COMPARISON BETWEEN AUTOMATED AND MANUAL DSM PUMPING PROJECTS

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ABSTRACT

Title: Comparison between Automated and Manual DSM Pumping Projects

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Key words: DSM, Eskom, load shifting, manual and automated clear water pumping systems

The purpose of this dissertation is to identify the best alternative method of load shifting on clear water pumping systems in the mining industry. This can be done through a comparison analysis between manual and automated Demand Side Management (DSM) projects.

The study holds benefits for Eskom and any client wishing to participate in the program. Eskom, by choosing the best method, will ensure sustainable load shifting while the client benefits financially through lower electricity costs.

In order to perform this study, research was conducted on the requirements for additional electricity supply in South Africa. Research showed that there is an urgent requirement for additional electricity supply to ensure continued economical growth. DSM was identified as one of the most favourable methods that could be implemented to address the problem. A reason for this is DSM projects are economically viable and can be implemented in a relatively short time. The initiative would also decrease the need for increasing electrical generation capacity.

During the research study important information regarding the computation process for load shifting and cost saving performance was gathered. Research was also conducted on the effect of DSM on labour and maintenance cost reduction, as well as economical engineering methods that can be used for alternative selection.

The difference in performance between automated and manual systems was compared. The results showed that a 40% improvement of automated systems over manual systems were attainable and sustainable. This will realise a total saving of approximately 45% in electricity costs for the client.

Savings in labour and maintenance costs are shown to be achievable through the automation of pumping systems. These saving results were used in the Engineering Economic alternative selection methods where applicable. Economic calculations confirmed that automated projects are the most viable control method.

From the comparison study, it is shown that automated controlled systems are more advantageous than manually controlled systems. It will therefore be in the best interest of the client to automate a manually controlled pumping system, as it will result in additional load shifting and cost saving.

SAMEVATTING

Titel: Vergelyking Tussen Geoutomatiseerde en Handbeheerde DSM Pompprojekte

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Promotor: Dr. R.Plezer

Sleutelwoorde: DSM, Eskom, lasverskuiwing, handbeheerde en geoutomatiseerde skoonwater pompstelsels

Die doel van hierdie studie is om die beste lasverskuiwingsmetode te bepaal, soos van toepassing op skoonwater-pompstelsels in die mynbousektor. Dit is gedoen deur 'n vergelykende studie tussen handbeheerde en volledig geoutomatiseerde DSM projekte te doen.

Die studie hou nie net slegs groot voordele vir Eskom in nie, maar ook vir die kliënt wat bereid is om deel te wees van die DSM program. Eskom kan direk baat vind by die studie, aangesien die keuse van die korrekte lasverskuiwingsmetode kan lei tot addisionele elektrisiteitsbesparing gedurende hoë elektrisiteitsaanvraagperiodes. Wat die kliënt betref kan groter finansiële besparings verkry word indien die korrekte metode gebruik word.

Alvorens die vergelykende studie begin is, is navorsing gedoen aangaande die huidige elektrisiteitstekort in Suid-Afrika. Vanuit die navorsing blyk DSM projekte die mees geskikte keuse as korttermyn oplossing. Vir die doel van die studie is lasverskuiwingsmetodes as deel van die DSM program in diepte bestudeer.

Gedurende die studie is belangrike inligting rakende die bepalingsmetodes vir lasverskuiwing en resultate vir kostebesparing versamel. Navorsing is ook gedoen om die effek van arbeidsen herstelwerkkostes vir verskillende opsies te bepaal. Om die studie af te rond is verskillende metodes van ingenieursekonomie, wat gebruik kan word in die seleksieproses, ook bestudeer.

Vanuit die vergelykende studie is daar bepaal dat resultate van lasverskuiwings met tot 40% verbeter word indien ‘n handbeheerde pompsisteem geoutomatiseer word. Hierdie verbetering lei tot ‘n besparing in elektrisiteitskoste van ongeveer 45%.

Addisionele kostebesparings wat arbeids- en herstelwerkskoste insluit is ook bepaal. Hierdie komponente is verder gebruik in die berekeninge van ingenieursekonomie. Vanuit hierdie berekeninge was dit weereens duidelik dat geoutomatiseerde sisteme die mees aanvaarbare resultate oplewer.

'n Algemene gevolgtrekking van die studie dui dus daarop dat geoutomatiseerde pompsisteme beter resultate oplewer as handbeheerde stelsels. Indien 'n DSM-projek dus geïmplementeer word op 'n pompsisteem, sal 'n geoutomatiseerde stelsel van groter waarde wees.

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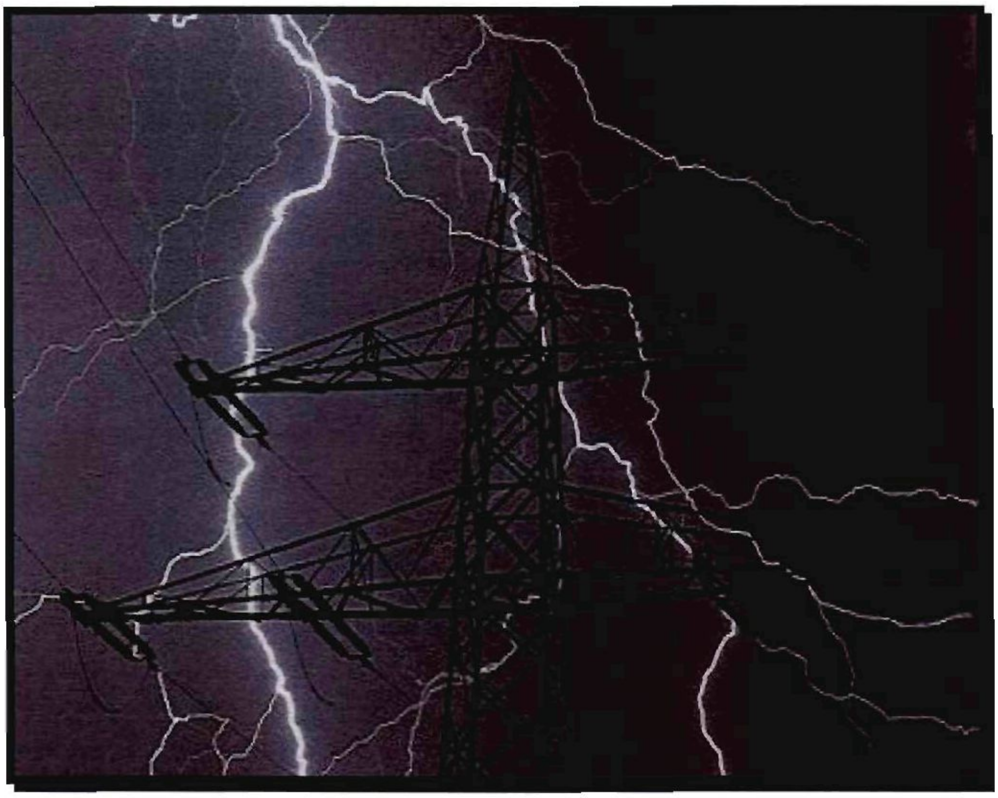
LIST OF ABBREVIATIONS

A	Annual Worth
ACS	Additional Cost Savings
AI	Artificial Intelligent
c/kWh	Cent per Kilowatt Hour
DME	Department of Minerals and Energy
DSM	Demand Side Management
EIA	Environmental Impact Assessment
ECS	Electricity Cost Savings
ESCO	Energy Service Company
F	Future Worth
g	Constant rate of change (interest rate)
GW	Gigawatt
GWh	Gigawatt Hour
i	Interest rate
ISEP	Integrated Strategic Electricity Planning
kVA	Kilo Volt Ampere
kW	Kilo Watt
LM	Load Management
m	Meter
MD	Maximum Demand
MW	Mega Watt
MWh	Mega Watt Hour
n	Number of interest periods
OCGT	Open Cycle Gas Turbine
P	Present Worth
PBMR	Pebble Bed Modular Reactor
PLC	Programmable Logic Controller

SCADA	Supervisory Control and Data Acquisition
REMS	Real Time Energy Management System
R/c	Rand/Cent
t	Time
US	United States
#	Shaft

CHAPTER 1: INTRODUCTION AND BACKGROUND



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In this chapter the worldwide, but more specifically, the electricity demand situation in South Africa will be discussed. Long- and short-term solutions to keep up with the country's growing electricity demand are investigated. Load shifting opportunities in the industry are identified as a short term solution.

1.1 Preface

"South Africa has an advanced electricity generation system, produces the world's cheapest electricity and generates almost 50% of all electricity on the African continent. There is a surplus of generation capacity now, but this will end by about 2007, when new capacity will be required" [1], [2]. This prediction was made in 2001 when the total electricity generation capacity of South Africa's main electricity supplier Eskom, was 37 056 MW [1]. Six years later South Africa had an electricity generation capacity of 37 716 MW [3]. This is an increase of less than two present over the period.

With peak time demand records being set, South Africa is facing electrical blackouts as Eskom continues to experience maintenance breakdowns. This resulted in unplanned outages of 4 600 MW during January 2008 [4] - [6].

1.2 World wide electricity demand

As the world's population continues to grow, consumer demand for electricity is rapidly increasing. Global electricity generation will be required to increase from 16,424 billion kilowatt-hours to 30,364 billion kilowatt-hours over the next 25 years. The growth over this period can be seen in Figure 1 [7].

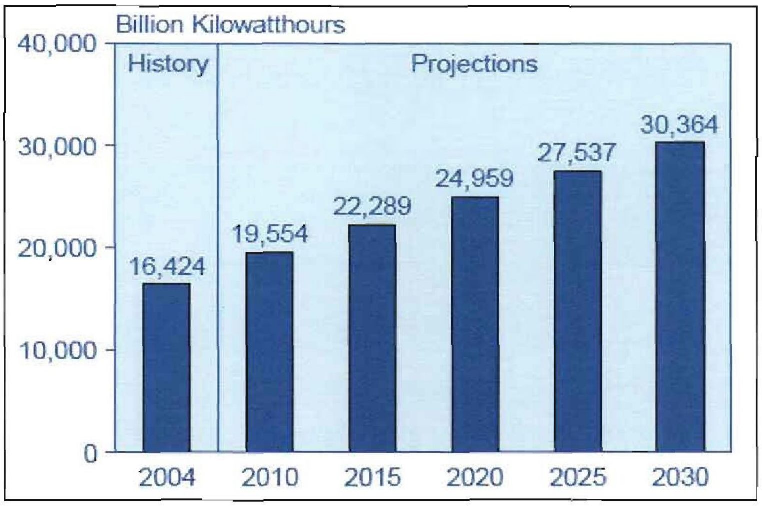


Figure 1: World electricity power generation [7]

As electricity amounts to 30% of the world's total energy consumption, it is of paramount importance to focus on energy efficiency projects in order to meet future demands. The US Department of Energy calls energy efficiency "the greatest energy resource of the future" [9].

1.3 Electricity usage in South Africa

At the time of writing, statistics showed that South Africa consumed approximately 45% of the electricity generated on the continent and Eskom, South Africa's largest supplier of electricity, generates 95% of this electricity. A further 5% is generated by other companies or the private sector. Almost 90% of the total electricity supplied by Eskom is generated by coal-fired power stations and a further 5% by pumping schemes. The remaining 5% is generated by Nuclear reactors [10], [2].

In 2007, Eskom took the world's tenth place in terms of generating capacity and is among the top eleven suppliers in terms of electricity sales. 218 120 MWh electricity was sold to users during 2007. The electricity supply is distributed via a complex grid to 3 963 164 customers using 359 854 km of transmission lines [3].

1.3.1 Electricity demand and capacity

Electricity demand in South Africa used to be substantially lower than the generated capacity. This all changed in 2007 when peak demand exceeded the generation capacity. This was mainly due to the country's healthy economic growth of 4%. The Soccer World Cup, to be held in 2010, will increase electricity demand even further [8], [11], [13]. The reserve and maximum capacity, as well as the maximum demand for the country, can be seen in Figure 2 [3].

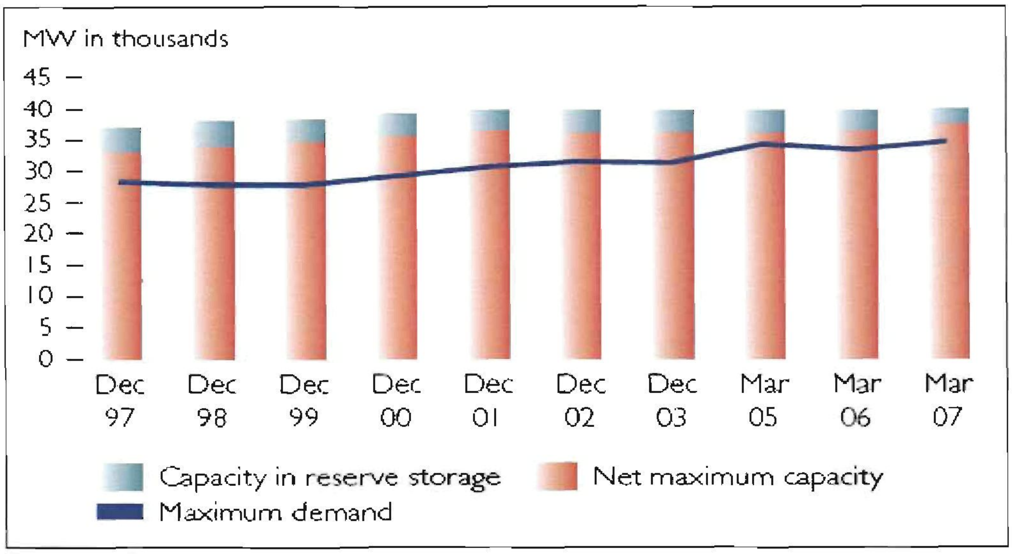
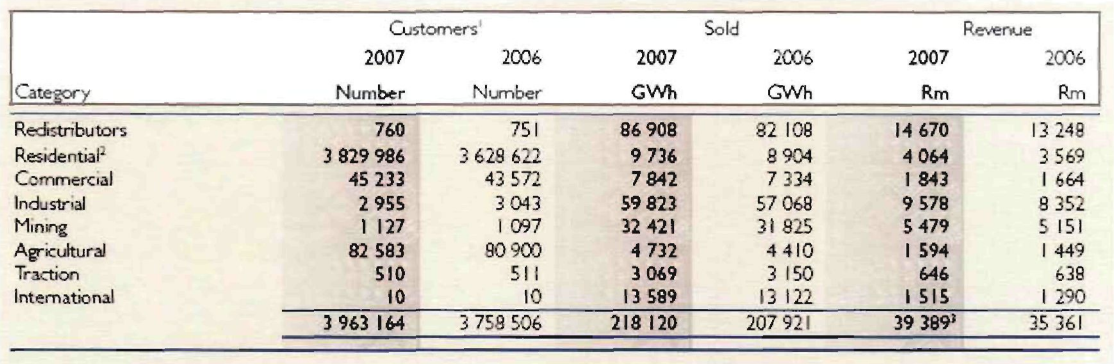


Figure 2: Generation plant capacity and demand [3]

South Africa's electricity demand can be categorised into various sectors, as seen in Table 1. From these figures it is clear that mining and industry consume almost 50% of the country's electricity. These two sectors are the best areas to focus on when planning electricity savings by energy efficiency projects [3], [13].

Table 1: Sale of electricity and revenue per category of customer [3]



	Customers[1]		Sold		Revenue	
	2007	2006	2007	2006	2007	2006
Category	Number	Number	GWh	GWh	Rm	Rm
Redistributors	**760**	751	**86 908**	82 108	**14 670**	13 248
Residential[2]	**3 829 986**	3 628 622	**9 736**	8 904	**4 064**	3 569
Commercial	**45 233**	43 572	**7 842**	7 334	**1 843**	1 664
Industrial	**2 955**	3 043	**59 823**	57 068	**9 578**	8 352
Mining	**1 127**	1 097	**32 421**	31 825	**5 479**	5 151
Agricultural	**82 583**	80 900	**4 732**	4 410	**1 594**	1 449
Traction	**510**	511	**3 069**	3 150	**646**	638
International	**10**	10	**13 589**	13 122	**1 515**	1 290
	3 963 164	3 758 506	**218 120**	207 921	**39 389[3]**	35 361

The increasing electricity demand is creating a negative impact on the country's economic growth and may negatively influence the hosting of the Soccer World Cup in 2010. In order to overcome this negative impact, Eskom must provide additional electricity supply to the country's consumers.

1.4 Addressing the electricity situation in South Africa

By making use of Integrated Strategic Electricity Planning, (ISEP), Eskom is able to estimate the electricity demand over a 20 year period as shown in Figure 3 [3]. This strategy is used to establish the requirement for alternative generation capacity and to determine the most suitable alternative [3], [12].

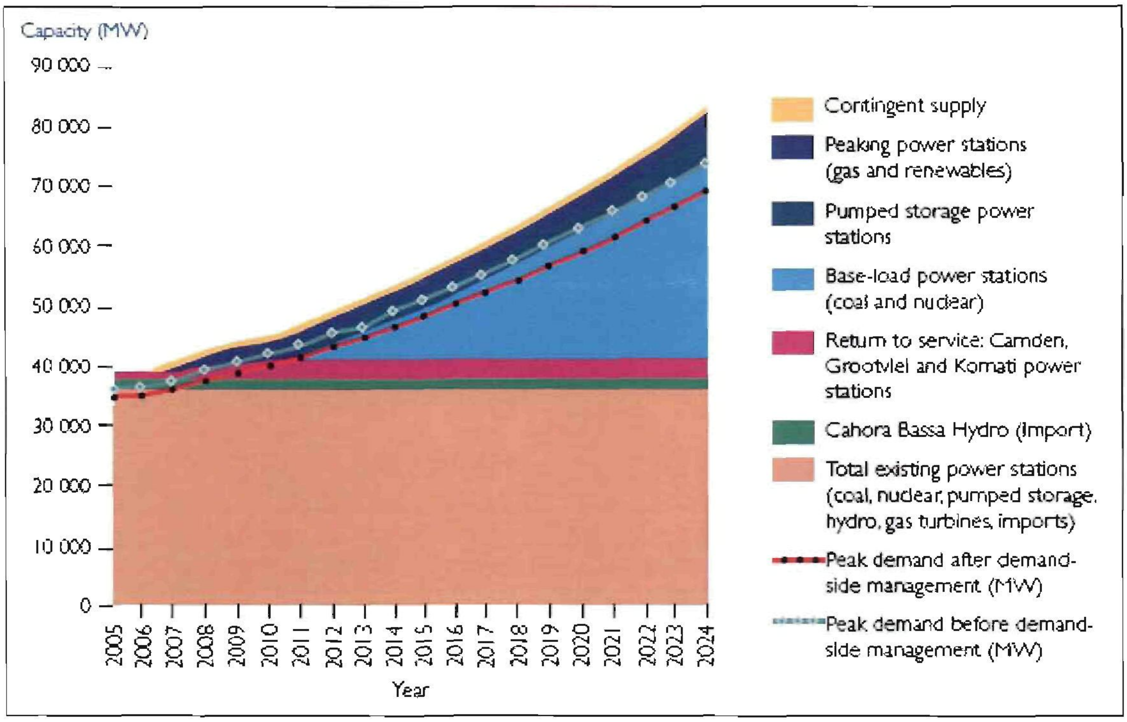


Figure 3: Time frame for new capacity outlook [3]

During 2007 Eskom revised their R97 billion budget by increasing it to R150 billion in order to finance future expansion projects. This money will be invested into a variety of new projects to address the growing electricity demand in South Africa [3], [4].

1.4.1 Long-term solutions

Eskom is presently evaluating several long-term projects and research programs in order to meet the increasing electricity demand. 72% of the capital expansion budget, as shown by Table 2, has been allocated for new generation projects [3], [4], [14].

Table 2: New electricity generation projects

Name	Type	Capacity	Completion date
Project Alpha / Medupi	Coal-fired station	4 200 MW	2010
Project Hotel / Ingula	Pump storage plant	1 330 MW	2012
Grootvlei	Upgraded power station	1 200 MW	2009
Komati	Upgraded power station	961 MW	2011
Amot	Upgraded power station	300 MW	2011

These projects will add approximately 8 GW to South Africa's electricity grid when completed. This additional generation capacity will only be sufficient - taking the present demand growth rate into account - to meet the electricity demand until 2014. Eskom must therefore identify and implement more long-term projects [15].

Research, focusing on the viability of power generation technologies for long-term electricity generation solutions, is currently in progress. The research includes [16]:

- Nuclear research on the Pebble Bed Modular Reactor (PBMR);
- Wind energy;
- Solar thermal power technology;
- Photovoltaic and biomass gasification applications;
- Underground coal gasification;
- Underground high head pumped storage (hydro) schemes using worked out mines.

In accordance with the Environmental Impact Assessment (EIA) Regulations, the environmental impact of these technologies must first be evaluated before being implemented. This will require the construction of demonstration plants, which will act as testing and evaluation facilities. This testing period could take several years to complete, which will result in major delays. Eskom must therefore identify short-term solutions to keep up with the existing electricity demand [16] - [18].

1.4.2 Short-term solutions

As part of Eskom's short-term solutions, the company is evaluating two Open Cycle Gas Turbine (OCGT) projects viz. Ankerlig and Gourikwa. Both these projects are situated in the Cape Province and will have a combined capacity of 2 054 MW. A few of the several generation units at Ankerlig were commissioned in 2007. The completion date for both projects is expected to be December 2008 [3], [4].

Short term solutions, such as Demand Side Management (DSM) provide an alternative to address the present electricity shortages and will be discussed in more detail in section 1.5. The relatively short time taken to implement a DSM project offers Eskom almost immediate extra electricity capacity, compared to the construction or restoration of a decommissioned power station. According to Eskom's 2007 annual report, DSM projects have demonstrated their contribution to electricity savings and load shifting by delivering 169.8 MW during the previous year [3].

1.5 Demand side management (DSM)

The term Demand Side Management was first coined in the USA in the 1970s when energy shortages - created by the worldwide oil crisis - were experienced in 1973 and 1979. As the instigator of DSM, the USA has invested millions of dollars in programs over the last three decades, establishing DSM as one of the world's most powerful energy saving tools [24], [25]. The success of DSM in the USA was followed by similar DSM projects implemented in Europe, Australia, and the United Kingdom. Eskom recognised the potential of DSM in 1992 and created the first action plan in 1994 [26], [27].

Demand Side Management (DSM) is the process whereby an electricity supplier, (for example Eskom), controls the way electricity is consumed by clients. This means that DSM implementation can be used to encourage consumers to modify patterns of electricity usage, as well as the timing and level of electricity demand [19] - [21].

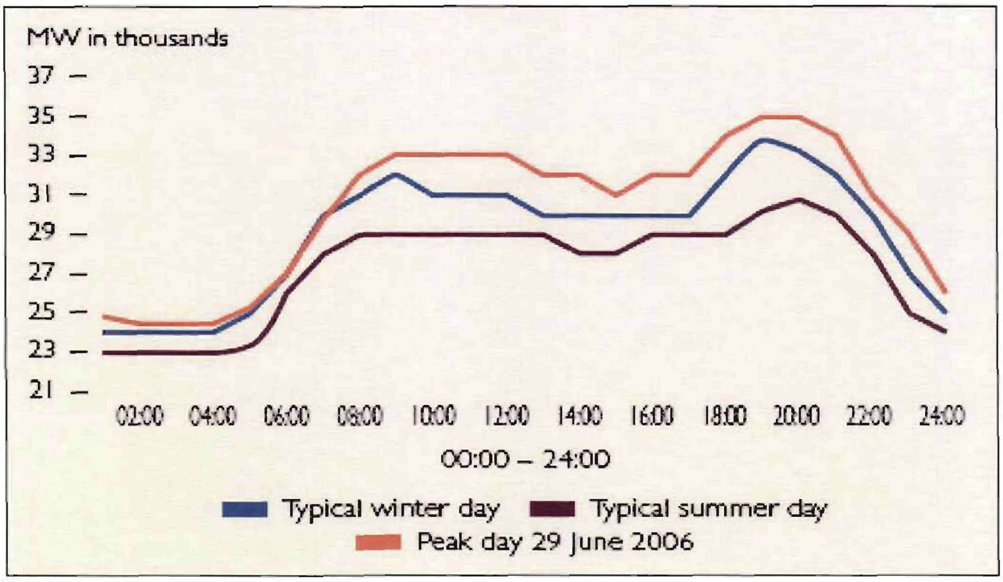


Figure 4: Typical electricity demand patterns during a 24 hour profile [3]

The reason for controlling demand is that it is not consistent. It can be seen from the electricity demand profile in Figure 4 [3], that peaks occur during 07:00 – 10:00 and 18:00 – 20:00. These periods are better known as Eskom peak times. By implementing DSM initiatives, such as load shifting or peak clipping, the electricity demand during peak periods will be reduced and the 24 hour power consumption profile will become smoother.

The DSM program consists of various load management strategies. Typical examples include load shifting, peak clipping, valley filling, and energy efficiency projects [22], [23].

1.5.1 DSM in South Africa

As Eskom attempts to provide sufficient electricity to meet the growing demand in SA, DSM is becoming a generally accepted solution to solving supply problems. Eskom has stated that DSM forms a crucial part of its short and long term capacity expansion program.

Eskom expects to make a further 1 900 MW available before the end of 2009 through the implementation of DSM projects. This program will be expanded to 3 000 MW by 2012 and reach a total of 8 000 MW by the end of 2025 [4]. In order to meet this target, projects that show DSM potential must be identified and implemented as soon as possible.

1.5.2 DSM potential in South Africa

The Department of Minerals and Energy (DME) has set a target to decrease electricity consumption in South Africa by 12% before the end of 2015. This involves a complicated program affecting electricity consumers in various sectors. The reduction targets set for the different sectors are [3]:

- 15% for industrial and mining [28],[29]
- 15% for power generation
- 15% for commercial and public buildings
- 10% for the residential sector
- 9% for the transport sector

In order to meet these targets, most of the industrial groups in South Africa have signed the Energy Efficiency Accord in terms of which signatories pledge to investigate the reduction of their electricity consumption [30], [31]. This electricity reduction will mainly be obtained by making use of DSM projects.

The University of Cape Town has completed a study on DSM potential for large electricity consumers in South Africa [32]. This DSM potential can be seen in Table 3:

Table 3: Ranking of DSM savings potential based on current electricity consumption [32]

	Electricity use		DSM potential	
	Rank	% of total	Rank	GWh saved
Iron and Steel	1	22.91	2	2 289
Precious and non ferrous metals	2	16.55	10	184
Gold mining	3	15.36	1	2 311
Chemicals	4	12.54	4	1 370
Wood and wood products	5	8.18	3	1 458
Platinum mining	6	6.13	5	927
Non-metallic minerals	7	5.02	8	524
Rest of man	8	4.12	7	542
Food, beverages and Tobacco	9	3.20	6	605
Coal mining	10	2.52	9	381
Copper mining	11	0.88	11	133
Rest of mining	12	0.80	12	121
Diamond mining	13	0.60	13	91
Textile, cloth and leather	14	0.38	14	67
Iron ore mining	15	0.32	15	48
Rest of basic metals	16	0.18	18	13
Chrome mining	17	0.16	16	24
Manganese mining	18	0.13	17	19
Asbestos mining	19	0.02	19	3

It is clear from the figures shown in Table 3 that South Africa has the potential for multiple DSM projects which will result in a significant reduction in energy consumption.

1.5.3 Eskom tariffs and the financial benefit of DSM

Eskom has introduced a variable pricing structure for the use of electricity [19]. By applying this method Eskom encourages electricity consumers to use less electricity during peak periods of the day when prices are high.

In order to meet the different requirements of its clients, Eskom has divided consumers into three classes according to the amount of electricity they use. The different classes can be seen in Table 4 [33].

Table 4: Tariff rate component summary

	Tariff	Supply size
Urban	NIGHTSAVE Urban	≥ 25 kVA
	MEGAFLEX	≥ 1 MVA
	MINIFLEX	≥ 25 kVA and ≤ 5 MVA
	BUSINESSRATE 1	≤ 25 kVA
	BUSINESSRATE 2	> 25 kVA and ≤ 50 kVA
	BUSINESSRATE 3	> 50 kVA and ≤ 100 kVA
	BUSINESSRATE 4	≤ 25 kVA
Residential	HOMEPOWER Bulk*	No limit
	HOMEPOWER 1	25 kVA
	HOMEPOWER 2	50 kVA
	HOMEPOWER 3	> 50 kVA and ≤ 100 kVA
	HOMEPOWER 4	16 kVA^1
	HOMELIGHT 1	60 A, 20 A or 10 A
	HOMELIGHT 2	60 A or 20 A
Rural	NIGHTSAVE Rural	≥ 25 kVA
	RURAFLEX	≥ 25 kVA$^{2/3}$
	LANDRATE 1	16 kVA^1/32 kVA^2/25 kVA^3
	LANDRATE 2	64 kVA^2/50 kVA^3
	LANDRATE 3	100 kVA$^{2/3}$
	LANDRATE 4	16 kVA^1
	LANDRATE Dx	10 A

This study focuses only on large electricity consumers (≥ 1MVA supply connections) and therefore only the MegaFlex tariff structure will be discussed. The MegaFlex tariff structure has been divided into three different time periods of the day. These different periods can be seen in Figure 5.

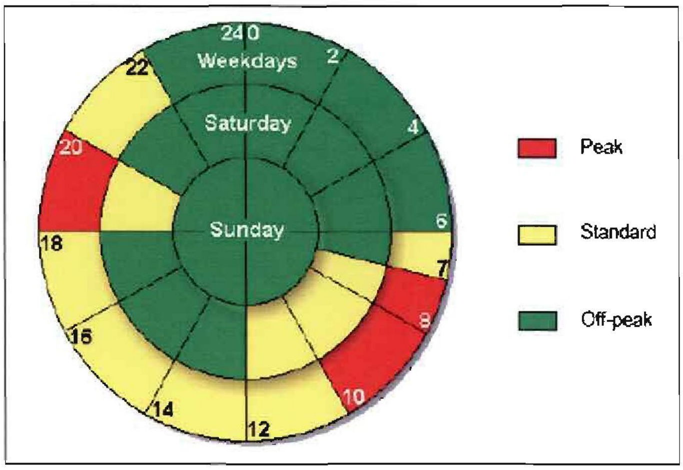


Figure 5: Eskom peak periods for MegaFlex tariff structure [33]

The three different periods are known as Peak time, Standard time and Off-peak time. The rates, at which consumers are charged, differ for the respective periods. The 2007/8 MegaFlex rates for active energy consumption during the different periods [33] are:

High-demand season (June – August)		Low-demand season (September – May)
55,30c + VAT = **63,04c/kWh**	**Peak**	15,69c + VAT = **17,89c/kWh**
14,62c + VAT = **16,67c/kWh**	**Standard**	9,74c + VAT = **11,10c/kWh**
7,95c + VAT = **9,06c/kWh**	**Off-peak**	6,90c + VAT = **7,87c/kWh**

Electricity consumption during peak time is far more expensive. During the high-demand season peak rates are nearly 300% higher than the standard rate and about 600% higher than the off-peak rate. This difference is even larger during the high-demand season starting in June and ending in August. This high rate will encourage, or compel, consumers to reduce electricity usage during peak time.

By introducing DSM techniques and projects such as load shifting and peak clipping, consumers will be able to reduce electricity usage during peak time. This will result in substantial financial savings for electricity users. Furthermore the reduction in maximum peak demand will alleviate Eskom's supply problems during peak periods. For example, if DSM projects can be implemented on 60 gold and platinum mines, potential annual cost savings of

R75 million can be achieved. These savings will be obtained as result of 360 MW electricity shifted from Eskom's peak demand periods [12].

1.6 Problem statement and objectives of this study

Economic growth in South Africa is consistently breaking previously set records [8]. With an annual economic growth rate of 4%, large-scale infrastructure expansion and life style improvements are taking place at an unprecedented rate [34]. This economic growth leads to an increasing electricity demand and Eskom is experiencing problems in supplying sufficient electricity to consumers.

Short and long-term solutions to alleviate the inadequate electricity generation capacity has been established and implemented by Eskom. As part of the short-term solution Eskom has successfully launched several DSM projects. These projects vary from small energy saving projects in households, to large energy efficiency and load shifting projects in the industrial and mining sectors.

The objective of this study is to compare automated and manual DSM projects in order to find the best alternative for both the client, (mining industry) and the electricity supplier, (Eskom). This thesis will focus on comparing DSM implementation between automated and manual pumping projects in excess of 1 MW.

By comparing automated and manual DSM projects, important conclusions can be made regarding the:

- Sustainability of electricity savings or load management to the supplier (Eskom);
- Sustainability of automated and manual DSM projects;
- Sustainability of cost savings to the client;
- Payback period of automated and manual infrastructure cost of DSM projects.

Large financial investments are made by Eskom in DSM pumping projects, with the focus on the mining industry. It is therefore of the utmost importance to determine the value and sustainability of the investment. This is also applicable to the client, since the mine subscribes to responsibilities within a DSM contract. There are legal and financial consequences if the contractual electricity savings are not obtained.

1.7 Overview of this dissertation

In **Chapter 1** the worldwide but more specifically, the electricity demand situation in South Africa is discussed. Long and short-term solutions to keep up with the increasing electricity demand in South Africa were discussed. The implementation of DSM in large electricity consuming industries appears to be a viable solution.

Chapter 2 introduces the basic principals of automated and manual clear water pumping systems in the mining industry. The theory behind DSM and the development of a simulation model for pumping systems is discussed. In order to do a comprehensive comparison study, engineering economic methods are also investigated.

In **Chapter 3** load shifting and cost savings for automated and manually controlled projects are determined. Calculations are made to determine the cost of the initial infrastructure and capital depreciation over time for each project.

In **Chapter 4** the accuracy of the simulation models is determined. The simulation results are used to compare automated and manually controlled projects at different tunnel depths. Economic methods are employed to determine the best alternative.

Chapter 5 concludes the dissertation, and recommendations to broaden the study are made.

CHAPTER 2: DSM ON CLEAR WATER PUMPING SYSTEMS

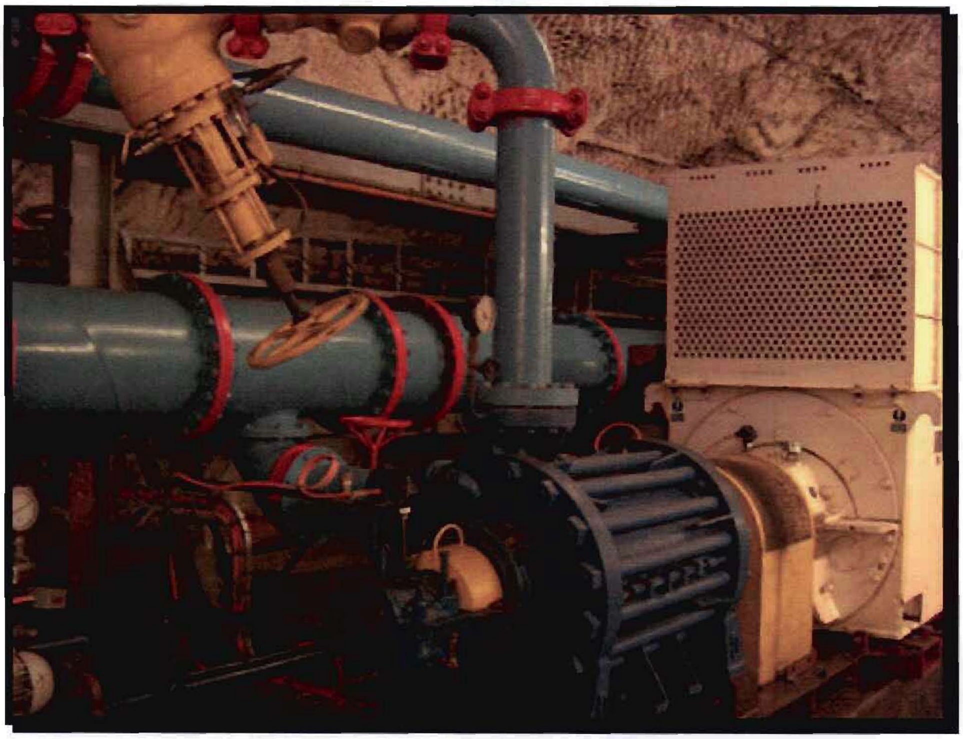


Photo: By HVAC International personnel

In this chapter automated and manual DSM projects on clear water pumping systems in the mining industry are investigated. The theory behind the procedures and methods to be used in the comparison study will also be discussed in detail.

2.1 Introduction

South Africa's electricity is distributed to millions of customers. This ranges from small household consumers to large industrial electricity users. Large industries can be divided into different categories. The focus in this study will be on the mining sector which is one of the largest electricity consumers.

South Africa's mining sector consists of a variety of mines including, coal, copper, asbestos, manganese, chrome, iron ore, platinum and gold mines. Most of these mines are opencast or shallow decline shafts, with the exception of gold and some platinum mines.

On investigating electricity consumption in South Africa, it is clear that large electrical equipment is being used throughout the mining industry [42]. The size of the equipment used differs for each mine and is in most cases extremely electrical intensive. Typical examples of large electrical equipment on mines are compressors, refrigeration plants, electrical drills, rock winders, and clear water pumping systems. South Africa has the world's deepest goldmines, requiring large capacity pumps to prevent flooding. The intrinsic design of mine water pumping systems offers enormous DSM potential in terms of load shifting.

Eskom provides considerable financial assistance for DSM projects, in particular for load shifting on clear water pumping systems in the mining industry. The financial assistance is used for the installation of infrastructure ensuring sustainable load shifting results. For most projects the installed infrastructure forms a fully automated system.

In some mines the infrastructure required to fully automate pumping systems, is too expensive. Under these circumstances load shifting is obtained by managing clear water pump systems manually. In terms of manual operation, human interaction, such as the starting and stopping of pumps, is required to control the load shifting between peak periods.

Although load shifting can be accomplished either manually or automatically, it is important to apply the best alternative to ensure sustainable results. In order to find the most appropriate method for load shifting, it is important to understand:

- automated and manual clear water pumping systems in the mining industry;
- the implementation of a DSM project on a clear water pumping system;
- the possible electricity savings and financial benefit of a DSM project;
- the process to construct a DSM model on a clear water pumping system; and
- different engineering economic methods that can be used to do project selections.

2.2 Automated and manual clear water pumping systems in the mining sector

In South Africa clear water pumping systems can be found throughout the mining industry. The purpose of these systems is to pump water from underground dams to the surface. This is done to prevent underground flooding of the mines.

In theory all clear water pumping systems operate on the same principal with only minor differences encountered depending on the specific requirements of the mine. Differences are encountered in the system layout and size. In general the type of pumps used also differs, but the various system requirements are essentially the same.

The installed capacity for clear water pumping systems can vary from a few kilowatts to tens of thousands of kilowatts. Examples of large clear water pumping systems can be found in most of South Africa's gold mines. These pumping systems are responsible for approximately 35% of the total electricity consumed at a gold mine and is one of a mine's largest electricity expenditures [32], [35].

2.2.1 Clear water pumping systems in general

Certain procedures must be followed before starting and stopping pumps. These procedures might differ slightly for various pumping systems, but in general the procedures are similar and as follows:

Start-up procedures:

1. Remove lock stop;
2. Check the oil level and make sure the suction valve is open;
3. Press the start button;
4. Open the delivery valve slowly.

Stopping procedures:

1. Close delivery valve;
2. Press stop button;
3. Record hour meter reading;
4. Check oil level.

While the pumps are running, certain parameters need to be monitored continuously in order to ensure safe and efficient operation of the system. These parameters are:

- bearing temperatures;
- vibration levels on bearings;
- suction and discharge pressures;
- ammeter readings; and
- minimum and maximum dam levels.

These procedures can be carried out and monitored either manually or by an automated system. Both systems are encountered in the mining industry. Manually operated pump systems are more often found in the older, less productive gold mines while automated pumping systems are common in modern platinum mines.

2.2.2 Manual clear water pumping system

In the mining sector a manual pumping system will require 24 hour attendance because of the varying underground water flow. The responsibilities of pump attendants will include the constant monitoring of the parameters mentioned in 2.2.1, as well as the starting and stopping of pumps.

Pumping systems in the mining industry have been manually operated since deep shaft mining commenced. This was due to a lack of high tech equipment such as PLC's, static excitation, fibre optic cable, etc. Although automation equipment and technology are now available, some mines still prefer to make use of the older, but proven, manually operated method. Some perceived advantages of a manual system are:

- Human supervision and interaction during operations.
- Lower infrastructure cost compared to an automated system [27].

Although manually operated systems have unique advantages they also have significant disadvantages. Typical problems occurring when pumping systems are manually controlled are:

- damage to pumps caused by a delay in opening the discharge valves;
- fail to capitalise on cheaper tariffs due to oversight caused by manual intervention [25];
- high maintenance due to pump cycling;
- inadequate bearing temperature and vibration monitoring; and
- invalid or incorrectly logged data used for maintenance purpose.

These problems are taken into account when a risk assessment is done on manually operated pumping systems.

2.2.3 Automated pumping system

"Automated" refers to a process that may have been performed manually, but has been modified in some way, allowing a computer to manipulate the process. When a clear water pumping system is automated, the starting, stopping and running procedures are controlled without human input apart from initiating the control system.

To automate a pumping system various parameters must be monitored to ensure control of the system within predetermined values. Typical system components required to automate a pumping system are [25], [35]:

- Connection cables: fibre optic cable, copper cable, leaky feeder cable, etc. required for communication between different pumps, pumping levels and the central point.
- Networking equipment: switches, Programmable Logic Controllers (PLC) and a Supervisory Control and Data Acquisition (SCADA) system.
- Monitoring devices: pump bearing temperature transmitters, vibration monitors, flow and pressure monitors, dam level indicators, etc.

Gathered data is transmitted to a computer. Software will manage the system according to pre-programmed schedules and parameters. An example of such a computer package is REMS - Real Time Energy Management System [25].

The combination of infrastructure and software mentioned in the previous two paragraphs is a typical example of a fully automated pumping system. This type of system is more commonly found in modern gold and platinum mines.

By making use of an automated system, pumps will be started and stopped by REMS depending on predefined inputs. Typical control inputs are dam levels, dam capacities, temperature readings and pressure and vibration measurements. Pump stop/start actions are software controlled and do not require manual intervention.

Similar to manual pumping systems there are advantages and disadvantages to an automated pumping system. Some benefits are:

- Accurate logging of data at predetermined intervals.
- Pumps can be stopped and started according to predefined schedules.
- Continuous monitoring and immediate response to trip conditions to prevent damage to equipment.

Disadvantage of automated clear water pumping systems are:

- Additional maintenance to control systems.
- Under certain emergency conditions control by automated systems is inadequate.

2.3 DSM on clear water pumping systems

Demand Side Management has already been implemented on various clear water pumping systems in the mining industry. With sustainable results, DSM on clear water pumping projects has become the benchmark for DSM projects [36].

Due to the nature of clear water pumping systems, the most common forms of DSM projects implemented on pumping systems are load shifting and/or water efficiency projects. As this thesis focuses on load shifting projects, it is important to understand load-shifting principles.

2.3.1 Load shifting on clear water pumping systems

Load shifting forms part of Load Management, (LM), which is achieved by implementing activities to influence the electricity usage time pattern of a consumer without affecting production [37]. Clear water pumping systems must therefore pump water during off peak periods to several reservoirs. This will allow pumps to be switched off during Eskom peak demand periods.

The graph in Figure 6 shows the typical electricity usage profile before (Baseline) and after the implementation of a load shift project (REMS2) on a clear water pumping system [36].

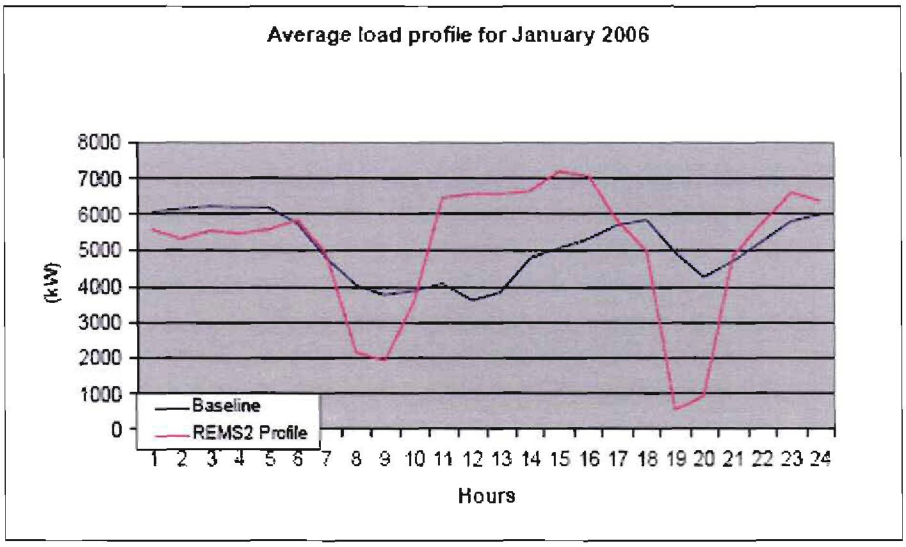


Figure 6: Baseline and load shifting profile [36]

Figure 6 also shows the concept of Load shifting where less electricity is used during the morning and evening peak periods while more electricity is used during the off-peak periods. When comparing the two profiles in the graph, it can be seen that the time of electricity usage has changed.

In order to conduct a successful load-shifting project on a clear water-pumping system, the general DSM project stages in Figure 7 have to be followed [38]. By following this procedure, the actual load shifting potential, required infrastructure, and capital before commencement of a project, can be determined. Although these project stages will determine the viability of a project, sustainable results will be directly dependent on the method used to obtain load shifting.

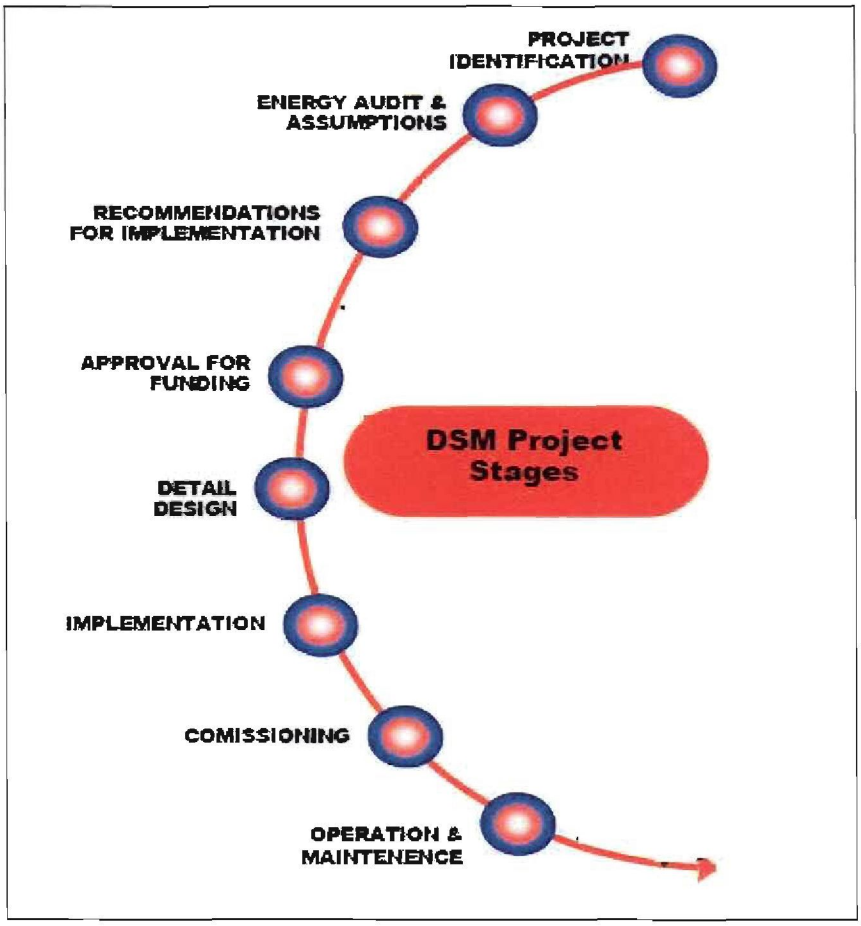


Figure 7: DSM project stages [38]

Ensuring sustainable operation will be beneficial to both Eskom and the client. Eskom will benefit by the reduction in electricity demand during peak periods. The client will benefit through financial savings obtained, because less electricity is used during high cost periods.

2.4 Electricity management and financial impacts of load shifting

The primary function of DSM is to minimise or manipulate the amount of electricity being used. Electricity usage will also be minimised if energy efficient methods are applied to electrical equipment. In the case of clear water pumping systems, energy efficient projects are not always feasible. This is because of high infrastructure costs compared to the savings that will be realised. Preference is therefore given to the implementation of load-shifting projects.

In order to determine whether the implementation of load shifting on pumping systems will be beneficial, the terms *electricity management*, *cost savings* and *financial benefits* need to be discussed.

2.4.1 Electricity management

Managing electricity consumption on a pumping system, particularly in the mining industry, can become very complex. This is mainly due to unpredictable water flow from natural water drainage. Water requirements for mining activities are more predictable, but large variations in water flow are commonly found. Load shifting is accomplished by managing electricity demand in such a manner that less electricity is consumed during peak and expensive tariff periods, without affecting production.

2.4.2 Cost Savings

Financial savings are obtained by managing electricity usage correctly. This can be divided into two categories:

- Financial savings by Eskom.
- Cost savings by the client.

The cost savings to both parties will be large and is a compelling motivation for load shifting to be implemented on clear water pumping systems [39].

2.4.3 Financial Benefits

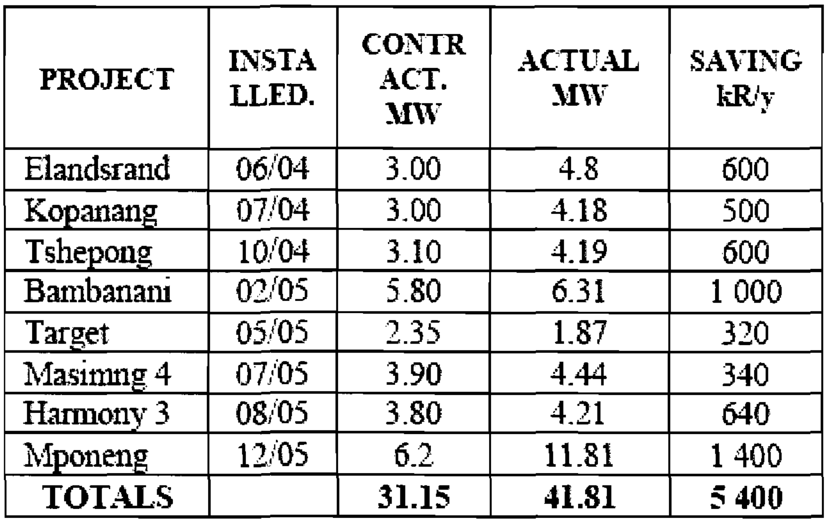
Eskom is experiencing problems in providing sufficient electricity to consumers during peak periods. In order to address this problem, the supplier would need to build additional electricity generation plants. This will cost billions of Rands and the construction process would take several years to complete. A viable alternative is to invest in DSM load shifting projects. This will reduce the electricity demand during peak periods and the requirement for additional generation capacity will be delayed. The advantage of DSM projects is that it can be implemented in a relatively short period of time and holds significant financial benefits for Eskom [19].

Financial benefits to the client can be found as:

- Eskom subsidises 100% of the client's infrastructure cost when committing to a DSM load shifting project [19] and;
- Electricity cost savings are obtained by using less electricity during Eskom peak periods.

The largest financial benefit to the client will be obtained from electricity savings achieved by using less electricity during Eskom's peak periods. These cost savings can be calculated by making use of Eskom's 24 hour tariff structure and electricity usage profiles over the same period. The savings will be calculated by determining electricity cost for each hour, before and after implementing DSM [33]. Electricity cost savings experienced by clients through implementing load shifting projects on clear water pumping systems are shown in Table 5 [36].

Table 5: Successfully completed load shifting projects on clear water pumping systems [36]



PROJECT	INSTALLED.	CONTRACT. MW	ACTUAL MW	SAVING kR/y
Elandsrand	06/04	3.00	4.8	600
Kopanang	07/04	3.00	4.18	500
Tshepong	10/04	3.10	4.19	600
Bambanani	02/05	5.80	6.31	1 000
Target	05/05	2.35	1.87	320
Masimng 4	07/05	3.90	4.44	340
Harmony 3	08/05	3.80	4.21	640
Mponeng	12/05	6.2	11.81	1 400
TOTALS		**31.15**	**41.81**	**5 400**

It is clear from the table that load shifting projects on clear water pumping systems hold financial benefits to both Eskom and the client. The financial benefit to the client will increase over time, as Eskom has constantly been increasing electricity tariffs at an average of 5.7 % per annum [41], [52]. The tariff increase for 2008 is even greater. For the purpose of this dissertation the tariff increase are based on audited values available.

2.4.4 Financial implication due to early determination of DSM contract

Eskom will provide financial support to upgrade infrastructure on a DSM project whenever sustainable load shifting and electricity savings are identified. In exchange for the capital provided by Eskom, the client is contractually bound to apply load shifting over a period of three to five years [50]. The contractual load shifting saving agreed upon will be used as a standard to determine whether the client is meeting its contractual requirements. If the client is unable to meet the contractual load-shifting target for any reason, the DSM contract can be terminated.

Rules applicable to the early termination of the DSM contract will require the payment of a termination penalty. Taking a five year project lifetime as an example, the amount payable by the client to Eskom can be calculated by making use of the following formula [41].

$$\text{Termination penalty} = \left(\frac{\text{Total cost of DSM measures}}{365\text{ days} \times 5\text{ (contractural period) years}}\right) \times \left(\text{Number of days falling short of the 5 year period}\right)$$

2- 1

2.4.5 Reduction of labour cost

Labour cost on a mine consists of approximately 40% – 50% of the mine's total overhead costs and is therefore one of the biggest monthly expenses [25]. Research is conducted on a regular basis to find alternatives in order to cut back on labour. However, simply reducing the number of labourers, without proper system changes or infrastructure upgrades will most likely have a negative impact on production.

The responsibility of pump attendants in the mining industry is to stop and start the pumps. The constant monitoring of bearing temperatures, vibration levels and the completion of log sheets are also additional responsibilities. On average, three attendants per shift per pump station are employed to complete these tasks. By automating clear water pumping systems, the number of pump attendants required per shift can be reduced.

In a previous study conducted on pumping systems in the mining industry, it was found that a 61.1% labour cost reduction can be achieved by implementing automated systems. The study was based on three load shifting projects where pumping systems were fully automated as part of Eskom's DSM initiative [25].

Under certain circumstances some mines prefer to leave the number of pump attendants per shift unchanged after the system is automated. This is only done under exceptional conditions and due to management preferences. The reduction in labour might therefore differ for each mine despite the automation of the system. The figures obtained from this study can however be used as a benchmark for further calculations regarding automated pumping systems.

2.4.6 Reduction of maintenance cost

One of the main reasons for high maintenance cost on large pumping systems is the frequent stopping and starting of pumps. On average, pump cycling contributes approximately 15% to maintenance cost during the operating life of a pump [25]. Research has shown that the operating life of a pump, between service intervals, can be increased by 8.5%, if the system is fully automated [25]. The implementation of an automated LM project is therefore an essential requirement to ensure maintenance cost savings.

With a typical monthly maintenance cost of approximately R 30 000 per pump, it is important to minimise pump cycling as far as possible [25]. According to studies conducted, the benefit of an automated system can be converted into a monthly cost saving of R2, 350 per pump [25].

2.5 Computer modelling and simulations

Computer modelling and simulations have become two of the most powerful tools used for decision making in the modern business age. This is mainly due to the contributions these methods have made in the understanding of how new concepts will function. Simulations also give an indication of the essential information required to ensure satisfactory design [43], [44].

In general, computer modelling can be defined as an allocation that simulates the reaction of a real-world system [45]. After a computer model is created, the accuracy can be determined by running the simulation using actual system data [46].

2.5.1 Modelling

In order to design a working model three basic steps must be followed:

- The first step will be to create a conceptual model, based on the characteristics of the actual systems. These characteristics will differ for each individual system according to the specifications and requirements of the system [27].
- Following the conceptual model, a mathematical model within the constraints of the concept model must be created. This model contains detailed mathematical information regarding the parameters by which the system will be controlled.
- After creating conceptual and mathematical models a simulation model can be developed. The purpose of the simulation will be to determine the accuracy of the modelling process within the given parameters.

Because this document is concerned with the implementation of DSM on pumping systems in the mining industry, the modelling process is only discussed with respect to this particular application.

Step 1

Most of the pumping systems in the mining industry are similar in many ways but show certain intrinsic discrepancies. This will not have a negative influence on the design process of a conceptual model, as the purpose of the first step in the modelling process is to create a simplified model. A conceptual model for a typical clear water pumping system in the mining industry can be seen in Figure 8.

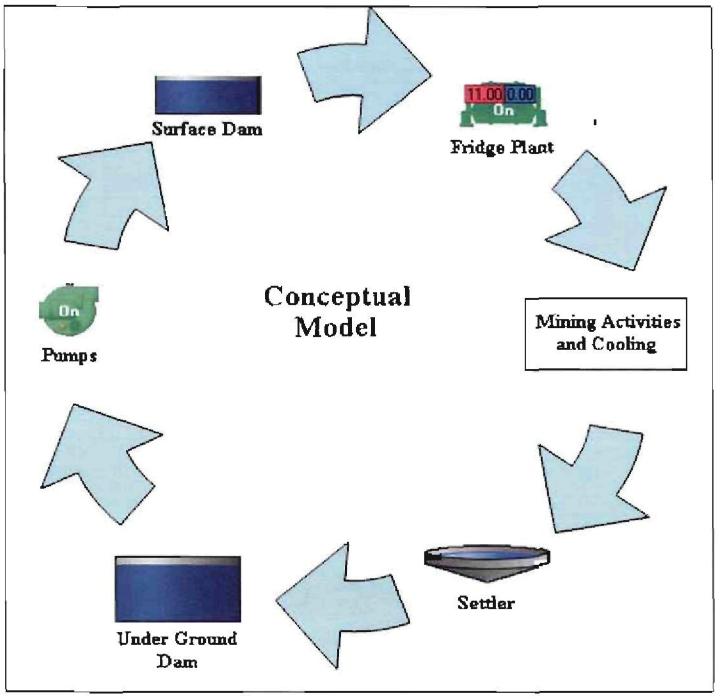


Figure 8: Conceptual Model

Step 2

Typical information required to set up a mathematical model for a pumping system are:

Dams

- Dam capacity
- Flows into and out of dams
- Maximum and minimum dam level constrains

Pumps

- Number of available pumps
- Maximum and minimum number of pumps that can run simultaneously
- Installed capacity of the pumps
- Efficiency of pumps

General

- Water usage over a 24 hour period
- Maximum Demand for the specific mine
- Water constraints due to refrigeration and cooling

Step 3

Various software packages are available in order to create a simulation model for clear water pumping systems. This includes Matlab, Microsoft Excel, QUICKcontrol, and technology developed by TEMMI (Pty.)(Ltd.), called REMS [47],[27],[35].

Although software packages might differ in terms of design, interface, etc., the basic input parameters are the same. This implies that input values from the mathematical model will set the foundation for the simulation, regardless of the software package being used.

The purpose of the simulation model for a clear water pumping system will be to determine the electricity usage over a 24 hour period. This will be done according to input parameters obtained from the mathematical model.

Because the electricity usage profile can be predicted, electricity cost savings can also be determined. Cost savings are calculated by making use of Eskom's variable tariff structure and the hourly electricity usage profile for the day.

2.6 Engineering economics

As previously stated the implementation of a DSM project holds important financial benefits to both Eskom and the client. The benefit to Eskom can be calculated in terms of postponing the immediate requirement for increased generation capacity expansion. Benefits for the client will accrue directly from electricity cost savings.

Before implementing a DSM project, some important questions must be answered. Typical examples are:

- How large can the initial capital investment on a project be before the return investment becomes unfeasible?
- Which method of load shifting is the best alternative taking infrastructure cost and annual savings into account?

In order to answer these questions, different engineering economic techniques and methods can be used. The purpose of these techniques and methods is to determine the feasibility of different projects in order to select the best alternative. Typical engineering economic methods that can be used to compare alternatives are Present Worth Analysis, Capitalized Cost Analysis, and Payback Period Analysis [48], [49].

2.6.1 Terminology and basic equations

Before different engineering economic methods are explained, it will be useful to understand the terms and symbols being used in the equations. The following symbols were encountered during literature study [48], [49]:

- P = Present Worth; value or amount of money at present or at time 0 (time 0 indicates the time of project commencement)
- F = Future Worth; value or amount of money at some future time
- A = Annual Worth; series of consecutive, equal, end-of-period amounts of money
- n = number of interest periods
- i = interest rate
- t = time
- g = constant rate of change

As the change in money worth is related to time, some calculations require monetary payments to be adjusted with time. This is done to ensure that inflationary effects over a period of time are taken into account throughout the calculations. In order to determine the change in money worth various equations will be used (Equations ***2-2 to 2-6***). These equations are also known as factors, which differ according to input data [48], [49].

The Present/Future (P/F) factor is used to determine the *P* value for a known amount *F* that occurs *n* periods in the future.

$$P = F\left[\frac{1}{(1+i)^n}\right] \qquad \textbf{2-2}$$

The Present/Annual (P/A) factor is used to determine the *P* value of a uniform series *A*.

$$P = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \qquad \textbf{2-3}$$

The following equation can be used if the *P* value of a geometric gradient series *A* must be calculated.

$$P = A\left[\frac{1-\left(\frac{1+g}{1+i}\right)^n}{i-g}\right] \quad \text{if } g \neq i \qquad \textbf{2-4}$$

or

$$P = A\left[\frac{n}{1+i}\right] \quad \text{if } g = i \qquad \textbf{2-5}$$

The Future/Annual (F/A) factor is used to determine the *F* value of a uniform series *A*.

$$F = A\left[\frac{(1+i)^n - 1}{i}\right] \qquad \textbf{2-6}$$

By making use of equations ***2-2 to 2-6*** [49], the appropriate factors (using variable input data) can be determined as required. These factors will further be used to complete Present Worth Analysis, Capital Cost Analysis, and Payback Period Analysis.

2.6.2 Present Worth Analysis

The Present Worth analysis is one of the easiest methods that can be used to compare alternatives in the industry. This method is very popular in the engineering industry, because future cost and revenue estimations are converted into present equivalent Rand/cent values. This makes it easier to determine the economic advantage of one alternative over another.

In order to choose between alternatives, the present worth of each alternative needs to be calculated. This is done by making use of equations ***2-2 to 2-6*** as applicable to each alternative. Once the present worth for each option is determined, the values can be compared. The option with the largest numerical present worth value will be the best option.

2.6.3 Capitalized cost analysis

The Capitalized Cost (CC) analysis differs slightly from the present worth analysis and is used in situations where projects have very long life expectancies (letting n approaching ∞). Typical examples are dams, irrigation systems, bridges, etc.

The formula used to calculate CC can be found as [49]:

$$CC = \frac{A}{i} \qquad \textbf{\textit{2-7}}$$

In order to use this method the CC for each alternative needs to be calculated. As each alternative has a very long life expectancy (n approaching ∞), they will automatically be compared over the same number of years. The option with the smallest capitalised cost value will represent the best option.

2.6.4 Payback Period analysis

In general the payback period n_p can be defined as the estimated time it will take for revenues and other benefits to recover the initial investment. This method is indirectly an extension of the present worth method where either i > 0% or i = 0%. When i > 0% the discounted payback period is calculated and when i = 0%, the no-return payback period is determined.

In order to calculate the discounted payback period, equations ***2-8 or 2-9*** can be used, where P represents the initial investment and NCF_t the estimated net cash flow for each year indicated by the subscript t [49].

$$0 = -P + \Sigma \sum_{t=1}^{t=n_p} NCF_t (P/F,i,t) \qquad \textbf{2-8}$$

If i = 0% and the no-return payback period needs to be calculated the equation becomes:

$$0 = -P + \sum_{t=1}^{t=n_p} NCF_t \qquad \textbf{2-9}$$

These equations are used to calculate the payback period to recover the funds used as the initial capital investment. The option with the shortest payback period will be the best option.

The Payback Period analysis can be used to select the preferred option. It is however important to note that the Payback Period method is based on the assumption that after n_p years the initial investment will be recovered by the cash flow of the alternative over the period. Should the asset or alternative be used for more than n_p years, a larger return may result. On the other hand, if the useful life of the alternative is less than n_p years, the recovery time for the initial investment will be insufficient. Taking these aspects into account, the Payback Period analysis will lead to the incorrect selection of an alternative if the method is used incorrectly.

2.7 Conclusion

Clear water-pumping systems in the mining industry are ideal for managing electricity usage in terms of Demand Side Management techniques. This is the motivation for Eskom to make large capital investments in load-shifting projects on clear water pumping systems.

Because of the great depths and large volumes of underground water, pumps with large installed capacities are required to prevent mines from flooding. With these large installed capacities, pumping operations have become one of the largest electricity consumers in the mining industry.

By employing DSM methods, such as load shifting, electricity usage on pumping systems can be managed in such a way that less electricity is used during Eskom peak periods. This is accomplished by following a controlled pumping schedule in order to manipulate operating times of the pumping system. The DSM schedule can either be accomplished manually or by making use of software control in a fully automated system.

It is also clear that the implementation of load shifting projects on clear water pumping systems results in significant financial benefits to both Eskom and the client. By shifting load from peak periods the peak power demand is reduced. This means that the installation of additional electricity generating equipment can be delayed, resulting in large financial benefits to Eskom. For the client, electricity cost savings are obtained, because less electricity will be used during expensive peak periods.

With large financial implications for both Eskom and the client, in terms of capital investments and financial savings, it is important to obtain sustainable results when a DSM project is implemented. The most viable method of load shifting therefore needs to be determined and implemented.

CHAPTER 3: SAVING RESULTS AND ADDITIONAL CALCULATIONS

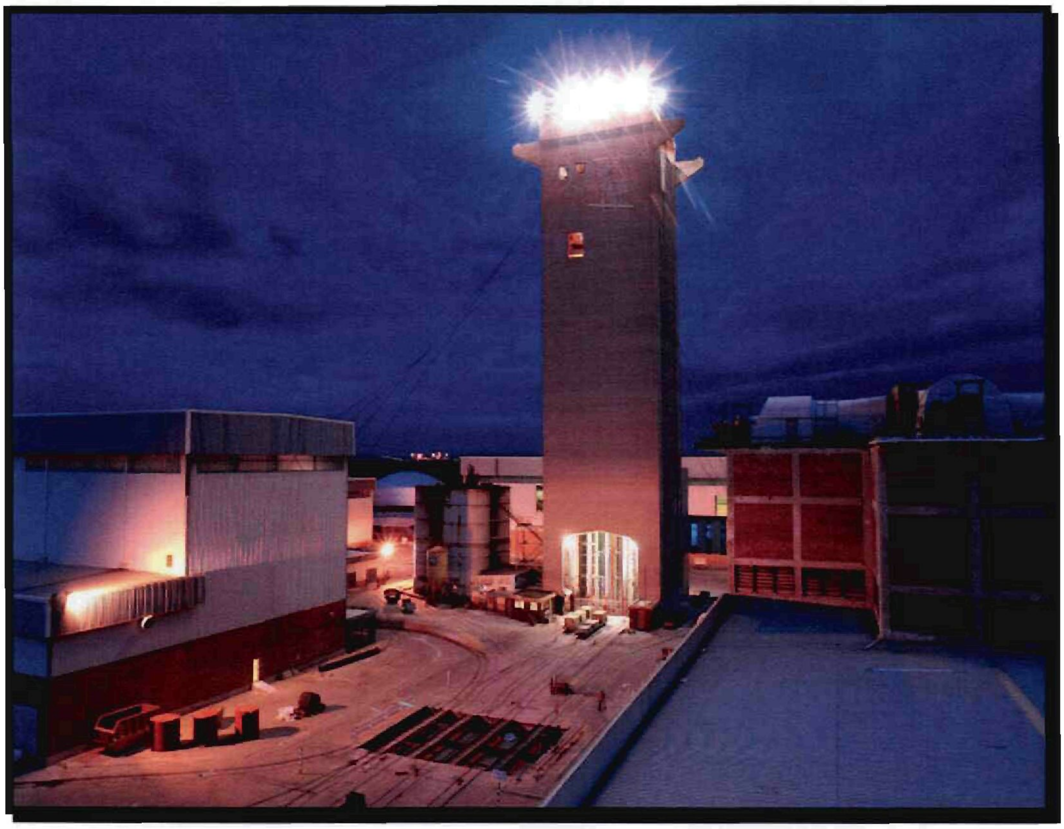


Photo: By HVAC International personnel

In this chapter predicted and actual load shifting performance together with cost savings are determined for each case study. Initial infrastructure costs and labour, as well as maintenance cost savings are also calculated.

3.1 Introduction

Together with existing load shifting projects, Eskom is planning to implement DSM projects on a variety of new pumping systems in the mining sector. A large amount of capital investment is required. It is therefore extremely important that the most efficient method of load shifting, with sustainable load shifting results is implemented. From the perspective of the client the optimum selection of a control system is also essential to ensure cost savings.

In order to determine the best control system or control method, a comparison must be made between the different systems, and/or the different methods of load shifting. This will ensure that both Eskom and the client will benefit, as the results will indicate which is the most viable system and method of load shifting.

A rational comparison can only be made by investigating a variety of projects. The purpose of this chapter is to focus on existing automated and manually operated projects as case studies. Data from these case studies will be used to draw up a comparison between the different methods of load shifting that will be discussed in Chapter 4.

In order to set up a realistic comparison, six projects were selected as case studies. These projects were selected by making use of the following factors:

- Three of the six projects are fully automated. LM is achieved by making use of software (REMS);
- Three of the six projects are manually controlled. LM is achieved through the interaction of control room operators and pump attendants.

The information obtained was collected from actual case studies taken at the mines which were obtained from data logged by REMS or SCADA systems. Monthly electricity and cost saving reports were generated by the Energy Service Company (ESCO), responsible for the implemented DSM projects on the specific mines. Predicted load shifting results were obtained by making use of simulation software (REMS simulator). The load shifting results were further processed in order to obtain the predicted cost savings.

3.2 *Predicted and actual saving results for automated projects*

3.2.1 Amandelbult 2#

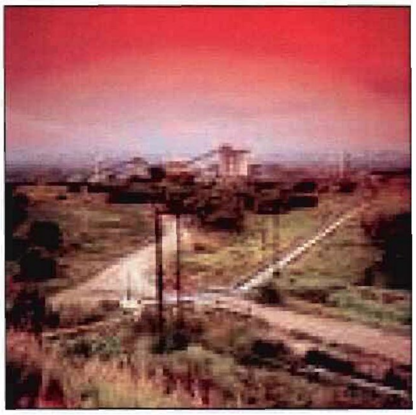


Figure 9: Photo of Amandelbult 2# platinum mine

3.2.1.1 Introduction

The clear water pumping system at Amandelbult 2# has been fully automated as part of a previously implemented DSM project. System components are controlled by a central computer. The commencement date of the project was scheduled for August 2007. However the system was already fully installed in October 2006 as part of a trial period. This was done to confirm the compatibility of the new automated system with the existing equipment on the mine.

3.2.1.2 Project Information

Simulated MW target:	5.10 MW
Proposed MW target to Eskom by ESCO:	3.60 MW
Average performance over project lifetime:	5.00 MW

The simulated target is determined by making use of the simulation software. The proposed target is the contractual target recommended by the ESCO. This target is based on the simulated target, while including a predetermined safety factor as suggested by the ESCO. The average performance is calculated over the project lifetime.

The clear water pumping system layout for Amandelbult 2# can be seen in Figure 10. The blue lines indicate the cold water that's been used for mining purposes. The red lines indicate the excess mining and natural underground water that must be pump to surface in order to prevent the mine from flooding. This arrangement is typical for all the mines used as case studies with the exception of Masimong 4#.

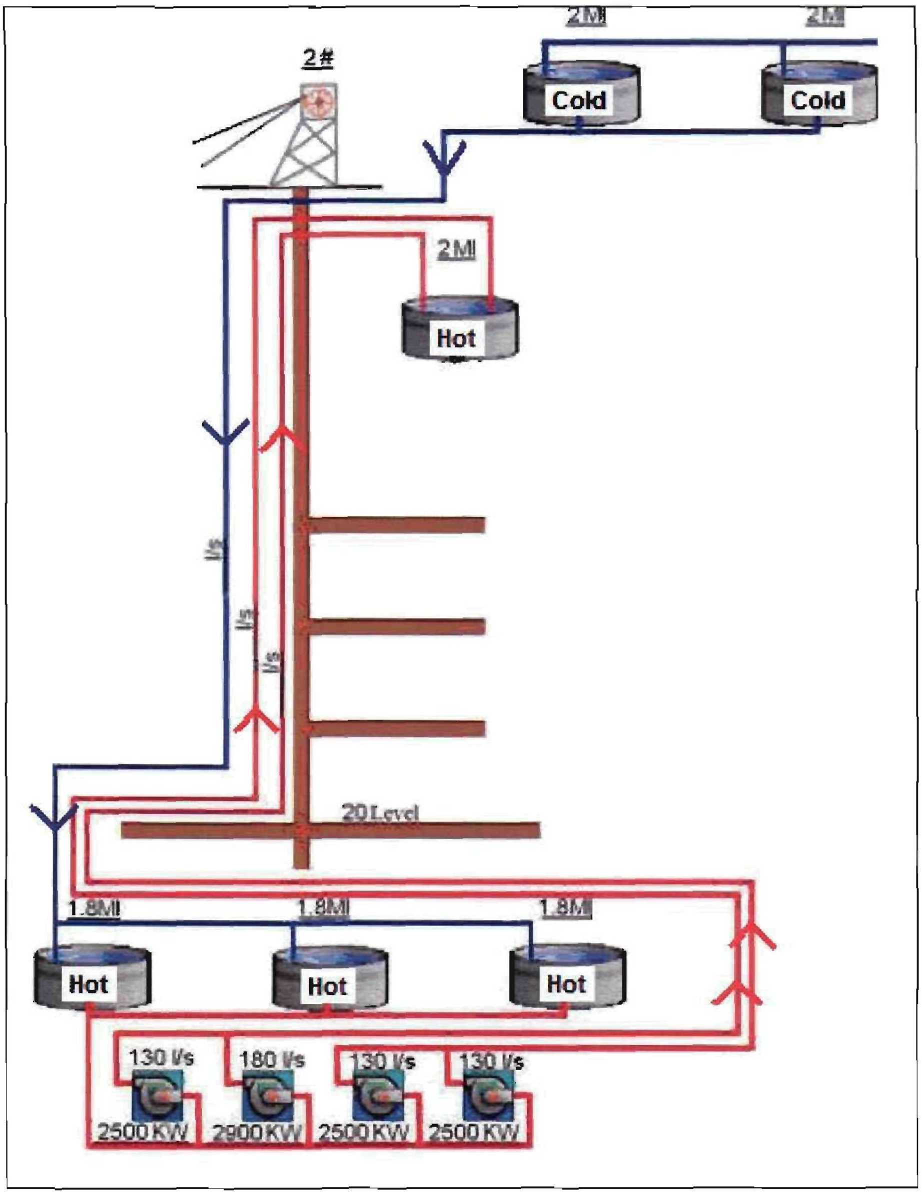


Figure 10: Amandelbult 2# pumping system layout

3.2.1.3 Load profile data for DSM project

The graph of Figure 11 shows three different load profiles:

- Original baseline: Energy usage profile for the clear water pumping system before implementation of the DSM program. This baseline was obtained from previously logged data;
- Simulated load profile: A simulation was done to determine the load shifting potential after implementation of a DSM project;
- Actual load profile: The actual load profile is the electricity usage profile of the pumping system after the DSM project was implemented.
- Peak periods The morning and evening peak periods are indicated by the highlighted areas.

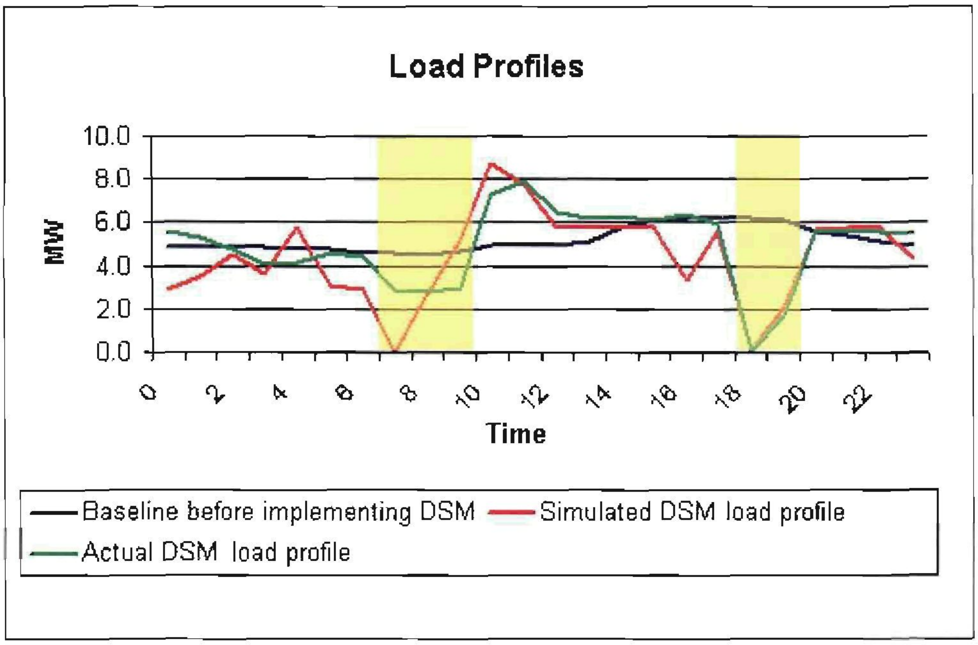


Figure 11: Amandelbult 2# load profiles

The load shifting potential is determined before actual implementation. This is done by calculating the difference in electricity consumption between the original baseline and the simulated load profile during the evening peak (18:00h – 20:00h). After DSM implementation, actual load shifting values are determined in a similar manner over the same period.

Figure 11 shows that the predicted and actual electricity consumption profiles during the evening peak are very similar after the introduction of a LM project on Amandelbult 2#. A significant deviation in the electricity profile between the predicted and actual electricity consumption occurs during the off-peak periods. This is mainly due to changes in electricity consumption, caused by the unpredictable underground water flow and mining operations.

It is important to note that the contractual load shifting value is only applicable to the evening peak period. The client therefore prefers to pump during morning peak periods, in order to have sufficient water reservoir capacity during the evening peak.

3.2.1.4 DSM project performance

Figure 12 shows the actual load shifting performance in MW over the case study project lifetime of five months. This data shows that the actual DSM performance at Amandelbult 2# is better than the contractual requirements. Although limited data is available, because of the short project lifetime, the graph shows that sustainable results were obtained. The results can be accepted as sustainable, because the data used was taken from periods in both the high and low demand seasons.

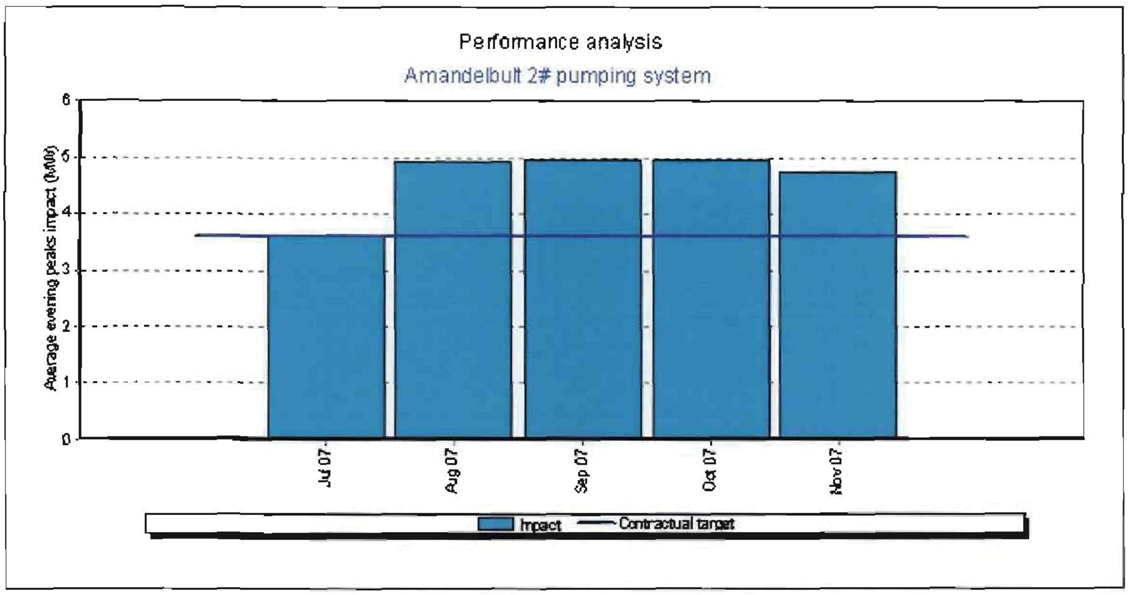


Figure 12: Amandelbult 2# actual load shifting results

Predicted and actual monthly cost savings obtained from September 2007 – November 2007 can be seen in Figure 13. The difference in predicted and actual cost savings is related to the deviation occurring in the morning peak period (high tariffs) between the simulated and actual electricity consumption profiles as shown in Figure 11.

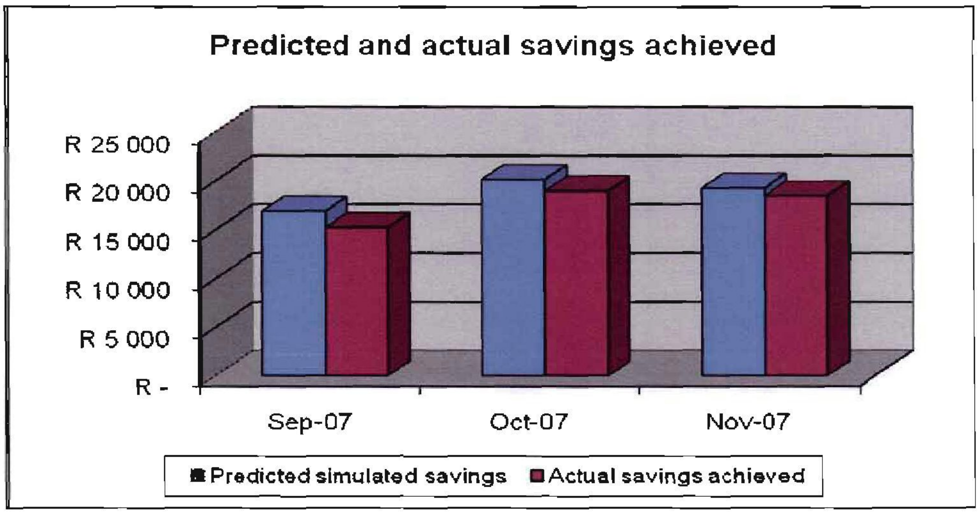


Figure 13: Amandelbult 2# predicted and actual cost savings

Due to typical problems such as seismic activity and accidents, insufficient load shifting occurs from time to time. Eskom has therefore agreed to exclude these non-performing days from the performance calculation as it is beyond human control. These days are also known as "condonable" days.

For the purpose of this study all load shifting and cost saving results excludes condonable days to ensure an equal comparison between the different projects which will be described in Chapter 4. Condonable day are excluded because the maintenance problems encountered are different for each mine.

3.2.2 Masimong 4#

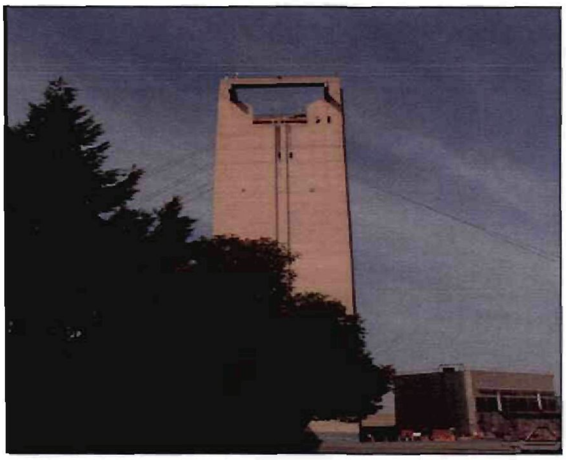


Figure 14: Photo of Masimong 4# gold mine

3.2.2.1 Introduction

The clear water pumping system at Masimong 4# has also been fully automated as part of the LM project. Although Masimong 4# has a control room which is attended 24 hours per day, clear water pumps are computer controlled through REMS software.

3.2.2.2 Project Information

Simulated MW target:	4.26 MW
Proposed MW target to Eskom by ESCO:	3.90 MW
Average performance over project lifetime:	4.32 MW

The clear water pumping system layout for Masimong 4 # can be seen in Figure 15. All mining activities at Masimong 4# have been stopped and the mine therefore only act as a pumping shaft. The water being pumped (indicated by the blue lines) is therefore from natural underground water sources.

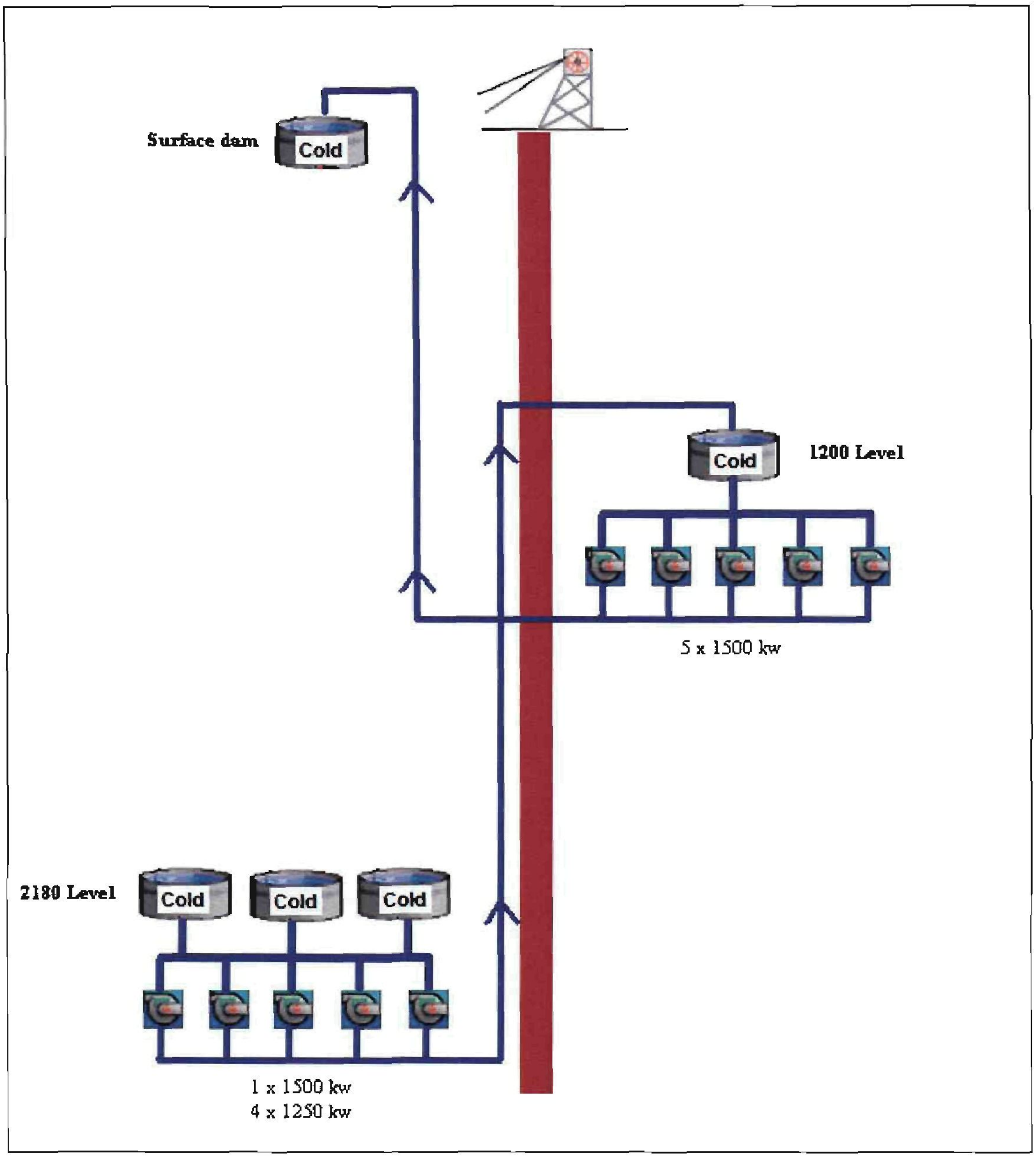


Figure 15: Masimong 4# pumping system layout

3.2.2.3 Load profile data for DSM project

The original, simulated DSM and actual DSM load profiles for the project are shown in Figure 16. From this graph it can be seen that the simulated and actual power consumption profiles are in close agreement during peak periods. This implies that predicted load shifting values were accurate. Deviations between the simulated DSM and actual DSM load profiles however occur during off-peak periods. A small decrease in electricity usage between 20:00h and 07:00h can be seen. An increase in power consumption was experienced during the period 10:00h to 18:00h. These differences can be explained as a change in the water flow pattern, caused by varying mining operations. The amount of water pumped over the 24 hour period however remained constant, with the only difference a change in the time of pumping.

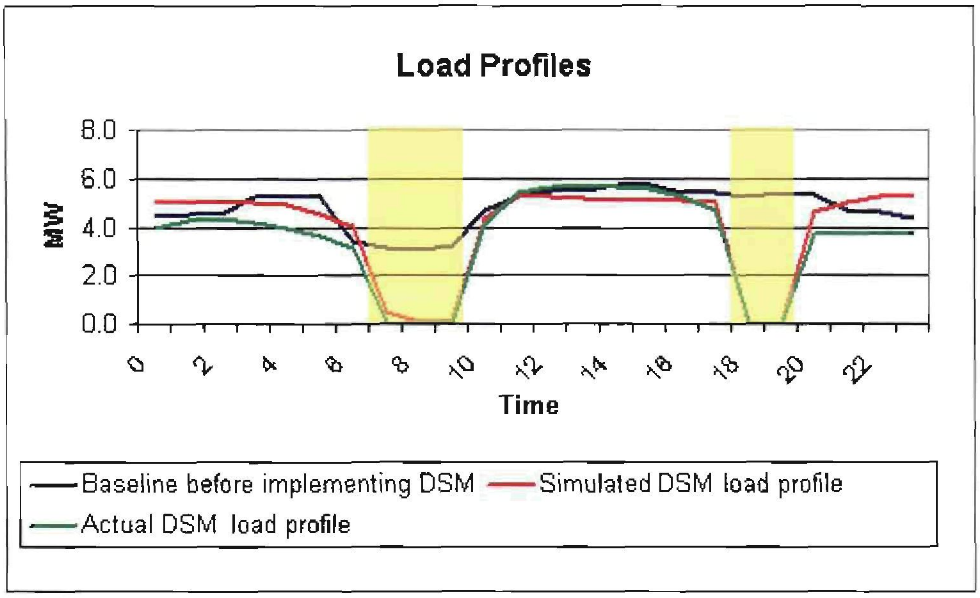


Figure 16: Masimong 4# load profiles

3.2.2.4 DSM project performance

Figure 17 shows the load shifting performance over the 27 month period of this study. From the graph it is clear that the DSM performance at Masimong 4# exceeded the contractual target during this period. Exceptional performance can be seen during the performance assessment period, from September 2005 to December 2005. This highlights the advantage of involvement by the Esco who implemented the DSM project. It can also be seen that DSM performance is better during the summer months. This can be attributed to the rainy season, which requires an increase in the amount of water to be pumped daily. An increase in the baseline will therefore increase the load shifting potential during the peak periods, as sufficient storage capacity is available.

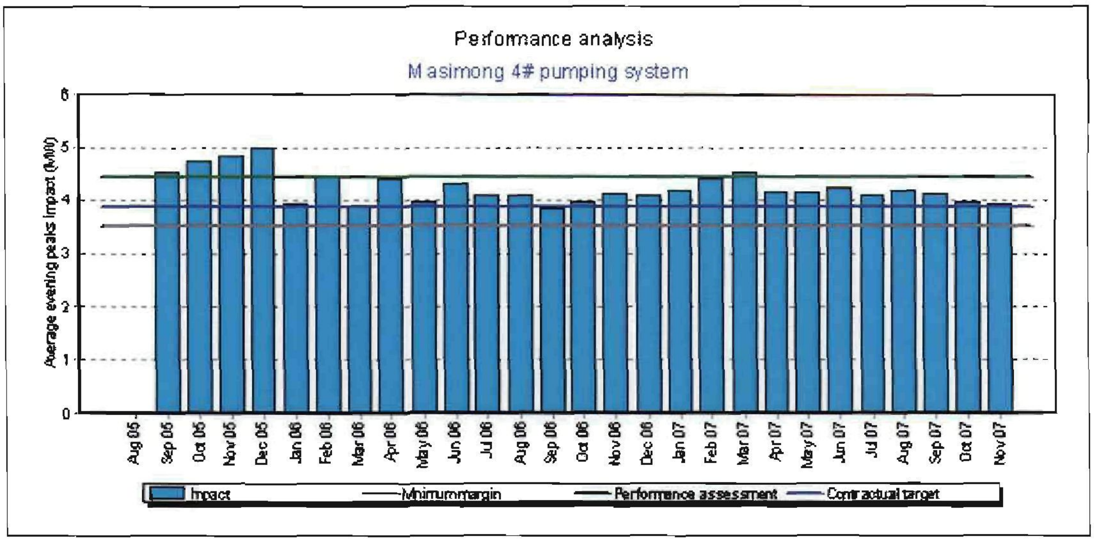


Figure 17: Masimong 4# actual load shifting results

Figure 18 displays the predicted and actual monthly cost savings for Masimong 4#. The cost savings were calculated for the period 1 June 2007 – 30 November 2007. The significant difference in predicted and actual cost savings during June 2007 was due to unscheduled maintenance on the control system. A large difference in cost savings between the winter months (June – August) and the summer months (September – November) can also be seen. This is due to the difference in the tariff structure between the low and high demand seasons as explained in section 1.5.3.

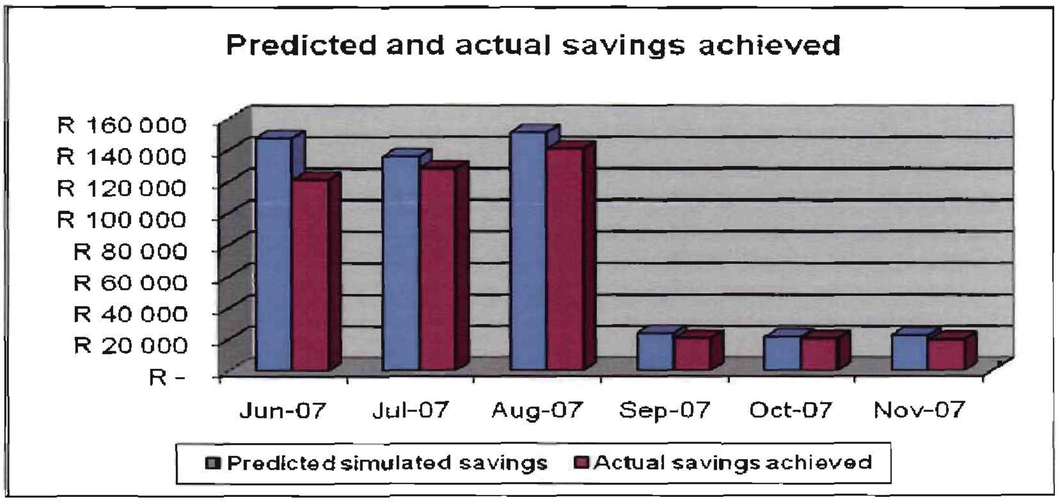


Figure 18: Masimong 4# predicted and actual cost savings

3.2.3 Beatrix 4# / Oryx

Figure 19: Photo of Beatrix 4# gold mine

3.2.3.1 Introduction

The clear water pumping system on Beatrix 4# has also been fully automated as part of the DSM project that has been implemented. The layout for the clear water pumping system on Beatrix 4# can be seen in Figure 20.

3.2.3.2 Project Information

Simulated MW target:	11.20 MW
Proposed MW target to Eskom by ESCO:	7.00 MW
Average performance over project lifetime:	10.10 MW

System layout:

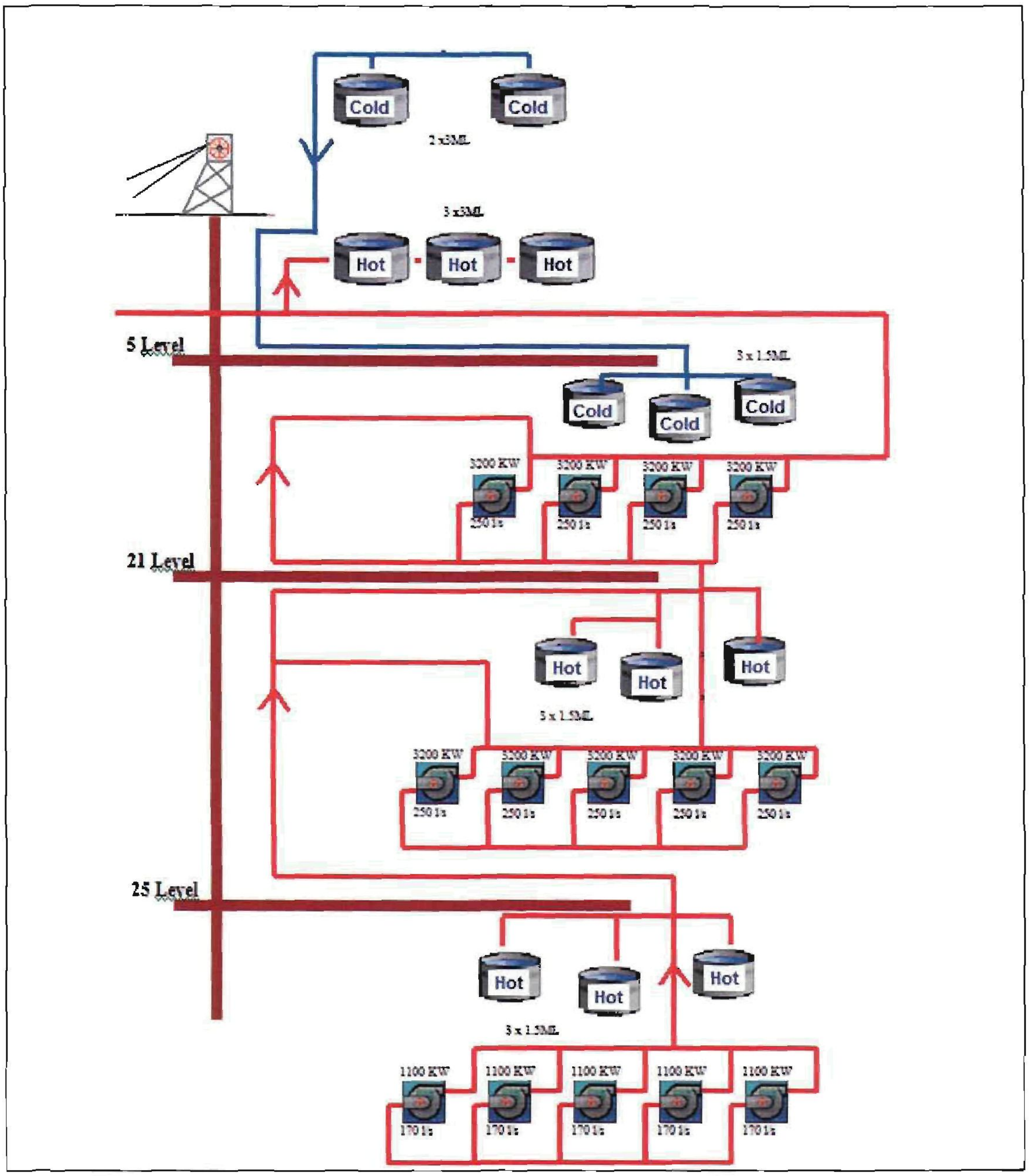


Figure 20: Beatrix 4# pumping system layout

3.2.3.3 Load profile data for DSM project

The original, simulated DSM and actual DSM load profiles for this project can be seen in Figure 21 and show that performance results exceeded predicted load shifting during the morning peak period. In other words the automated system shifted more than the predicted load out of the morning peak period. The additional load shifting was obtained as a result of the optimisation of the automated system.

From the graph it can also be seen that less water was pumped during the early morning hours than predicted by the simulation. The additional water however was pumped after the morning peak period. This can be explained as a result of a change in the time of water usage by mining activities.

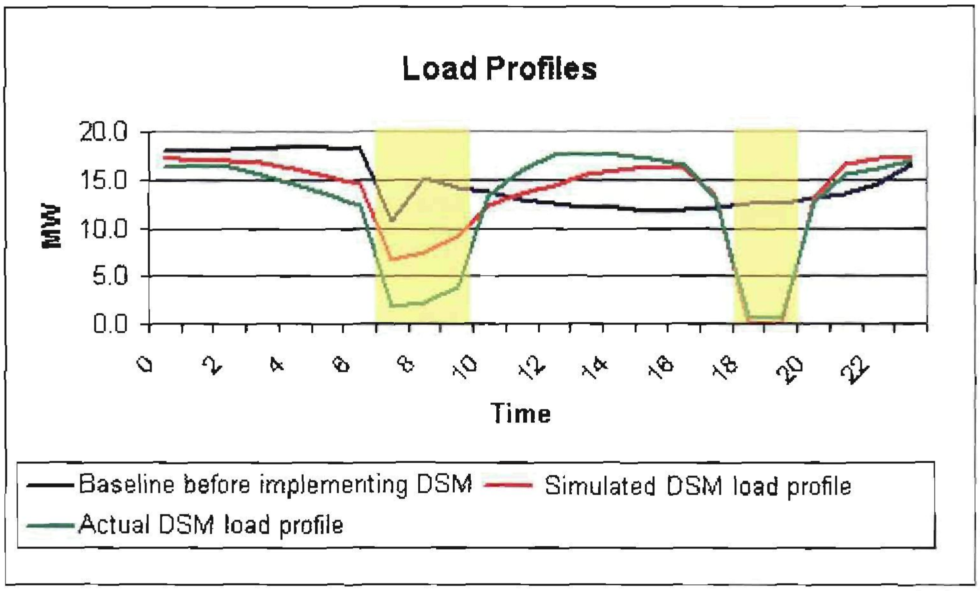


Figure 21: Beatrix 4# load profiles

3.2.3.4 DSM project performance

Figure 22 shows the load shifting performance over the study period of 20 months. When comparing the results with the contractual target (blue line), an over performance can be seen. Similar to Masimong 4# exceptional performance during the performance assessment period (first three months) was obtained. Once again the direct involvement of Esco shows an improvement on load shifting results. Dam cleaning operations took place from July 2006 to September 2006. These operations had a negative influence on the load shifting performance, because of limited dam capacity. During December 2006 maintenance problems on the communication network were encountered, which prevented the capturing of performance data over this period.

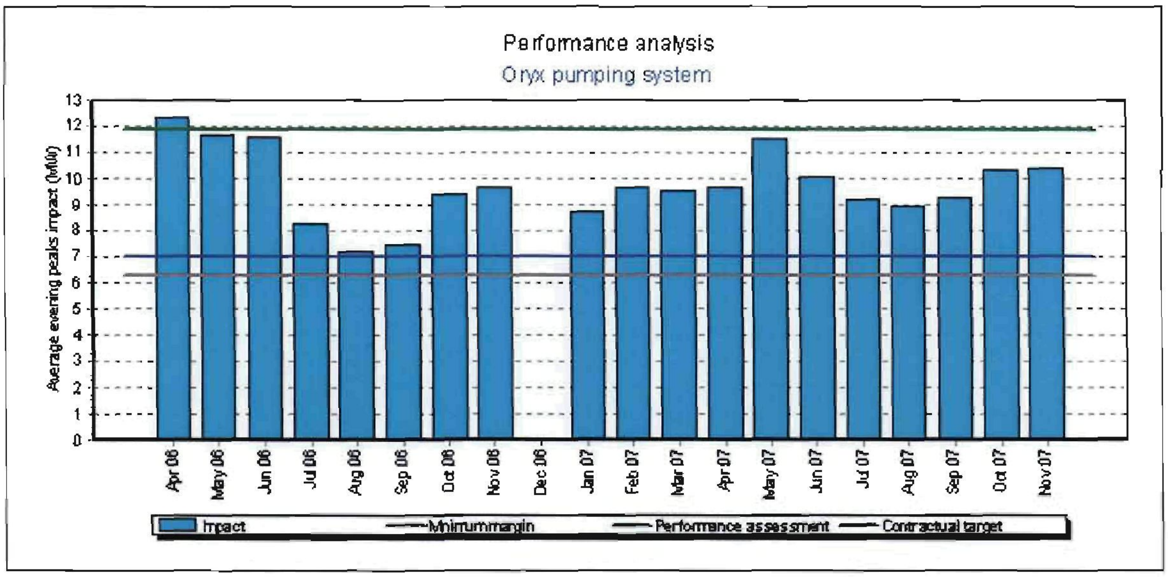


Figure 22: Beatrix 4# actual load shifting results

The predicted and actual monthly cost savings for Beatrix 4# can be seen in Figure 23. An over performance was achieved during June, August, October and November. These additional cost savings were realised because of extra load shifting obtained during the morning peak period.

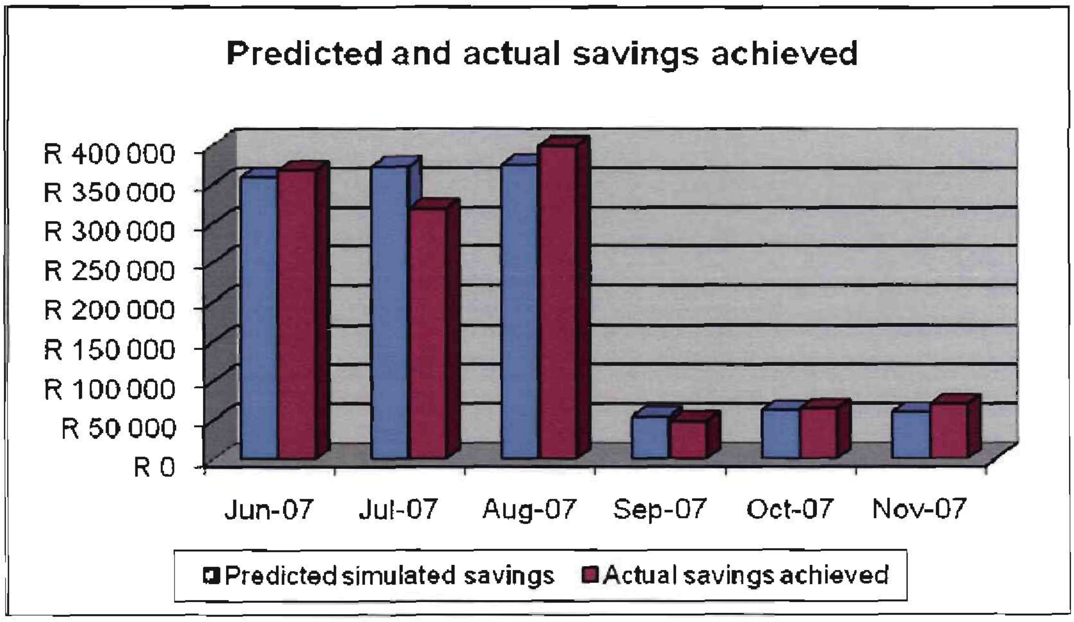


Figure 23: Beatrix 4# actual cost savings

3.3 *Predicted and actual saving results for manual projects*

3.3.1 TauTona

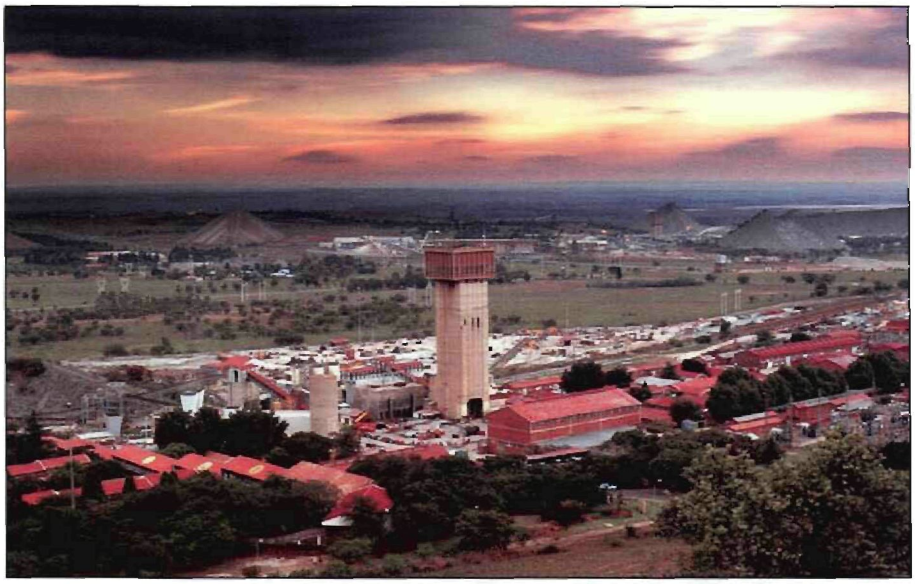


Figure 24: Photo of TauTona gold mine

3.3.1.1 Introduction

The clear water pumping system at TauTona has only been partly automated as part of the DSM project implemented. The infrastructure installed consists of a communication network and essential monitoring instrumentation, allowing manual control from the surface. Because the infrastructure is very old, it is not compatible with modern equipment. This prevents the pumps from being automatically controlled. Additional modifications or replacement to the existing infrastructure will be required to ensure automatic control of the system. Presently, control room operators are applying load shifting manually. Whenever required, the pump attendants are contacted via telephone to stop and start the pumps. The system layout for the clear water pumping system on TauTona can be seen in Figure 25.

3.3.1.2 Project Information

Simulated MW target:	12.20 MW
Proposed MW target to Eskom by ESCO:	5.50 MW
Average performance over project lifetime:	9.90 MW

System layout:

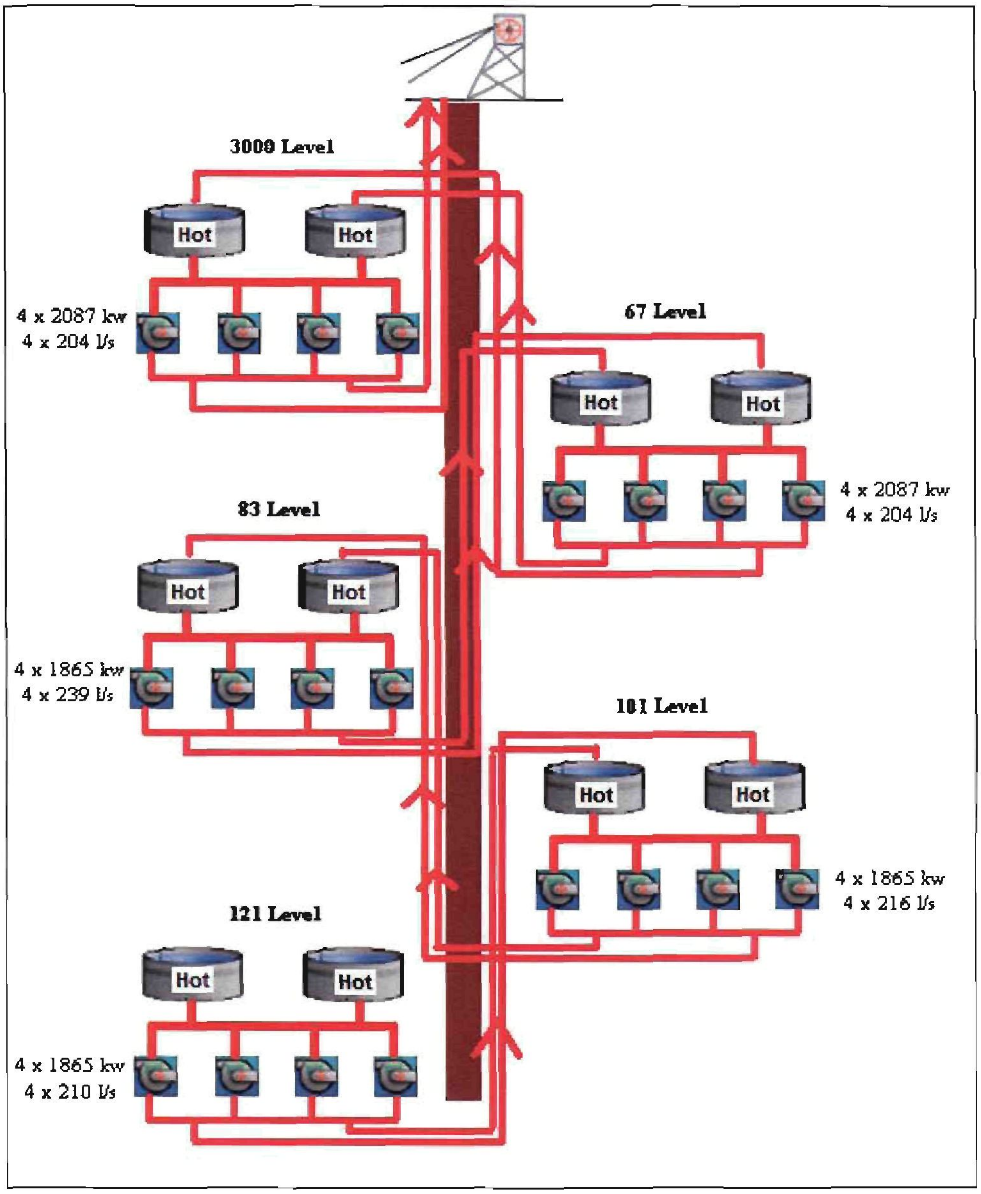


Figure 25: TauTona pumping system layout

3.3.1.3 Load profile data for DSM project

The original, simulated DSM and actual DSM load profiles for the project are displayed in Figure 26. The graph in Figure 26 shows a large difference between the simulated and actual load profiles. The simulated profile predicted a larger load shifting potential during both peak periods than what was actually obtained. This is because of insufficient LM caused by manual control as no maintenance issues were logged.

At TauTona mine, control room operators have multiple responsibilities. As dedicated attention to, and continuous monitoring of LM, is not always possible, sufficient load shifting results can not be obtained. This is in particular visible during the morning peak, as no contractual obligations are fixed for this period.

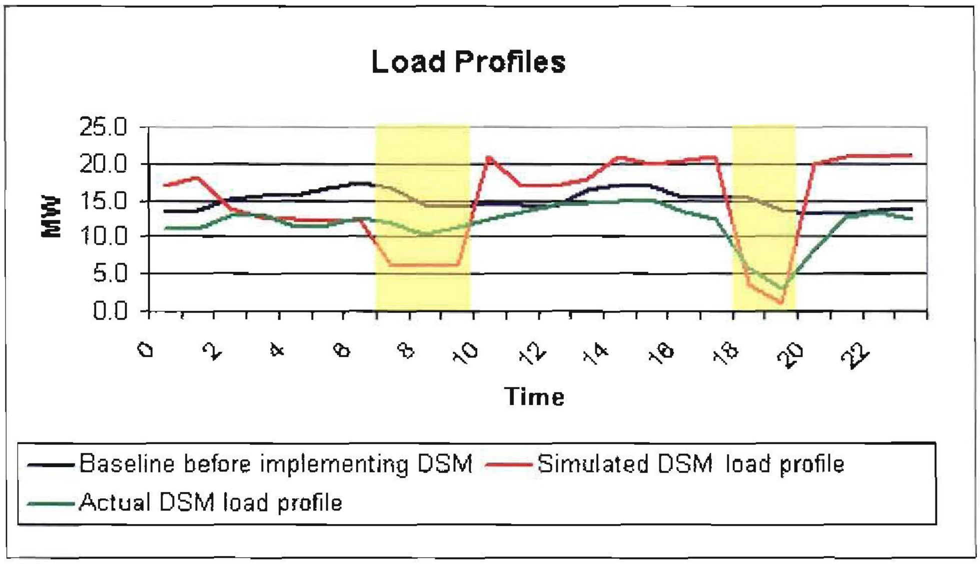


Figure 26: TauTona load profiles

3.3.1.4 DSM project performance

Figure 27 shows the load shifting performance over the 10 month project lifetime. Although the contractual target has been met over the project lifetime, the opportunity for better performance and larger cost savings was available. This can be demonstrated by comparing load shifting results obtained during April 2007 in Figure 27 with the possible simulated value of 12.20 MW in Section 3.3.1.2.

Similar to the automated projects, exceptional load shifting results were obtained during the performance assessment period. Once again this can be explained as a result of the Esco's continuous involvement during this period. A reduction in load shifting performance can be seen from May 2007 until November 2007. This is the result of insufficient manual load shifting as previously mentioned in Section 3.3.1.3.

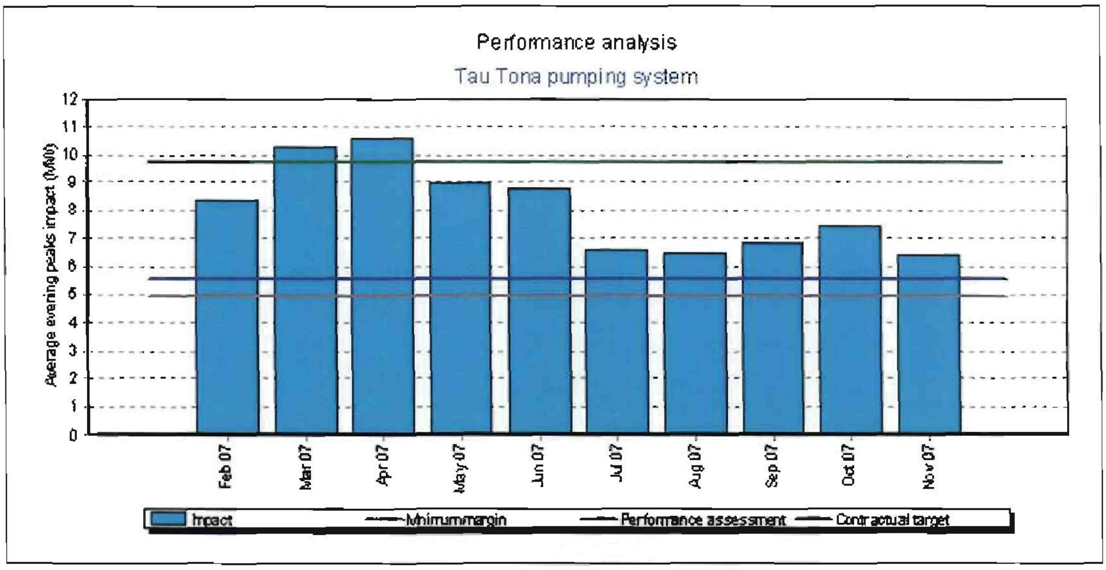


Figure 27: TauTona actual load shifting results

Figure 28 displays the predicted and actual monthly cost savings for TauTona. Calculations show an opportunity for additional electricity cost savings, when LM is manually executed as predicted by simulation. The effect of no load shifting during morning peak periods (high tariff periods) is also shown in Figure 28. This is because cost saving calculations includes possible savings that can be obtained during the morning peak period.

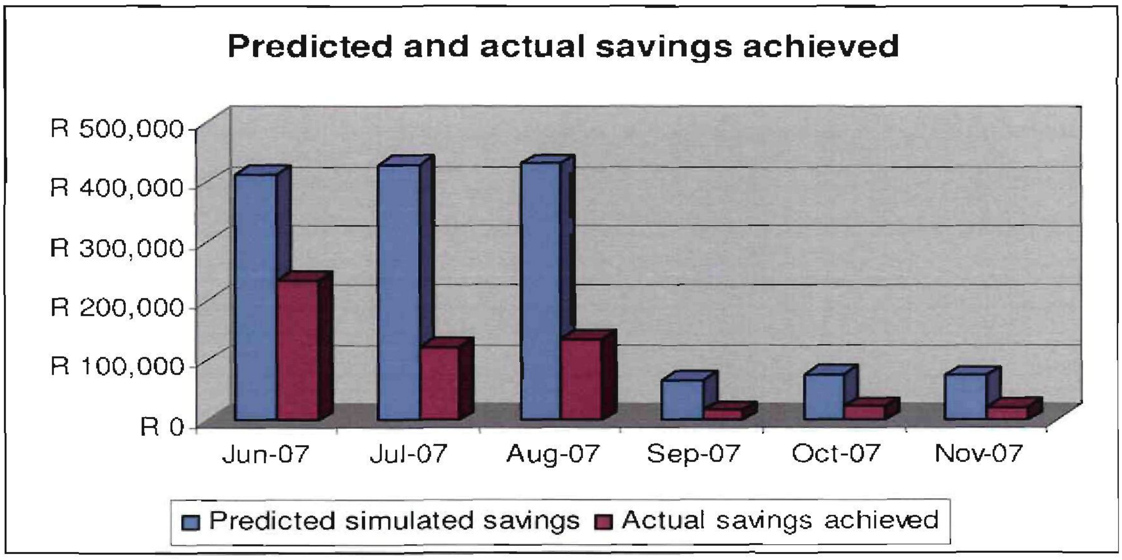


Figure 28: TauTona predicted and actual cost saving results

3.3.2 Beatrix 1, 2 & 3#

Figure 29: Photo of Beatrix 1,2 &3# gold mine

3.3.2.1 Introduction

The clear water pumping system on Beatrix 1, 2 & 3# has also been partly automated as part of the DSM project. The project is a combination of three different pumping systems. Insufficient control infrastructure prevents fully automated control. Similar to TauTona, control room operators are responsible for monitoring dam levels. The pump attendants are responsible for starting and stopping the pumps. The system layout for Beatrix 1,2 & 3# can be seen in Figure 30.

3.3.2.2 Project Information

Simulated MW target:	6.10 MW
Proposed MW target to Eskom by ESCO:	6.00 MW
Average performance over project lifetime:	4.00 MW

System layout:

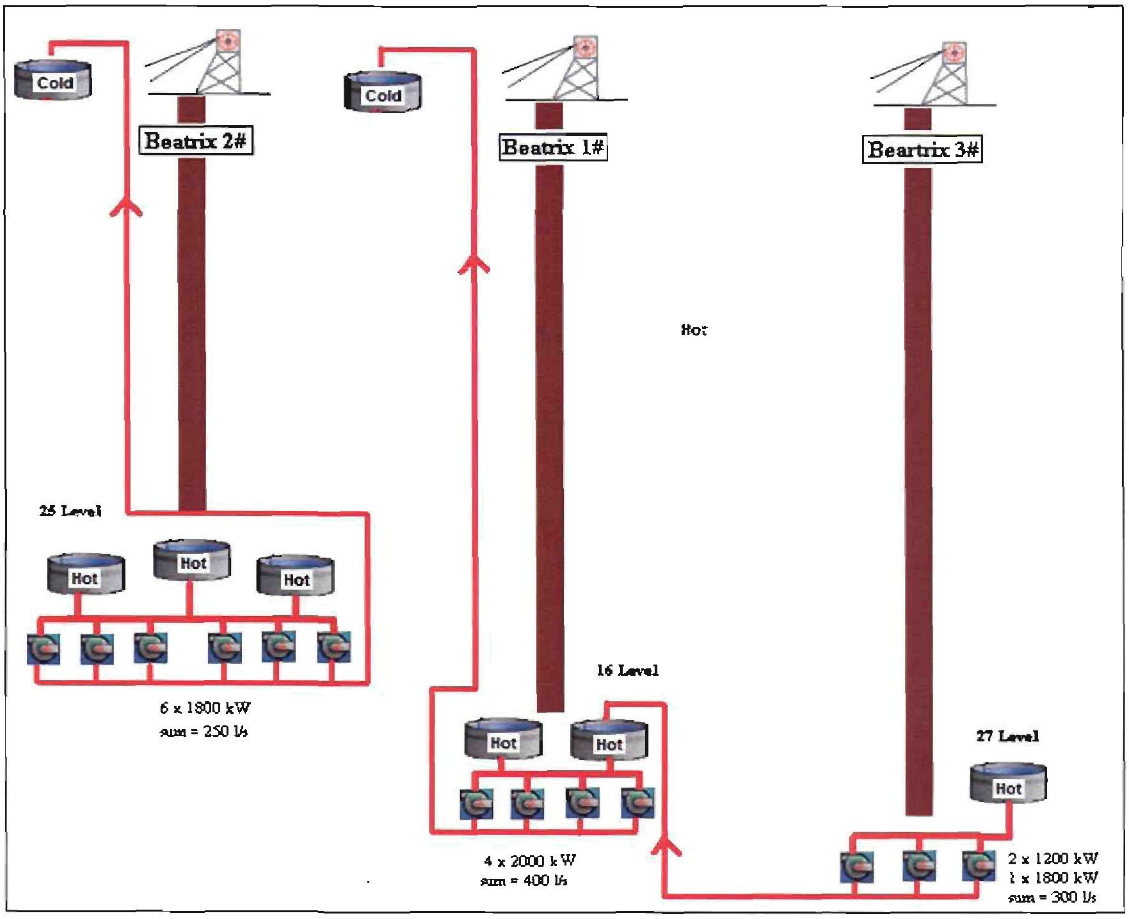


Figure 30: Beatrix 1, 2 & 3# pumping system layout

3.3.2.3 Load profile data for DSM project

The original, simulated DSM and actual DSM load profiles for the project are displayed in Figure 31. Predicted reduction in electricity usage during the peak periods was not realised. This underperformance is a result of human error caused by manual control, as no other problems causing insufficient load shifting were logged. Apart from the unrealised load shifting performance, an increase in electricity consumption over the total 24 hour period can also be seen. This is because of an increase in the amount of water that had to be pumped. The increase in underground water was caused by new underground mining activities forming part of an expansion program by the mine. Although additional water had to be pumped, a negative effect on load shifting was not expected since sufficient water storage capacity was made available. This additional capacity is used as reservoir during the peak periods.

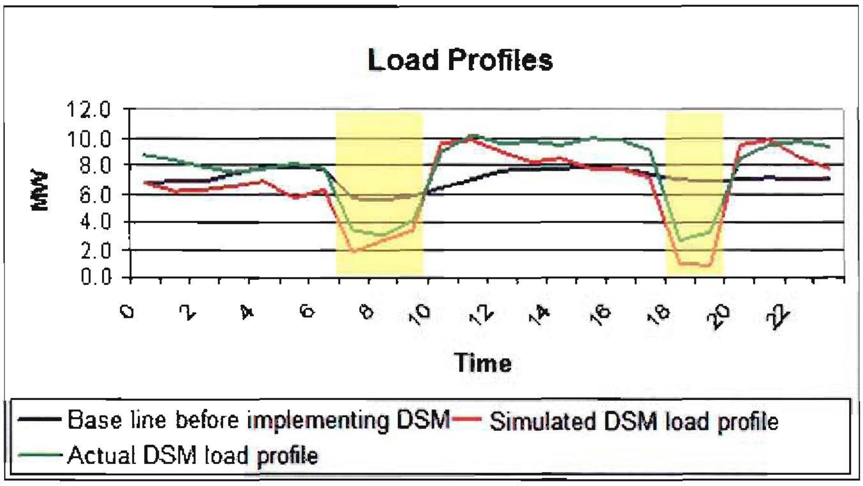


Figure 31: Beatrix 1, 2 & 3# load profiles

3.3.2.4 DSM project performance

Figure 32 shows the load shifting performance over the project lifetime of 17 months. From the graph it can be seen that the contractual target is only met in four months. A fluctuation in load shifting performance over the project life time can also be seen. Although there was an increase in the amount of water to be pumped*, typical months like June, September and October 2006 showed that the predicted load shifting target can be met. The deviation is therefore a typical characteristic of manual intervention.

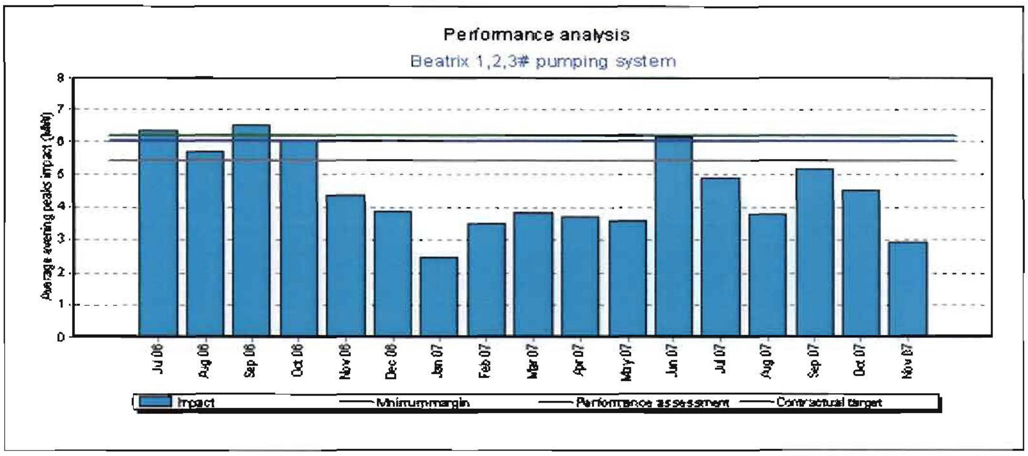


Figure 32: Beatrix 1, 2 & 3# actual load shifting results

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* See Section 3.3.2.3

Figure 33 displays the predicted and actual monthly cost savings for Beatrix 1,2 & 3#. During June 2007 the contractual load shifting target was achieved. During the remaining period the predicted cost savings could not be obtained, due to insufficient load shifting caused by manual intervention.

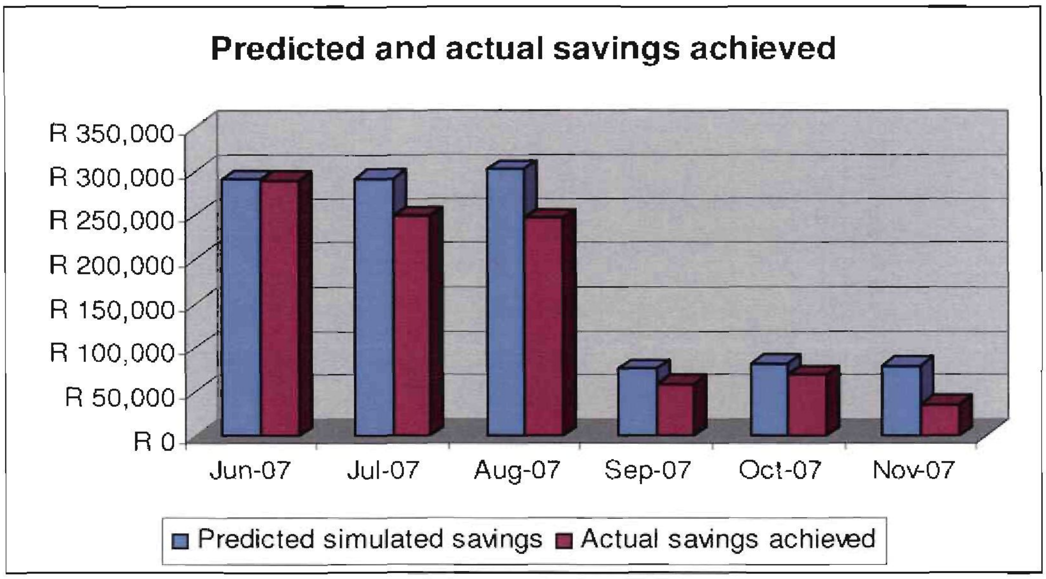

Figure 33: Beatrix 1, 2 & 3# predicted and actual cost saving results

3.3.3 South Deep

Figure 34: Photo of South Deep gold mine

3.3.3.1 Introduction

Due to old infrastructure, LM on South Deep's clear water pumping system is accomplished manually. In addition to the capital supplied by Eskom's DSM program, the mine will have to provide its own capital to fully automate the pumping system. The system layout for South Deep can be seen in Figure 35.

3.3.3.2 Project Information

Simulated MW target:	7.80 MW
Proposed MW target to Eskom by ESCO:	6.00 MW
Average performance over project lifetime:	5.90 MW

System layout:

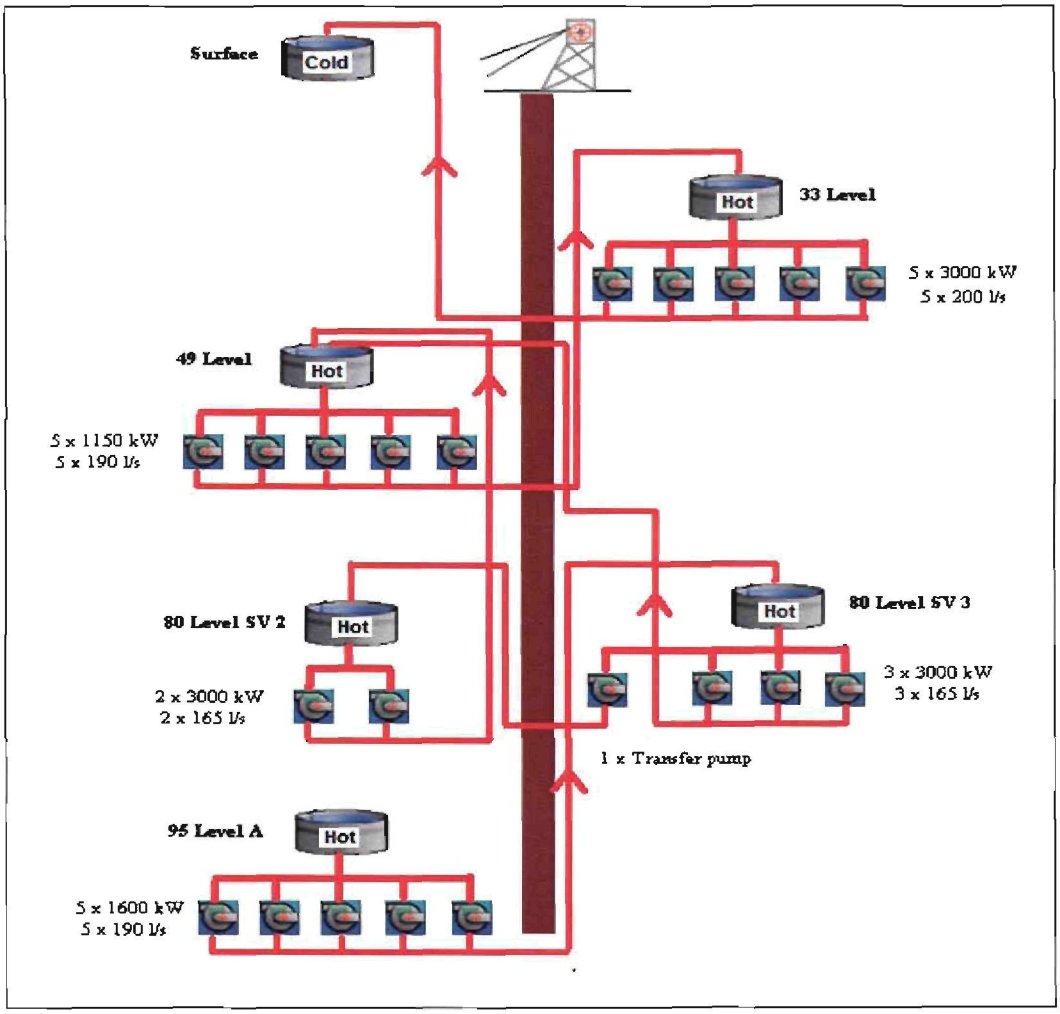

Figure 35: South Deep pumping system layout

3.3.3.3 Load profile data for DSM project

The original, simulated DSM and actual DSM load profiles for South Deep are displayed in Figure 36. The actual load profile shows that very little load shifting was done during the morning peak period. During the evening peak the actual load profile reflects improved load shifting. The simulated load profile indicates that more potential was available.

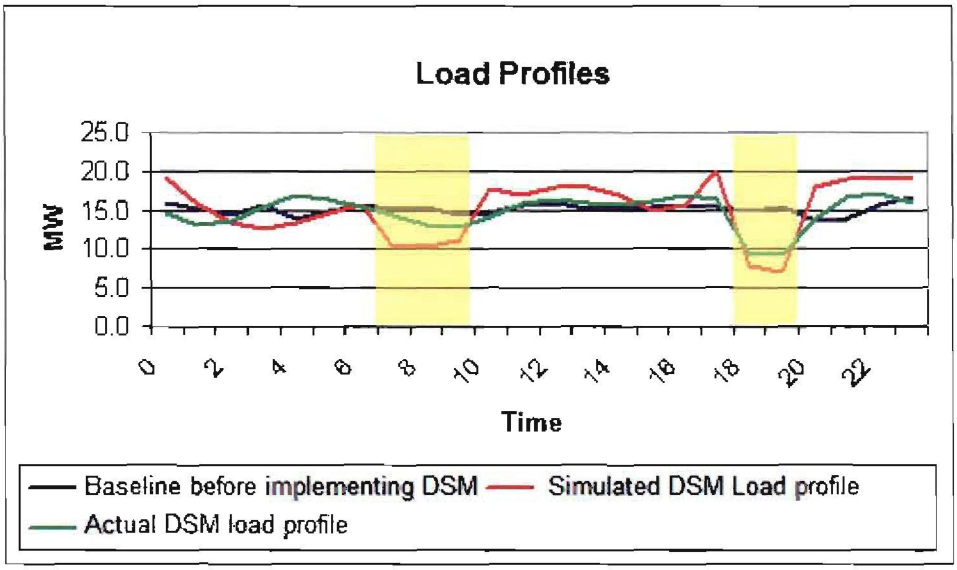

Figure 36: South Deep load profiles

3.3.3.4 DSM project performance

Figure 37 shows the load shifting performance over the project lifetime of nine months. The graph indicates that the contractual target was only achieved during March, October and November. During April 2007 South Deep experienced electricity supply problems, causing insufficient load shifting results. As April 2007 formed part of the performance assessment period, the performance during this month was carefully assessed. Under performing days were therefore treated as condonable days.

When evaluating the load shifting performance over the total study period, inconsistent load shifting performance can be seen. Although an increase in performance is found from July 2007 to September 2007, the calculated average showed the contractual target had not been met. This is again an indication that manual load shifting is an inefficient method for operating pump systems.

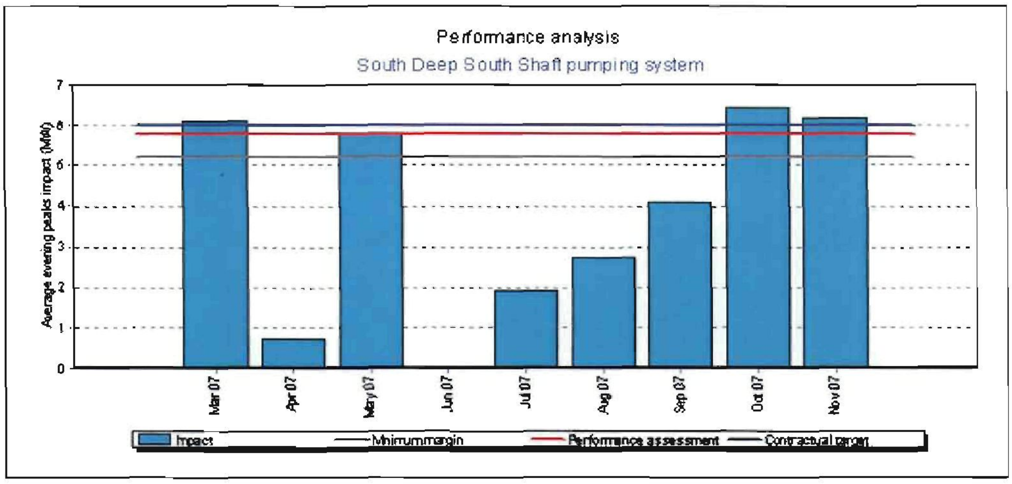

Figure 37: South Deep actual load shifting results

The effect of insufficient load shifting results is reflected in the lack of cost savings as displayed in Figure 38. Although there was no evening load shifting during June 2007, the graph indicates that a cost saving was realised. The cost saving was achieved by load shifting obtained during the morning peak period.

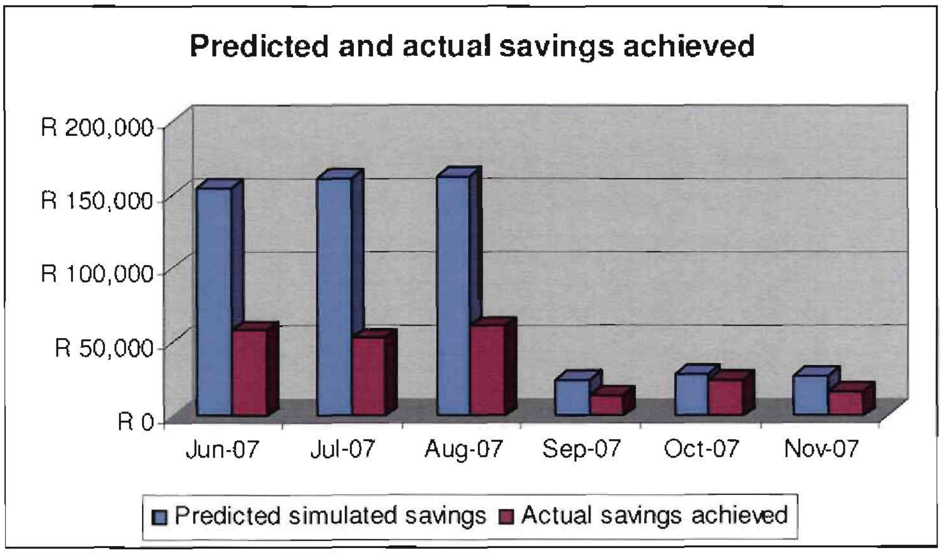

Figure 38: South Deep's predicted and actual cost savings

3.4 Calculating DSM infrastructure cost

As part of the DSM initiative, Eskom will make funds available to clients who intend to participate in the program. These funds will be used to install additional infrastructure on existing systems to ensure sustainable energy efficiency or load shifting results. In most instances funds are sufficient to ensure complete automation of the system. Unfortunately the costs involved to automate older systems, in particular on old gold mines, are sometimes too high. As a cost saving measure, only monitoring equipment will be installed at mines where full automation is not possible. This monitoring equipment will simplify the procedure for manual load shifting.

Due to a confidentiality agreement between Eskom and their clients, the exact infrastructure cost for each project cannot be revealed in this document. In order to determine an estimated, but realistic infrastructure cost value for each project, general infrastructure requirements will be evaluated. Infrastructure costs will be based on a general pricelist obtained from an automation company.

The estimated infrastructure cost on the three manually controlled DSM projects can be determined by evaluating the requirements according to predefine parameters. These parameters are the number of pump stations, the type and number of pumps, the number and size of dams, the depth of each shaft, and the existing infrastructure on each project. Because of the similarity of the infrastructure on the various pumping systems in the mining industry, the evaluation can be calculated based on the data in Table A[†]. The values given in Table A are based on actual data obtained from the mine during investigations into DSM potential.

The total infrastructure cost for each project can be calculated, using the quantities in Table A and the unit price for each separate piece of equipment displayed in Table B[‡]. Infrastructure cost for TauTona, South Deep, and Beatrix 1, 2 & 3# is shown in Table 6.

[†] See Appendix A - Table A

[‡] See Appendix A - Table B

Table 6: Infrastructure cost for Manual DSM projects

	TauTona	South Deep	Beatrix 1,2&3#
Total	R 4,234,720	R 4,079,200	R 3,056,030

These values will be used for the initial capital cost in further calculations.

3.5 Labour and maintenance cost analysis

One of the key advantages of DSM projects is the financial savings that can be realised. The largest cost saving is usually obtained by managing electricity consumption efficiently. Together with electricity cost savings, other financial benefits can also be obtained. One of the additional benefits is the reduction of labour costs if a system is automated. A further advantage will be the reduction in maintenance cost. This benefit can be obtained from both manual and automated systems if pumping schedules are followed correctly.

If load shifting is done manually, labour reduction will not be possible. Pump attendants will still be required to perform manual tasks, such as stopping and starting of pumps. Labour reduction cost savings can only be claimed as an additional DSM benefit, if a manually controlled system is converted to a fully automated system.

The financial benefit in the reduction of maintenance cost is most likely to be obtained only if the system is automatically controlled. Reduction in maintenance can also be obtained from a manually controlled system if a LM schedule is followed correctly. However, these results are less significant compared to automated systems. This is because pump schedules need to be adjusted frequently and are not always strictly adhered to by the pump attendants.

3.5.1 Calculating labour cost and possible savings

Calculations applicable to labour cost savings will be based on the results of previous studies as discussed in Section 2.4.4. This is possible because previous studies were based on actual figures obtained from the mining industry.

The first step in the calculation process is to determine the number of pump attendants required to control a manually operated system. Manually controlled pumping systems require operator attendance on a 24 hour/day basis. Three eight hour shifts per day are commonly used in the mining industry. According to Section 2.4.4 three people are employed on each shift.

The number of personnel required and labour costs for TauTona, Beatrix 1,2 & 3 #, and South Deep are shown in Table 7.

Table 7: Number of pump attendants and labour cost

	Number of levels	Number of pump attendants	Total monthly labour cost
TauTona	5	45	R 180,000
Beatrix 1,2 & 3#	3	27	R 108,000
South Deep	4	36	R144,000

Studies have shown that labour costs can be reduced by 61.1% if pumping systems are fully automated[§]. The reduction in labour cost due to the reduction in labour for TauTona, Beatrix 1, 2 & 3# and South Deep can be seen in Table 8:

Table 8: Monthly labour cost for manual and automated systems

	Monthly labour cost for a manual system	Monthly labour cost for an automated system	Average monthly cost saving due to the reduction in labour
TauTona	R 180,000	R 70,020	R 109,980
Beatrix 1,2 & 3#	R 108,000	R 40,012	R 65,988
South Deep	R144,000	R 55,016	R 87,984

The results in Table 8 will be used for further calculations in Chapter 4.

3.5.2 Calculating maintenance cost and possible savings

Calculations used to determine maintenance cost savings are also based on actual figures and theory obtained from previous studies as explained in Section 2.4.5. The financial savings will

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[§] See Section 2.4.4

therefore be a reflection of cost savings that could be obtained, by minimising pump cycling when a manual system is automated.

Maintenance costs usually differ for each mine due to differences in pump sizes, different operating hours, varying water quality, etc. An average cost saving value will be used for the purpose of this study. This value was obtained from a previous study conducted on clear water pumping systems in the mining industry[**].

In order to determine the potential monthly cost saving due to the reduction in maintenance cost by minimising pump cycling, the number of pumps on each mine must be known. The monthly cost savings can then be calculated by multiplying the number of pumps with an average monthly cost saving value. This value was determined during a previous study conducted, as explained in Section 2.4.5.

Table 9 shows the number of pumps on each mine as well as the possible maintenance cost savings per month that can be obtained by limiting pump cycling. Calculations were made for TauTona, Beatrix 1, 2 & 3#, and South Deep.

Table 9: Possible maintenance cost savings

	Number of pumps	Possible maintenance cost saving per month for an automated system
TauTona	20	R 47,000
Beatrix 1, 2 & 3#	20	R 47,000
South Deep	13	R 30,550

[**] See section 2.4.5

3.6 Conclusion

The purpose of Chapter 3 was to research background information on the different projects that were selected as case studies. Load shifting and cost saving data was gathered in order to determine the performance of the different projects. These performance results are used in Chapter 4 to draw up a comparison between automated and manually controlled systems.

Information used in Chapter 3 was obtained from information supplied by the mines. The data used to determine the load shifting and cost saving results was gathered from the REMS database. This data is logged at two-minute intervals for 24 hours a day. After the data was processed, the load shifting and cost saving graphs were generated. The performance of each individual project was calculated.

Six projects were selected as case studies for the purpose of this thesis. Three of the six projects (Amandelbult 2#, Masimong 4# and Beatrix 4#) are fully automated. The remaining three projects (Tau Tona, Beatrix 1, 2 & 3#, and South Deep), are all manually controlled.

CHAPTER 4: COMPARISON STUDY BASED ON SAVINGS AND CALCULATIONS

Photos: By HVAC International personnel

In this chapter a comparison study is make between automated and manual DSM projects. Three independent comparison studies are done based on load shifting performance, cost savings obtained, and engineering economic evaluations.

4.1 Introduction

In Chapter 3 predicted as well as actual load shifting and cost saving results were determined. These results are used in the comparison study between the different methods for load shifting.

Load shifting and cost saving results are essential barometers for determining the optimum method of load shifting. However, other influences must also be taken into consideration. This includes parameters such as infrastructure costs and the payback period of invested capital. In order to include these factors in realistic calculations, engineering economic methods will be used.

Throughout this chapter comparisons will be made between manually and automated DSM projects. These comparisons are made taking external factors such as condonable days, project lifetimes, labour reduction, and maintenance cost reduction into account. This will ensure that the comparison between the different methods will be objective.

4.2 Validation of simulation model

4.2.1 Preface

Before a comparison study between manual and automated projects can be made, the standard by which the different methods are compared should be stipulated and validated. For the purpose of this dissertation the simulation model used to predict load shifting and cost saving results was taken as the standard.

As previously stated, simulation models can be used to determine the DSM potential for a specific project. This potential is dependant on the amount of electricity usage that can be shifted from Eskom peak periods. Once the electricity usage is calculated, the cost saving potential, based on Eskom's 24 hours tariff structure, can be determined.

As it is virtually impossible to predict the effect of manual intervention when a simulation model is created, all simulations will be based on automatic control of the systems. This concept will be discussed later in the chapter when applied. The simulation results are compared to actual automated results, in order to determine the accuracy of the simulation models.

If the accuracy of these simulation models is found to be acceptable, similar models can be developed to simulate automated control of manually controlled systems. These models can then be used to determine the difference in savings between manually and automatically controlled systems. The savings will indicate the best method of control.

4.2.2 Validation of simulation model based on load shifting results

A simulation was conducted for each project to determine the possible load shifting and cost savings potential. The accuracy of the simulation models can be verified by comparing the simulation results of automated projects with the actual results after DSM implementation. Figure 39 shows the predicted and actual load shifting results for the three automated projects.

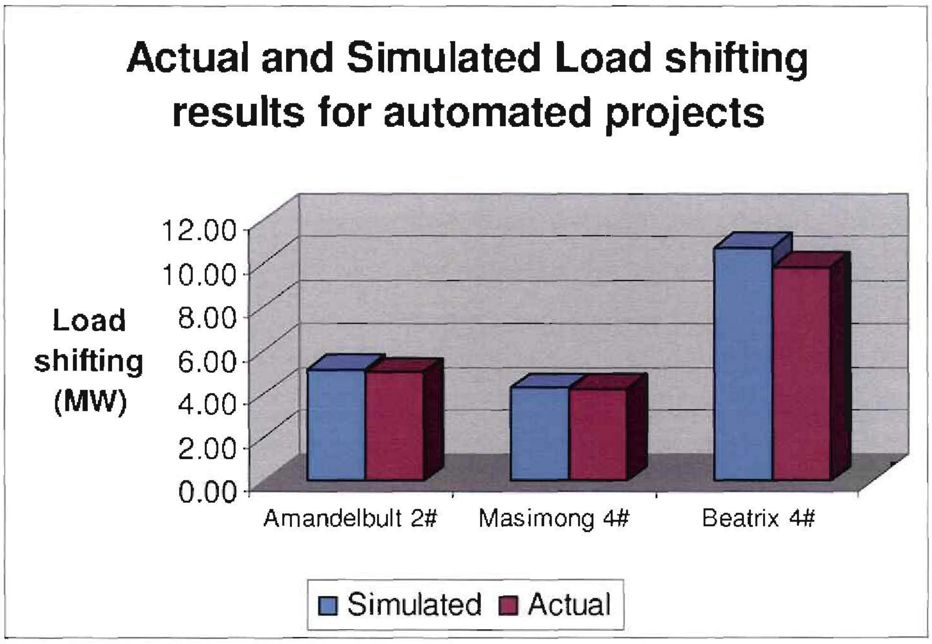


Figure 39: Actual and simulated load shifting results for automated projects

The differences between the simulated and actual results were: Amandelbult 2#: 2.4%, Masimong 4 #: 1.2% and Beatrix 4#: 8.3%. These calculations were based on load shifting results from the evening peak period.

Comparing the accuracy of the simulation models, a large deviation between Beatrix 4# and the other two projects is found. Despite the large difference, the average in accuracy of the simulation models was calculated by making use of the results from all three projects. This was done because only three automated projects were selected as case studies. If more projects were used, and a deviation still occurred, the results from Beatrix 4# would have been excluded from the calculations.

Despite the deviation in accuracy, an average value below 4% was calculated. The simulation model is therefore 96% accurate and can be accepted as an accurate representation of an actual system. It is therefore acceptable to use the simulation model to predict the maximum load shifting potential for any clear water pumping system within the constraints applicable to this study.

4.2.3 Validation of simulation model based on cost saving results

The cost saving performance of the simulation model can also be determined. This is accomplished by comparing actual cost savings with the predicted savings of the simulation model. Data obtained over the six month period of this study was used to determine the accuracy of the simulation model.

The actual and simulated cost savings for the three automated projects were discussed in Chapter 3. In order to compare the cost saving performance for the three projects, the difference in performance will be expressed as a percentage. The percentage difference for the three mines can be seen in Figure 40.

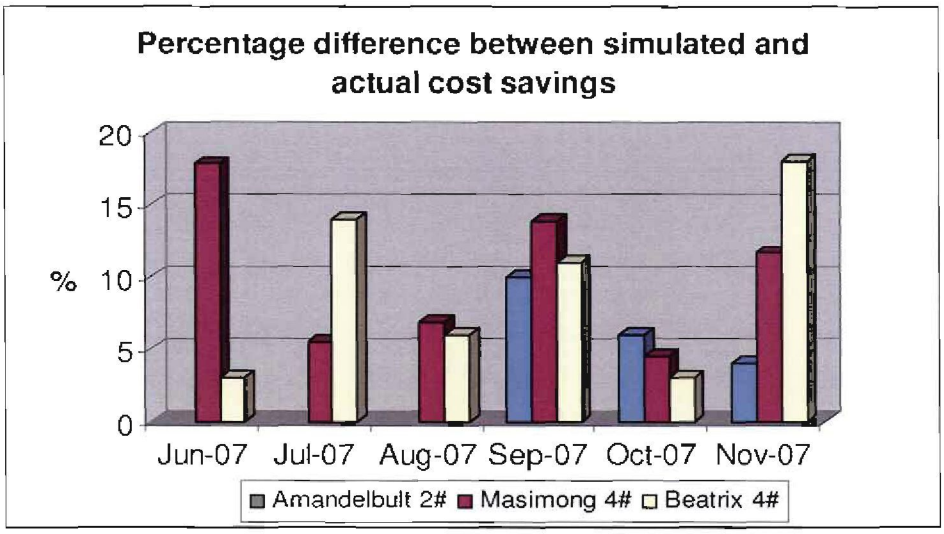


Figure 40: Percentage difference between simulated and actual cost savings

The average differences between the simulated and actual cost saving results, calculated over the six months, were: Amandelbult 2#: 6.6%, Masimong 4 #: 10% and Beatrix 4#: 9.1%. The average percentage deviation for cost savings will be 8.6%. The cost saving model is therefore between 90 % and 93.4 % accurate.

4.3 Comparison study based on load shifting performance

4.3.1 Preface

Load shifting performance is used to determine whether the predicted load shifting target is met by the actual load shifting obtained during the evening peak period. The evening peak is the period from which the agreed contractual load shifting value between Eskom and the client is determined. For the purpose of this dissertation, the load shifting performance is measured over the total project lifetime, as applicable to each project.

The main purpose of Section 4.2 was to determine the accuracy of the model used to predict load shifting potential on pumping systems. From the calculations it is clear that the load shifting results obtained from the model is within acceptable limits of the actual results. The model has therefore been shown to be an accurate simulation of the actual conditions encountered and will be used in the comparison study where applicable.

4.3.2 Manual and automated load shifting results

In order to ensure an accurate comparison between automated and manually controlled systems, a comparison between both methods is required for each project. Actual manual results are compared with predicted simulated results in order to obtain the best control method of load shifting. The simulated and actual load shifting results for the three manual projects can be seen in Figure 41.

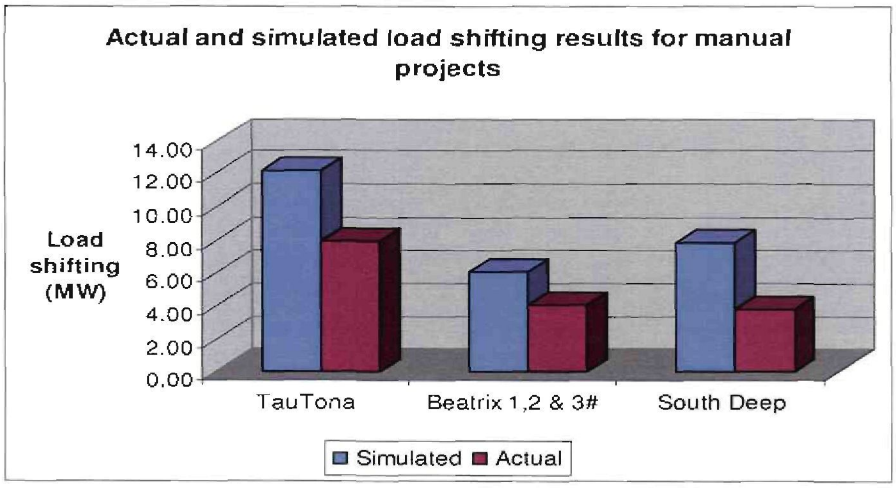


Figure 41: Actual and simulated load shifting results for manual projects

A significant difference between the simulated predictions and actual load shifting results for the three manually controlled projects can be seen.

In Section 4.2.2 the simulation model was shown to be accurate for automated systems. It is therefore reasonable to assume that if the manual projects were automatically controlled, the actual load shifting results would have been similar to the simulation results.

TauTona, Beatrix 1, 2 & 3#, and South Deep were selected for the manually controlled case studies. The actual load shifting data obtained (from Chapter 3) for these projects are a representation of manual load shifting results. The results from the simulation model will be used as predicted automated load-shifting results.

Table 10: Compared load shifting results

	Contractual load shifting value (MW)	Manual load shifting (MW)	Predicted automated load shifting (MW)	Difference in load shifting (MW)	Av. difference between manual and automated load shifting (%)
Tau Tona	5.50	7.96	12.20	4.24	34.7
Beatrix 1,2 & 3#	6.00	4.04	6.10	2.06	33.8
South Deep	6.00	3.80	7.80	4.00	51.2
Total/*Av.*	**17.50**	**15.80**	**26.10**	**10.30**	***40.0***

The comparison between the simulated and actual load shifting results can be seen in Table 10. Load shifting would have improved by 40% on average if all the manually controlled systems were automated. Automation should therefore result in an additional 10.3 MW load that can be shifted from the Eskom evening peak period.

4.3.3 DSM funding applied for infrastructure upgrades

The capital provided by Eskom is in some cases insufficient to cover the cost required for automating a pumping system. At TauTona, Beatrix 1, 2 & 3#, and South Deep, the funds were only sufficient to partly automate the pumping systems. Only essential infrastructure, such as a communication network, SCADA system, selected field instrumentation, etc. was installed. This infrastructure is used to monitor the status of essential system parameters such as the levels of the dams. Control of the pumping systems will still be done manually. Implementation of this monitoring equipment will therefore improve the decision making process of the control room operators.

4.3.4 Consistency and sustainability of load shifting

The consistency and sustainability of load shifting must also be considered. This is a very important aspect, because load shifting projects form part of Eskom's Integrated Strategic Planning. If load shifting results are not consistent or sustainable, high demands during peak periods would still occur. This would make load-shifting projects inefficient and a waste of money. Figure 42 shows the load shifting performance for the six projects.

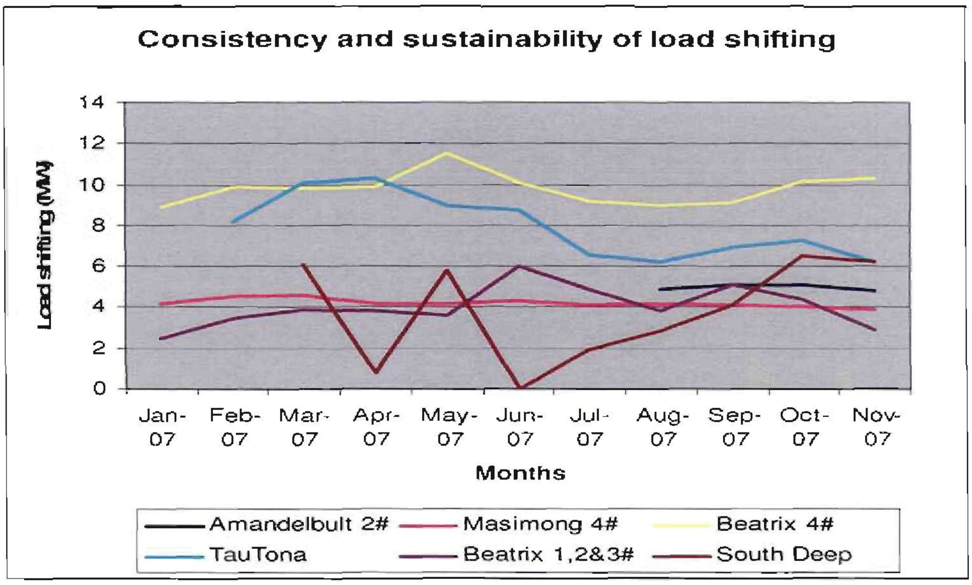


Figure 42: Consistency and sustainability of load shifting

It is clear from Figure 42 that the load-shifting performance of the three automated projects, (Amandelbult 2#, Masimong 4# and Beatrix 4#) is very consistent.

TauTona, Beatrix 1, 2 & 3# and South Deep, display the load-shifting performance for the manually controlled projects. These profiles show large fluctuations in load shifting, which is an indication of inconsistent load shifting performance.

4.3.5 Summary

A comparison study between manually and automatically controlled load shifting systems was conducted. The automated systems showed significantly improved performance and cost savings over the manually operated systems. The poor performance of the manually controlled systems resulted in contractual targets not being realised.

Large deviations in load shifting performance were experienced with manually controlled load shifting projects. This will have negative implications on the generation capacity of Eskom. The inconsistency of a manual load shifting system will therefore not ensure viable reduction in peak time electricity usage. In direct contrast to manual load shifting, automated projects proved to be consistent and sustainable.

4.4 *Comparison study based on cost savings*

4.4.1 Preface

Cost saving performance is used to determine whether the predicted cost saving target is met by the actual cost savings obtained. The cost savings are determined by calculating the difference between the electricity cost before and after the DSM project was implemented. Electricity cost is determined by taking variable tariff structures for different times of the day into account. This includes morning and evening peak periods.

For the purpose of this dissertation cost saving performance will not be calculated over the total project lifetime. This is because of the difference in project lifetime between the projects and the continuous increase in Eskom's electricity tariffs. In order to ensure an objective comparison between the different projects, cost saving performance will be calculated by making use of data obtained over a six month period where tariffs were the same for each project. This will include three months in the high-demand season (higher electricity tariffs) and three months in the low demand season (lower electricity tariffs).

In a similar method to the comparison study based on load-shifting performance, the cost saving simulation model was also verified[††]. An accurate and acceptable basis was determined, by which all the manually operated projects could be compared.

4.4.2 Manual and automated cost saving results

Results from the manually operated and simulated systems at TauTona, Beatrix 1, 2 & 3# and South Deep were obtained. The actual and simulated cost savings for the three projects can be seen in Table 11.

[††] See Section 4.2.3

Table 11: Compared cost saving results

	Season	Av. monthly manual savings (R/c)	Av. predicted monthly automated savings (R/c)	Difference in avg. monthly savings (R/c)	Av. difference between manual and predicted automated savings (%)
Tau Tona	**High demand**	R 164,625	R 424,305	R 259,680	61.20
	Low demand	R 20,071	R 73,189	R 53,118	72.58
Beatrix 1,2 & 3#	**High demand**	R 261,401	R 294,507	R 33,106	11.2
	Low demand	R 54,310	R 78,397	R 24,087	30.7
South Deep	**High demand**	R 56,988	R 159,512	R 102,524	64.2
	Low demand	R 17,919	R 26,542	R 8,622	32.4
Total/Av.	**High demand**	**R 483,014**	**R 878,324**	**R 395,310**	**45.5**
	Low demand	**R 92,300**	**R 178,128**	**R 85,827**	**45.2**

These savings were calculated from actual electricity usage data obtained from the REMS system. Potential load shifting was calculated by making use of simulation models. This data was used to determine the actual and simulated cost savings, based on the Eskom 24-hour tariff structure. The model used to determine predicted cost savings has already been shown to be accurate (Section 4.2.3). These results can therefore be assumed to be representative of automated cost savings. Cost savings for the high demand season were calculated from June '07 to August '07 and from September '07 to November '07 for the low season.

From Table 11 it can be seen that manually controlled projects realise significantly lower cost savings than automated projects. If the projects were automated, an additional cost saving of between 36% and 45% could be expected. These conclusions are based on the accuracy of the simulation model in Section 4.2.3.

4.4.3 Benefits of additional cost savings

One of the unique advantages of the DSM program is that both Eskom and the client benefit. In order to gain optimum load shifting results, the client needs to be convinced of the significant cost savings attainable. When cost savings are maximised, the DSM program can play a decisive role in the financial planning of any large electricity consumer.

4.4.4 Summary

From the comparison study based on cost saving performance, automated projects have been shown to be the best method of load shifting. Significant cost savings are realised especially during high demand seasons when electricity tariffs are extremely high. With a potential cost saving increase of between 36% and 45%, an automated load shifting system will be of great benefit to the electricity consumer.

4.5 Present Worth Analysis

4.5.1 Preface

Most of the load shifting projects in the DSM program are fully automated. Either the client or Eskom may decide to allocate additional capital in order to fully automate manual projects since it has been shown that significant additional savings will be obtained.

It is therefore important to establish whether the implementation of an automated system will be financially viable. A comparison study, based on the engineering economics, between manual and automated projects is required before a decision can be made.

4.5.2 Important economic background information

The different engineering economic methods have already been described in Chapter 2. As part of the process to perform these calculations, inflation needs to be taken into account as well.

The purpose of this section will therefore be to determine the money depreciation factor for each project, taking initial infrastructure cost, and annual cost savings into account. All calculations will be based on the following assumptions:

- The lifetime for all the projects is assumed to be five years. This is in accordance with the DSM contract period.
- A 12% annual interest rate is used in the calculations. The rate is taken as the highest expected South African inflation rate for January 2008. An annual 2.5% increase is assumed to compensate for inflation increase [51].

- Electricity tariff increase over the five-year period will be taken as 5.7% compounded annually. This assumption is based on the average tariff increases that were introduced over the last three years [52].

The alternative selection methods to be used in this dissertation are based on the present worth analysis. All monthly revenues and expenses must be converted to present worth values. Present worth calculations must also be applied to annual income and costs as applicable.

When implementing DSM projects the monetary values to be converted are:

- Monthly revenues obtained from electricity cost savings;
- Monthly labour cost savings as applicable to each project;
- Monthly maintenance cost savings on pumps (treated as revenues where applicable).

Most of the infrastructure installed during the automation process has extended guarantees. Maintenance cost on the automated system itself is therefore not included in the calculations.

4.5.3. Converting monthly revenues and expenses

The monthly and annual expenses and revenues are converted to present worth values using equations and techniques as described in Section 2.6[‡‡]. In order to understand the economic analysis, a breakdown of calculations will be shown in the following steps.

Step 1: Constructing a cash flow diagram

Cash flow diagrams are constructed in order to simplify and display revenues and expenses as applicable to each project. The reduction in pump maintenance and labour cost is not taken into account for the manual projects. Figure 43 illustrates the general cash flow over a 12-month period for a DSM project that is manually operated.

[‡‡] See Appendix B Example A

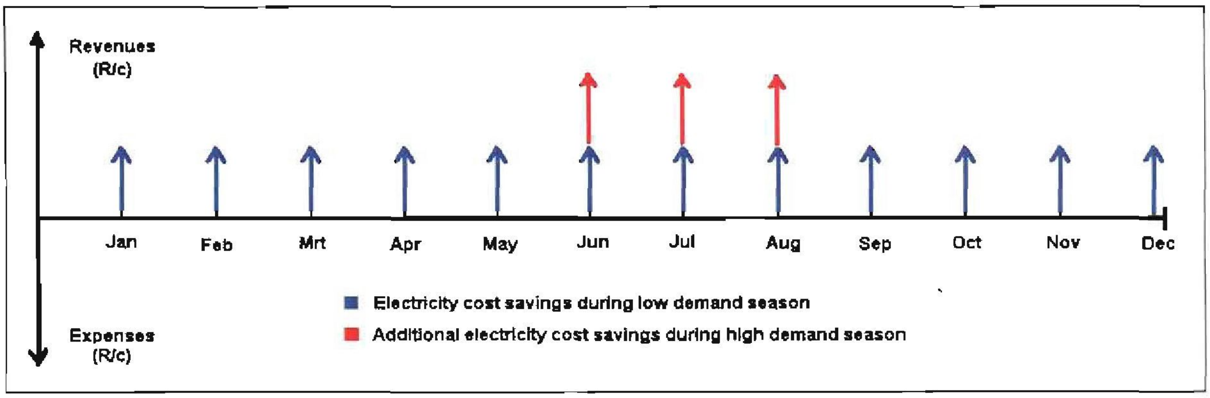


Figure 43: Monthly cash flow diagram for manual projects

Annual cash flow diagrams for automated DSM projects differ from manually operated projects, because of additional cost savings obtained by automated systems. Figure 44 shows the monthly cash flow for an automated DSM project also over a one month period.

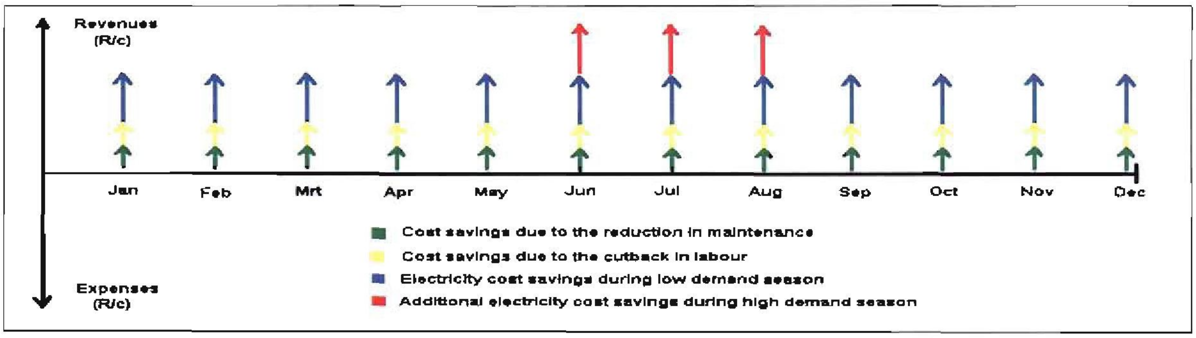


Figure 44: Monthly cash flow diagram for automated projects

Figure 43 and Figure 44 only display the monthly revenues over a 12- month period. With a life expectancy of five years, cash flow diagrams need to be derived over the total 5 year period. Figure 45 displays the annual cash flow for a typical DSM project over a five year period.

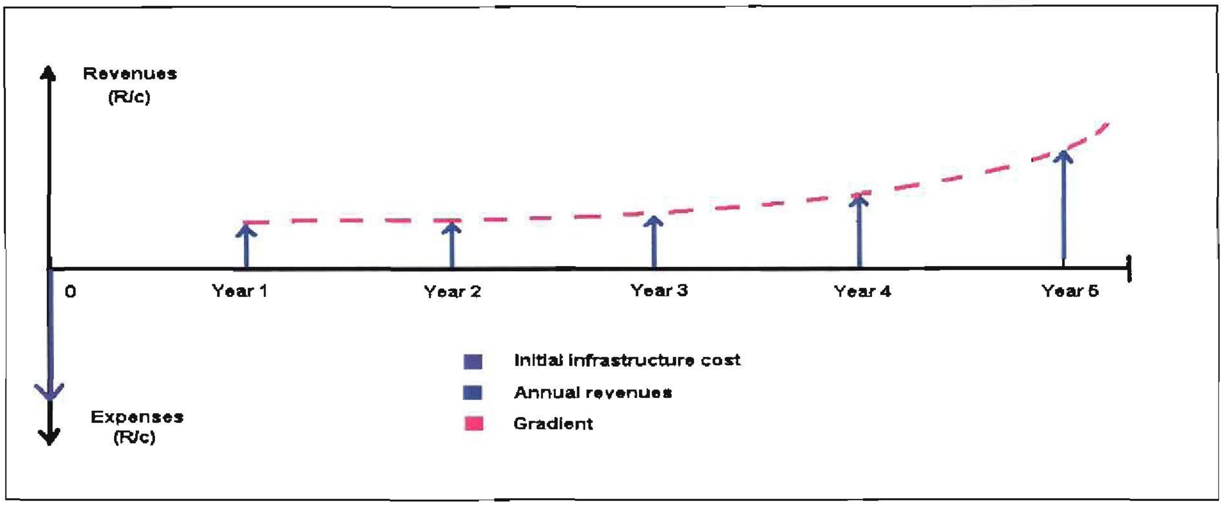


Figure 45: Typical annual cash flow diagram for a DSM project

Step 2: Converting monthly cash flows to a single future value

The second step in the calculation process is to convert all monthly revenues and expenses to a single annual value. Figure 43 and Figure 44 display the typical monthly cash flow for both manual and automated projects. These cash flows will be converted to a single future value (A), for the time that is one year from the commencement date of the project, namely Year 1. Figure 46 illustrates this concept.

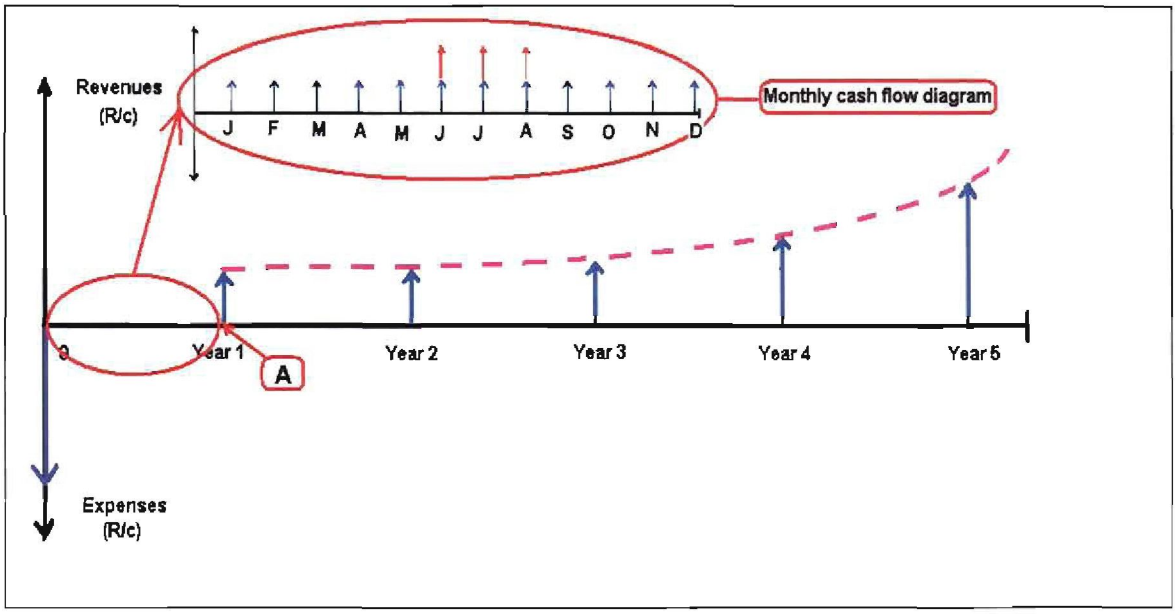


Figure 46: Monthly and annual cash flow diagrams

Although present worth values are required for the comparison study, all monthly cash flows are initially converted to a future value. This is done because the first annual value in the five-year period is only 12 months after the commencement date, or time 0. In order to determine the single future value, Equations ***2-2*** and ***2-6*** are used.

Manual conditions

A combined equation for manually operated DSM projects can now be created. The equation will be set up according to the cash flow diagram in Figure 43, which is only applicable to manual projects.

$$F_{year1} = W + X + Y + Z \qquad \textbf{\textit{4-1}}$$

Where:

$$W = A\left[\frac{(1+i)^{n_{12}} - 1}{i}\right]$$

$$X = P(1+i)^{n_5}$$

$$Y = P(1+i)^{n_7}$$

$$Z = P(1+i)^{n_8}$$

$$F_{year1} = A\left[\frac{(1+i)^{n_{12}} - 1}{i}\right] + P(1+i)^{n_6} + P(1+i)^{n_7} + P(1+i)^{n_8}$$

Equation ***4-1*** can be used as a general equation for manual DSM pumping projects, taking constraints as defined in this study into account. The input values for the equation as applicable to each project are listed in Table 12.

Table 12: Future Worth analysis input values for manual conditions

	Description	**TauTona**	**Beatrix 1, 2 & 3 #**	**South Deep**
A	Monthly electricity cost savings (low demand season) (R)	R 20,071	R 54,310	R 17,919
P	Additional electricity cost saving (high demand season) (R)	R 144,554	R 207,091	R 39,069
i	Monthly interest rate (%)	1%	1%	1%
n_{12}	Total period (months)	12	12	12

	Description	TauTona	Beatrix 1, 2 & 3 #	South Deep
n_6	High demand season, month 6 (month)	6	6	6
n_7	High demand season, month 7 (month)	5	5	5
n_8	High demand season, month 8 (month)	4	4	4

By substituting the appropriate values from Table 12 into Equation *4-1*, the Future Worth for TauTona can be calculated as follows:

$$F_{year1} = W + X + Y + Z$$

$$F_{year1} = A\left[\frac{(1+i)^{n_{12}} - 1}{i}\right] + P(1+i)^{n_6} + P(1+i)^{n_7} + P(1+i)^{n_8}$$

$$F_{year1} = 20{,}071\left[\frac{(1+0.01)^{12} - 1}{0.01}\right] + 144{,}554(1+0.01)^{6} + 144{,}554(1+0.01)^{5} + 144{,}554(1+0.01)^{4}$$

$$F_{year1} = 254{,}550 + 153{,}447 + 151{,}928 + 150{,}423$$

$$F_{year1} = R710{,}348$$

The F_{year1} results for Beatrix 1, 2 & 3#, and South Deep were also calculated by making use of Equation *4-1*. The results for the three manual projects are summarised in Table 13.

Table 13: Future Worth results for manual conditions

	F_{year1}
Tau Tona	R 710,348
Beatrix 1, 2 & 3#	R 1,341,765
South Deep	R 350,446

F_{year1} is the future value at the end of year one. The values obtained for F_{year1}, as applicable to each project, will be used as annual values for each year one to five. The effect of monetary depreciation is determined by using the P/A gradient factor.

Automated conditions

Before Step 3 calculations can be made, an equation similar to ***4-1*** must be developed for automated conditions. The cash flow diagram displayed in Figure 44 is used.

The future annual value equation ***4-2*** for automated conditions is very similar to Equation ***4-1***. Two additional terms however, representing labour and maintenance costs are included in this equation. The subscript ECS will indicate Electricity Cost Savings and ACS Additional Cost Savings. Additional Cost Savings include savings obtained from labour and maintenance reduction.

$$F_{year1} = F_{ECS} + F_{ACS} \qquad \textbf{\textit{4-2}}$$

$$F_{year1} = (U + V + W + X) + (Y + Z)$$

Where:

$$U = A_{Elec}\left[\frac{(1+i)^{n_{12}} - 1}{i}\right]$$

$$V = P(1+i)^{n_6}$$

$$W = P(1+i)^{n_7}$$

$$X = P(1+i)^{n_8}$$

$$Y = A_{Lab}\left[\frac{(1+i)^{n_{12}} - 1}{i}\right]$$

$$Z = A_{Main}\left[\frac{(1+i)^{n_{12}} - 1}{i}\right]$$

$$F_{year1} = (A_{Elec}\left[\frac{(1+i)^{n_{12}} - 1}{i}\right] + P(1+i)^{n_6} + P(1+i)^{n_7} + P(1+i)^{n_8}) + (A_{Lab}\left[\frac{(1+i)^{n_{12}} - 1}{i}\right] + A_{Main}\left[\frac{(1+i)^{n_{12}} - 1}{i}\right])$$

Equation ***4-2*** can now be used to calculate future worth values for automated DSM projects. Table 14 shows the relevant input values for further calculations.

Table 14: Future Worth analysis input values for automated conditions

	Description	TauTona	Beatrix 1,2 &3 #	South Deep
A_{Elec}	Monthly electricity cost savings (low demand season) (R)	R 73,189	R 78,397	R 26,542
P	Additional electricity cost saving (high demand season) (R)	R 351,116	R 216,110	R 132,970
A_{Lab}	Additional labour cost saving (R)	R 109,980	R 65,988	R 87,984
A_{Main}	Additional maintenance cost savings (R)	R 47,000	R 30,550	R 47,000
i	Monthly interest rate (%)	1%	1%	1%
n_{12}	Total period (months)	12	12	12
n_6	High demand season, month 6 (month)	6	6	6
n_7	High demand season, month 7 (month)	5	5	5
n_8	High demand season, month 8 (month)	4	4	4

By substituting the appropriate values from Table 14 into Equation *4-2*, the Future Worth for TauTona can be calculated as follows:

$$F_{year1} = F_{ECS} + F_{ACS}$$

$$F_{year1} = (U + V + W + X) + (Y + Z)$$

$$F_{year1} = (A_{Elec}\left[\frac{(1+i)^{n_{12}}-1}{i}\right] + P(1+i)^{n_6} + P(1+i)^{n_7} + P(1+i)^{n_8}) + (A_{Lab}\left[\frac{(1+i)^{n_{12}}-1}{i}\right] + A_{Main}\left[\frac{(1+i)^{n_{12}}-1}{i}\right])$$

$$F_{year1} = (73{,}189\left[\frac{(1+0.01)^{12}-1}{0.01}\right] + 351{,}116(1+0.01)^{6} + 351{,}116(1+0.01)^{5} + 351{,}116(1+0.01)^{4}) + (109{,}980\left[\frac{(1+0.01)^{12}-1}{0.01}\right] + 47{,}000\left[\frac{(1+0.01)^{12}-1}{0.01}\right])$$

$$F_{year1} = (928{,}220 + 372{,}717 + 369{,}026 + 365{,}373) + (1{,}394{,}821 + 596{,}078)$$

$$F_{year1} = R2{,}035{,}336 + R1{,}990{,}899$$

$$F_{year1} = R4{,}026{,}235$$

The F_{year1} results for Beatrix 1, 2 & 3#, and South Deep were also calculated by making use of Equation *4-2.* The results for the three manual projects are summarised in Table 15.

Table 15: Future Worth results for automated conditions

	F_{ECS}	F_{ACS}	F_{year1}
Tau Tona	R 2,035,336	R 1,990,899	R 4,026,235
Beatrix 1, 2 & 3#	R 1,675,686	R 1,224,343	R 2,900,029
South Deep	R 755,886	R 1,711,934	R 2,467,820

The results from Table 13 and Table 15 will be used in the P/A calculations.

Step 3: Converting annual cash flows to a single Present Worth value

The final step in the computation process is to convert all annual future values back to a single present value. The effect of inflation and electricity tariff increases are taken into account by making use of the Gradient P/A factor.

Manual conditions

Equation *4-3* is similar to Equation *2-4* from Section 2.6.1 and will be used to determine the Present Worth value for annual electricity savings as applicable to manual conditions.

$$P_{ECS} = A\left[\frac{1-\left(\frac{1+g}{1+i}\right)^{n}}{i-g}\right] \qquad \textbf{4-3}$$

The parameter values of this equation are summarised in Table 16. Figure 45 shows the cash flow over the lifetime of a typical DSM project and serves as a guideline to explain Equation *4-3*.

Table 16: Present Worth analysis input values for manual conditions

	Description	TauTona	Beatrix 1, 2 & 3 #	South Deep
A	Annual electricity cost savings (F_{year1}, Table 13)	R 710,343	R 1,341,765	R 350,446
i	Annual interest rate (%)	12%	12%	12%
g	Gradient interest rate / electricity tariff increase (%)	5.7%	5.7%	5.7%

By replacing the variables in Equation 4-3 with the applicable values from Table 16, the P_{ECS} results can be obtained for each project.

Table 17: Present Worth results for manual conditions

	P_{ECS}	P_{ORIG}
Tau Tona	R 2,833,926	R 4,234,720
Beatrix 1,2 & 3#	R 5,352,996	R 4,079,200
South Deep	R 1,398,110	R 3,056,030

The P_{ECS} results are the Present Worth values determined from electricity cost savings, while P_{ORIG} is the initial infrastructure cost for the project. Both P_{ECS} and P_{ORIG} results will be used in the Present Worth analysis.

Automated conditions

In order to determine the Present Worth value for annual income and expenses as applicable to automated conditions, a new combined equation is required. Equation 4-5 (representation of Equation 2-4), is used to determine the present worth value for electricity cost saving. By making use of this equation, electricity tariff increases are taken into account. Equation 4-6 (representation of Equation 2-2), is used to calculate the present worth value for additional cost savings. A combined equation, Equation 4-4 gives the summarised present worth value.

$$P_{Annual} = P_{ECS} + P_{ACS} \tag{4-4}$$

where

$$P_{ECS} = A_{ECS}\left[\frac{1-\left(\frac{1+g}{1+i}\right)^{n}}{i-g}\right] \tag{4-5}$$

and

$$P_{ACS} = A_{ACS}\left[\frac{(1+i)^{n}-1}{i(1+i)^{n}}\right] \tag{4-6}$$

Subscripts ECS and ACS refer to electricity cost savings and additional cost savings respectively. Variables will be replaced with values as previously defined or calculated to determine the present worth values. These values are summarised in Table 18. Figure 45 shows the typical cash flow over the project lifetime.

Table 18: Present Worth analysis input values for automated conditions

	Description	**TauTona**	**Beatrix 1, 2 & 3 #**	**South Deep**
A_{ECS}	Annual electricity cost savings (F_{ECS} , Table 15)	R 2,035,323	R 1,675,686	R 755,886
A_{ACS}	Additional annual cost savings (F_{ACS} , Table 15)	R 1,990,898	R 1,224,343	R 1,711,934
i	Annual interest rate (%)	12	12	12
g	Gradient interest rate / electricity tariff increase (%)	5.7	5.7	5.7

By replacing the variables in Equation ***4-5*** and ***4-6*** with the values in Table 18, P_{ECS} and P_{ACS} can be calculated for each project. The results for automated conditions can be seen in Table 19.

Table 19: Present Worth results for automated conditions

	P_{ECS}	P_{ACS}
Tau Tona	R 8,119,958	R 7,176,741
Beatrix 1, 2 & 3#	R 6,685,180	R 4,413,482
South Deep	R 3,015,621	R 6,171,138

4.5.4 Comparing manual and automated conditions

In Section 2.6 three different engineering economic methods, used for comparison purposes, were investigated. All three methods are based on the same principal. The actual method used will be dependent on its own unique application. The first step in the comparison analysis will therefore be to identify the most suitable comparison method applicable to DSM projects. This is accomplished by the evaluation of different parameters and limitations for each method.

Selecting the most viable economic comparison method

Table 20 shows the different economic methods, and the constraints for each method. The compatibility of each method is indicated in the right hand column.

Table 20: Selection table for different comparison methods

	Method constrains	**Compatible to DSM projects**
Present Worth Analysis Method *(Section 2.6.2)*	• All revenues and expenses must be converted to a single present worth value.	√
Capital Cost Method *(Section 2.6.3)*	• All revenues and expenses must be converted to a single present worth value. • Project must have an infinite life expectancy.	√ X
Payback Period Method *(Section 2.6.4)*	• All revenues and expenses must be converted to a single present worth value. • Payback period must be equal to project lifetime.	√ X

The results of Table 20 show that the Present Worth Analysis Method is the only suitable method to use. The procedures for the Present Worth Analysis Method can now be applied to compare manual and automated conditions for each project.

Present Worth Analysis

In order to conduct a Present Worth Analysis study for a project, revenues, expenses and once off payments must to be converted to a present worth value at the commencement date of the project, also sometimes referred to as time 0. Converted revenues, cost saving and future sales are positive values, while initial infrastructure cost and other expenses are considered as negative values. After the present worth value for each option is determined, different values can be compared. The largest numerical calculated present worth value will be the best option to select. Table 21 gives a summary of all the values required to determine the present worth for each condition.

Table 21: Summary of values required to conduct a Present Worth analysis

	Condition	Initial infrastructure cost (P_{ORIG})	Electricity cost savings (P_{ECS})	Additional cost savings (P_{ACS})
TauTona	**Manual**	R 4,234,720	R 2,833,926	--
	Automated	x	R 8,119,958	R 7,176,741
Beatrix 1, 2 & 3#	**Manual**	R 3,056,030	R 5,352,996	--
	Automated	y	R 6,685,180	R 4,413,482
South Deep	**Manual**	R 4,079,200	R 1,398,110	--
	Automated	z	R 3,015,621	R 6,171,138

In order to determine the present worth value for each project and condition, the algebraic values of, P_{ECS} and P_{ACS} are taken as positive. The algebraic value P_{ORIG} will be negative. An equation can be set up as follows:

$$P_{project} = P_{ECS} + P_{ACS} + P_{ORIG} \tag{4-7}$$

In Chapter 3 it was explained that additional capital is required to fully automate manual systems. The exact amount of capital required for each project is unknown. A different approach is therefore followed in order to determine the x, y and z values, as indicated in Table 22, respectively.

Table 22: Present Worth results for each condition

	Condition	Present Worth Value
TauTona	**Manual**	- R 1,400,794
	Automated	R 15,296,699 - x
Beatrix 1,2 & 3#	**Manual**	R 2,296,966
	Automated	R 11,098,662 - y
South Deep	**Manual**	- R 2,681,090
	Automated	R 9,186,759 - z

Additional capital must be added to the known initial infrastructure cost of the manually operated systems in order to determine x, y and z. The maximum capital outlay for automation infrastructure is determined by comparing manual and automated present worth values for each option. To obtain a better understanding of this concept, present worth graphs displaying the different options are given in Figure 47, Figure 48 and Figure 49.

Because the infrastructure cost for manual conditions is known, the present worth value can be calculated. It is important to note that present worth values for manual conditions are not affected by the additional infrastructure cost as plotted on the x-axis.

The exact amount of additional infrastructure cost required to fully automate the systems is unknown. Therefore present worth values for different infrastructure cost must be determined. The present worth values of these graphs are plotted against the increasing infrastructure capital for each project.

The first value plotted on the magenta line represents the present worth value for automated conditions if the infrastructure cost is the same as for the manual conditions. Although this is unlikely, this value is taken as the starting point in the comparison analysis. The second value indicates the present worth value if an additional capital outlay of R2,000,000 is spent to fully automate a manual system. Subsequent points are plotted, taking an increase of R2,000,000 per increment in initial infrastructure capital into account.

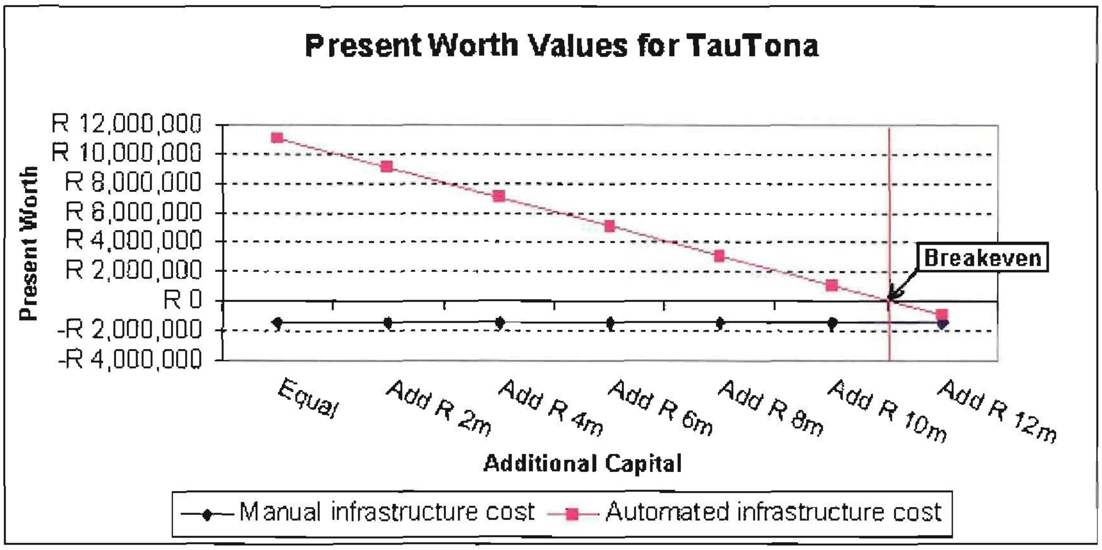


Figure 47: Present Worth Values for TauTona

In Figure 47 the present worth values for manual and automated conditions calculated, are plotted. The graph shows a negative present worth value for the manual system. This implies that the financial savings obtained from manual load shifting attempts over the project lifetime will be inadequate to cover the initial infrastructure cost.

The magenta line indicates present worth values at different infrastructure costs. The graph shows that nearly R10 million and R12 million can be spent on automation infrastructure before a breakeven point for the project is reached.

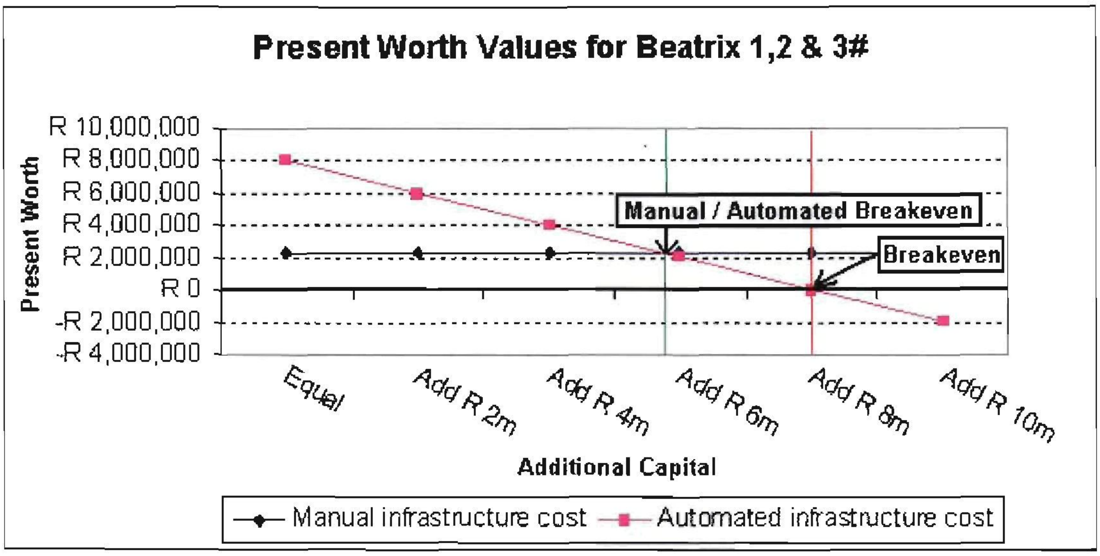


Figure 48: Present Worth Values for Beatrix 1,2 & 3#

The graph of Figure 48 shows the comparison figures for Beatrix 1, 2 & 3#. At this mine the manual present worth value is positive. This indicates that the cost savings realised over the project lifetime will be sufficient to cover the initial infrastructure cost. An additional R5,7 million can be spent on automated infrastructure before this system becomes less viable than the manual system. The breakeven point on the graph shows that a maximum of just over R8 million can be spent on automated infrastructure.

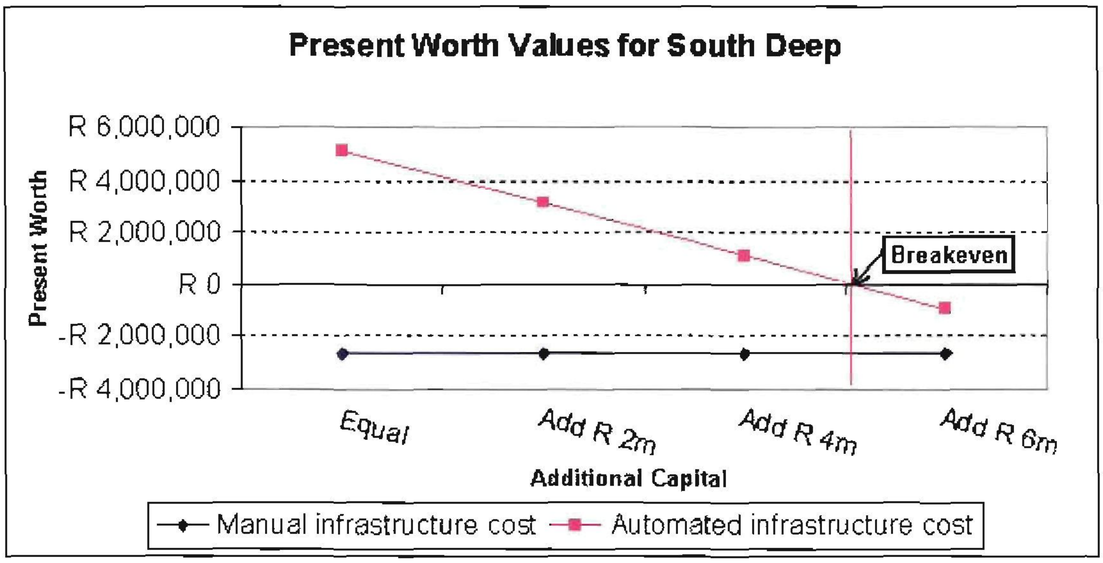


Figure 49: Present Worth Values for South Deep

The present worth value for manual conditions at South Deep is negative which was the same result obtained at TauTona. This implies that cost savings obtained by manual load shifting attempts over the project lifetime will be insufficient to cover the initial investment. Additional capital can however be used to automate the system in order to obtain better saving results. Calculations show that just over R5 million can be spent before the breakeven point is reached.

4.6 Conclusion

The purpose of Chapter 4 was to determine the best method of load shifting by making use of different comparison analyses. Three different approaches were used, in order to compare and determine the best alternative method. The first comparison was based on load shifting performance. Actual load shifting data obtained from manually operated systems was compared to predicted automated results. The results showed that load shifting performance can be increased by 25% when a manually controlled system is fully automated. Load-shifting performance of automated systems showed greater consistency and viability over time.

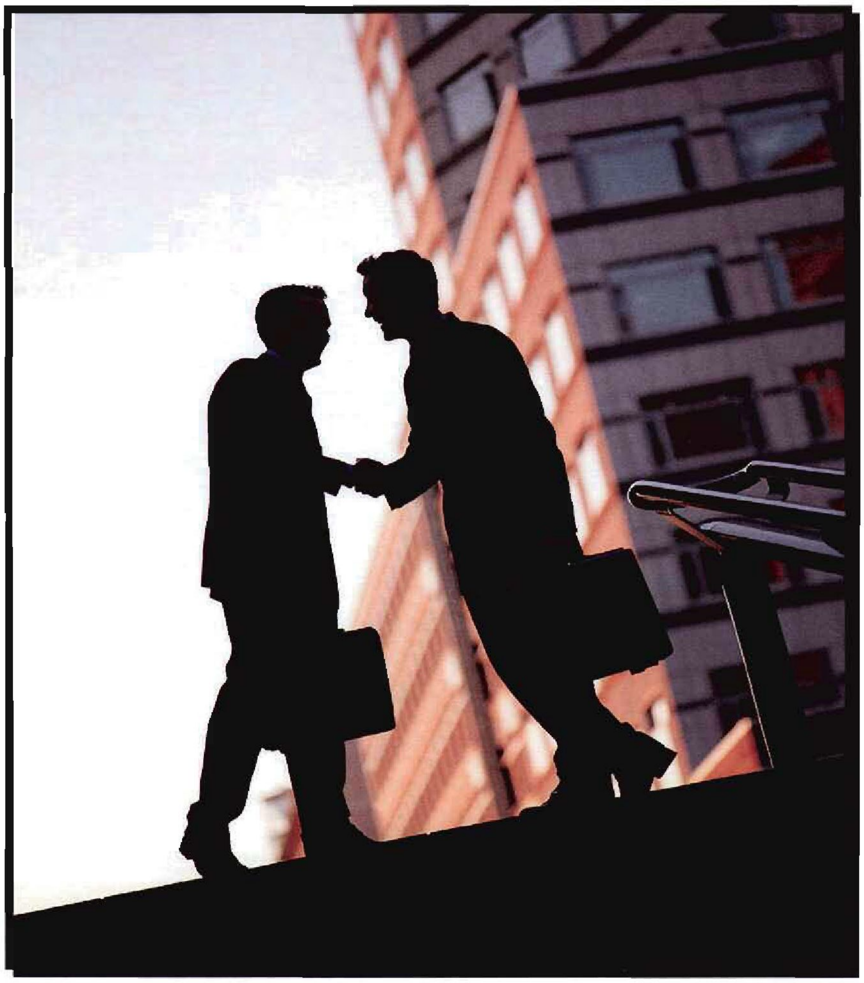
The second comparison analysis was based on electricity cost savings. Results for this analysis were determined by comparing actual electricity cost savings of manual projects with predicted automated results. Similar to the load shifting comparison, automated conditions also showed improved performance. Electricity cost savings of approximately 43% can be obtained if a manual system is fully automated.

The third comparison was made by using engineering economic methods. The Present Worth Analysis Method was shown to be the best method and was used in this study. This was the only method that complied with all constraints applicable to DSM projects. Present worth values were determined for each condition with additional savings, such as maintenance and labour cost savings for automated conditions, taken into consideration.

These comparisons also confirmed that fully automated systems would provide greater savings. The results show that automated systems consistently perform better than manually operated projects.

Additional capital expenditure required for automation was calculated for each project. Capital investments were shown to be feasible. The viability of automated systems over its manual counterpart was compared and shown to be a consistently better option.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS



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This chapter outlines the conclusion of the research study and contains recommendations for future study.

5.1 Conclusion

In order to keep up with the growing electricity demand in South Africa, Eskom introduced a variety of long and short-term projects. Typical examples of the long term projects are the construction of new coal fired generation plants, and investigations into wind power generation. Short-term projects include the re-commissioning of previously mothballed generation plants and the implementation of DSM on existing electrical equipment.

DSM projects consist of various methods such as Energy Efficiency and Load Management. Due to the distinctive advantages of DSM, load-shifting projects have already been implemented on various clear water pumping systems in the mining sector.

The implementation of load shifting projects on pumping systems has far reaching financial implications and responsibilities for both Eskom and the client. It is therefore important to ensure sustainable load-shifting results throughout the projected lifetime of the DSM project.

Because load shifting can be implemented either manually or by a fully automated system, it is extremely important to ensure that the optimum method is selected. This will be of direct benefit to Eskom if the more efficient load shifting technique, even if it is the more costly option, is implemented. Additional cost savings to the consumer will also be realised. The optimum method was determined by conducting a comparison study between the manual and automated methods of load shifting.

Data from six different DSM projects was captured. Three of these projects were fully automated and three were manually implemented DSM projects. The data includes initial infrastructure cost, predicted and actual load shifting performance, and monthly electricity cost savings obtained.

Simulation models were used to predict automated load shifting results. These models were tested and verified on fully implemented automated load shifting systems. The accuracy and validity of these simulations were shown to be acceptable. Similar models were used to simulate and predict automated conditions of manually operated DSM systems. Actual data obtained from the mines was used during this process.

Data was also used to compare the results obtained between manual and automated control of the pumping systems. These comparisons were based on:

- load shifting results;
- consistency of load shifting results;
- cost saving results which includes electricity, maintenance and labour cost savings; and
- engineering economic methods.

The conclusions of the comparison study showed that load shifting results obtained from automated projects consistently performed better than manually controlled projects. Load shifting performance can be improved by 38% if a manually controlled system is changed to a fully automated system. Automated projects were also shown to be giving more consistent and accurately predictable results.

The cost saving comparison also showed that automated systems perform better than manual systems. Additional cost savings of between 36% and 45% can be expected if a manual system is automated.

Engineering economic methods were used to determine the feasibility of additional investment, and to calculate breakeven values for the manually operated projects. The Present Worth Analysis method was used for this application. The results showed that it would be economically viable to spend additional capital on the three manual projects.

It will be more beneficial to both Eskom and the client to implement fully automated systems. The improved load shifting performance will enable Eskom to meet short term electricity demands. The proven consistency of automated load shifting results will also ensure sustainable load shifting results throughout the projected lifetime of the DSM project. Additional cost savings will accrue to the client.

This study has succeeded in identifying the most viable method of load shifting. These results can also be used to motivate the expenditure of the additional capital required to implement full automation of manual pumping systems. Furthermore, this study can also serve as a guideline when the potential for new load shifting projects are being investigated. Investigations and the results of studies based on this one, will indicate the most viable method of load shifting on a new project. The results of this study have also shown that the capital expenditure on infrastructure can be pre-determined to ensure that an automated project does not become less viable than a manually controlled DSM project.

5.2 Recommendations

In order to broaden this study, other forms of DSM projects can also be investigated. Typical examples will be peak clipping projects on compressed air management, water efficiency projects by valve control, and load management on industrial fans. Because the method of control for each type of project differs, the results of a comparison study based on other DSM projects may vary considerably.

As part of the comparison study labour and maintenance cost savings on automated systems were used in calculations. These calculations were based on basic information obtained from previous studies conducted. To ensure a more accurate model, additional research can be done in this area. The area of focus would typically be detailed research, focusing on maintenance costs as a result of pump cycling. An in-depth study focusing on labour reduction as a result of an automated system can also be conducted.

The operational and economical implications between manually and automated pumping systems were investigated. The development of a software package, based on the philosophy of this study, could ensure that the feasibility of capital investments on future projects could be determined more quickly and accurately.

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APPENDIX A – INFRASTRUCTURE REQUIREMENTS

Table A

Description	Unit	TauTona	South Deep	Beatrix 1,2&3#
PRELIMINARY AND GENERAL				
Medical & Teba	hr	10	10	10
Induction Costs	hr	10	10	10
Traveling	km	1500	1500	2000
Safety Representative	MONTH	3	3	2.5
COMMUNICATION				
Fiber	m	4000	3800	5000
Splice Cabinet	Each	6	5	4
Patch Leads	Each	72	60	48
Splicing	Each	144	120	96
PLC EQUIPMENT				
MASTER PLC	Each	5	4	3
PUMP PLC'S	Each	20	20	13
PUMP INSTRUMENTATION				
Pressure Transmitter for Dam Level Measurement	Each	12	10	8
Suction Pressure Transmitter	Each	10	10	7
Delivery Pressure Transmitter	Each	20	20	13
Delivery Valve Proximity	Each	20	20	13
Electric actuator	Each	20	20	13
CABLES				
Instrumentation cable	Meter	2000	1800	1300
Ethernet Cable	Meter	2000	1800	1300
Electrical cable	Meter	2000	1800	1300
Cable Racking	Meter	500	400	200
INSTALLATION AND WIRING				
Technicians	hr	280	270	240
Boilermaker	hr	62	60	48
Engineering Helpers	hr	720	680	550

Description	Unit	TauTona	South Deep	Beatrix 1,2&3#
SOFTWARE				
PLC software development	hr	240	240	240
SCADA system	hr	1	1	1

Table B

DESCRIPTION	UNIT	TYPICAL COST
PRELIMINARY AND GENERAL		
Medical & Teba	hr	R 130.00
Induction Costs	hr	R 130.00
Traveling	km	R 3.00
Safety Representative	MONTH	R 9,500.00
COMMUNICATION		
Fiber	m	R 100.00
Splice Cabinet	Each	R 2,500.00
Patch Leads	Each	R 80.00
Splicing	Each	R 90.00
PLC EQUIPMENT		
MASTER PLC	Each	R 81,000
PUMP PLC'S	Each	R 60,000.00
PUMP INSTRUMENTATION		
Pressure Transmitter for Dam Level Measurement	Each	R 12,000.00
Suction Pressure Transmitter	Each	R 5,000.00
Delivery Pressure Transmitter	Each	R 5,000.00
Delivery Valve Proximity	Each	R 700.00
Electric actuator	Each	R 70,000.00
CABLES		
Instrumentation cable	meter	R 20.00
Internet Cable	meter	R 30.00
Electrical cable	meter	R 30.00
Cable Racking	meter	R 40.00
INSTALLATION AND WIRING		
Technicians	hr	R 250.00
Boilermaker	hr	R 200.00
Engineering Assistants	hr	R 50.00
SOFTWARE		
PLC software development	hr	R 350.00
SCADA system	hr	R 70,000.00

APPENDIX B – WORK EXAMPLE

Example A [49]

An independent engineering consultant reviewed records and found that the cost of office supplies varied as follow:

Year 0: R600
Year 1: R175
Year 2: R300
Year 3: R135
Year 4: R250
Year 5: R400

If the engineer wants to know the equivalent value in year 10 of only the three largest amounts, what is it at an interest rate of 5% per annum?

Solution A

$$P = F_0 + F_2[\frac{1}{(1+i)^n}] + F_5[\frac{1}{(1+i)^n}]$$

$$P = 600 + 300[\frac{1}{(1+0.05)^2}] + 400[\frac{1}{(1+0.05)^5}]$$

$$P = 600 + 300(0.9070) + 400(0.785)$$

$$P = R1{,}185.50$$

$$F = P(1+i)^n$$

$$F = 1{,}185.50(1+0.05)^{10}$$

$$F = 1{,}931.06$$