periods created considerable electricity cost savings. An average summer weekly saving of R1 569 was achievable. An average weekly saving of R 4 644 is proposed during the winter months. If quantified to a year, the average electricity cost saving was approximately R186 000 per year. Table 5-7 shows the average daily potential cost savings in rands.

<table>
<thead>
<tr>
<th>TOU period</th>
<th>Tariff (R/kWh)</th>
<th>Baseline cost</th>
<th>Optimised cost</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak</td>
<td>0.7093</td>
<td>R14 782</td>
<td>R8 246</td>
<td>R6 536</td>
</tr>
<tr>
<td>Standard</td>
<td>0.4882</td>
<td>R22 573</td>
<td>R28 353</td>
<td>R-5 780</td>
</tr>
<tr>
<td>Off-peak</td>
<td>0.3097</td>
<td>R15 853</td>
<td>R15 040</td>
<td>R813</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>R53 208</td>
<td>R51 639</td>
<td>R1 569</td>
</tr>
</tbody>
</table>

Average savings per week: R1 569
**Ore transportation system storage levels**

Due to the underground mining conditions and capabilities, a safety margin was used with the ore input in the underground storage. The upper and lower boundaries were determined by the standard deviation of the daily ore mined as discussed in Section 3.3.1. The boundaries were used to illustrate the margin within which the daily rock mine could vary at any given moment.

Assumptions: The initial underground and surface storage levels for the simulated operational mining week were required to quantify the effect of an optimised rock winder schedule on the respective storage units.

- Initial underground storage level: 30%
- Initial surface silo level: 65%

Figure 5-15 shows the underground rock storage level during a 24-hour day in which OTS-B1 is optimised. The maximum and minimum limits are indicated on the graph as 20% and 40%. The maximum and minimum limits are identified by the relevant on site team to ensure efficient operation without compromising production. It is seen that the boundary constraints were satisfied.

![Graph](image)

**Figure 5-15: OTS-B1 underground storage level percentage**

Figure 5-16 shows the underground rock storage level during a 24-hour day in which OTS-B1 was optimised. The maximum and minimum boundaries are indicated on the graph as 40% and 80%. It can be seen that the boundary constraints were satisfied.
It was found that the underground and surface storage were able to absorb the mined rock with minimal utilisation of OTS-B1 rock winder during the peak periods.

**Mined ore extraction and distribution**

Figure 5-17 shows the rate at which the mined rock was extracted from underground to surface. It was interpreted that the total amount of ore mined was hauled to surface by implementing the optimisation. It is clearly seen that the rate at which the tonnes were extracted from underground flattened during the peak periods.

Figure 5-17 also indicates that the total amount of rock extracted was transported to the gold plant. Due to the use of the railway distribution network, the ore transportation to the gold plant had an minimum of two hours return time between each trip. As seen, all the rock
mined during the specific day was hauled to surface and transported to the gold plant within the specified call period.

**OTS-B2**

**Optimised power profile versus baseline**

The optimised power profile and the scaled baseline of OTS-B2 are illustrated in Figure 5-18. The optimised power profile of the rock winder in OTS-B2 was obtained by following the procedures and adhering to the constraints as set out in the optimisation model. A typical daily production profile was scaled to fit the average daily production of Mine-B2 to determine the production rate of OTS-B2.

An average evening peak load shift of 1 256 kW and morning peak load shift of 564 kW were proposed by the optimisation of OTS-B2. Although the primary focus was on the evening peak, the optimised model indicated a morning peak load reduction was possible as well.

The rock winder load reduction of OTS-B2 during Eskom’s peak periods created considerable electricity cost savings. An average summer weekly saving of R 8 117 was achievable. An average weekly saving of R 15 226 is proposed during the winter months. If quantified to a year, the average electricity cost savings could add up to R645 535 per year. Table 5-8 shows the average daily potential cost savings in rands.
Table 5-8: OTS-B2 optimised cost savings

<table>
<thead>
<tr>
<th>TOU period</th>
<th>Tariff (R/kWh)</th>
<th>Baseline cost</th>
<th>Optimised cost</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak</td>
<td>0.7093</td>
<td>R20 494</td>
<td>R5 577</td>
<td>R14 917</td>
</tr>
<tr>
<td>Standard</td>
<td>0.4882</td>
<td>R33 072</td>
<td>R33 857</td>
<td>R-785</td>
</tr>
<tr>
<td>Off-peak</td>
<td>0.3097</td>
<td>R15 374</td>
<td>R21 389</td>
<td>R-6 015</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>R68 940</td>
<td>R60 834</td>
<td>R8 117</td>
</tr>
</tbody>
</table>

Average savings per week: R8 117

Refer to Appendix B to view the optimisation results obtained from the optimisation model.

**OTS-B3**

**Optimised power profile versus baseline**

The optimised power profile and the scaled baseline of OTS-B3 are illustrated in Figure 5-19. The optimised power profile of the rock winder in OTS-B3 was obtained by following the procedures and adhering to the constraints as set out in the optimisation model. A typical daily production profile was scaled to fit the average daily production of Mine-B3 to determine the production rate of OTS-B3.

![Figure 5-19: OTS-B3 optimised profile versus scaled baseline](image)

An average evening peak load shift of 1 097 kW and morning peak load shift of 123 kW were proposed by the optimisation of OTS-B3. Although the primary focus was on the evening peak, the optimised model indicated that a morning peak load reduction was possible as well.
Optimising gold ore transportation systems for electricity cost savings

The rock winder load reduction of OTS-B3 during Eskom’s peak periods proposed considerable electricity cost savings. An average summer weekly saving of R1 867 was achievable. An average weekly saving of R 6 044 is proposed during the winter months. If quantified to a year, the average electricity cost savings was approximately R240 000 per year. Table 5-9 shows the average daily potential cost savings in rands.

Table 5-9: OTS-B3 optimised cost savings

<table>
<thead>
<tr>
<th>TOU period</th>
<th>Tariff (R/kWh)</th>
<th>Baseline cost</th>
<th>Optimised cost</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak</td>
<td>0.7093</td>
<td>R27 466</td>
<td>R18 376</td>
<td>R9 090</td>
</tr>
<tr>
<td>Standard</td>
<td>0.4882</td>
<td>R42 619</td>
<td>R51 518</td>
<td>R-8 899</td>
</tr>
<tr>
<td>Off-peak</td>
<td>0.3097</td>
<td>R22 737</td>
<td>R21 061</td>
<td>R1 676</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>R92 823</td>
<td>R90 955</td>
<td>R1 867</td>
</tr>
</tbody>
</table>

Average savings per week: R1 867

Refer to Appendix B to view the optimisation results obtained from the optimisation model.

**OTS-B4**

**Optimised power profile versus baseline**

The optimised power profile and the scaled baseline of OTS-B4 are illustrated in Figure 5-20. The optimised power profile of the rock winder in OTS-B4 was obtained by following the procedures and adhering to the constraints as set out in the optimisation model. A typical daily production profile was scaled to fit the average daily production of Mine-B4 to determine the production rate of OTS-B4.

![Figure 5-20: OTS-B4 optimised profile versus scaled baseline](image-url)
An average evening peak load shift of 1 651 kW and morning peak load shift of 600 kW were proposed by the optimisation of OTS-B4. Although the primary focus was on the evening peak, the optimised model indicated that a morning peak load reduction was possible as well.

The rock winder load reduction of OTS-B4 during Eskom’s peak periods proposed considerable electricity cost savings. An average summer weekly saving of R5 756 was achievable. An average weekly saving of R 15 303 is proposed during the winter months. If quantified to a year, the average electricity cost savings could add up to approximately R620 000 per year. Table 5-10 shows the average daily potential cost savings in rands.

<table>
<thead>
<tr>
<th>TOU period</th>
<th>Tariff (R/kWh)</th>
<th>Baseline cost</th>
<th>Optimised cost</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak</td>
<td>0.7093</td>
<td>R24 566</td>
<td>R5 055</td>
<td>R19 511</td>
</tr>
<tr>
<td>Standard</td>
<td>0.4882</td>
<td>R41 479</td>
<td>R47 057</td>
<td>R-5 578</td>
</tr>
<tr>
<td>Off-peak</td>
<td>0.3097</td>
<td>R19 994</td>
<td>R28 170</td>
<td>R-8 176</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>R86 039</td>
<td>R80 282</td>
<td>R5 757</td>
</tr>
</tbody>
</table>

Average savings per week: R5 756

Refer to Appendix B to view the optimisation results obtained from the optimisation model.

**OTS-B5**

**Optimised power profile versus baseline**

The optimised power profile and the scaled baseline of OTS-B5 are illustrated in Figure 5-21. The optimised power profile of the rock winder in OTS-B5 was obtained by following the procedures and adhering to the constraints set out in the optimisation model. A typical daily production profile was scaled to fit the average daily production of Mine-B5 to determine the production rate of OTS-B5.
An average evening peak load shift of 814 kW and morning peak load shift of 340 kW were proposed by the optimisation of OTS-B5. Although the primary focus was on the evening peak, the optimised model indicated that a morning peak load reduction was possible as well.

The rock winder load reduction of OTS-B5 during Eskom’s peak periods proposed considerable electricity cost savings. An average summer weekly saving of R4 092 was achievable. An average weekly saving of R 8 452 is proposed during the winter months. If quantified to a year, the average electricity cost savings could add up to R360 000 per year. Table 5-11 shows the average daily potential cost savings in rands.

<table>
<thead>
<tr>
<th>TOU period</th>
<th>Tariff (R/kWh)</th>
<th>Baseline cost (R)</th>
<th>Optimised cost (R)</th>
<th>Savings (R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak</td>
<td>0.7093</td>
<td>11 159</td>
<td>1 678</td>
<td>9 481</td>
</tr>
<tr>
<td>Standard</td>
<td>0.4882</td>
<td>17 724</td>
<td>21 141</td>
<td>3 417</td>
</tr>
<tr>
<td>Off-peak</td>
<td>0.3097</td>
<td>10 299</td>
<td>12 271</td>
<td>1 972</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>39 181</td>
<td>35 089</td>
<td>4 092</td>
</tr>
</tbody>
</table>

Average savings per week: R4 092

Refer to Appendix B to view the optimisation results obtained from the optimisation model.

**ODN-B integrated optimisation results**

Figure 5-22 represents the integrated optimised power profile for the whole ODN-B. A total load shift of 1.9 MW was seen to be achievable during the morning peak with an evening peak load shift of 4.9 MW.
Optimising all the ore transportation systems included in ODN-B resulted in a large load reduction during Eskom’s peak periods, which created considerable electricity cost savings. An average summer weekly saving of R24 887 was achievable. During winter months, for the same load shift opportunity, an average weekly saving of R58 325 is proposed. If quantified to a year, the average electricity cost savings could add up to approximately R2.1 million per year. Table 5-12 shows the average daily potential cost savings in rands.

<table>
<thead>
<tr>
<th>TOU period</th>
<th>Tariff (R/kWh)</th>
<th>Baseline cost</th>
<th>Optimised cost</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak</td>
<td>0.7093</td>
<td>R89 445</td>
<td>R32 518</td>
<td>R56 927</td>
</tr>
<tr>
<td>Standard</td>
<td>0.4882</td>
<td>R143 463</td>
<td>R163 138</td>
<td>R-19 675</td>
</tr>
<tr>
<td>Off-peak</td>
<td>0.3097</td>
<td>R78 248</td>
<td>R90 623</td>
<td>R-12 375</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>R311 156</td>
<td>R286 279</td>
<td>R24 877</td>
</tr>
</tbody>
</table>

Average savings per week: R24 887

Gold Plant B

As discussed in Section 4.2.3, the gold plant required a constant ore feed from each of the ore transportation systems in the ore distribution network. Optimising each individual ore transportation system in a single ore distribution network can influence the gold plant operation. Although electrical cost saving could have been possible on each of these ore transportation systems, it would not be feasible if the gold plant operation would be compromised.
The ore distribution schedule assigned to each mine during the optimisation of ODN-B allowed each mine to deliver the total amount of ore mined to the gold plant without the schedules overlapping.

![Figure 5-23: ODN-B gold plant average daily ore supply](image)

Figure 5-23 shows the daily average gold ore transported from the five ore transportation systems included in ODN-B to the gold plant. The forecasted ore supply was seen to react within the operational limits specified to satisfy the required targets. It is important to understand that all the ore mined, referred to as the forecasted ore supply, was transported to the gold plant and reacted within the gold plant operational limits.

The maximum and minimum boundaries are indicated in Figure 5-23 as 6 840 tonnes and 16 416 tonnes, with the forecasted ore supply being 12 100 tonnes. It can be seen that the optimisation of the ore transportation systems included in ODN-B did not have a negative impact on the gold mining operation.

### 5.3.3 Implementation and results

In Section 5.3.2, the feasibility and maximum potential load shifting opportunities on each ore transportation system included in ODN-B were discussed. The electricity cost savings potential of implementing load shift initiatives on these ore transportation systems was also illustrated. The integrated electricity cost savings of the ore transportation systems in ODN-B was also discussed.

During the modelling of each ore transportation system included in ODN-B, average production data and multiple assumptions were used to optimise the winder schedule to
obtain electricity cost savings. To be able to compare the actual electricity cost savings with the optimisation model, the power usage of the model was scaled energy neutral to the actual results obtained. This ensured that the comparison between the optimised model and actual results reflected accurately according to the actual production of a mine.

As discussed, the goal of the optimisation model was investigating the total electricity cost savings achievable in ODN-B and analysing the effect of implementing such an initiative on multiple ore transportation systems on the gold plant operation and ore distribution network. Thus, the optimised schedule of the rock winder of each ore transportation system was not discussed in detail. However, the rock winder schedule optimisation of an individual ore transportation system was discussed in detail in two other studies [13], [18].

From 26 May to 30 May 2014, tests were conducted on OTS-B1, OTS-B2, OTS-B3, OTS-B4 and OTS-B5, all of which formed part of ODN-B. During the test period, the focus was set on weekdays only. The rock winder operator of each ore transportation system in ODN-B was instructed to halt the rock winder operation between 18:00 and 20:00 provided that the normal process constraints of the extraction process would not be impaired.

If the rock winder operator received instruction from management to hoist or if the normal conditional constraints were exceeded, the test was stopped for the day. Thereafter the operational schedule of the ore transportation system continued as it would have previously. The winder operators were instructed to continue operations as usual after the evening peak period.

The power data of each rock winder in OTS-B1 to OTS-B5 during the test week was obtained from the power meters installed in the mine substation.

**Load management results of OTS-B1**

The rock winder utilisation of OTS-B1 was minimal during the Eskom peak period as shown in Figure 5-24. The average evening peak load shift achieved was 370 kW over the period of five weekdays.

The savings achieved did not measure up to proposed savings of the optimised schedule. Mine-B1 was only willing to shift the total rock winder load from the evening peak period. Due to the low daily production of Mine-B1, the objective was still to hoist the rock mined as soon as it was available to fulfil their daily call.
The actual cost savings due to the optimised rock winder schedule for the week resulted in R122 as indicated in Table 5-13. This can be quantified to an annual saving of R51 412.

Table 5-13: OTS-B1 actual cost savings

<table>
<thead>
<tr>
<th>TOU period</th>
<th>Tariff (R/kWh)</th>
<th>Baseline cost</th>
<th>Optimised cost</th>
<th>Actual cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak</td>
<td>0.7093</td>
<td>R14 223</td>
<td>R7 934</td>
<td>R12 122</td>
</tr>
<tr>
<td>Standard</td>
<td>0.4882</td>
<td>R21 719</td>
<td>R27 281</td>
<td>R24 625</td>
</tr>
<tr>
<td>Off-peak</td>
<td>0.3097</td>
<td>R15 051</td>
<td>R14 471</td>
<td>R14 328</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>R51 196</td>
<td>R49 686</td>
<td>R51 074</td>
</tr>
</tbody>
</table>

Actual average savings per week during summer: R122

Load management results of OTS-B2

As can be seen in Figure 5-25, the actual evening peak load reduction correlated with the optimisation model during the test week. The average evening peak load shift achieved was 1 259 kW over the period of five weekdays.
The test performed on OTS-B2 showed large evening peak load reduction accompanied with considerable electricity cost savings. Mine-B2 considered it a risk to halt the rock winder operation during the morning peak of each weekday.

Rock winder maintenance was scheduled on two weekday mornings. Thus, if the rock winder operation was halted during the other weekdays as well, the high production targets might not have been reached. The actual evening peak load shift did not achieve the full load shifting potential proposed by the optimisation model. This is due to the rock winder being controlled manually.

The actual cost savings due to the optimised rock winder schedule for the week resulted in R4 238 as indicated in Table 5-14. This can be quantified to an annual saving of R447 100.

Table 5-14: OTS-B2 actual cost savings

<table>
<thead>
<tr>
<th>TOU period</th>
<th>Tariff (R/kWh)</th>
<th>Baseline cost</th>
<th>Optimised cost</th>
<th>Actual cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak</td>
<td>0.7093</td>
<td>R23 235</td>
<td>R6 323</td>
<td>R14 215</td>
</tr>
<tr>
<td>Standard</td>
<td>0.4882</td>
<td>R37 496</td>
<td>R38 386</td>
<td>R39 803</td>
</tr>
<tr>
<td>Off-peak</td>
<td>0.3097</td>
<td>R17 430</td>
<td>R24 250</td>
<td>R19 905</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>R78 161</td>
<td>R68 959</td>
<td>R73 923</td>
</tr>
</tbody>
</table>

Actual average savings per week during summer: R4 238

Load management results of OTS-B3

The average evening peak load shift achieved was 345 kW over the period of five weekdays. Figure 5-26 shows the actual power profile during the test week versus the optimised model.
and the ore transportation system scaled baseline. During the optimisation of OTS-B3, it was determined that a full load shift during the evening peak period was not possible. The actual load shifting result reflected this as well.

![Graph](image)

**Figure 5-26: OTS-B3 average scaled baseline versus the actual average daily and optimised power (26–30 May 2014)**

The test performed on OTS-B3 was challenging due the limited underground storage capacity available to absorb the mined rock. Although considerable savings were achieved, the actual savings did not reach the potential savings proposed by the optimisation model during the evening peak period. This is due to a large production week and limited storage capacity underground.

The actual cost savings due to the optimised rock winder schedule for the week resulted in R1 712 as indicated in Table 5-15. This can be quantified to an annual saving of R131 130.

**Table 5-15: OTS-B3 actual cost savings**

<table>
<thead>
<tr>
<th>TOU period</th>
<th>Tariff (R/kWh)</th>
<th>Baseline cost</th>
<th>Optimised cost</th>
<th>Actual cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak</td>
<td>0.7093</td>
<td>R18 108</td>
<td>R11 670</td>
<td>R16 827</td>
</tr>
<tr>
<td>Standard</td>
<td>0.4882</td>
<td>R27 735</td>
<td>R32 718</td>
<td>R25 023</td>
</tr>
<tr>
<td>Off-peak</td>
<td>0.3097</td>
<td>R13 746</td>
<td>R13 376</td>
<td>R16 006</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>R59 568</td>
<td>R57 764</td>
<td>R57 856</td>
</tr>
</tbody>
</table>

*Actual average savings per week during summer: R1 712*
Load management results of OTS-B4

Figure 5-27 shows the actual power profile during the test week versus the optimised model power profile and the ore transportation system scaled baseline. The average evening peak load shift achieved was 1 114 kW over the period of five weekdays.

Due to unplanned maintenance and rock winder stoppages, the load shifting potential of OTS-B4 could not be verified fully. The considerable evening peak load reduction was obtained regardless of the situation. During the morning peak period, the winder hoisted all available rock to enable the ore transportation system to reach the daily call.

![Figure 5-27: OTS-B4 average scaled baseline versus the actual average daily and optimised power (26–30 May 2014)](image)

The actual cost savings due to the optimised rock winder schedule for the week resulted in R2 686 as indicated in table. This can be quantified to an annual saving of R273 512.

Table 5-16: OTS-B4 actual cost savings

<table>
<thead>
<tr>
<th>TOU period</th>
<th>Tariff (R/kWh)</th>
<th>Baseline cost</th>
<th>Optimised cost</th>
<th>Actual cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak</td>
<td>0.7093</td>
<td>R27 006</td>
<td>R5 557</td>
<td>R21 761</td>
</tr>
<tr>
<td>Standard</td>
<td>0.4882</td>
<td>R45 599</td>
<td>R51 731</td>
<td>R46 333</td>
</tr>
<tr>
<td>Off-peak</td>
<td>0.3097</td>
<td>R25 493</td>
<td>R30 968</td>
<td>R27 317</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>R98 098</td>
<td>R88 256</td>
<td>R95 412</td>
</tr>
</tbody>
</table>

Actual average savings per week during summer: R2 686

Load management results of OTS-B5

The test performed on OTS-B5 proved successful and correlated with the load shifting potential indicated through the optimisation model. Although large electricity cost savings
was achieved, the full load shift was not accomplished during the test week as proposed by the optimisation model because of the underground mining dynamics and the rock winder being controlled manually.

Figure 5-28 shows the actual power profile during the test week versus the optimised model power profile and the ore transportation system scaled baseline. The average evening peak load shift achieved was 486 kW over the period of five weekdays. A full load shift during the evening peak period was accomplished as illustrated with the optimisation of the ore transportation system.

```
<table>
<thead>
<tr>
<th>TOU period</th>
<th>Tariff (R/kWh)</th>
<th>Baseline cost</th>
<th>Optimised cost</th>
<th>Actual cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak</td>
<td>0.7093</td>
<td>R6 873</td>
<td>R1 033</td>
<td>R1 940</td>
</tr>
<tr>
<td>Standard</td>
<td>0.4882</td>
<td>R10 917</td>
<td>R12 063</td>
<td>R11 281</td>
</tr>
<tr>
<td>Off-peak</td>
<td>0.3097</td>
<td>R6 344</td>
<td>R8 160</td>
<td>R8 267</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>R24 134</td>
<td>R21 256</td>
<td>R21 488</td>
</tr>
</tbody>
</table>
```

Actual average savings per week during summer: R2 646
Integrated results

The test concluded that OTS-B1, OTS-B2, OTS-B3, OTS-B4 and OTS-B5 were capable of achieving large electrical cost savings by optimising the operational schedule of the rock winders. The integrated evening peak load reduction of ODN-B is illustrated in Figure 5-29. The average evening peak load shift achieved was 3 571 kW over the period of five weekdays.

![Figure 5-29: ODN-B integrated average scaled baseline versus the actual average daily and optimised power profile (26–30 May 2014)](image)

The cost savings associated with the load shift is summarised in Table 5-18. It is evident that peak load was shifted to the less expensive off-peak and standard periods. The weighted average cost showed cost saving of R0.05 per kWh of electrical energy consumed. This led to an 8% decrease in the specific hoisting energy costs of the rock hoisting sections in the ore transportation systems included in ODN-B. The combined cost savings amounted to R11 404 over the summer week. This can be quantified to an annual saving of R1.1 million.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Baseline period</th>
<th>Optimisation period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak energy consumption (%)</td>
<td>19 %</td>
<td>14 %</td>
</tr>
<tr>
<td>Standard energy consumption (%)</td>
<td>44 %</td>
<td>45 %</td>
</tr>
<tr>
<td>Off-peak energy consumption (%)</td>
<td>37 %</td>
<td>41 %</td>
</tr>
<tr>
<td>Average peak load reduction (MW)</td>
<td>0</td>
<td>3.1</td>
</tr>
<tr>
<td>Weighted average cost (R/kWh)</td>
<td>R0.65</td>
<td>R0.60</td>
</tr>
<tr>
<td>Electrical energy consumption (kWh)</td>
<td>134 525</td>
<td>134 525</td>
</tr>
<tr>
<td>Specific hoisting energy cost (R/tonne)</td>
<td>R8.32</td>
<td>R7.68</td>
</tr>
</tbody>
</table>
**Impact on Gold Plant B**

During the test week, the operation of Gold Plant B was monitored to determine the effect of implementing load shifting initiatives on each ore transportation system included in ODN-B. Figure 5-30 shows Gold Plant B production capacity versus the optimised and actual daily average tonnes delivered to Gold Plant B during the test week.

![Figure 5-30: ODN-B gold plant operation](image)

As discussed, during the optimisation of each ore transportation system, average production profiles and operational data were used to determine the total production of the ore transportation system for each day. This explains the variation in the total ore supplied to the gold plant by the optimised model and the actual ore supply.

As seen in Figure 5-30, the actual ore supplied to Gold Plant B during the test week satisfied the boundary targets. It is evident that the optimisation of OTS-B1 to OTS-B5 did not negatively affect Gold Plant B operation.

**5.3.4 Conclusion**

Implementing load shifting initiatives on each ore transportation system included in ODN-B illustrated that optimised rock winder schedules do not impair gold plant production capabilities, whilst large cost savings is achieved. If the savings achieved during the test week should be extrapolated over a year, an average ore transportation electricity cost reduction of 8% is possible on ODN-B. This amounts to approximately R1.1 million annually.
5.4 Application on other South African gold mines

Results from two isolated case studies were presented. It could, therefore, be an indication that potential for electrical load management also exists on other South African gold ore transportation systems. An average of 72 500 tonnes of ore is hoisted annually in South Africa at an average cost of R7.27 per tonne.

If an average specific hoisting electricity cost saving of 8% is extrapolated across the South African gold mining industry, the potential cost savings could amount to R37 million per annum.

5.5 Conclusion

Results from the two case studies implemented in Chapter 5 concluded that electricity cost savings on gold ore transportation systems are achievable in the form of load shifting initiatives. Although considerable electricity cost savings were achieved on each ore transportation system, the actual electricity cost savings could not reach the proposed savings indicated by the optimisation model. This is due to the dynamic conditions of the production and operation of the mine.

Furthermore, the optimisation of each ore transportation system included in ODN-A and ODN-B was executed without influencing the production of the respective gold plants negatively. Although the electricity cost savings achieved on an individual ore transportation system in an ore distribution network is reflected to be small, the total electricity cost savings achieved in the ore distribution network amounts to a large figure.

The estimated cost savings resulted in R380 000 for Case Study 1 and R1.1 million for Case Study 2. Load management strategies were implemented without additional capital or operational expenditure. The estimated load management potential on the entire South African gold mining industry could amount to R37 million per annum.
Chapter 6

Conclusion and recommendations

“Science is about knowing, engineering is about doing” – Henry Petroski
6.1 Conclusion

It is evident that South African gold mines are energy intensive with large electrical components. With increasing electricity prices and shortage in electricity supply in South Africa, electricity cost-saving measures such as DSM initiatives are widely welcomed on gold mines. Multiple DSM initiatives are implemented to reduce the overall power consumption on the Eskom power grid. The reader was introduced to the benefits of such cost-saving interventions.

Various electricity cost-saving initiatives are implemented on large energy-intensive components in the gold mining sector. Gold mine ore transportation systems, specifically, consumes approximately 14% of a typical deep-level gold mine’s electricity. Electricity cost-saving measures are most commonly implemented on single components such as rock winders and crushers in ore transportation systems. The integrated effect of implementing such initiatives on an ore transportation system has not yet been analysed.

A generic investigation methodology for the integration of electricity cost-saving intervention on an ore distribution network was developed. The investigation methodology focused on acquiring essential information to understand the complex operation of an ore transportation system and the integrated operation of multiple ore transportation systems in an ore distribution network. The operation of the gold plant included in an ore distribution network was also investigated.

Two real-life ore distribution networks (ODN-A and ODN-B) in South Africa were selected as case studies. These case studies were used to test the methodology and strategies developed in this dissertation. The investigation methodology was implemented on ODN-A and ODN-B and information was gathered. An optimisation model for the integrated operation of an ore distribution network was developed and verified. The model was used to determine the feasibility of optimising each ore transportation system included in ODN-A and ODN-B respectively. The model was also used to analyse the effect of such optimisation on the integrated system.

ODN-A and ODN-B were analysed in terms of the optimisation strategy proposed. Several constraints and requirements were identified. The proposed optimisation, with the aid of the optimisation model, was tested on the ore transportation systems included in ODN-A and ODN-B. The effect of the optimisation on the integrated ore distribution network during the actual test period was also analysed and discussed.
Due to the dynamic operation and unpredictable underground conditions of a deep-level mine, the actual test performance could not reach the proposed electricity cost saving. A 1 MW load shift for Case Study 1 and 3.5 MW for Case Study 2 were achieved. The load shifting intervention resulted in an 8% and 9% reduction in the specific hoisting electricity costs of the ore transportation systems included in the two case studies.

The resultant electricity cost savings amounted to R3 585 and R11 404 for the test week of ODN-A and ODN-B, respectively. If extrapolated, the total annual savings could approximately amount to R380 000 for ODN-A and R1.1 million for ODN-B, respectively. To ensure sustainable load management performance in an ore distribution network, a reporting structure was created to inform relative personnel about the daily performance of the system.

Implementing load management initiatives on an integrated ore distribution network is viable and beneficial. Large electricity cost savings are achievable on an ore distribution network and the implementation of the load shifting intervention did not require additional capital expenditure. The estimated potential load management on South African gold ore transportation systems could amount to cost savings of R37 million per annum.

### 6.2 Recommendations for further studies

During the investigation and optimisation of the study, several areas were identified that could not be fully covered due to time restrictions, data availability and mine personnel’s lack of adopting optimised control strategies. The following are recommended to assist in further research on the study:

- In this study, the feasibility of implementing load management initiative on multiple ore transportation system in a single ore distribution network was determined. Real-time test data concluded that large savings are achievable without compromising the integrated production process of an ore distribution network. Further studies can be conducted to automate such an initiative fully to enable sustainable savings on a long-turn basis.

- The average production profile of each individual mine can be investigated. This will subsequently improve the accuracy of the optimisation results as it will reflect the real-time production operation of each mine included in a specific ore distribution network.
It is recommended that the cost-saving strategies investigated and discussed in this study be implemented on other gold mines with significant energy savings potential across South Africa.
References


Optimising gold ore transportation systems for electricity cost savings


Optimising gold ore transportation systems for electricity cost savings


Optimising gold ore transportation systems for electricity cost savings


Appendix A:

ODN-A investigation

OTS-A1

Mine-A1 undertakes scattered underground mining of the Basal, Elsburg and Dreyerskraal reefs, with depths up to 2300 m. The shaft contributes a total of approximately 8% of the mining group’s total production. An average of 1900 tonnes of ore is produced daily which must be transported to surface.

Mine-A1 consist of a single surface shaft system and a decline. Ore Transportation System A1 (OTS-A1) consists of underground tramming systems, crushers and surface winders, that are used to haul personnel and material to surface. The underground tramming system consists of railway hoppers and conveyors. Figure A-1 shows Mine-A1’s ore transportation system layout with all of its components included.
Underground trams are used to transport mined rock from the stopes to the underground storage. The ore is extracted from the underground storage, from where it is sent to the crushers to be pulverised into smaller rock. As rock is crushed, it is loaded into the rock winder skips and hoisted to surface.

The rock winders are dedicated to transporting mined rock from underground to surface. Table A-1 shows the required characteristics of the OTS-B1 rock winder.

Table A-1: OTS-A1 rock winder characteristics summary

<table>
<thead>
<tr>
<th>Description</th>
<th>Data</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winder type</td>
<td>Double drum</td>
<td>N/A</td>
</tr>
<tr>
<td>Rated power</td>
<td>3 150</td>
<td>kW</td>
</tr>
<tr>
<td>Baseload</td>
<td>60</td>
<td>kW</td>
</tr>
<tr>
<td>Hoisting depth</td>
<td>2300</td>
<td>Metres (m)</td>
</tr>
<tr>
<td>Skip factor</td>
<td>20</td>
<td>Tonnes (t)</td>
</tr>
<tr>
<td>Skips per hour</td>
<td>9</td>
<td>N/A</td>
</tr>
</tbody>
</table>
The ore transportation system operation schedule varies from day to day, due to the dynamic underground operations. Once the mined rock is hoisted to surface, it is stored in separate ore- and waste rock surface storage. The ore is stored in surface silos and the waste rock is moved to the waste dump.

The ore on surface is transported to the gold plant by means of road transportation. Multiple truck are allocated to a mine to transport the mined ore to the gold plant for further processing. A delay is experienced during the transportation of the ore from the mine to the gold plant, this is better known as the retour time from point A to point B. The required characteristics of the ore distribution is illustrated in Table A-2.

Table A-2: Mine-A1 ore distribution summary

<table>
<thead>
<tr>
<th>Description</th>
<th>Data</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Trucks</td>
<td>3</td>
<td>N/A</td>
</tr>
<tr>
<td>Truck capacity</td>
<td>50</td>
<td>Tonnes (t)</td>
</tr>
<tr>
<td>Retour time</td>
<td>45</td>
<td>Minutes (min)</td>
</tr>
</tbody>
</table>

**Ore handling capacity**

The ore transportation system at Mine-A1 was originally designed to transport 3 960 tonnes to surface per day. As determined during the investigation period in 2013, the daily call is 1 900 tonnes of ore and there is 750 tonnes of waste per day. The ore transportation system has a total underground rock storage capacity of approximately 3 500 tonnes. This includes two separate storage units: a 2 500 tonne ore pass is dedicated for ore storage; a 1 000 tonne ore pass is used to store waste rock.

An average of 2 520 tonnes of rock was transported to surface daily over a period of three months in 2014. This indicates that, in the current operation of the ore transportation system is being utilised at approximately 63% of the total capacity during an average day.

Due to the unpredictable condition underground and the dynamic nature of daily ore production the daily ore transported to surface may vary greatly from the average determined above. An error factor is calculated which is implemented on the daily rock mined and transported to surface.

The ore production error factor is determined by calculating the deviation of the actual daily rock transported versus the three-month average used. This is quantified as a standard
deviation in the tonnes of rock mined and transported daily. The standard deviation in tonnes of rock transported daily is quantified to be 360 tonnes (14.2%).

This indicates that the tonnes of rock transported daily can vary between 2 160 and 2 880. To determine the average idle time of the ore transportation system, the upper boundary of the tonnes transported is used. The idle time of OTS-A1 is used to determine the feasibility of implementing a load shifting intervention on the system. In this case, the idle time was determined to be 27%.

The fact that the OTS is not utilised to its full capacity to hoist all the mined material to surface, the possibility exists to optimise the operational schedule of the system.

Normal operation

The mines labour priorities are divided into three main shifts, namely, a morning, afternoon and night shift. During each of these shifts various secondary activities take place in different sector across the underground operations. Production is a primary objective shared during these shifts. Table A-3 shows the times in which the shifts are divided.

<table>
<thead>
<tr>
<th>Shift</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morning</td>
<td>05:00–13:00</td>
</tr>
<tr>
<td>Afternoon</td>
<td>13:00–21:00</td>
</tr>
<tr>
<td>Night</td>
<td>21:00–05:00</td>
</tr>
</tbody>
</table>

A gold mine’s key priority is gold ore production. The current control philosophy implemented on OTS-A1 is to transport mined rock to surface as soon as it is available.

The average tonnes of mined rock transported to surface daily of Mine-A1, is used to scale the rock production profile to match the specific daily production. Figure A-2 shows the scaled average weekday rock production during each shift.
Optimising gold ore transportation systems for electricity cost savings

Figure A-2: Mine-A1 weekday rock production profile

From Figure A-2, three prominent time periods of production can be determined. As seen during the shift changes the production is impacted immensely. During the morning and night shift the most tonnes are delivered to be hauled to surface. During the afternoon shift the available tonnes to haul to surface is minimal. The ore production decreases during the weekends.

Shaft and hoist inspection occurs on two different predetermined weekdays. The purpose of these examinations is to ensure that the shaft meets required standards to deliver effect production. Both examinations lasts from 3-4 hours if no problems arise.

Power consumption

From the investigation it is evident that the rock winder is the largest energy consumer in OTS-A1. It is also clear that the rock winder is a key component in an ore transportation system, owing to the unique operation of extracting ore stored underground. Thus the electricity cost saving intervention will focus on the rock winder included in OTS-A1.

Figure A-3 shows the power baseline for an average weekday calculated over a three-month period during 2014. The power data required to calculate the baseline was obtained from the power meters installed in the mine’s substation during the site investigation.
OTS-A2

Mine-A2 undertakes scattered underground mining of the Basal, Elsburg and Dreyerskraal reefs, with mining to a depth of 2 300 m. The shaft contributes approximately 5% of the mining group’s total production. An average of 1 450 tonnes of rock is produced daily, which must be transported to surface. Mine-A2 is nearing the end of its operation life, and is proposed to be placed in care and maintenance within the following year or two.

Mine-A2 consists of a single surface shaft, sub-shaft and a decline. Ore Transportation System A2 consists of underground tramming systems, crushers, surface man and rock winder, single sub-shaft with a man and rock winder. Figure A-4 shows Mine-A2’s ore transportation system layout with all of its components included.
Table A-4 shows the required characteristics of the OTS-A2 rock winder.

<table>
<thead>
<tr>
<th>Description</th>
<th>Data</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winder type</td>
<td>Double drum</td>
<td>N/A</td>
</tr>
<tr>
<td>Rated power</td>
<td>3 150</td>
<td>kW</td>
</tr>
<tr>
<td>Baseload</td>
<td>80</td>
<td>kW</td>
</tr>
<tr>
<td>Hoisting depth</td>
<td>2300</td>
<td>Metres (m)</td>
</tr>
<tr>
<td>Skip factor</td>
<td>20</td>
<td>Tonnes (t)</td>
</tr>
<tr>
<td>Skips per hour</td>
<td>7</td>
<td>N/A</td>
</tr>
</tbody>
</table>

The ore transportation system operational schedule varies from day to day, due to the dynamic underground operations. Once the mined rock is hoisted to surface, it is stored in separate ore- and waste rock stockpiles. The ore on surface is transported to the gold plant by means of road transportation.
Multiple truck is allocated to a mine to transport the mined ore to the gold plant for further processing. Depending on the distance between the mine and the gold plant, a retour period in the transportation in the transportation occurs. The required characteristics of the ore distribution is illustrated in Table A-5.

Table A-5: Mine-A2 ore distribution summary

<table>
<thead>
<tr>
<th>Description</th>
<th>Data</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Trucks</td>
<td>2</td>
<td>N/A</td>
</tr>
<tr>
<td>Truck capacity</td>
<td>50</td>
<td>Tonnes (t)</td>
</tr>
<tr>
<td>Retour time</td>
<td>40</td>
<td>Minutes (min)</td>
</tr>
</tbody>
</table>

**Ore handling capacity**

OTS-A1 was originally designed to transport 3 080 tonnes to surface per day. As determined during the investigation period in 2013, the daily call of 1 450 tonnes of ore and there is 435 tonnes of waste per day as well. The ore transportation system has a total underground rock storage capacity of approximately 1 800 tonnes. This includes two separate storage units: a 1 000 tonne ore pass dedicated for ore storage; an 800 tonne ore pass is used to store waste rock.

The tonnes mined from the sub-shaft is directly hauled to the main shaft storage units. An average of 1 880 tonnes of rock was transported to surface daily during the investigation in 2013. This indicates that the ore transportation system is being utilised at approximately 65% of the total capacity during an average day.

Due to the unpredictable condition underground and the dynamic nature of daily ore production the daily ore transported to surface may vary greatly from the average determined above. An error factor is calculated which is implemented on the daily rock mined and transported to surface.

The ore production error factor is determined by calculating the deviation of the actual daily rock transported versus the three-month average used. This is quantified as a standard deviation in the tonnes of rock mined and transported daily. The standard deviation in tonnes of rock transported daily is quantified to be 157 tonnes (8.3%).

This indicates that the tonnes of rock transported daily can vary between 1 723 and 2 037 tonnes. To determine the average idle time of the ore transportation system the upper
boundary of the tonnes transported is used. The idle time of the ore transportation system is used to determine the feasibility of implementing a load shifting intervention on the system. In this case, the idle time was determined to be 33%.

The fact that OTS-A2 was not utilised at its full capacity to hoist all the mined material to surface, the possibility exists to optimise the operational schedule of the system. In the case where the mined ore is stored in stockpiles on surface, unlimited storage capacity is considered. Thus, the surface storage will not be considered as a constraint. This is rarely the case, surface silos are most commonly used as surface rock storage units.

**Normal operation**

The current control philosophy implemented on OTS-A2 is transporting mined rock to surface as soon as it is available. The average tonnes of mined rock transported to surface daily by OTS-A2 is used to scale the typical rock production profile to match the specific daily production of Mine-A2. Figure A-5 shows the scaled average weekday rock production during each shift.

![Figure A-5: Mine-A2 weekday rock production profile](image)

Shaft and hoist inspection occurs on two different predetermined weekdays. The purpose of these examinations is to ensure that the shaft meets required standards to deliver effective production. Both examinations last from 3-4 hours if no problems arise.
Optimising gold ore transportation systems for electricity cost savings

Power consumption

Figure A-6 shows the average weekday power baseline calculated over a three months period. The power data required to calculate the baseline was obtained from the power meters installed in the mine’s substation during the site investigation.

![Power consumption graph](image)

Figure A-6: OTS-A2 average weekday electricity consumption

ODN-A gold plant requirements

With the use of road distribution the supply of ore to the on-site gold plant is consistent if the mine’s production allows it. Each mine has a daily call to fulfil to supply the gold plant with suitable tonnes for effective processing operations.

The gold plant consists of two ore silos on surface, each with 2 500 tonnes capacity. Which indicates the gold plant has total silo capacity of 5000 tonnes. The plant’s milling circuit consists of a ROM (run-of-mine) mill and a SAG (semi-autogenous) mill. The details of the mills are summarised in Table A-6.

<table>
<thead>
<tr>
<th>Type</th>
<th>Quantity</th>
<th>Average tonnage (tph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROM Mill</td>
<td>1</td>
<td>90</td>
</tr>
<tr>
<td>SAG Mill</td>
<td>1</td>
<td>65</td>
</tr>
<tr>
<td>Total</td>
<td>2</td>
<td>155</td>
</tr>
</tbody>
</table>
ODN-A Electricity tariff structure

Mine-A1 and A2 is registered on the Megaflex TOU tariff structure. Refer to Appendix C for detailed overview of the Megaflex structure.

ODN-A Integrated layout

An integrated layout of Ore Distribution Network A (ODN-A) was compiled using all the information acquired, the investigation methodology and on-site experience. Figure A-7 shows the integrated operation layout of the ODN-A.

![Figure A-7: ODN-A integrated operation layout](image)

The total power consumption of the rock winders in each ore transportation system in an ore distribution network can be combined as the electricity cost-saving intervention is implemented on an integrated ore distribution network. Figure A-8 shows the typical power profile of the ore transportation systems in ODN-A.
Figure A-8: Combined OTS power profile of ODN-A
Appendix B:

ODN-B investigation and simulation results

OTS-B1

Mine-B1 consists of two surface shafts of which only one shaft is operational. For this reason only the one will be investigated. Mine-B1 undertakes in scattered underground mining and pillar reclamation on the Basal Reef with a mining depth of 2 200 m. The shaft contributes approximately 7% of the mining group’s total production. An average of 1 600 tonnes of ore is produced daily, which must be transported to surface.

Mine-B1 consists of a single surface shaft system. Ore Transportation System B1 (OTS-B1) consists of underground tramming systems, crushers, two rock winders and a man winder. Table B-1 shows the required characteristics of the rock winders included in OTS-B1.

<table>
<thead>
<tr>
<th>Description</th>
<th>Data</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Winder type</strong></td>
<td>Double drum</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Rated power</strong></td>
<td>4 200</td>
<td>kW</td>
</tr>
<tr>
<td><strong>Baseload</strong></td>
<td>465</td>
<td>kW</td>
</tr>
<tr>
<td><strong>Hoisting depth</strong></td>
<td>2 240</td>
<td>Metres (m)</td>
</tr>
<tr>
<td><strong>Skip factor</strong></td>
<td>16</td>
<td>Tonnes (t)</td>
</tr>
<tr>
<td><strong>Skips per hour</strong></td>
<td>15</td>
<td>N/A</td>
</tr>
</tbody>
</table>

OTS-B1 operational schedule varies from day to day, due to the dynamic underground operations. Once the mined rock is hoisted to surface it is stored in separate ore and waste rock surface storage. The ore is stored in surface silos and the waste rock is moved to the waste dump.

The ore on surface is transported to the gold plant by means of railway transportation. Multiple trains are allocated to a single distribution network between Mine-B1 and other mines included in ODN-B to transport the mined ore to the gold plant for further processing.
A delay is experienced during the transportation of the ore from the mine to the gold plant, this is better known as the retour time from point A to point B. The required characteristics of the ore distribution are illustrated in Table B-2

### Table B-2: Mine-B1 ore distribution summary

<table>
<thead>
<tr>
<th>Description</th>
<th>Data</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Hoppers</td>
<td>10</td>
<td>N/A</td>
</tr>
<tr>
<td>Hopper capacity</td>
<td>50</td>
<td>Tonnes (t)</td>
</tr>
<tr>
<td>Retour time</td>
<td>120</td>
<td>Minutes (min)</td>
</tr>
</tbody>
</table>

### Ore handling capacity

OTS-B1 has a total ore storage capacity of approximately 5,500 tonnes. The total ore storage capacity includes underground and surface storage. The underground ore storage consists of an ore pass (1,500 tonnes) and the crusher used to pulverise the rock. A separate 1,500 tonne ore pass is used for underground waste rock storage. On surface a 2,500 tonne silo is used to store ore and the waste rock is dumped.

OTS-B1 was originally designed to transport 5,280 tonnes to surface per day. As determined during the investigation period in 2013, the daily call is 1,600 tonnes of ore and there is 500 tonnes waste per day as well.

An average of 2,100 tonnes of rock was transported to surface daily during the investigation in 2013. This indicates that the ore transportation system is being utilised approximately 38% of the total capacity during an average day.

Due to the unpredictable condition underground and the dynamic nature of daily ore production the daily ore transported to surface may vary greatly from the average determined above. An error factor is calculated which is implemented on the daily rock mined and transported to surface.

The ore production error factor is determined by calculating the deviation of the actual daily rock transported versus the three months average used. This is quantified as a standard deviation in the tonnes of rock mined and transported daily. The standard deviation in tonnes of rock transported daily is quantified to be 360 tonnes (18%).

This indicates that the tonnes of rock transported daily can vary between 1,640 and 2,360 tonnes. To determine the average idle time of the ore transportation system, the upper
boundary of the tonnes transported is used. The idle time of the ore transportation system is used to determine the feasibility of implementing a load shifting intervention on the system.

In this case, the idle time was determined to be 55%. The fact that the ore transportation system was not utilised at its full capacity to hoist all the mined material to surface, the possibility exists to optimise the operational schedule of the system. Approximately nine hours is required per day to haul all the mined rock from underground to surface.

**Normal operation**

The mine’s labour priorities are divided into three main shifts namely, morning, afternoon and night shift. During each of these shifts various secondary activities take place in different sectors across the underground operations. Production is the primary objective during these shifts. Table B-3 shows the operational shifts.

<table>
<thead>
<tr>
<th>Shift</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morning</td>
<td>05:00-13:00</td>
</tr>
<tr>
<td>Afternoon</td>
<td>13:00-21:00</td>
</tr>
<tr>
<td>Night</td>
<td>21:00-05:00</td>
</tr>
</tbody>
</table>

A gold mine’s key priority is gold ore production. The current control philosophy implemented on OTS-B1 is transporting mined rock to surface as soon as it is available. The daily rock production of one mine in the mining group could be obtained. The rock production profile is allocated to each of the mines included in the mining group.

Figure 3-4 shows the scaled rock production for an average weekday during each shift, with the upper and lower boundaries determined by the ore handling capabilities of OTS-B1. The upper and lower production boundaries are obtained by means of the standard deviation in the average amount of ore produced daily as discussed above.
Shaft and hoist inspections occur on two different predetermined weekdays between 07:00 and 11:00. The purpose of these inspections is to ensure that the shaft meets the required standards to deliver effective production.

**Power consumption**

Figure B-2 shows the power baseline for an average weekday calculated over a three-month period. Once again the direct correlation between the average daily production and power profile is seen.
OTS-B2

Mine-B2 undertakes conventional undercut mining on the Basal and B Reefs with a mining depth of 2 300 m. The shaft contributes approximately 8% of the mining group’s total production. An average of 3 000 tonnes of ore is produced daily which must be transported to surface.

Mine-B2 consists of a single surface shaft system. Ore Transportation System B2 (OTS-B2) consists of underground tramming systems, crushers, with a rock and man winder. Table B-4 shows the required characteristics of the OTS-B2 rock winder.

<table>
<thead>
<tr>
<th>Description</th>
<th>Data</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winder type</td>
<td>BMR</td>
<td>N/A</td>
</tr>
<tr>
<td>Rated power</td>
<td>4 200</td>
<td>kW</td>
</tr>
<tr>
<td>Baseload</td>
<td>124</td>
<td>kW</td>
</tr>
<tr>
<td>Hoisting depth</td>
<td>2 100</td>
<td>Metres (m)</td>
</tr>
<tr>
<td>Skip factor</td>
<td>18</td>
<td>Tonnes (t)</td>
</tr>
<tr>
<td>Skips per hour</td>
<td>14</td>
<td>N/A</td>
</tr>
</tbody>
</table>

OTS-B2 operational schedule varies from day to day, due to the dynamic underground operations. Once the mined rock is hoisted to surface it is stored in separate ore- and waste rock surface storage. The ore is stored in surface silos and the waste rock is moved to the waste dump.

The ore on surface is transported to the gold plant by means of railway transportation. Multiple trains are allocated to a single distribution network between Mine-B2 and other mines included in ODN-B to transport the mined ore to the gold plant for further processing. A retour delay is experienced during the transportation of the ore from the mine to the gold plant. The required characteristics of the ore distribution are illustrated in Table B-5.

<table>
<thead>
<tr>
<th>Description</th>
<th>Data</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Hoppers</td>
<td>10</td>
<td>N/A</td>
</tr>
<tr>
<td>Hopper capacity</td>
<td>50</td>
<td>Tonnes (t)</td>
</tr>
<tr>
<td>Retour time</td>
<td>120</td>
<td>Minutes (min)</td>
</tr>
</tbody>
</table>
Ore handling capacity

OTS-B2 has a total ore storage capacity of 6 600 tonnes. The total ore storage capacity includes underground and surface storage. The underground ore storage consists of a 1 800 tonne ore pass. A separate 1 800 tonne ore pass is used for underground waste rock storage. On surface a 3 000 tonne silos is used to store ore and the waste rock is dumped.

OTS-B2 was originally designed to transport 5 000 tonnes to surface per day. As determined during the investigation period in 2013, the daily call is 3 000 tonnes of ore and there is 900 tonnes waste per day.

An average of 3 900 tonnes of rock was transported to surface daily during the investigation in 2013. This indicates that the ore transportation system is being utilised at approximately 60% of the total capacity during an average day.

As with OTS-B1, ore production error factor is determined by calculating the deviation of the actual daily rock transported versus the three-month average used. This is quantified as a standard deviation in the tonnes of rock mined and transported daily. The standard deviation in tonnes of rock transported daily is quantified to be 276 tonnes (9.2%).

This indicates that the tonnes of rock transported daily can vary between 2 724 and 3 276 tonnes. In order to determine the average idle time of OTS-B2 the upper boundary of the tonnes transported is used. The idle time of the ore transportation system is used to determine the feasibility of implementing a load shifting intervention on the system. In this case, the idle time was determined to be 34%. The fact that the OTS is not utilised to its full capacity to hoist all the mined material to surface, a possibility existed to optimise the operational schedule of the system.

OTS-B2 consists of a single rock winder which is used to haul ore and waste rock to surface. Extracting ore from underground to surface is the key focus, secondary winder operations include waste rock extraction. The ore is transported to the gold plant by means of railroad transportation. The waste rock is dumped on a stockpile on-site.

Normal operation

The mining shifts at Mine-B2 is the same as at Mine-B1, due to the standardising of mines in a mining group. The key priority for a gold mine is gold ore production. The current control philosophy implemented on OTS-B2 is to transport ore to surface as soon as it is available. Figure B-3 shows the average weekday ore production during each shift.
Shaft and hoist inspection occurs on two different predetermined weekdays between 07:00 and 11:00. The purpose of these inspections is to ensure that the shaft meets required standards to deliver effective production.

**Power consumption**

Figure B-4 shows the power baseline for an average weekday calculated over a three-month period. Once again the direct correlation between the average daily production and power profile is seen.
Load management potential of OTS-B2

In Section 5.3.3 the optimal load management potential of OTS-B2 is discussed using the optimisation model created in Chapter 4. See below the optimisation model results of OTS-B2.

Ore transportation system silo levels

As with OTS-B1 the standard deviation in the daily rock mined over a three-month period is used to determine upper and lower boundaries. These boundaries are used to illustrate the margin within which the daily rock mine can vary at any given moment.

Assumptions: The initial underground and surface storage levels for the simulated operational mining week were required to quantify the effect of an optimised rock winder schedule on the respective storage units.

- Initial underground storage level: 30%
- Initial surface silo level: 60%

Figure B-5 shows the underground rock storage level during a 24-hour day in which OTS-B2 was optimised. The underground storage maximum and minimum limits are indicated on the graph as 20% and 40%. It can be seen that the underground storage constraints are satisfied.

![Figure B-5: OTS-B2 underground storage level percentage](image)

Figure B-6 shows the surface rock storage level during a 24-hour day in which OTS-B2 was optimised. The surface silo maximum and minimum limits are indicated on the graph as 40% and 80%. It is seen that the surface silo constraints are satisfied.
Figure B-6: OTS-B2 surface silo storage level percentage

Figure B-5 and Figure B-6 shows that the underground and surface storage were able to absorb the mined rock with minimal utilisation of OTS-B2 rock winder during the peak periods.

**Mined ore extraction and distribution**

Figure B-7 shows the rate at which the mined rock was extracted from underground to surface. It was interpreted that the total amount of ore mined was hauled to surface by implementing the optimisation. It is clearly seen that the rate at which the tonnes were extracted from underground flattens during the peak periods.

Figure B-7 also indicates that the total amount of rock extracted was transported to the gold plant. Due to the use of the railway distribution network the ore transportation to the gold
plant has a minimum of two hours return time between each trip. As can be seen, the total amount of rock mined during the specific day was hauled to surface and transported to the gold plant within the specified call period.

**OTS-B3**

Mine-B3 consist of a single surface shaft system with two rock winders and a single man winder. OTS-B3 is used to hoist ore and waste rock to surface and serves as a secondary escape route. The two rock winders in OTS-B3 are identical.

No mining takes place at Mine-B3, the ore is transported approximately 5.5 km using underground rail-veyor system from an adjacent mine. The rail-veyor operates in a continuous loop as the carts are open ended. Table B-6 shows the required characteristics of the OTS-B3 rock winders.

<table>
<thead>
<tr>
<th>Description</th>
<th>Data</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winder type</td>
<td>Double drum</td>
<td>N/A</td>
</tr>
<tr>
<td>Rated power</td>
<td>4200</td>
<td>kW</td>
</tr>
<tr>
<td>Baseload</td>
<td>670</td>
<td>kW</td>
</tr>
<tr>
<td>Hoisting depth</td>
<td>1750</td>
<td>Metres (m)</td>
</tr>
<tr>
<td>Skip factor</td>
<td>10</td>
<td>Tonnes (t)</td>
</tr>
<tr>
<td>Skips per hour</td>
<td>16</td>
<td>N/A</td>
</tr>
</tbody>
</table>

OTS-B3 operational schedule varies from day to day, due to the dynamic underground operations. Once the mined rock is hoisted to surface it is stored in separate ore and waste rock surface storage. The ore is stored in surface silos and the waste rock is moved to the waste dump.

The ore on surface is transported to the gold plant by means of railway transportation. Multiple trains are allocated to a single distribution network between Mine-B2 and other mines included in ODN-B to transport the mined ore to the gold plant for further processing. A delay is experienced during the transportation of the ore from the mine to the gold plant. The required characteristics of the ore distribution are illustrated in Table B-7.
Table B-7: Mine-B3 ore distribution summary

<table>
<thead>
<tr>
<th>Description</th>
<th>Data</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Hoppers</td>
<td>14</td>
<td>N/A</td>
</tr>
<tr>
<td>Hopper capacity</td>
<td>52</td>
<td>Tonnes (t)</td>
</tr>
<tr>
<td>Return time</td>
<td>120</td>
<td>Minutes (min)</td>
</tr>
</tbody>
</table>

**Ore handling capacity**

The ore transportation system at Mine-A3 is divided into two sections, namely ore transportation system east and west. The east ore transportation system is dedicated to hauling the mined ore to surface, this usually occurs from 14:00 to 07:00. The west ore transportation system is dedicated to hauling the mined waste rock to surface, which is scheduled between 10:00 to 14:00.

The east and west ore transportation system was originally designed to transport 3 520 tonnes to surface per day. As determined during the investigation period in 2013, the daily call is 2 600 tonnes of ore and there is 1 150 tonnes waste per day as well.

To simplify OTS-B3’s operation, the two rock winders operational schedule is combined to form a single ore transportation system. It can now be determined that OTS-B3 was originally designed to transport 7 040 tonnes of rock to surface per day.

OTS-B3 has a total underground rock storage capacity of approximately 600 tonnes. This includes two separate storage units: a 300 tonne ore pass is dedicated for ore storage and; a 300 tonne ore pass is used to store waste rock.

An average of 3 750 tonnes of rock was transported to surface daily during the investigation in 2013. This indicates that ore transportation system is being utilised at approximately 56% of the total capacity during an average day.

Due to the unpredictable condition underground and the dynamic nature of daily ore production the daily ore transported to surface may vary greatly from the average determined above. An error factor is calculated which is implemented on the daily rock mined and transported to surface.

The ore production error factor is determined by calculating the deviation of the actual daily rock transported versus the three-month average used. This is quantified as a standard
deviation in the tonnes of rock mined and transported daily. The standard deviation in tonnes of rock transported daily is quantified to be 350 tonnes (9%).

This indicates that the tonnes of rock transported daily can vary between 3 600 and 4 300 tonnes. To determine the average idle time of the ore transportation system the upper boundary of the tonnes transported is used. The idle time of the ore transportation system is used to determine the feasibility of implementing a load shifting intervention on the system. In this case, the idle time was determined to be 61%.

The fact that OTS-B3 was not utilised at its full capacity to hoist all the mined material to surface, a possibility existed to optimise the operational schedule of the system. The ore hauled to surface is directly moved to a surface silo from where it is transported to the gold plant by railroad transportation. The waste rock is dumped on a stockpile on-site.

**Normal operation**

The mining shifts at Mine-B3 is the same as at Mine-B2, due to the standardising of mines in a mining group. A gold mine’s key priority is gold ore production. The current control philosophy implemented on OTS-B3 is transporting ore to surface as soon as it is available. Figure B-8 shows the scaled rock production for an average weekday during each shift, with the upper and lower boundaries determined by the ore handling capabilities of the ore transportation system.

![Figure B-8: Mine-B3 weekday rock production profile](image)

From Figure B-8, two prominent periods of production can be determined. As seen during the shift changes the production is impacted immensely. During the morning and night shifts,
the most tonnes are delivered, which must be hauled to surface. During the afternoon shift, the available tonnes to haul to surface is minimal.

Shaft and hoist inspection occurs on three different predetermined weekdays between 07:00 and 11:00. The purpose of these inspections is to ensure that the shaft meets required standards to deliver effect production.

**Power consumption**

Analysing the average ore production profile indicates that the majority of ore supply to OTS-B3 is received during the morning and night shift. As the current control philosophy strives to extract ore immediately, Figure B-9 shows that the power profile is directly linked to the underground ore supply.

![Figure B-9: OTS-B3 average weekday electricity consumption](image)

**Load management potential of OTS-B3**

In Section 5.3.3 the optimal load management potential of OTS-B3 is discussed using the optimisation model created in Chapter 4. See below the optimisation model results of OTS-B3.

**Ore transportation system storage levels**

Assumptions: The initial underground and surface storage levels for the simulated operational mining week were required to quantify the effect of an optimised rock winder schedule on the respective storage units.

- Initial underground storage level: 40%
- Initial surface silo level: 65%

Upper and lower boundaries are used to indicate the possible variation in the amount of rock mined. This is used to demonstrate the possible variation in the storage level at any given time. Figure B-10 shows the underground rock storage level during a 24-hour day in which OTS-B3 was optimised. The underground storage maximum and minimum limits are indicated on the graph as 20% and 40%. It can be seen that the underground storage constraints were satisfied.

![Graph of OTS-B3 underground storage level percentage](image)

Figure B-10: OTS-B3 underground storage level percentage

Figure B-11 shows the surface rock storage level during a 24-hour day in which OTS-B3 was optimised. The surface silo maximum and minimum limits are indicated on the graph as 40% and 80%. It can be seen that the surface silo constraints are satisfied.
It can be seen that the underground and surface storage were able to absorb the mined rock with minimal utilisation of OTS-B3 during the peak periods.

**Mined ore extraction and distribution**

Figure B-12 shows the rate at which the mined rock was extracted from underground to surface. It was interpreted that the total amount of ore mined was hauled to surface by implementing the optimisation. It is clearly seen that the rate at which the tonnes were extracted from underground flattens during the peak periods.

Figure B-12 indicates that the total amount of rock extracted was transported to the gold plant. Due to the use of the railway distribution network the ore transportation to the gold plant has a minimum of two hours retour time between each trip. As seen all the rock mined
during the specific day is hauled to surface and transported to the gold plant within the specified “call” period.

**OTS-B4**

Mine-B4 undertakes conventional undercut mining on the Basal and B Reefs with a mining depth of 2200 m. The shaft contributes approximately 14% of the mining group’s total production, which makes the shaft one of the largest operations in its mining group. An average of 4 000 tonnes of ore is produced daily which must be transported to surface.

Ore Transportation System B4 (OTS-B4) consists of underground tramming systems, crushers and surface winders, that are used to haul personnel and material to surface. Figure B-13 shows Mine-B4’s ore transportation layout with all its components.
Underground tramming is used to transport mined rock from the stope to the underground storage. The ore is extracted from the underground storage by crushers and pulverised into smaller rock. As rock is crushed, it is loaded into rock winder skips and hoisted to surface.

The rock winder is dedicated to transporting mined rock from underground to surface. Table B-8 shows the required characteristics of the OTS-B4 rock winder.
OTS-B4 operational schedule varies from day to day, due to the dynamic underground operations. Once the mined rock is hoisted to surface it is stored in separate ore and waste rock stockpiles.

The ore on surface is transported to the gold plant by means of railway transportation. Multiple trains are allocated to a single distribution network between Mine-B4 and other mines included in ODN-B to transport the mined ore to the gold plant for further processing. A delay is experienced during the transportation of the ore from the mine to the gold plant. The required characteristics of the ore distribution is illustrated in Table B-9.

### Table B-9: Mine-B4 ore distribution summary

<table>
<thead>
<tr>
<th>Description</th>
<th>Data</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Hoppers</td>
<td>14</td>
<td>N/A</td>
</tr>
<tr>
<td>Hopper capacity</td>
<td>52</td>
<td>Tonnes (t)</td>
</tr>
<tr>
<td>Retour time</td>
<td>120</td>
<td>Minutes (min)</td>
</tr>
</tbody>
</table>

### Ore handling capacity

The ore transportation system at Mine-B4 was originally designed to transport 6 600 tonnes to surface per day. As determined during the investigation period in 2013, the daily call is 4 500 tonnes of ore and there is 1 350 tonnes waste per day as well. The ore transportation system has a total underground rock storage capacity of approximately 4 150 tonnes. This includes two separate storage units: a 2 150 tonne ore pass is dedicated for ore storage; a 2000 tonne ore pass is used to store waste rock.
An average of 5 750 tonnes of rock was transported to surface daily during the investigation in 2013. This indicates that the ore transportation is being utilised at approximately 72% of the total capacity during an average day.

Due to the unpredictable conditions underground and the dynamic nature of daily ore production the daily ore transported to surface may vary significantly from the average determined above. An error factor is calculated to account for deviation in the daily rock mined and transported to surface.

The ore production error factor is determined by calculating the deviation of the actual daily rock transported versus the three months average used. This is quantified as a standard deviation in the tonnes of rock mined and transported daily. The standard deviation in tonnes of rock transported daily is quantified to be 420 tonnes (8.7%).

This indicates that the tonnes of rock transported daily can vary between 4 380 and 5 220 tonnes. In order to determine the average idle time of OTS-B4, the upper boundary of the tonnes transported is used. The idle time of the ore transportation system is used to determine the feasibility of implementing a load shifting intervention on the system. In this case, the idle time was determined to be 21%.

The fact that the ore transportation system was not utilised at its full capacity to hoist all the mined material to surface, meant that a possibility existed to optimise the operational schedule of the system.

**Normal operation**

The mining shifts at Mine-B4 is the same as at Mine-B3, due to the standardising of mines in a mining group. The key priority for a gold mine is gold ore production. The current control philosophy implemented on OTS-B4 is to transport ore to surface as soon as it is available. Figure B-14 shows the scaled rock production for an average weekday during each shift, with the upper and lower boundaries determined by the ore handling capabilities of the ore transportation system.
From Figure B-14, three prominent periods of production can be determined. Figure B-14 also illustrates that shift changes have a large impact on daily production. During the afternoon and night shift the most tonnes are delivered, which must be hauled to surface. During the morning shift, the available tonnes to haul to surface is minimal. Ore production decreases over weekends.

Shaft and hoist inspection occurs on two different predetermined weekdays. The purpose of these inspections is to ensure that the shaft meets required standards to deliver safe and effective production. Both examinations lasts three to four hours if no significant issues are reported.

These inspections causes a build-up of ore and waste rock in the underground storage which can possibly affect the daily call.

**Power consumption**

Analysing the average ore production profile indicates that the majority of ore supply to OTS-B4 is received during the morning and night shift. As the current control philosophy strives to extract ore immediately, Figure B-15 shows the power baseline for an average weekday calculated over a three-month period.
In Section 5.3.3 the optimal load management potential of OTS-B4 is discussed using the optimisation model created in Chapter 4. See below the optimisation model results of OTS-B4.

**OTS storage levels**

Assumptions: The initial underground and surface storage levels for the simulated operational mining week were required to quantify the effect of an optimised rock winder schedule on the respective storage units.

- Initial underground storage level: 30%
- Initial surface silo level: 65%

The same as with OTS-B2 and OTS-B3, upper and lower boundaries are used to indicate the possible variation in the amount of rock mined. This is used to demonstrate the possible variation in the storage level at any given time. Figure B-16 shows the underground rock storage level during a 24-hour day in which the OTS was optimised. The underground storage maximum and minimum limits are indicated on the graph as 20% and 40%. It can be seen that the underground storage constraints are satisfied.
Figure B-16: OTS-B4 underground storage level percentage

Figure B-17 shows the surface rock storage level during a 24-hour day in which the OTS is optimised. The surface silo maximum and minimum limits are indicated on the graph as 40% and 80%. It is seen that the surface silo constraints are satisfied.

Figure B-17: OTS-B4 surface storage level percentage

It is seen that the underground and surface storage were able to absorb the mined rock with the ore transportation system utilisation at a minimum during the peak periods.

**Mined ore extraction and distribution**

Figure B-18 shows the rate at which the mined rock was extracted from underground to surface. It was interpreted that the total amount of ore mined was hauled to surface by implementing the optimisation. It is clearly seen that the rate at which the tonnes were extracted from underground flattens during the peak periods.
Figure B-18 indicates that the rock extracted was transported to the gold plant. Due to the use of the railway distribution network the ore transportation to the gold plant has an average retour time of two hours. As can be seen, all the rock mined during the specific day was hauled to surface and transported to the gold plant within the specified call period.

**OTS-B5**

Mine-B5 undertakes in scattered underground mining and pillar reclamation on the Basal, Leader and Middle Reefs with a mining depths ranging from 1 000 to 2 000 m. The shaft contributes approximately 8% of the mining group’s total production. An average of 1 600 tonnes of ore is produced daily which must be transported to surface. Mine-B5 is nearing the end of its operation life.

Mine-B5 consists of a single surface shaft system. Ore Transportation System B5 (OTS-B5) consists of underground tramming systems, crushers, rock winder and a man winder. Table B-10 shows the required characteristics of the OTS-B5 rock winder.

**Table B-10: OTS-B5 rock winder characteristics summary**

<table>
<thead>
<tr>
<th>Description</th>
<th>Data</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winder type</td>
<td>Double drum</td>
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</tr>
<tr>
<td>Rated power</td>
<td>4600</td>
<td>kW</td>
</tr>
<tr>
<td>Baseload</td>
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<td>kW</td>
</tr>
<tr>
<td>Hoisting depth</td>
<td>1930</td>
<td>Metres (m)</td>
</tr>
<tr>
<td>Skip factor</td>
<td>10</td>
<td>Tonnes (t)</td>
</tr>
<tr>
<td>Skips per hour</td>
<td>15</td>
<td>N/A</td>
</tr>
</tbody>
</table>
OTS-B5 operation schedule varies from day to day, due to the dynamic underground operations. Once the mined rock is hoisted to surface it is stored in separate ore and waste rock surface storage. The ore is stored in surface silos and the waste rock is moved to the waste dump.

The ore on surface is transported to the gold plant by means of railway transportation. Multiple trains are allocated to a single distribution network between Mine-B5 and other mines included in ODN-B to transport the mined ore to the gold plant for further processing. A delay is experienced during the transportation of the ore from the mine to the gold plant. The required characteristics of the ore distribution network are illustrated in Table B-11.

<table>
<thead>
<tr>
<th>Description</th>
<th>Data</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Hoppers</td>
<td>10</td>
<td>N/A</td>
</tr>
<tr>
<td>Hopper capacity</td>
<td>50</td>
<td>Tonnes (t)</td>
</tr>
<tr>
<td>Retour time</td>
<td>120</td>
<td>Minutes (min)</td>
</tr>
</tbody>
</table>

### Ore handling capacity

OTS-B5 has a total ore storage capacity of approximately 4 500 tonnes. The total ore storage capacity includes underground and surface storage. The underground ore storage consists of a 1 000 tonnes ore pass for ore and a separate 800 tonne ore pass is used for underground waste rock storage.

OTS-B5 was originally designed to transport 3 300 tonnes to surface per day. As determined during the investigation period in 2013, the daily call is 2 000 tonnes of ore and there is 600 tonnes waste per day as well.

An average of 2 200 tonnes of rock was transported to surface daily over a period of three months in 2014. This indicates that the ore transportation system is being utilised at approximately 66% of the total capacity during an average day.

As with OTS-B4, ore production error factor is determined by calculating the deviation of the actual daily rock transported versus the three-month average used. This is quantified as a standard deviation in the tonnes of rock mined and transported daily. The standard deviation in tonnes of rock transported daily is quantified to be 192 tonnes (9%).
This indicates that the tonnes of rock transported daily can vary between 2,008 and 2,392 tonnes. In order to determine the average idle time of the ore transportation system, the upper boundary of the tonnes transported is used. The idle time of the ore transportation system is used to determine the feasibility of implementing a load shifting intervention on the system. In this case, the idle time was determined to be 30%. The fact that the ore transportation system is not utilised at its full capacity to hoist all the mined material to surface, a possibility existed to optimise the operational schedule of the system.

OTS-B5 consists of a single rock winder which is used to haul ore and waste rock to surface. Extracting ore from underground to surface is the key focus, secondary winder operations include waste rock extraction. The ore is transported to the gold plant by means of railway transportation. The waste rock is dumped on a stockpile on-site.

**Normal operation**

The mining shifts at Mine-B5 is the same as at Mine-B4 and B3, due to the standardising of mines in a mining group. A gold mine’s key priority is gold ore production. The current control philosophy implemented on OTS-B5 is transporting ore to surface as soon as it is available. Figure B-19 shows the scaled rock production for an average weekday during each shift, with the upper and lower boundaries determined by the ore handling capabilities of the ore transportation system.

![Figure B-19: Mine-B5 average weekday rock production profile](image)

Shaft and hoist inspection occurs on three different predetermined weekdays between 07:00 and 11:00. The purpose of these inspections is to ensure that the shaft meets required standards to deliver effect production.
Power consumption

Figure B-20 shows the power baseline for an average weekday calculated over a three-month period. Once again the direct correlation between the average daily production and power profile is seen. This is owing to the control implemented on the winder by extracting rock as it is available.

![Power Consumption Chart]

Figure B-20: OTS-B5 average weekday rock winder electricity consumption

Load management potential of OTS-B5

In Section 5.3.3 the optimal load management potential of OTS-B5 is discussed using the optimisation model created in Chapter 4. See below the optimisation model results of OTS-B5.

OTS storage levels

Assumptions: The initial underground and surface storage levels for the simulated operational mining week were required to quantify the effect of an optimised rock winder schedule on the respective storage units.

- Initial underground storage level: 30%
- Initial surface silo level: 70%

The same as OTS-B3 and OTS-B4, upper and lower boundaries are used to indicate the possible variation in the amount of rock mined. This is used to demonstrate the possible variation in the storage level at any given time. Figure B-21 shows the underground rock storage level during a 24-hour day in which the ore transportation system was optimised.
The underground storage maximum and minimum limits are indicated on the graph as 20% and 40%. It can be seen that the underground storage constraints were satisfied.

Figure B-21: OTS-B5 underground storage level percentage

Figure B-22 shows the surface rock storage level during a 24-hour day in which the ore transportation system was optimised. The surface silo maximum and minimum limits are indicated on the graph as 40% and 80%. It can be seen that the surface silo constraints are satisfied.

Figure B-22: OTS-B5 surface storage level percentage

It can be seen that the underground and surface storage were able to absorb the mined rock with the OTS utilisation at a minimum during the peak periods.
Mined ore extraction and distribution

Figure B-23 shows the rate at which the mined rock was extracted from underground to surface. It was interpreted that the total amount of ore mined was hauled to surface by implementing the optimisation. It is clearly seen that the rate at which the tonnes were extracted from underground flattens during the peak periods.

![Figure B-23: OTS-B5 cumulative production and ore distribution network transportation](image)

ODN-B gold plant requirements

The gold plant processes reef and waste rock from various shafts in the area. The plant consists of three process lines and is one of the largest gold plants in South Africa. The gold plant consists 12 ore silos on surface, each with a capacity of 2 000 tonnes, which indicates that the gold plant has total silo capacity of 24 000 tonnes. During normal daily operation the silo level is controlled between 50% and 80%. The plant’s milling circuit consists of six ROM (run-of-mine) mills. The details of the mills are summarised in Table B-12.

<table>
<thead>
<tr>
<th>Type</th>
<th>Quantity</th>
<th>Average tonnage (tph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROM Mill</td>
<td>6</td>
<td>100</td>
</tr>
<tr>
<td>Total</td>
<td>6</td>
<td>600</td>
</tr>
</tbody>
</table>

With the use of rail distribution the supply of ore to the gold plant is inconsistent because of the large retour times of the trains and the number of mines included in the ore distribution network.
ODN-B Electricity tariff structure

Mine-A1 and A2 is registered on the Megaflex TOU tariff structure. Refer to Appendix C for detailed overview of the Megaflex structure.

ODN-B Integrated layout

An integrated layout of Ore Distribution Network B (ODN-B) was compiled using all the information acquired, the investigation methodology and on-site experience. Figure B-24 shows the integrated operation layout of ODN-B.

The total power consumption of the rock winders in each ore transportation system in an ore distribution network can be combined as the electricity cost-saving intervention is
implemented on an integrated ore distribution network. Figure B-25 shows the typical power profile of the ore transportation systems in ODN-B.

Figure B-25: Combined ore transportation system power profile of ODN-B
Appendix C:

Eskom Megaflex tariff structure

Eskom rolled out a number of tariff structures, each focusing on different consumer needs and electricity demands. The main purpose of these structures is to persuade consumers to use electricity accordingly as electricity prices are increased during the high demand periods and reduced prices during low demand periods. Most mines in South Africa are billed according to Megaflex tariff structure as the notified maximum demand exceed 1MVA.

The Megaflex tariff structure entails three time periods, in which active energy charges vary, namely peak, standard and off-peak periods. These periods vary on time of day and a seasonal basis. Figure C-1 shows the Megaflex charges implemented during the study.

![Figure C-1: Megaflex active energy charges](image)

Figure C-2 shows the different TOU period intervals and cost per kWh consumed during these periods. As seen in Figure C-2, there is an extensive cost difference between the high demand winter season and the low demand winter season during the peak demand period.
Optimising gold ore transportation systems for electricity cost savings

Figure C-2: Megaflex TOU tariff structure
Appendix D:

Report
1 Summary

1.1 Hourly electricity consumption

Mine shaft weekly consumption (Monday (Date) - Sunday (Date))

1.2 Weekly average electricity consumption profiles

Mine shaft average electricity consumption profile:

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1.3 Weekly average savings (kW load shift)

- Morning impact: 9 kW
- Evening impact: 1259 kW

1.4 Time of use (kWh and cost)

**Energy distribution**

- Off-peak: 12%
- Standard: 39%
- Peak: 49%

**Cost distribution**

- Off-peak: R 14 315.39
- Standard: R 19 004.78
- Peak: R 38 803.19

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mine shaft total electricity consumption</td>
<td>155841 kWh</td>
</tr>
<tr>
<td>Mine shaft total electricity cost</td>
<td>R 73 923.33</td>
</tr>
<tr>
<td>Mine shaft rock hoist electricity cost savings</td>
<td>R 5 085.17</td>
</tr>
</tbody>
</table>

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