A NEW DSM SIMULATION MODEL FOR SOUTH AFRICAN CEMENT PLANTS

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ABSTRACT

Eskom is currently experiencing problems with its electricity supply because of rapidly increasing electricity consumption in Southern Africa. One of the relatively short-term solutions to this problem is demand side management (DSM) through load shifting.

DSM load shifting occurs when large electricity-consuming equipment is stopped during the peak hours of each weekday. In the cement industry, the two largest electricity users in a cement manufacturing plant are the raw mill and the finishing mill.

When load shifting is applied to cement plants for testing, because of the complex system, production can be lost. A cement plant will not tolerate any loss in production hence the need for a simulation model to simulate the effects of load shifting in a cement plant.

In this study, a new simulation model was developed to determine the viability of a DSM project in the raw mill and finishing mill sections of South African cement plants. For a DSM project to be possible there must be no loss in production. In the production process, the silos store the milled products. If the silo runs empty, there is no material for the kiln or packaging plant to process, which will result in a loss in production. The level of the silo is therefore vital in the simulation model.

The simulation model consists of two parts. The first part simulates the silo level over a period of one month to determine whether the level remains within the specified limits. The second calculates the optimised baseline versus the historical baseline, load shifting potential and possible annual cost savings. It is critical that the correct inputs to the simulation model are obtained to acquire accurate results. The second part of the simulation can only be applied if the silo level is within specifications.

The simulation was applied to the raw milling section of two different cement plants and also to the finishing milling section of two different cement plants. Both raw milling sections showed a potential for DSM intervention. For confidentiality purposes, the cement plants will be referred to as Plant A, B, C, and D.

In Plant A, five hours of load shifting, realising a maximum potential of 2.08 MW in morning peaks and 2.05 MW in evening peaks, were possible per weekday. Plant B had a possible 0.79 MW in morning peak hours and 1.96 MW evening peak hours load shifting potential per weekday for two hours each day. An annual cost saving of R 474,000 for Plant A and R 293,000 for Plant B could be realised.

There was possible load shifting potential of 3.52 MW in morning peaks and 3.94 MW in evening peaks in the finishing milling section of Plant C. Five hours of load shifting per weekday means an annual cost saving of R 898,000. The silo simulation on the finishing milling section of Plant D showed that the silo level could not remain within the limits when load shifting was applied. Hence there is no scope for a DSM project in the finishing milling section of Plant D.

The simulation model developed in this thesis provides an accurate indication of the silo level over a period of one month and projects the possible load shifting and annual cost savings where a cement plant is found to have a viable DSM load shift potential.

SAMEVATTING

Eskom ondervind huidiglik probleme met hulle elektrisiteitsvoorsiening as gevolg van die vinnig toenemende elektrisiteitsverbruik in Suid-Afrika. Een van die relatief korttermyn oplossings vir hierdie probleem, is lasverskuiwing.

Lasverskuiwing word toegepas wanneer groot masjiene met hoë elektrisiteitsverbruik tydens piektye van elke weeksdag, afgeskakel word. Wanneer gefokus word op die sementindustrie, is die twee grootste elektrisiteitsverbruikers op 'n sementvervaardigingsaanleg, die roumeul en die sementmeul.

In hierdie navorsingstudie is 'n nuwe simulasiemodel ontwikkel om die lewensvatbaarheid van 'n DSM-projek op die rou- en sementmeulseksies van Suid-Afrikaanse sementaanlegte te bepaal. Om 'n DSM-projek te laat slaag moet daar geen afname in produksie wees nie. Agter elke meul is daar 'n silo. As hierdie silo's leeg raak is daar geen grondstof vir die kiln of verpakkingsaanleg om te verwerk nie. Dit veroorsaak dat daar 'n afname in produksie is. Daarom is die silovlak in die simulasiemodel belangrik.

Die simulasiemodel bestaan uit twee dele. Die eerste deel simuleer die silovlak oor 'n tydperk van 'n maand om te bepaal of die silovlak binne die gespesifiseerde limiete bly. Die tweede deel bereken die optimale basislyn teenoor die historiese basislyn; energiebesparing en die moontlike jaarlikse kostebesparings. Dit is van uiterste belang dat die korrekte invoer na die simulasie model sal plaasvind, sodat akkurate resultate verkry kan word. Die tweede deel van die simulasie is geldig as die silovlak binne die spesifikasies is.

Die simulasie is toegepas op die roumeulseksie van twee verskillende sementaanlegte en ook die sementmeulseksie van twee verskillende sementaanlegte. Op altwee die roumeulseksies was 'n DSM-projek lewensvatbaar. Op Aanleg A was vyf ure van lasverskuiwing per weeksdag moontlik. Dit beteken 'n lasskuifpotensiaal van 2.08 MW in oggendpiektye en 2.05 MW in aandpiektye, met 'n jaarlikse kostebesparing van R 474,000. Op Aanleg B was daar twee ure se lasverskuiwing moontlik per weeksdag. Dit is 'n 0.79 MW lasverskuiwing in oggendpiektye en 1.96 MW lasverskuiwing in aandpiektye met 'n jaarlike kostebesparing van R293,000.

Daar was 'n moontlikheid van vyf ure lasverskuiwing op die sementmeulseksie van Aanleg C. Dis is 3.52 MW lasverskuiwing in oggendpieke en 3.94 MW lasverskuiwing in aandpieke met 'n jaarlikse kostebesparing van R 898,000. Die silosimulasie op die sementmeulseksie van Aanleg D toon dat die silovlak nie binne die limiete kan bly as lasverskuiwing toegepas word nie. Vervolgens is daar geen geleentheid vir 'n DSM projek op die sementmeulseksie van Aanleg D nie.

Die nuwe simulasiemodel voorsien 'n akkurate silovlak oor 'n tydperk van 'n maand en toon aan watter impak lasverskuiwing het op die silovlak. Hierdie simulasiemodel projekteer ook die lasverskuiwing moontlikhede en kostebesparing vir 'n lewensvatbare projek.

ACKNOWLEDGEMENTS

I would like this opportunity to thank Prof EH Mathews and Prof M Kleingeld for affording me the opportunity to complete this study under their guidance and support.

I dedicate this study to my wife, Marna. Thank you for all your encouragement and care throughout this study. With you by my side we can achieve anything. I love you.

I would also like to thank my parents for encouraging me throughout my life and for guiding me to become the person I am today.

Most importantly, I would like to thank God for providing me with the talent to complete my studies. He grants me strength and direction, without Him nothing would be possible.

ABBREVIATIONS

Abbreviation	Description
DSM	Demand side management
OECD	Organisation for Economic Cooperation and Development
MW	Megawatt
INEP	Integrated National Electrification Programme
GDP	Gross domestic product
kWh	Kilowatt-hour
VAT	Value-added tax
PBMR	Pebble bed modular reactor
DME	Department of Minerals and Energy
NERSA	National Energy Regulator of South Africa
ESCO	Energy Services Company
PPC	Pretoria Portland Cement
RDP	Reconstruction and Development Programme
NPC	Natal Portland Cement
m^3	Cubic metre
µm	Micrometre
°C	Degrees celsius
cm	Centimetre
EU	European Union
SABS	South African Bureau of Standards
p.a.	Per annum
R	Rand
SCADA	Supervisory control and data acquisition
RM	Raw mill
FM	Finishing mill
USA	United States of America
PP	Packaging plant
RSA	Republic of South Africa

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CHAPTER 1

INTRODUCTION TO THE STUDY

1.1 BACKGROUND TO THE RSA ENERGY SUPPLY PROBLEM

In a world with a fast-growing economy and ongoing advances in technology, the demand for energy is increasing rapidly. The global energy demand is projected to increase by over 50% between 2005 and 2030, according to the International Energy Agency's World Energy Outlook 2005 [1].

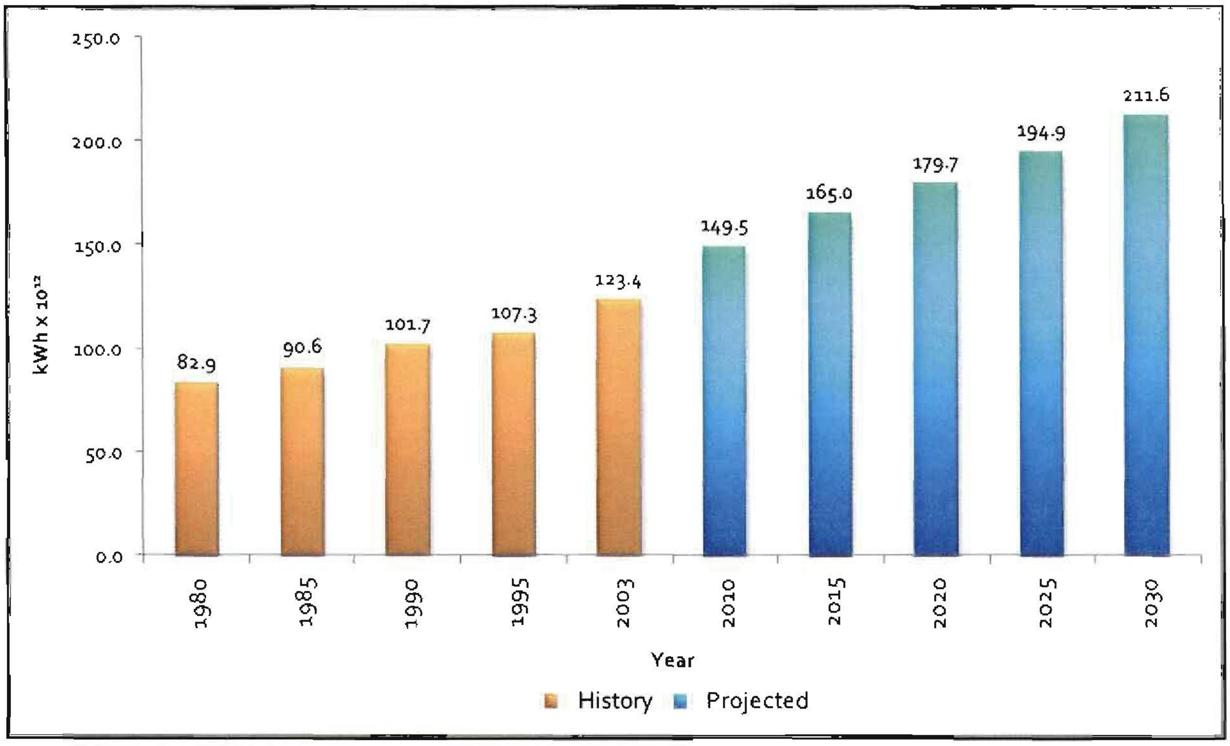

Figure 1 – World marketed energy consumption [1]

Figure 1 shows the global energy consumed from 1980 to 2003, and the projected world growth for energy from 2010 to 2030.

The Organisation of Economic Cooperation and Development (OECD) countries project an annual 1% energy demand growth from 2003 to 2030, whereas developing non-OECD countries project an annual 3% growth in energy consumption. Non-OECD countries account for three-fourths of the increase in world energy use. South Africa is categorised under the non-OECD countries in Africa.

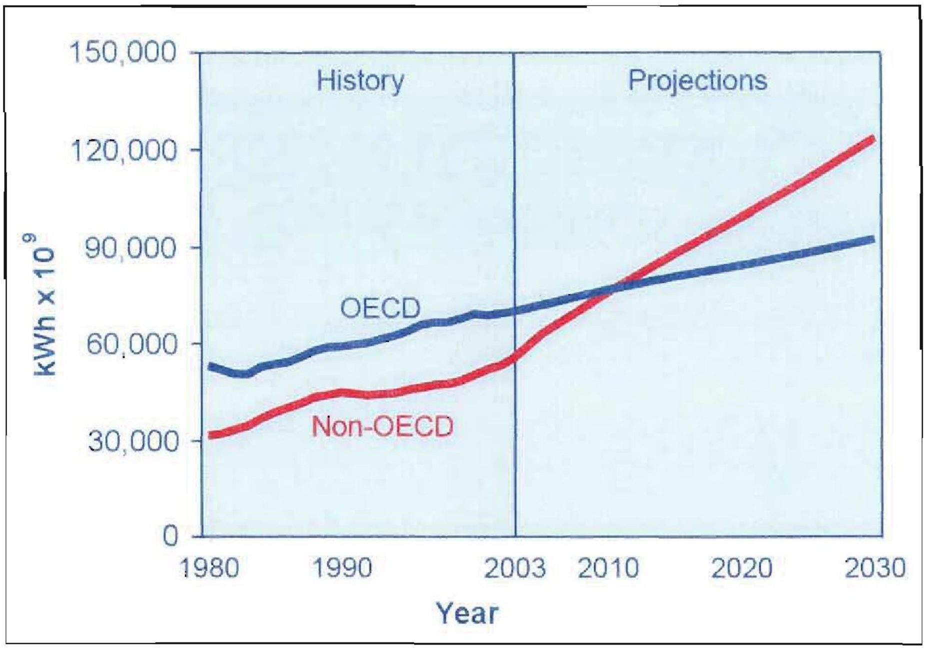

Figure 2 – World Energy Consumption: OECD and Non-OECD. [1]

As seen in Figure 2, after 2010, the non-OECD countries will also consume more energy than the OECD countries.

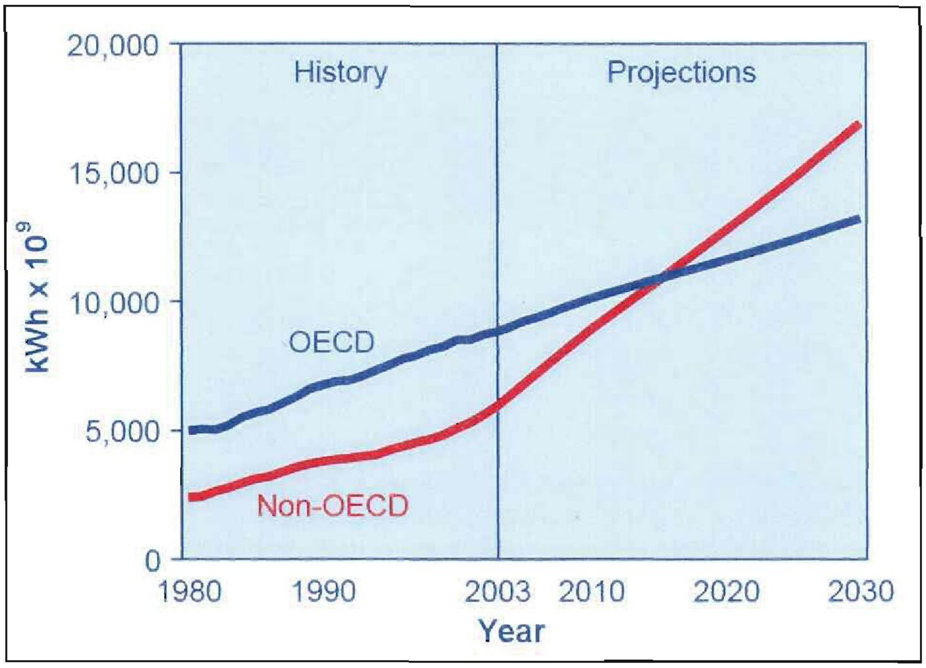

Figure 3 – World net electricity consumption: OECD and non-OECD countries [1]

Electricity is a vital component of the global energy consumption. The projected world net electricity consumption will double from 14,781 x 10^9 kWh in 2003 to 30,116 x 10^9 kWh in

2030. OECD countries contribute 29% of this growth. The non-OECD countries again contribute to the majority of growth at 71%. Figure 3 shows the difference in growth between the OECD and non-OECD countries [1].

On the African continent, the electricity demand will increase by 3% per annum from 2003 to 2030, reaching a total demand of 951 x 10^9 kWh per annum in 2030 [1]. South Africa supplies over two-thirds of Africa's electricity and is one of the four cheapest electricity producers in the world [2].

There are three groups of electricity producers in South Africa. The first is Eskom, which generates 93.5% of the electricity consumed in South Africa. Two percent is generated by municipal generators, while 4.5% of the electricity is generated by autogenerators. Electricity accounts for 20% of the total energy consumed in South Africa [3].

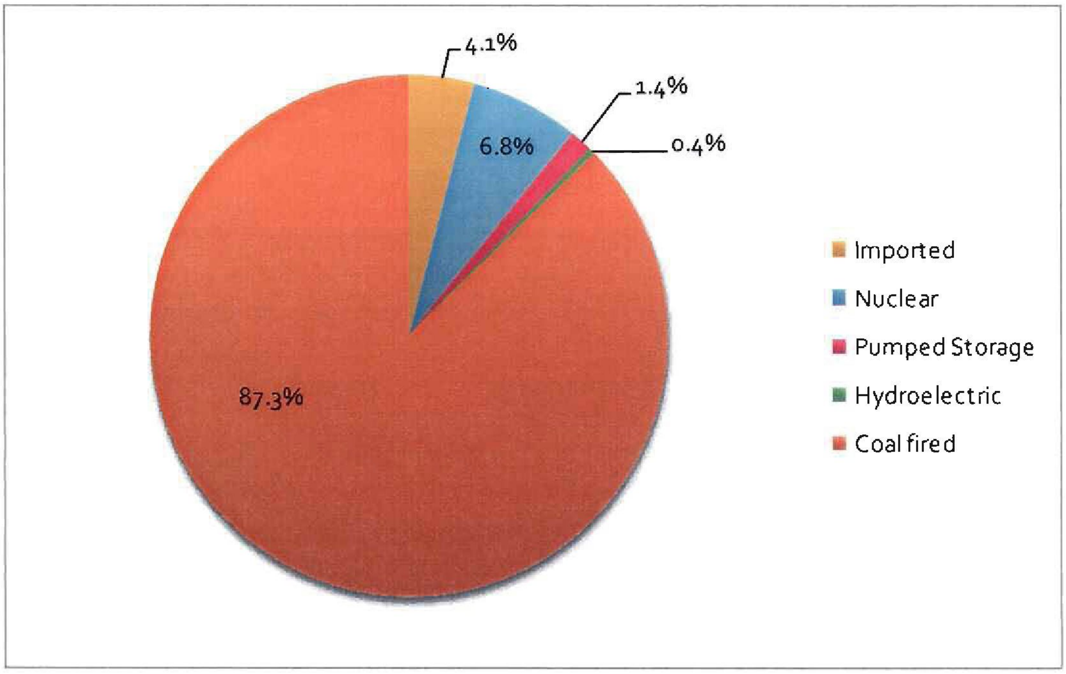

Figure 4 – Eskom electricity generation by energy source [3]

Coal-fired power stations generate 87.3% of the electricity supplied by Eskom. Nuclear power generates 6.8%, hydro power 0.4%, and pumped storage 1.4% while 4.1% is imported. The percentage of electricity generated by fuel type is illustrated in Figure 4.

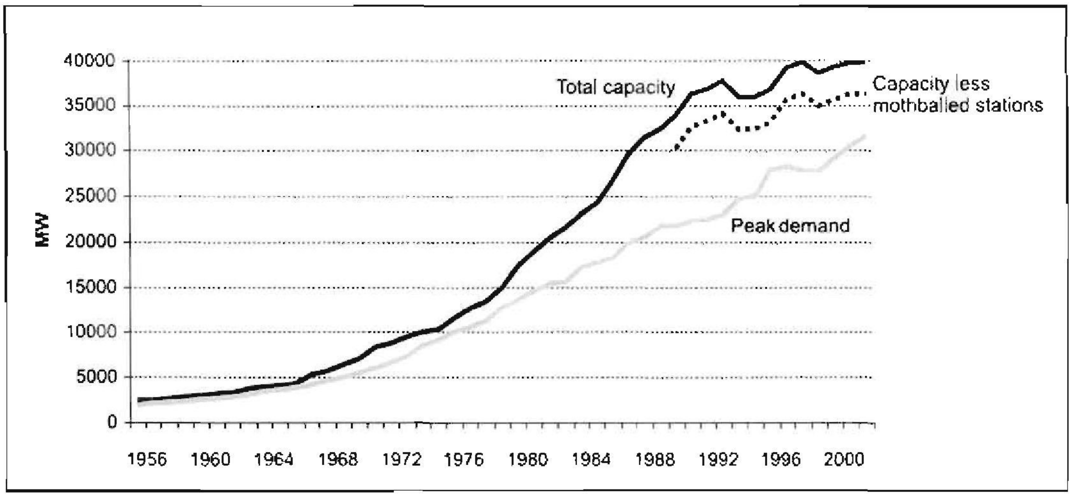

Figure 5 – Eskom generation capacity and peak demand, 1956 to 2002 [3]

Figure 5 shows Eskom's total capacity versus peak demand from 1956 to 2002. Eskom's total generating capacity declined in 1990 because of power stations that were mothballed, as illustrated by the dotted line in Figure 5. In 2003, South Africa increased its peak electricity demand by 7.1%, from a peak demand of 31,928 MW in 2003 to 34,195 MW in June 2004. The progressive increase in electricity demand over the last few years has resulted in the total demand almost reaching Eskom's maximum generation capacity[1].

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[1] "Electricity - introduction", 2007, Department of Minerals and Energy, http://www.dme.gov.za/energy/elect_inep.stm

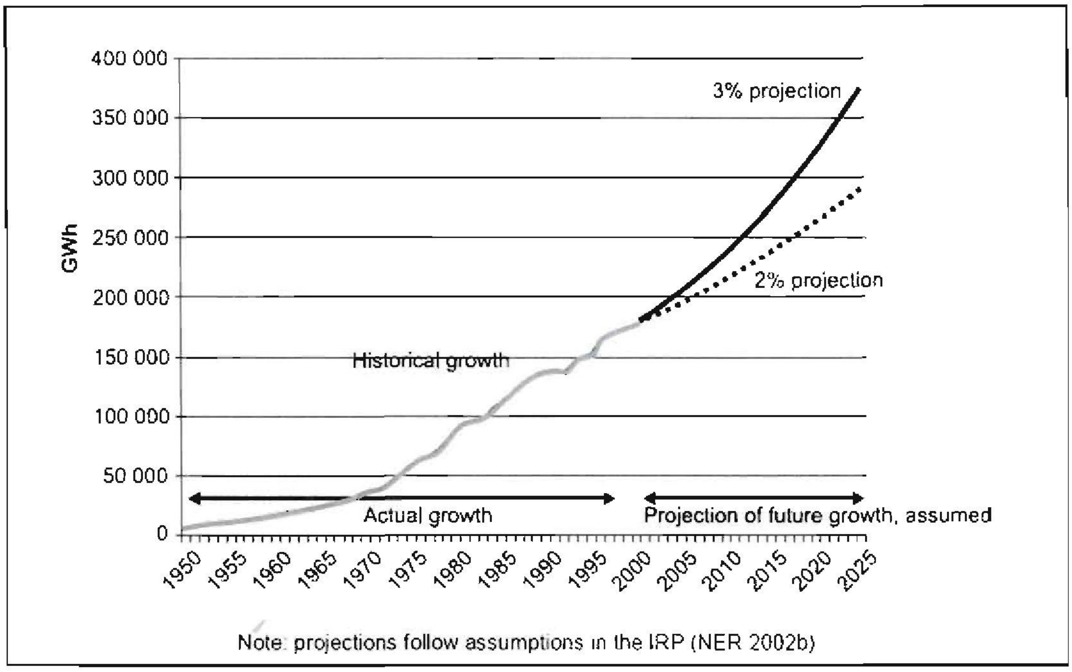

Figure 6 – Growth in electricity sales, actual historical and future projections [3]

Figure 6 illustrates South Africa's projected progressive growth in electricity consumption from 2005 to 2025. Figure 5 shows that there is a slow expansion of Eskom's total generation capacity from the year 1992 onwards. The demand for electricity is growing at a sharp rate. Figure 6 shows 2% and 3% growth projection.

Figure 7 shows the generating capacity of various power stations. The solid red line indicates the projected electricity demand. In 2007 the projected demand crosses the maximum capacity, which will result in blackouts and power outages.

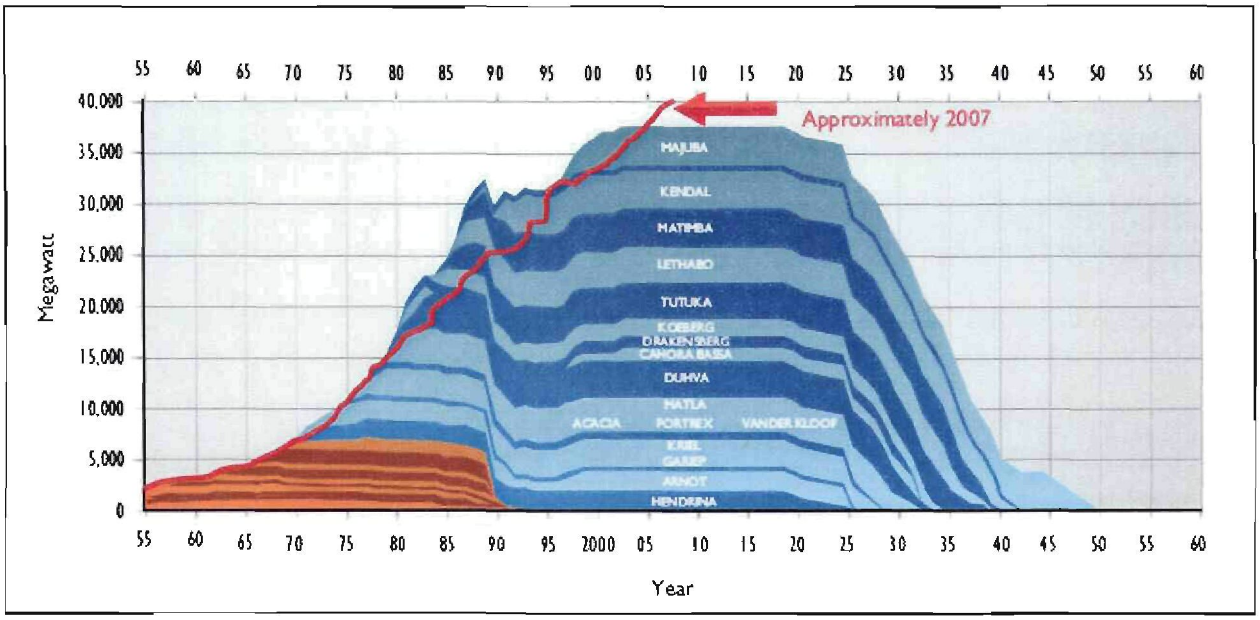

Figure 7 – Eskom's generating capacity as a function of time [4]

The Integrated National Electrification Program (INEP) of the Department of Minerals and Energy of South Africa contributes to the rapidly growing electricity demand. The target of the INEP was the provision of 2.5 million new electricity connections to disadvantaged communities from 1994 to 2000, providing approximately 72% of South Africa's population with access to electricity [6]. Figure 8 shows the connections completed from 1991 to 2000.

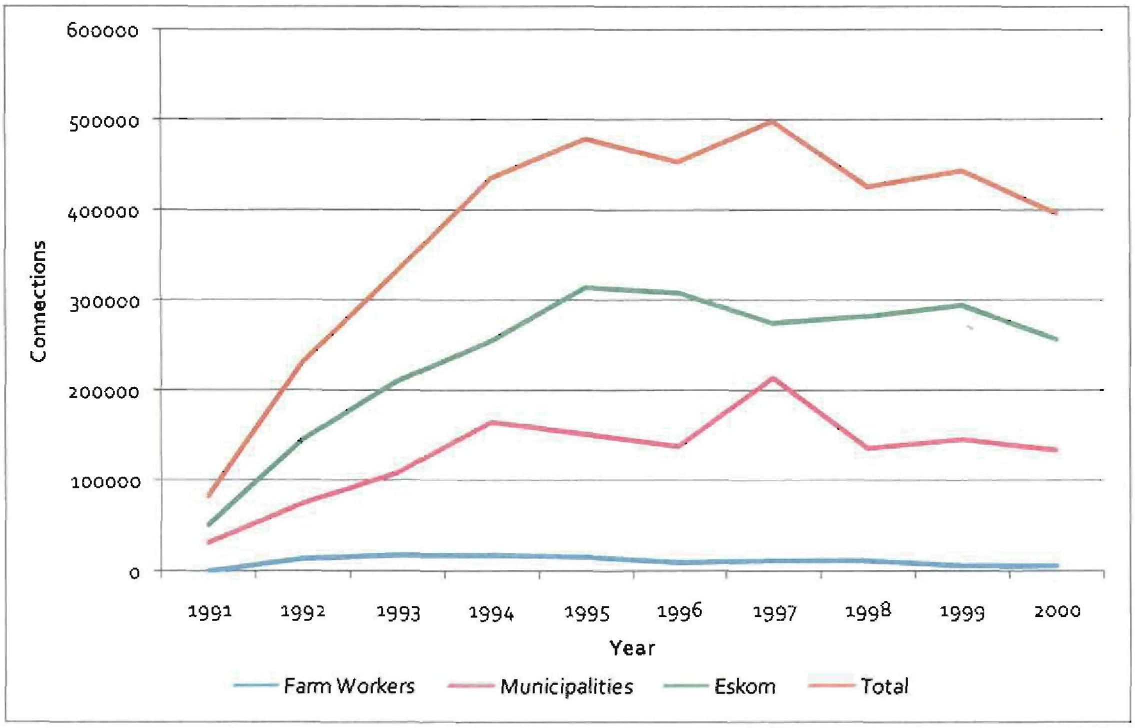

Figure 8 – Annual connections completed to 2000 [6]

In 2006, 3.2 million households were given connections to electricity, while 3.4 million households are still without electricity. The project is currently continuing at a rate of 230,000 households per annum [5]. The household connection history is shown in Figure 9.

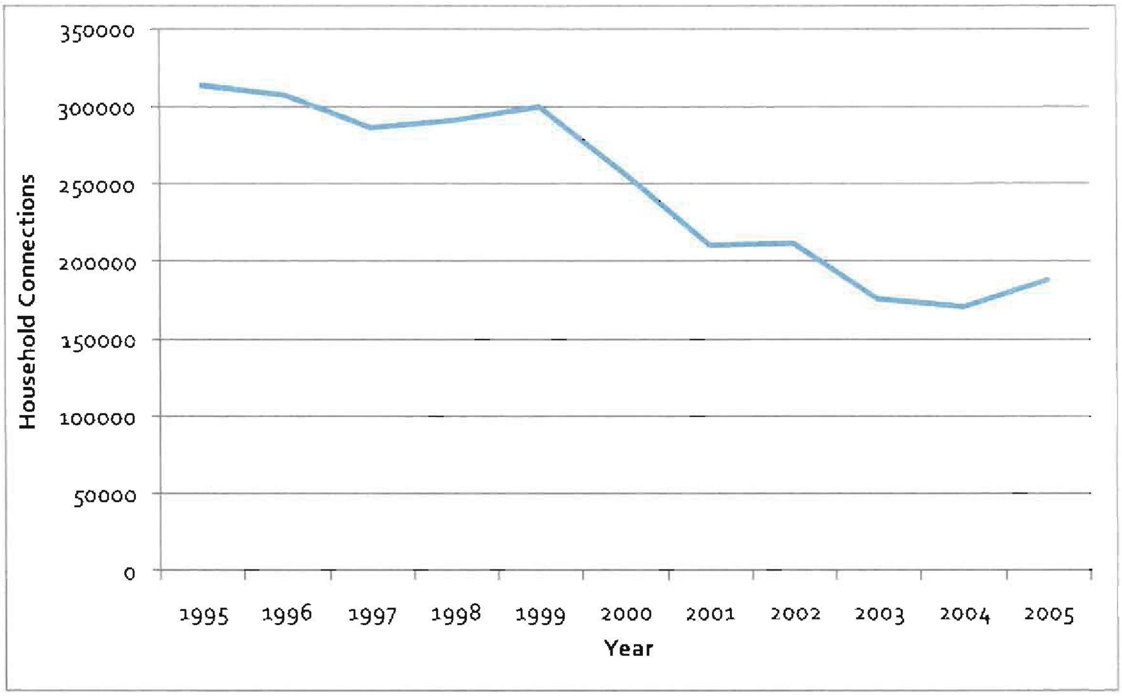

Figure 9 – Household connections made from 1995 to 2005 [5]

A significant factor that contributes to the increasing electricity demand is the growth of the South African economy. According to Statistics South Africa, the gross domestic product (GDP) increased by 4.7% in the first quarter of 2007 [6].

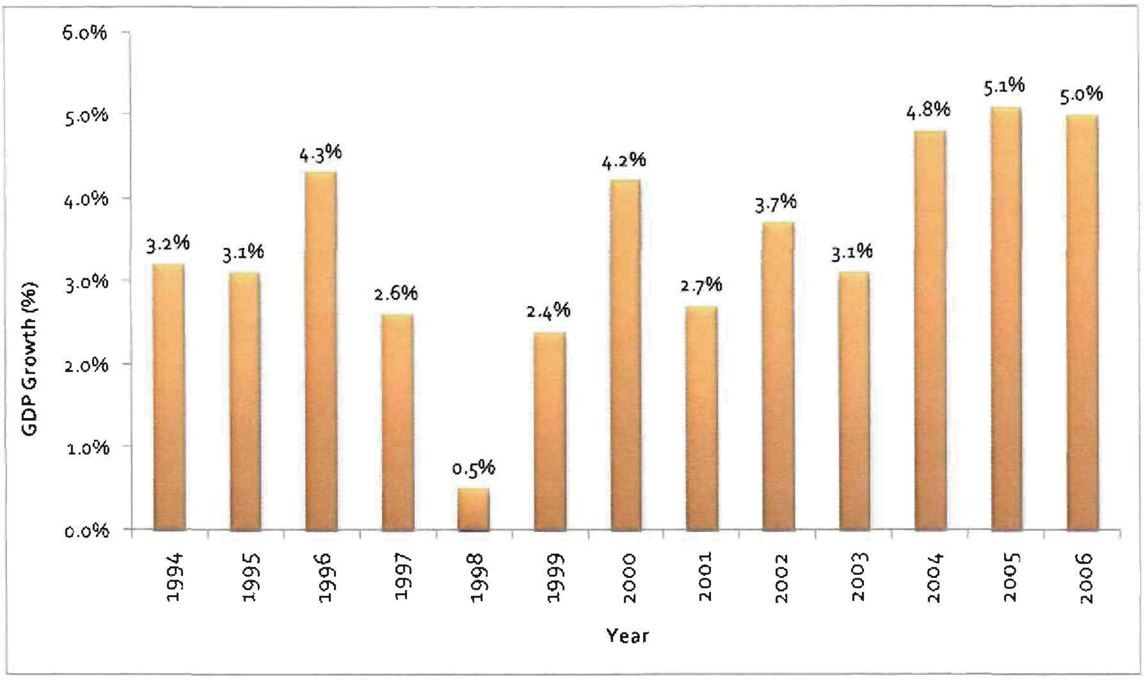

Figure 10 – Annual GDP growth [7]

Figure 10 depicts the growth in GDP from 1994 to 2006. This shows that the South African economy is growing at an increasing rate. The growth in GDP was at an all-time high in the past two years. Many new developments in all sectors of the economy resulted in an increasing demand for electricity.

On 24 May 2007, Eskom recorded a new record in the peak electricity demand, reaching a high of 34,361 MW[2]. Because Eskom is unable to meet these high demands during peak periods, there are increasing numbers of interruptions in electricity supply.

Load shedding occurs when electricity supply shortages are experienced. In May 2007, various parts of Gauteng experienced electricity interruptions because of load shedding[3].

Figure 11 displays the electricity demand of a typical winter's and summer's day. Peaks are experienced from 7:00 to 10:00 in the morning and 18:00 to 20:00 in the evening. It is during these peaks, that Eskom experiences its supply problem.

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[2] "Switch off, says Eskom", 24 May 2007, Eskom, http://www.eskom.co.za/

[3] "East Rand has 1 blackout a day", 16 May 2007, News24, http://www.news24.com/
"Pta battles electricity issues", 24 May 2007, News24, http://www.news24.com/

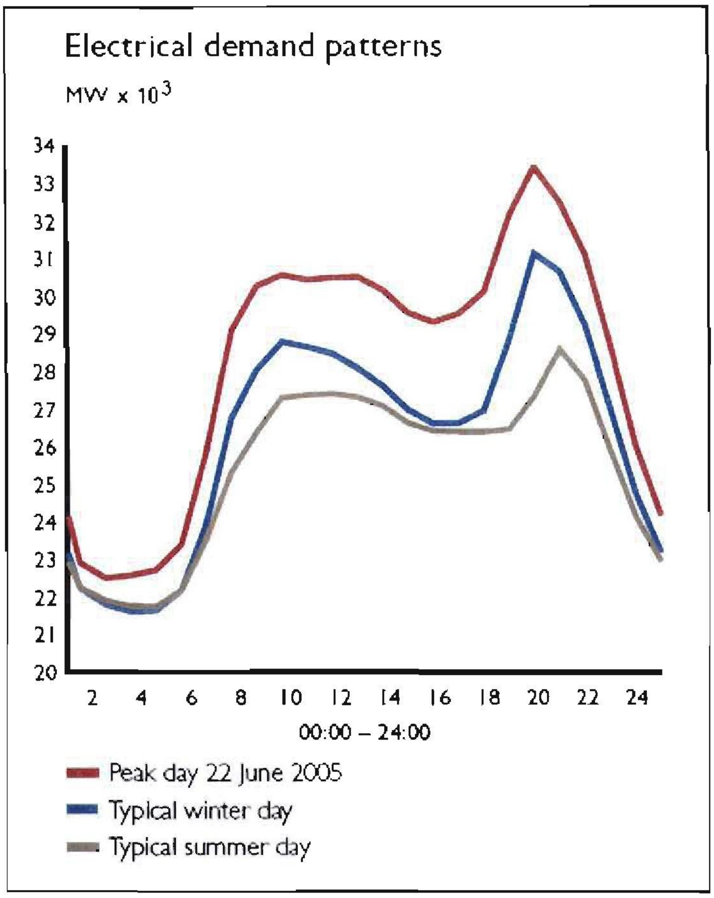
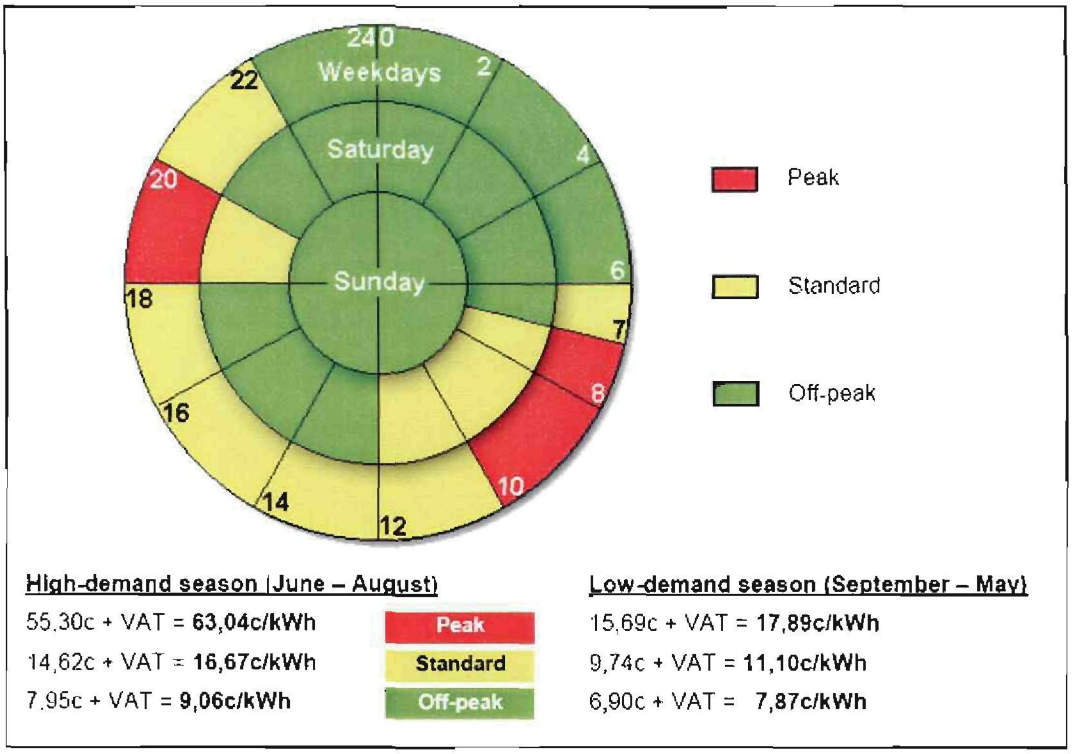


Figure 11 – Electricity demand on a typical day [8]

Depending on specific applications in the industry, Eskom provides different tariff structures. The megaflex tariff applies to users with a maximum demand of more than 1 MW. This includes the majority of the industrial and mining sectors. According to the megaflex tariff, different rates apply to different time frames as shown in Figure 12.



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**

Figure 12 – Megaflex tariffs and time periods (April '07 – March '08) [11]

1.2 CORRECTIVE MEASURES TAKEN BY ESKOM

The most attractive supply-side option for Eskom's energy supply problem is the re-commissioning of three previously mothballed power stations. Eskom is presently re-commissioning power stations at Camden, Grootvlei and Komati. The total combined generating capacity of these three power stations is 3,600 MW, and they should be fully operational by 2011. [8]

According to Eskom's annual report of 2006, feasibility studies for new power stations are well advanced. These projects include two combined cycle gas turbine power stations at Atlantis and Mosselbay with a minimum capacity of 1,800 MW each. [8]

Eskom has decided to build two new coal-fired power plants named Medupi located in Lephalale and Project-Bravo located in Mpumalanga. Medupi will have a total generation capacity of 4,788 MW and Project-Bravo will have a total generating capacity of 4,818 MW..[10] The plans for a 1,330 MW pumped storage facility in the Drakensberg, on the border between Free State and KwaZulu-Natal, are in an advanced state. [8]

One of Eskom's strategies is the research and construction of several pebble bed modular reactors (PBMRs). The PBMR makes use of nuclear energy to generate electricity. The reactor will generate a minimum of 165 MW [8]. The PBMR project aims to build and commission a pilot demonstration nuclear reactor by 2013[4]. Eskom is also part of the joint venture group developing the PBMR[5].

DSM is a cheaper solution to the electricity supply problem. DSM takes place when large electricity users lower their electricity usage. This is possible through energy efficiency or load shifting. Load shifting refers to the reduction of electricity during the peak periods of the day as shown in Figure 12. DSM is a joint initiative between the DME, NERSA and Eskom, which aims to save 4,255 MW over a 25-year period.

NERSA sets an annual target of 152 MW for DSM sustainable evening peak savings. Eskom's DSM project achieved a verified sustainable savings of 169.8 MW in 2007 and 72.3 MW in 2006 [9].

Eskom regards load shedding as a last resort for meeting the electricity demand. Load shedding entails scheduled and controlled power cuts, by rotating available capacity between all areas, when the demand for electricity exceeds the available supply.

The various options have different time frames and cost implications. The construction of new power stations would take too long to address the immediate supply problem. DSM projects are a cost-effective means of addressing the electricity supply problem, and can be implemented in a relatively short time.

1.3 DSM IN SOUTH AFRICA

DSM is the process where electricity usage is managed on the consumer's side, requiring the planning, implementation and monitoring of an improved electricity usage pattern by the consumer. The ultimate aim of DSM is to create a daily demand baseline with a minimum amount of variation. This enables the supplier to meet its customers' energy demands by

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[4] "PBMR – Who are we?", 2007, PBMR, http://www.pbmr.co.za

[5] "PBMR gets back to business with IFS applications", 2007, Eskom, http://www.eskom.co.za/

eliminating sudden demand peaks. The planned lowering of the peak periods is shown in Figure 13.

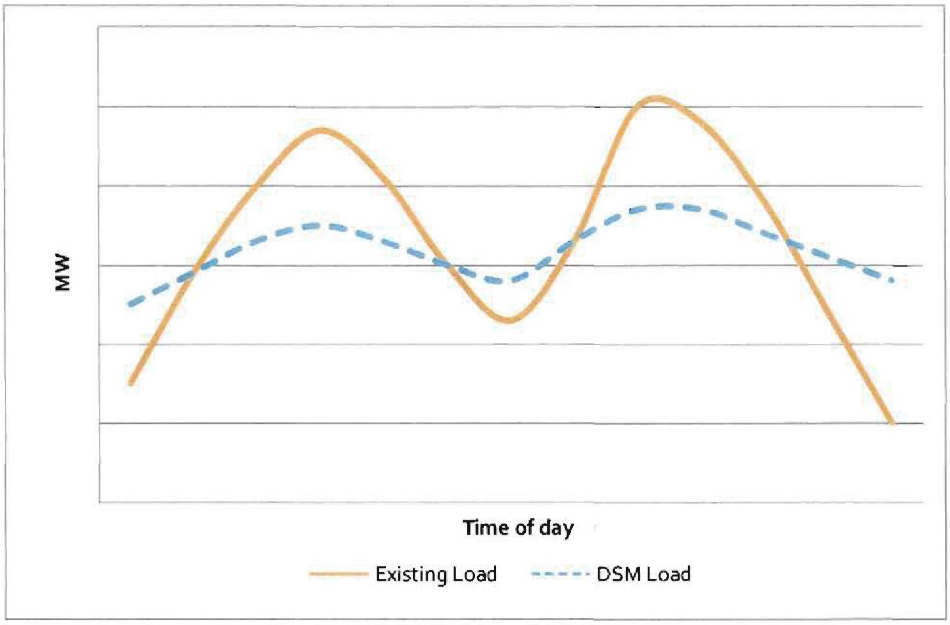

Figure 13 – Lowering morning and evening peaks [15]

In a typical project an Energy Services Company (ESCo) will propose a DSM project to a consumer. Research is required to evaluate whether any viable electricity cost saving exists. If an opportunity for DSM presents itself, planning will commence on how to successfully implement DSM for that specific process. Eskom and the ESCo will sign an agreement to meet certain demands.

The increase in electricity of domestic users is the main cause of the peaks appearing in the daily demand schedule. If the electricity consumption of large industries can be lowered in the peak times of each day, the overall daily baseline of electricity demand will become more even. It is easier to manage a few large electricity consumers than millions of domestic users.

DSM has already proven to be successful in South Africa. Table 1 shows some of the savings already achieved by HVAC International (Pty) Ltd through the application of DSM in South Africa.

Table 1 – DSM savings already achieved [16]

Project	**MW Load Shift**	**Annual Client Savings**
Kopanang pumping system	4.3	R 500,000
Elandsrand pumping system	5.1	R 600,000
Bambanani pumping system	5.8	R 1,000,000
Masimong#4 pumping system	3.9	R 340,000
Harmony#3 pumping system	3.8	R 640,000
Kopanang Fridge Plant	2.9	R 350,000
Mponeng pumping system	10.0	R 1,400,000
Oryx pumping system	7.0	R 1,300,000
South Deep pumping system	6.0	R 600,000
Beatrix pumping system	6.0	R 1,200,000
Tau Tona pumping system	5.5	R 900,000
Target pumping system	2.4	R 320,000
Evander #7 pumping system	4.0	R 350,000
Tshepong pumping system	4.1	R 340,000
Kopanang Compressed Air	2.1	R 1,100,000
Total	**73**	**R 11,000,000**

Future projects include conveyors and smelters in different mining industries. Smelters consume between 19 MW and 68 MW of electricity per hour [17]. A significant saving can be realised if the electricity consumption can be lowered by 20 to 25% during peak periods in the day. Use of this strategy, can achieve load shifting potential of 3.8 MW to 17 MW.

1.4 ENERGY USAGE IN THE CEMENT INDUSTRY

The process of cement manufacturing is an energy-intensive process. The energy cost in the total production of Portland cement is between 20 and 30% [12]. Figure 14 indicates the energy consumption, from 1994 to 2000, in the cement sector of the USA and Canada. This shows between 1,450 and 1,550 kWh energy consumed per ton of cement produced. The South African cement industry exclusively produces Portland cement using similar processes, and can relate to the values in Figure 14 and Figure 15.

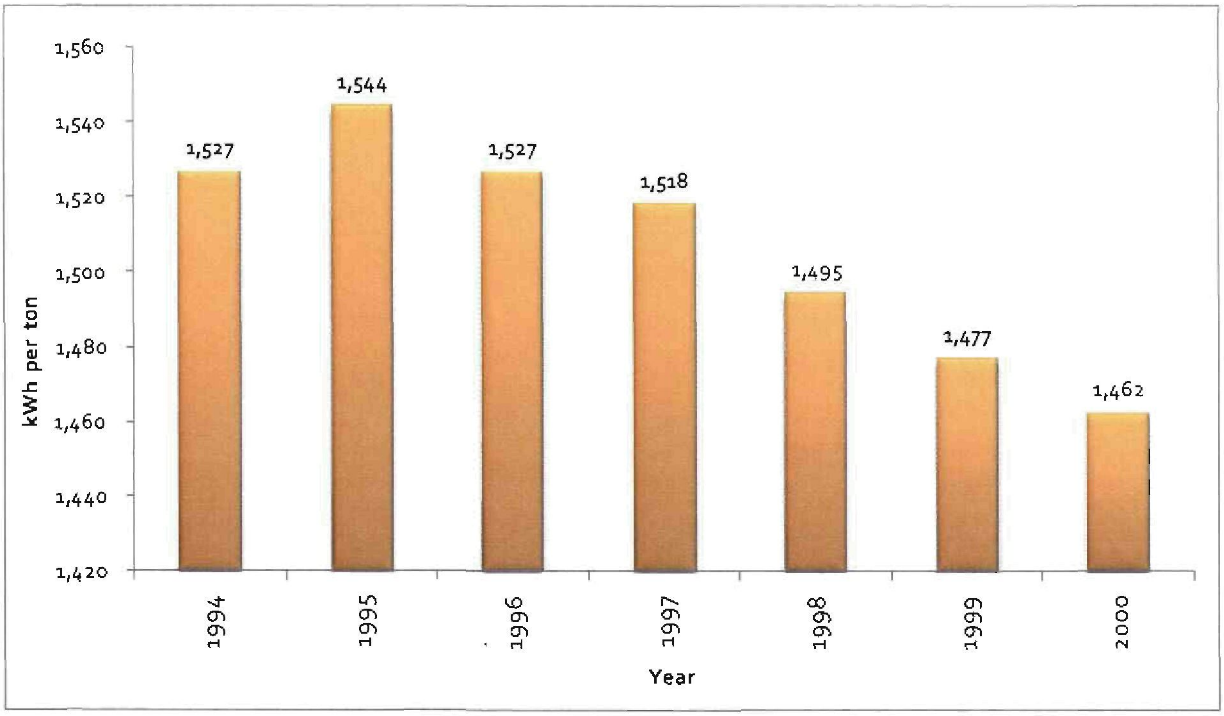

Figure 14 – Energy consumed in the cement sector in the USA and Canada [13]

In Figure 15, the energy consumption per ton of cement produced is shown separately as fuel and electricity. The electricity consumption in the cement industry was stable from 1970 to 2000. Electricity savings will benefit the cement industry because it is constant, unlike the fuel usage per ton of cement produced.

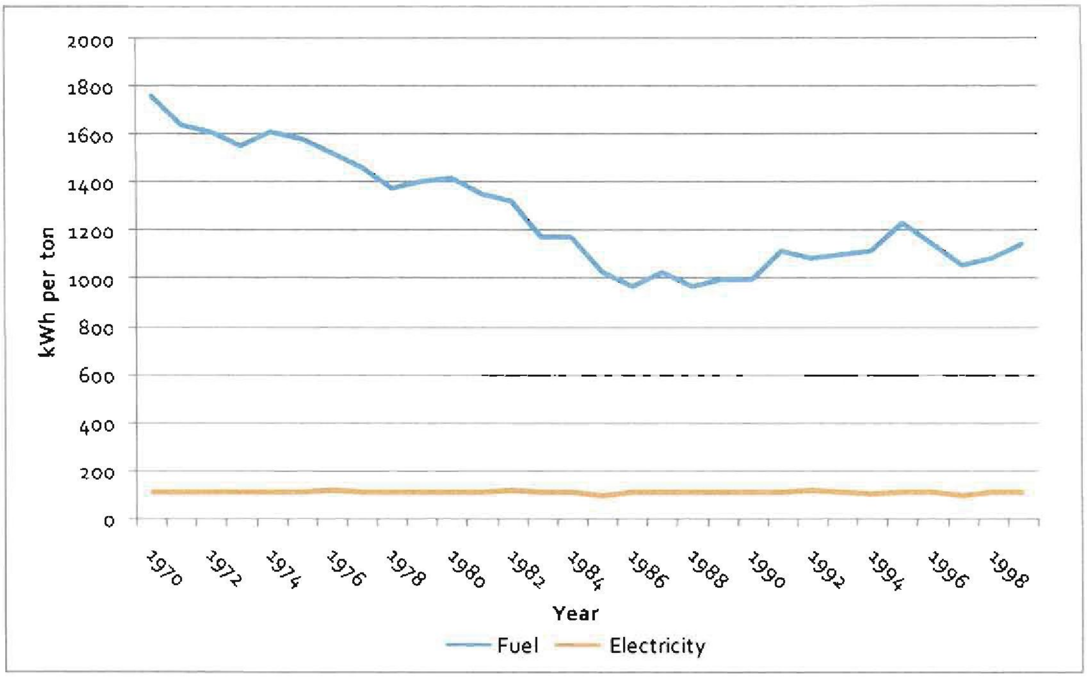

Figure 15 – Specific fuel and electricity consumed per ton of cement produced [14]

Approximately 150 kWh of electricity is consumed per ton of cement produced [13]. Forty percent of electricity is consumed in the finish milling process, and less than 30% of electricity is used in the raw material preparation process, as shown in Figure 16.

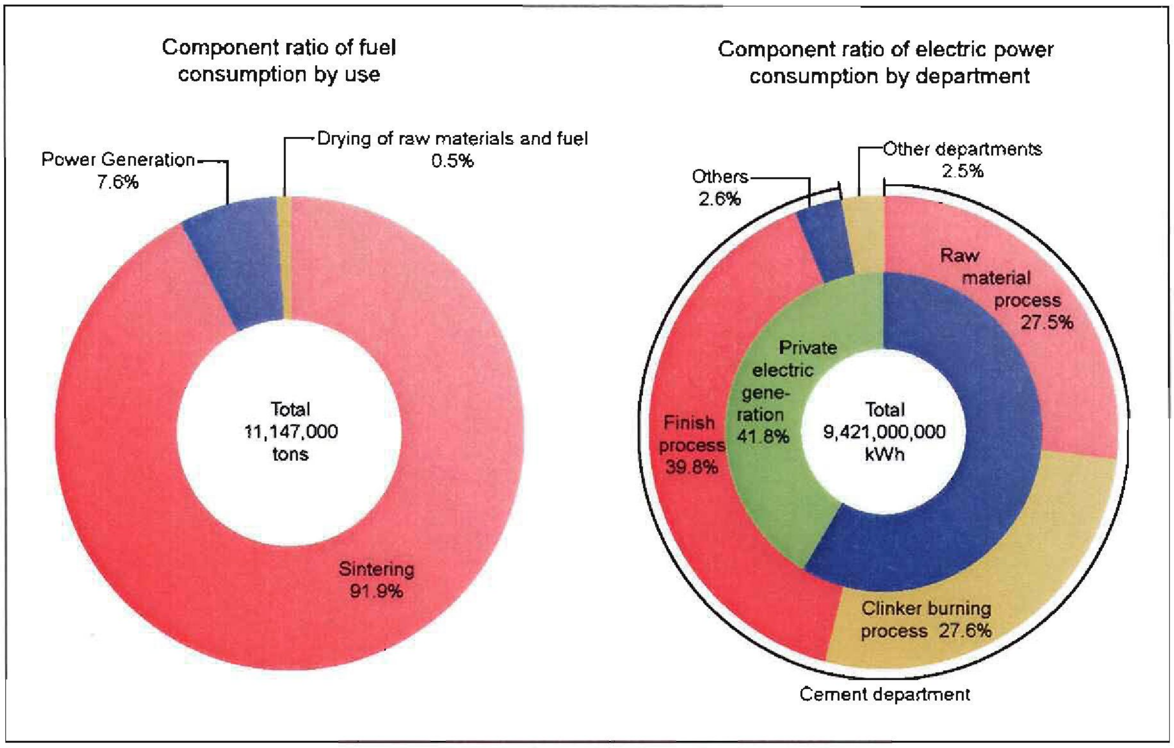

Figure 16 – Component ratio of energy consumption [12]

In both the finish milling and the raw material preparation sections, the mills consume a large amount of the electricity. These two consumers will be the main focus for DSM savings in the cement production process.

The installed capacity of a raw mill ranges between 1.5 MW and 5.6 MW and the installed capacity of a finishing mill range between 1.1 MW and 5.8 MW. The average installed capacity of a mill is 3.4 MW, calculated using the data from seven cement plants in South Africa. The values show that there is an opportunity for energy saving and DSM at cement plants.

1.5 OBJECTIVES OF THIS STUDY

The objective of this study is to create a simulation model to identify opportunities for DSM in South African cement plants. The simulation model will focus on both the raw mill and finishing mill sections at cement plants. Once the simulation model has been created, the relevant data, obtained from actual plant operations will be used to assess DSM potential. The simulated silo level, load shifting and annual cost saving results for each plant will be evaluated and discussed.

1.6 OVERVIEW OF THE DISSERTATION

A brief overview of each chapter is given below.

This chapter introduces the electricity supply problem in South Africa. The initiatives to combat this problem are discussed. DSM is briefly explained and successful projects highlighted. Insight is given into energy usage in the cement industry.

Chapter 2 describes the cement industry in South Africa and the possible opportunities for DSM. Challenges for DSM at cement plants are discussed and the need for a simulation model highlighted.

Chapter 3 describes the implementation of the simulation model. The simulation approach, input to the simulation and output results are explained. The simulation is also verified by using one month's data from a single cement plant to illustrate its accuracy.

Chapter 4 tests the accuracy of the initial verification of the simulation model against actual input data obtained from different cement plants.

Chapter 5 draws conclusions at the basis of the simulated test results. Several suggestions are also made for future research on this subject.

CHAPTER 2

DSM OPPORTUNITIES AT CEMENT PLANTS

2.1 INTRODUCTION

The first section of this chapter provides brief overview of the cement industry. The key components of a cement plant are highlighted, and the possible areas of DSM potential with its specific challenges are identified.

2.2 OVERVIEW OF THE CEMENT INDUSTRY

The South African cement industry is characterised by old plants built in the 1930s and new plants commissioned in 2000. Although some technologies vary, the basic process of cement production has remained the same.

The South African cement industry consists of four major manufacturers: Pretoria Portland Cement (PPC), Lafarge Cement, Holcim Cement and Natal Portland Cement [23]. Figure 17 shows the South African regional cement demand compound growth per decade. The demand for cement in South Africa increased greatly because of expanding economy and large projects needed for the forthcoming 2010 Soccer World Cup.

In 2003 the domestic cement consumption increased by 7.0%, the second consecutive year of positive growth. Exports represented less than 4.5% of the total cement supply in South Africa [24]. The population of Gauteng is predicted to increase by 40% to 12-million people by 2010, which will have an enormous impact on cement consumption in South Africa.

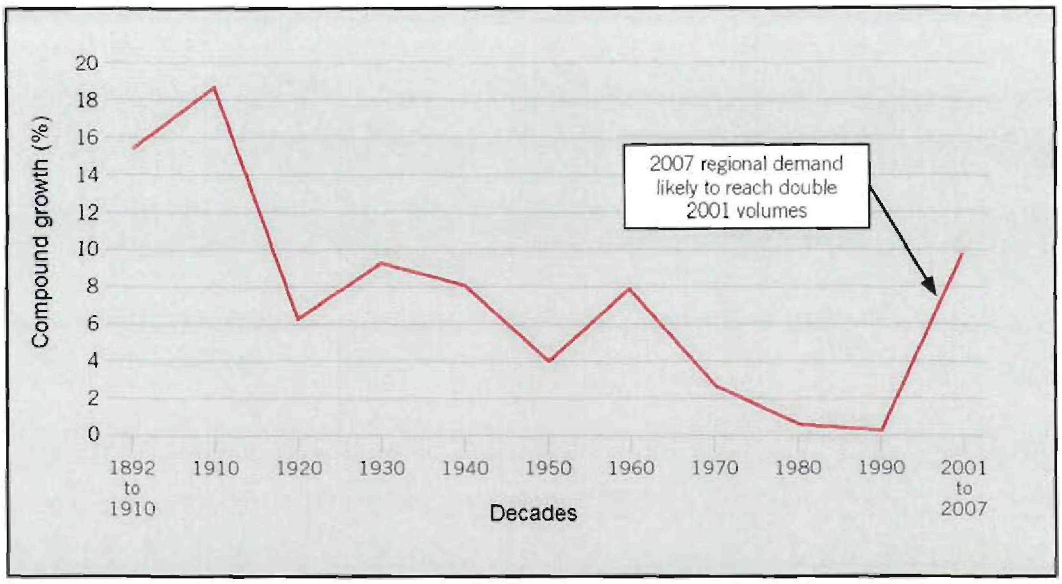

Figure 17 – South African regional cement demand compound growth per decade [25]

A number of major civil projects include the construction of the Gautrain project which is estimated to consume 300,000 tons of cement between 2005 and 2009[6]. Projects relating to the 2010 Soccer World Cup include five existing stadiums being upgraded, two stadiums being rebuilt and the construction of three new stadiums[7].

The Reconstruction and Development Programme (RDP) has also had a huge influence on the consumption of cement in South Africa. The aim of this programme is to provide low-cost housing to previously disadvantaged communities. According to the annual report 2005/2006 of the Department of Housing, 2,081,649 houses were built from 1994 until 28 March 2006, with 2,848,160 subsidies approved [19].

All South African cement plants produce Portland cement. This type of cement consists of a fine grey powder mixed with small amounts of gypsum and silica. Portland cement is blended in different ratios such as CEM I, CEM IIA, CEM IIB, CEM III and CEM V, depending on the application [26].

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[6] Martin Creamer, "Gauteng's per-capita cement consumption soaring to EU levels", September 2005, Engineering News, http://www.engineeringnews.co.za/article.php?a_id=73173

[7] "Smart Glass Network News - 3rd Quarter 2006", 2006, Smart Glass Network, www.smartglassnetwork.co.za

The manufacturing process of Portland cement requires that nearly 80 different operations run simultaneously. This process uses heavy machinery which requires a large amount of heat and energy. Twenty to twenty-five percent of the running cost at a cement plant can be attributed to energy consumption [21].

Limestone is retrieved from various quarries in the cement production process. The limestone is transported to a nearby cement plant where the production and packaging of cement takes place. This process is explained in more detail in section 2.3.

The cement plant is the main user of electricity in the cement creation process. The South African cement industry consists of 10 cement manufacturing plants, of which PPC holds the majority. A list of the cement plants in South Africa and their location is shown in Figure 18.

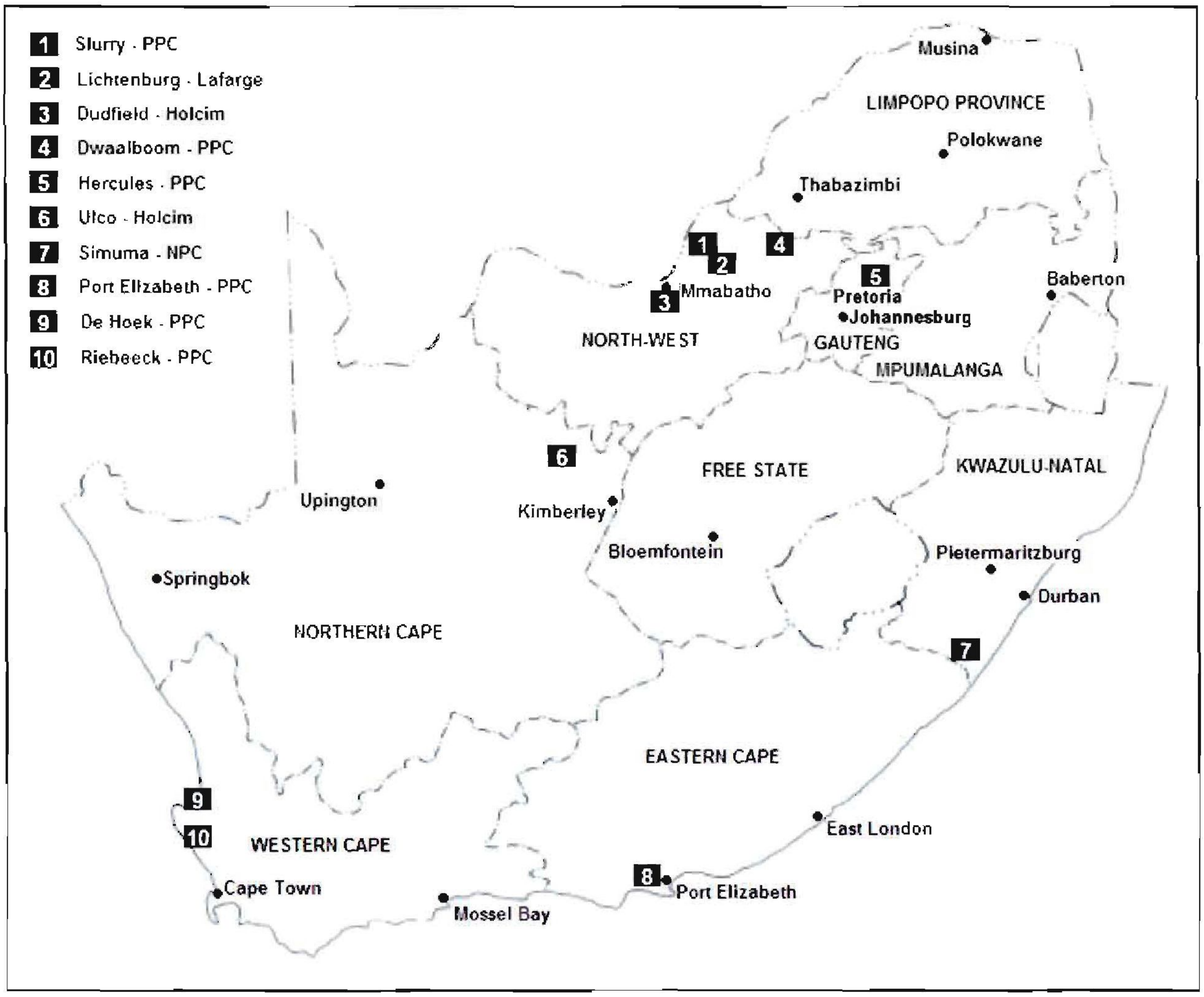

Figure 18 – Map of South African cement manufacturing plants (2005)

In August 2007, an Egyptian cement company, Orascom Construction Industries, announced the founding of Mafikeng Cement Company (MCC). Mafikeng Cement Company plans to build and operate a two-million ton a year cement plant. This cement plant is expected to become operational in 2010[8].

2.3 OPERATION OF A TYPICAL CEMENT PLANT

The cement production process consists of various main sections. It is critical for all these sections to function together successfully to achieve optimum cement production. Figure 20 shows a basic layout of a typical cement plant.

The following sections of this chapter will explain the basic flow of a cement plant and the factors of relevance to this dissertation will be highlighted.

2.3.1 Quarrying

The most predominant raw materials used in the production of cement are limestone, chalk and clay [28]. Limestone is transported via truck, train or conveyer belt from the limestone quarry to the cement plant.

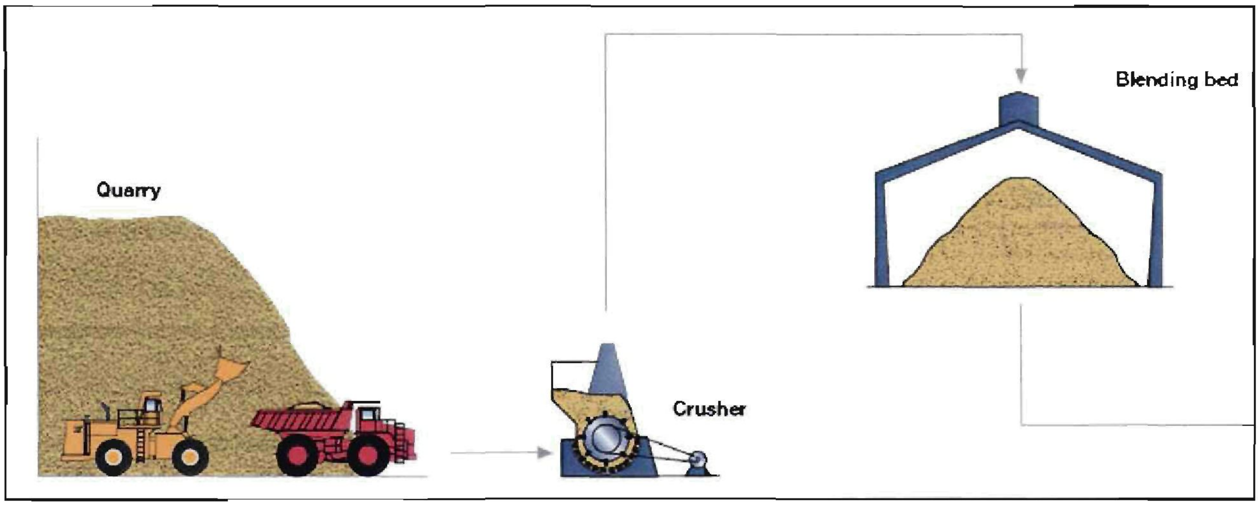

Figure 19 – Quarrying and crushing operations [18]

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[8] Mariaan Olivier, "Egyptian firm to build R3,18bn cement plant in SA", August 2007, Engineering News, http://www.engineeringnews.co.za/print_version.php?a_id=115716

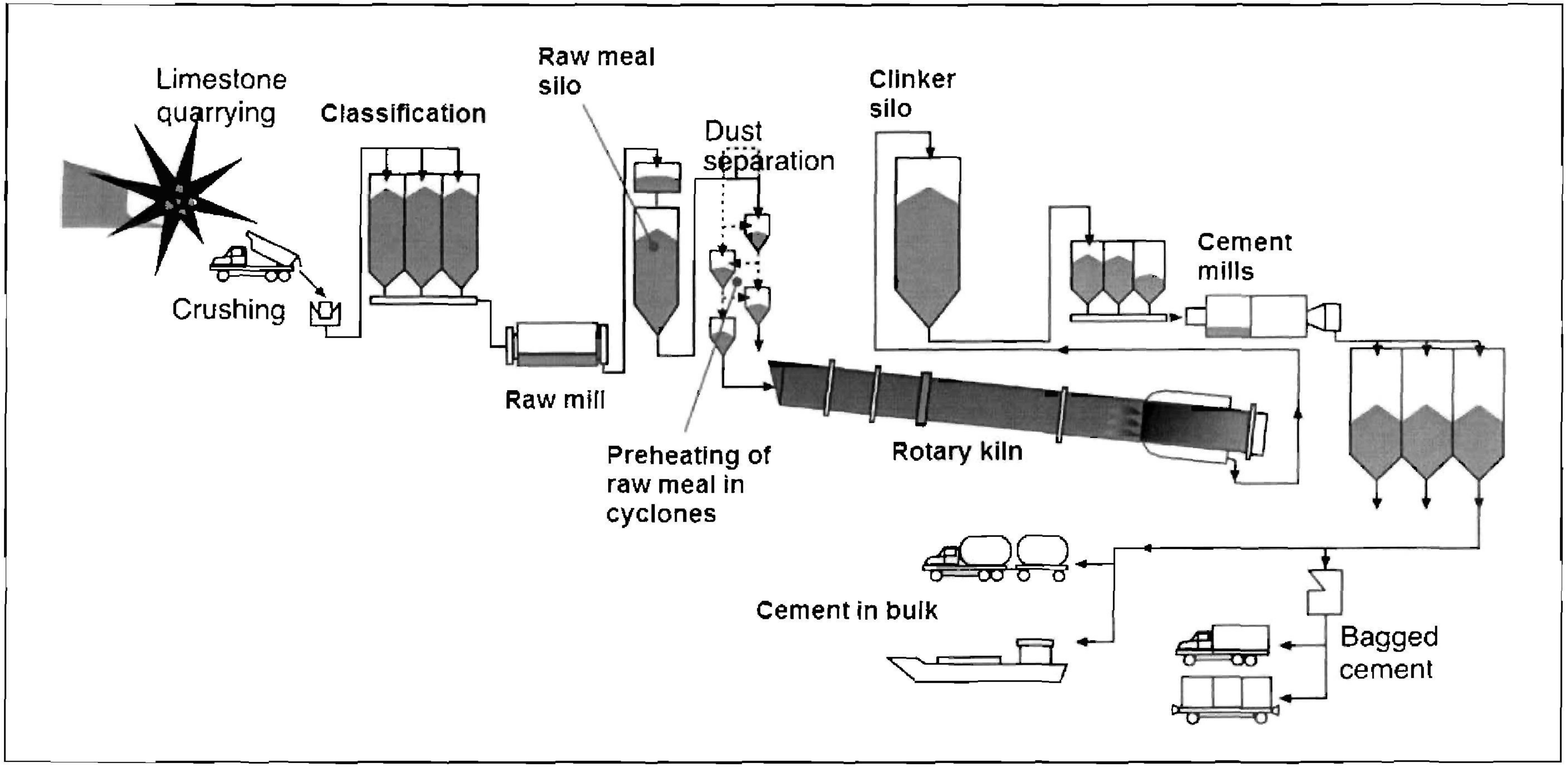

Figure 20 – Basic layout of the cement process at a cement plant. [35]

The quarrying operations are shown in Figure 19. In the raw state the size of the rock material before it is crushed is up to 1 m^3 and needs to be crushed until it is adequate for processing through the remaining process. After crushing, the raw material particles are smaller than 19 mm in diameter [20].

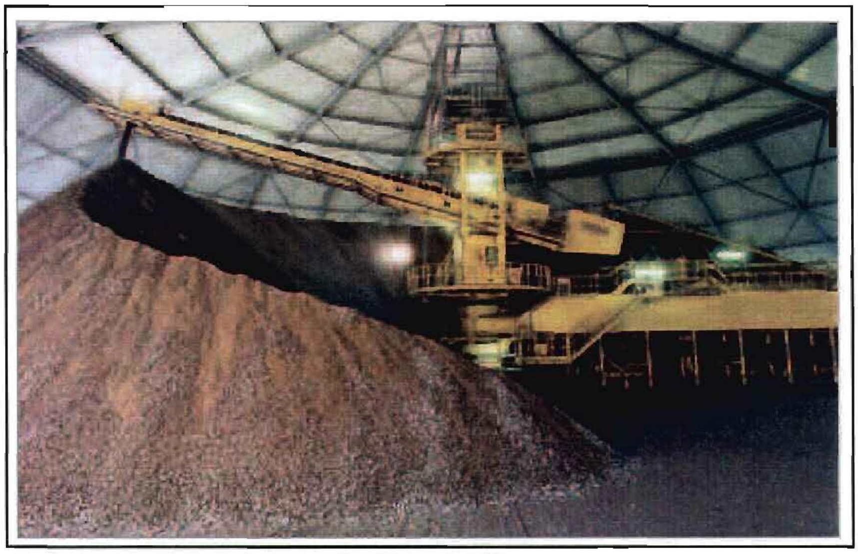

Figure 21 – Stockpile for storage of the raw material [18]

The raw material is then conveyed from the crusher to the stockpile, also referred to as the blending bed, where it is stored before going to the raw mill. The stockpile, shown in Figure 21, has a storage capacity that will hold between one and two weeks production supply. Different ratios of magnetite and ash are added to the limestone before it is conveyed into the raw mill to provide the specific composition of raw material required.

2.3.2 Raw milling

As shown in Figure 22, the mill is a large cylindrical object that rotates in the process of milling. Different types of raw mills are used in the industry. All South African cement plants make use of a dry process. Ball mills are used to crush the raw material.

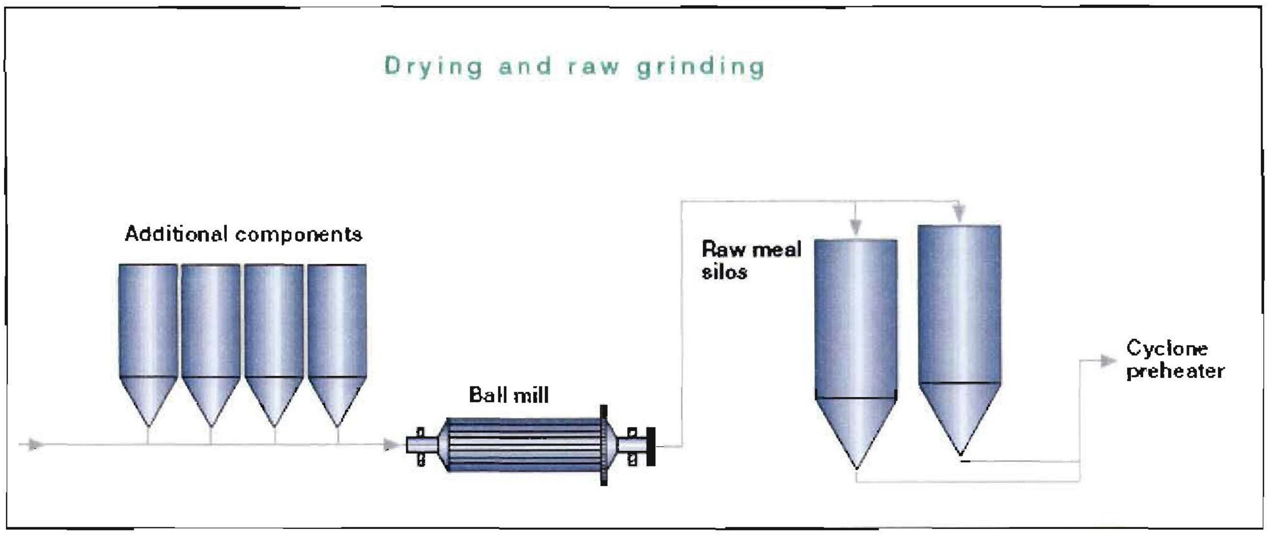

Figure 22 – Raw milling operation [18]

A ball mill contains steel balls inside the drum to crush the material. There are different compartments in the raw mill with screens between them. For the raw material to be ground more finely, the steel balls become smaller from compartment to compartment. Ninety percent of the material extracted from the raw mills is smaller than 75 µm[9]. Figure 23 shows the first compartment of a typical ball mill.

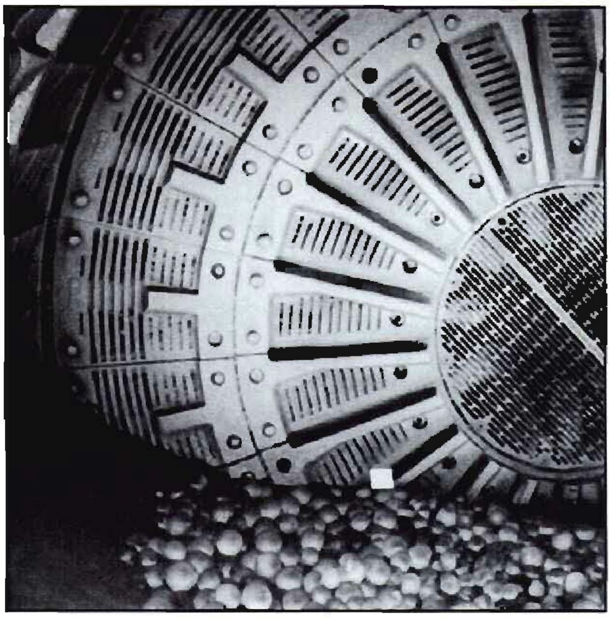

Figure 23 – First compartment of a ball mill [32]

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[9] "Cement process", 2007, Essroc Italcementi Group, http://www.essroc.com/default.aspx?pageid=183

After the raw mill, the coarse particles are separated from the fine particles, referred to as the raw meal. The coarse particles are sent back to the raw mill. Because of its dust-like composition the raw meal is usually transported from the electrostatic precipitator to the raw meal silos by fans or compressed air. The raw meal is stored there before being dispatched to the kiln.

The blending of the raw meal is controlled in the raw meal silos. The raw meal must have the correct average composition of materials before it goes into the kiln. These silos are also known as the kiln feed silos.

2.3.3 Pre-heating and kiln

From the raw meal silos, the raw meal is dropped into cyclones in the pre-heater or pre-calciner where 60% - 80% of the calcination takes place [34]. Hot off-gases from the kiln are used to preheat the raw meal from 70°C to 800°C [29]. The raw meal then goes to the kiln.

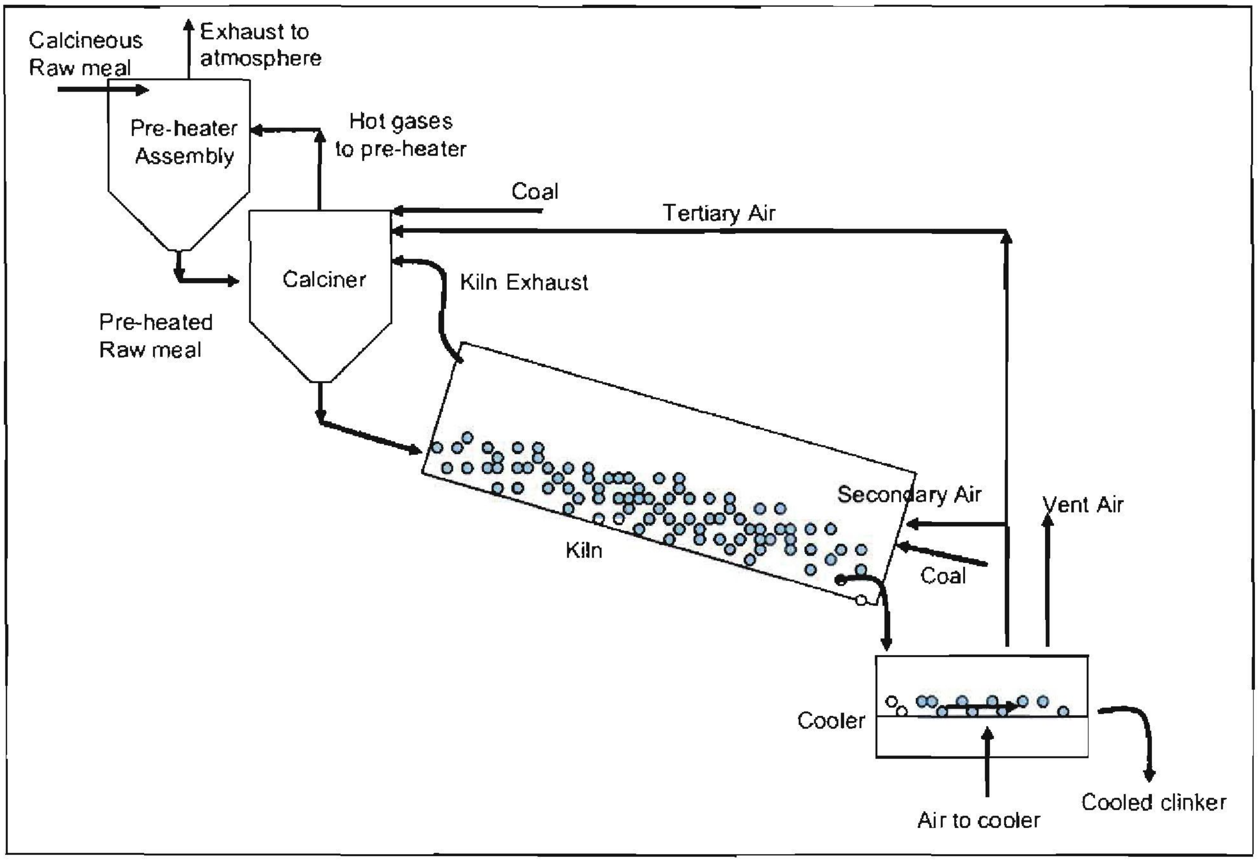


Figure 24 – Pre-heater and Kiln operation [30]

The kiln, which can be up to 8 m in diameter and between 110 and 120 m in length, is a huge cylindrical oven that rotates while it bakes the raw meal [28]. The kiln is the main consumer of energy on a cement plant, accounting for approximately 80% of the energy used in cement production in the USA [36]. Coal powder is burnt inside the kiln to maintain a temperature of above 1350°C [33]. The hot gases pass through the kiln and then upwards through several cyclones.

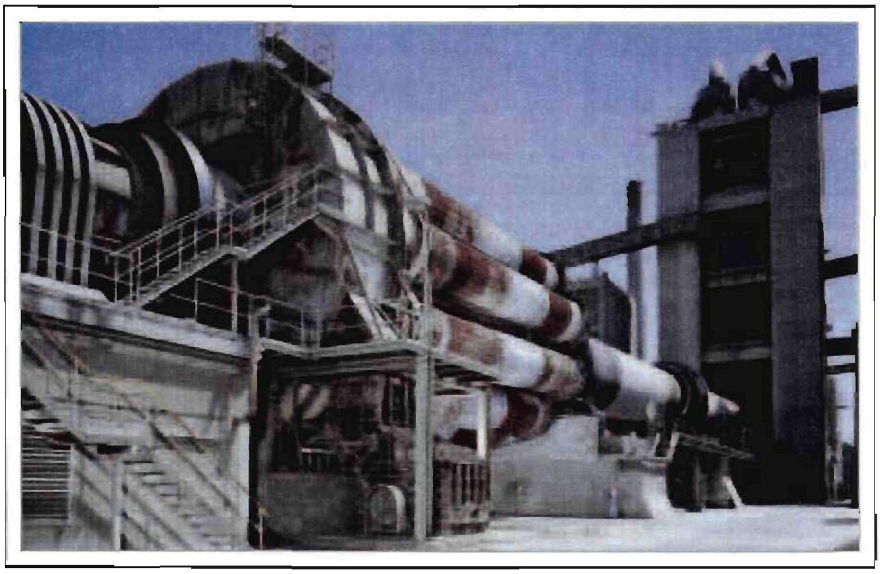


Figure 25 – Photo of a typical kiln [18]

The raw meal moves slowly through the kiln at a flow rate of about 80 tons per hour. Inside the kiln, 20 to 30% of the material is in a liquid phase [27]. This forms a medium in which chemical reactions occur. Aluminosilicate spheres are formed at the end of the kiln. These dry spheres, called clinker, are around 2 cm in diameter [22]. The clinker is the main ingredient to the final cement product, which consist of approximately 95% clinker and 5% other additives [32].

2.3.4 Clinker cooling and storage

Clinker is sent from the kiln to the cooling operation which recovers 30 to 35% of the kiln system heat. The most common types of clinker coolers are planetary and rotary coolers. The clinker is cooled by cool air passing through it. The cooled clinker is then transported via conveyer belt to the clinker storage silos.

A cement plant can normally store up to 25% of its annual clinker capacity. However, in South Africa, no more than two weeks of clinker production is kept on site. Because of its composition, clinker can be transported easily to other cement plants or to other countries for further processing. Clinker can also be sent to other plants consisting only of finish milling and packaging sections, as explained below.

2.3.5 Finish milling and packaging

In the finish milling section, the final cement product is made out of clinker and other additives. One of these additives is gypsum, which regulates the setting time of the cement. About 5% gypsum is added to the clinker before it goes into the cement mill. Other chemicals are added at this stage to provide specific characteristics to the cement.

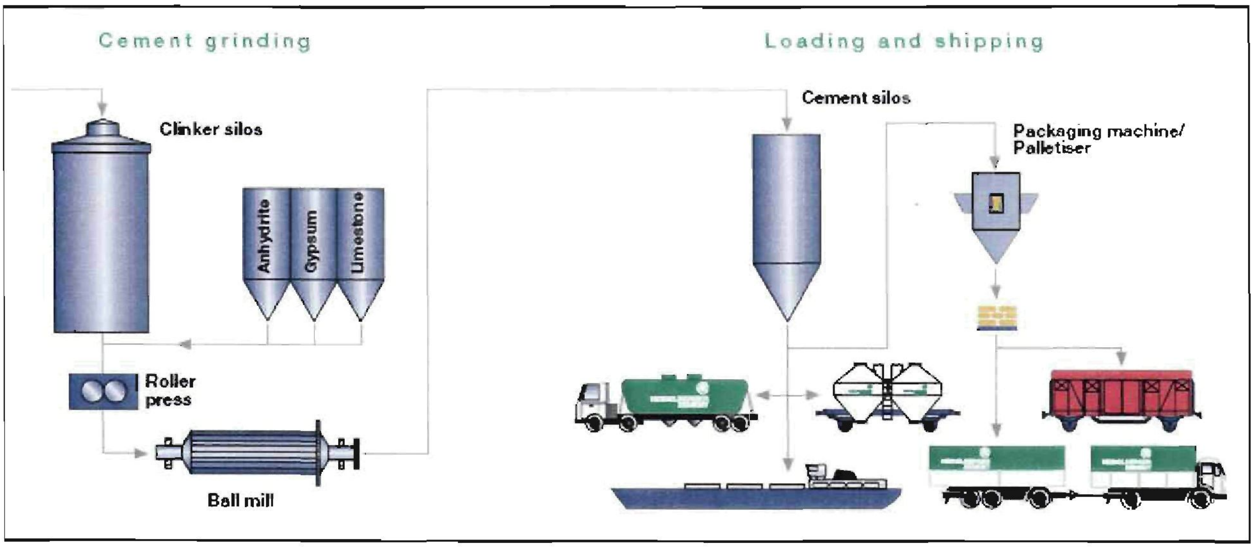


Figure 26 – Finish milling and packaging section [18]

The cement mill, as depicted in Figure 26, operates on the same principle as the raw mill, except that it mills the material into a much finer powder. The finish milling is a closed system. An air separator divides the particles according to size. The correct sized particles are sent to the cement storage silos, and the particles that are too large are returned to the finish milling process again.

The five cement types produced by South African cement plants are shown in Table 2. This product has a higher extender:clinker ratio, reduces kiln emissions and improves energy efficiency in the manufacturing process.

Table 2 – General local cement types, according to EU and SABS standards [20]

Cement Type	Extender content as percentage (%)
CEM I	Normal Portland cement, no extenders
CEM II A	Cement with extender content of 5 – 20%
CEM II B	Extender content of 20 – 35%
CEM III	Extender content of 30 – 60%, mostly a slag-based extender
CEM V	Composite cement with several extenders, total not exceeding 65%

From the silos the cement is blended in the correct ratios and sent to the packaging or bulk loading section from where it is dispatched into the market. CEM I is general purpose cement suitable for all uses where special properties are not required. Type II cements (CEM II A and B) are also for general use, especially when moderate sulphate resistance or moderate heat of hydration is required. Type III is for high early strength. Type V is for use when high sulphate resistance is required [31].

The kiln is the critical component in terms of production in the cement-manufacturing process. Any negative influence on the material throughput of the kiln will directly result in a loss of production. When the possibility of DSM on cement plants is investigated, it is crucial that there is no reduction in production.

2.4 DSM OPPORTUNITIES

When a production plant is evaluated for load shifting opportunities, the focus is on electric components with an installed capacity greater than 0.5 MW. This is a requirement from Eskom for DSM projects. The control over and monitoring of a single large electricity user are much easier than the control of numerous components with small electricity consumption.

The mills in both the raw milling and the finishing milling sections are the machinery with the largest installed capacity in the process. Both the raw and finishing mills have auxiliaries, which are also shut down with the mills. The total installed capacity of a ball mill and its auxiliaries range between 1.2 MW and 5.8 MW.

Load shifting has to be applied without influencing the production output of the plant. To achieve this, the slowest component in the cement production process has to be identified. The kiln is the component with the slowest material flow in the total process. A silo feeds the kiln with raw material. From a finishing milling perspective it is critical not to influence the production figures of the packaging plant. The packaging plant receives cement material from the cement silo.

To keep the kiln running at all times, the silo containing the raw meal must never run empty. The section before the kiln that feeds the raw meal into the silo is the raw milling section. The flow of material through the raw mill is far greater than through the kiln. This means that there are periods when the raw mill can be stopped to prevent the silos from overflowing.

In the finishing milling section, there must always be enough cement for the packaging plant to reach its production figures for the day. This means that the silo may never run empty. When the finishing mill's flow rate is faster than the rate at which the packaging plant delivers material, the cement silos will reach full capacity. The mill will have to be stopped to prevent the silos from overflowing.

The material flow of the mill in the process is usually faster than the process after the silos, presenting an opportunity for the mills to be stopped during the peak periods in a day.

All cement production lines have the same basic layout. Some plants consist of not only a single production line but up to four cement production lines. Some plants also have several smaller finishing mills in one production line. All these factors can increase the electricity cost savings potential at a cement plant. Each plant is unique with its own characteristics that have to be taken into account, which in turn have an impact on the DSM opportunities at each plant.

2.5 CHALLENGES FOR DSM AT CEMENT PLANTS

DSM opportunities in the cement industry present many challenges and have to be identified. These challenges have an impact on the research and implementation of DSM at a cement plant.

As discussed previously, the potential for load shifting lies in the milling sections of the cement production process. Hence the detailed operation of a mill and the influences each specific mill has on the process around it should be analysed.

The installed capacity of the mill motor on that specific mill should be identified for each mill in particular. The auxiliaries that operate with each mill and their installed capacities vary at each different plant. All the components that stop together with the specific mill should therefore be identified and their capacities included in the savings.

The constant starting and stopping may cause concern that the mill could be damaged. However, it was proven that such a concern can be eliminated, and the fact that several cement plants are already partially applying load shifting by stopping the mills frequently in peak periods confirms that it is possible [15]. However, it is still important to consult the plant engineer before implementing load shifting.

Cement production is a complex process, and several factors, that are sometimes difficult to determine, have to be taken into account. These factors are highlighted below.

At some cement production plants, there are different consumption and production cycles during the year. This is because of seasonal differences in the demand for cement which will have an impact on the DSM project. During a month when the demand for cement is lower than usual, there are more opportunities for load shifting. When the demand for cement is high, fewer stoppages are permitted leading to a strong increase in production. This results in fewer opportunities for load shifting.

There could be a sudden increase in cement demand in the market, which could result in an unscheduled increase in production. The influence of this on the load shifting schedule has to be taken into account.

To evaluate a cement production plant for the viability of load shifting, numerous data need to be accumulated. This data is absolutely critical in the process of determining the potential for DSM and are further explained in section 3.3.

The average running baseline of the mills during a typical day is crucial for a DSM project. The optimised baseline is measured against the baseline that was determined by the historical data, to calculate the savings that are possible. An example of an optimised baseline versus the existent baseline is provided in Figure 27.

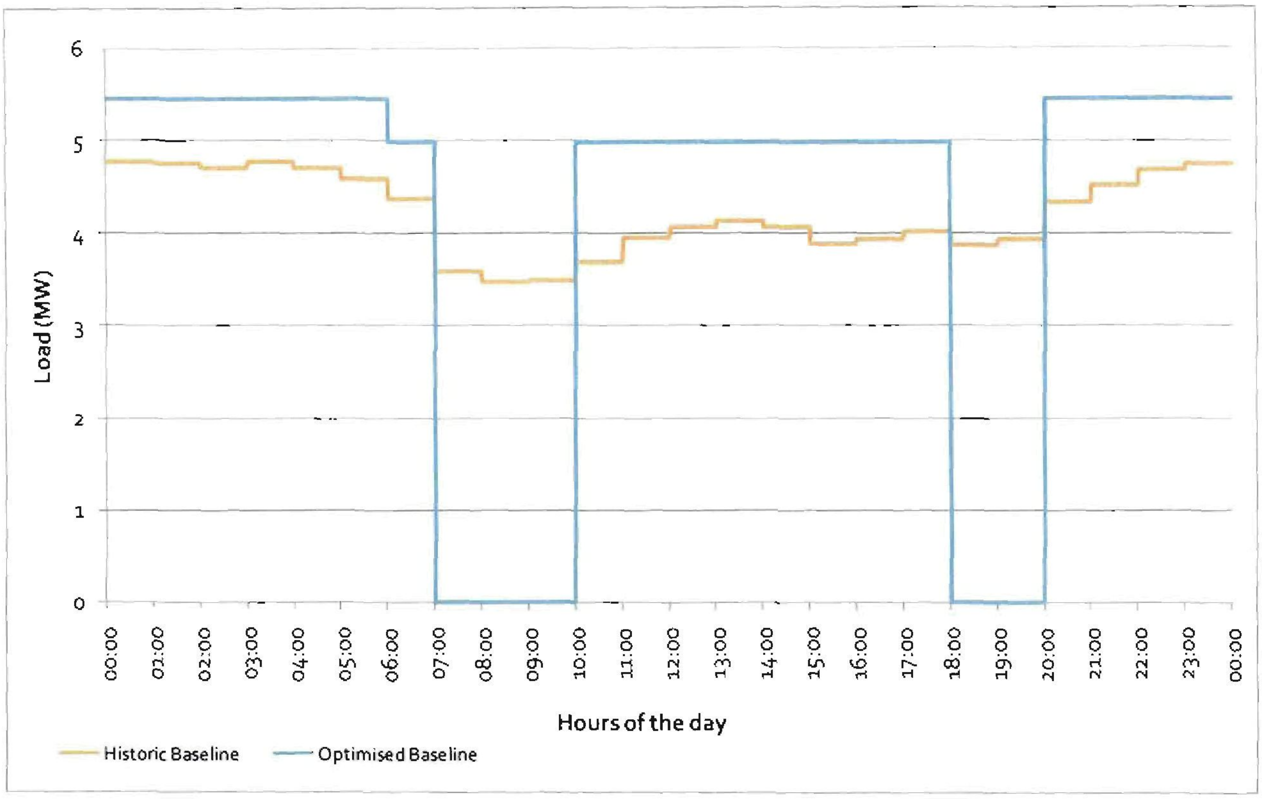


Figure 27 – Historic baseline versus optimised baseline

Eskom requires that at least six months of historical data must be used to calculate the average daily baseline for a project. A full 12 months' historical data are preferred to determine a realistic baseline. When a full year's data are used to determine the viability of a project, seasonal fluctuations in cement demand and other factors influencing the production can be determined.

It often happens that data necessary to determine the potential are not available. This is because data are sometimes not stored for more than six months, or the specific data are not recorded at a specific plant. The data needed to determine the baseline are the MW used each hour of the month for a whole year for that specific machine. If no SCADA or other form of data-capturing device is present, these data can be difficult to obtain.

Another means of determining a baseline for the mill can be done by using the daily running hours recorded in datasheets each day. There are several other variables that need to be obtained to conduct a successful simulation. Occasionally, meetings have to be scheduled to obtain this information from the people managing the specific cement plant.

To shift load and save the plant electricity costs, the operation schedule of the plant has to be changed from the existing operation schedule. However, plant managers will only change their operating schedules if these changes will not affect the safety and production of the plant.

2.6 NEED FOR A SIMULATION MODEL

A mechanism was needed to determine the DSM potential at a cement plant without influencing the standard operation and production of the plant.

The simulation model will take into account all the necessary variables, and will simulate the running schedule, daily running baseline and silo levels involved in the specific mill process. The output of the simulation will convince the cement plant, beyond any doubt, that DSM will not influence the production negatively.

A number of obstacles have to be overcome before DSM can be implemented at a cement plant. If the correct data can be obtained, the simulation could prove a major factor in the process of a DSM project.

The silo levels are an important component in the kiln and packaging plant's operation. When the silos before the kiln and packaging plant drop below the specified minimum silo level, there is a possibility that production may be negatively influenced. The simulation must therefore prove that the silo levels linked to that specific milling sector will be stable. This involves not exceeding the maximum and the minimum levels of the silo in particular.

The simulation should display the silo level projected over the period of a month. This is important because the mills run different hours on weekdays and weekends. There is often scheduled maintenance about once a month, which also influences the running hours of each mill between weeks. The simulation must take into account all stoppages currently incurred at the cement plant and how these affect the specific silo's level. This means that the mills are either switched off for two hours in the evening peak each weekday, or switched off for five hours for all the peak hours of the weekday.

Several factors are used to calculate this silo level. The simulation model is needed to bring all these different factors, which influence the silo level, together to provide a realistic and correct output for the simulation. The simulation will provide the following outputs, which can be used to determine whether there are DSM opportunities at a plant:

- *Silo level projected over the period of a month.* This will show if it is possible to keep the silo level stable when load is shifted.
- *The simulation calculates an optimised baseline for the mill.* The optimised baseline shows the MW usage over a typical day in that month.
- *The load shifting potential.* This is calculated from the difference between the optimised baseline and the historical baseline data.
- *The annual electricity cost savings.* This is calculated from the load shifting potential.

The outputs should show what the effects of load shifting will be on the specific sector in which the mill is situated. If there is load shifting potential, the simulation will automatically provide the possible annual cost savings.

Previous simulation models only simulated the silo level for one day in a year. This can be deceptive because a small change in one day can have a marginal impact on the silo level later in the month.

The average daily breakdown hours, planned maintenance stops and different load shifting schedules were not used as input in previous simulations. A one-hour deviation in the breakdown hours can have an impact on the gradient of the silo level. This implies that the breakdown hours and planned maintenance stops were not directly linked to the calculation of the silo level and the optimised baseline. Load shifting simulations were only done on the raw milling section, and the finishing milling section was not taken into account. The new simulation is designed to accommodate both.

The new simulation model can easily illustrate what effect a difference in load shifting hours, breakdown hours and planned maintenance stops has on the silo level. With little information the simulation can show the potential for DSM to the plant manager.

2.7 CONCLUSION

The cement industry is growing in South Africa providing increased opportunities for DSM projects to be implemented. Cement plants are highly intensive energy consumers, where electricity is one of the main forms of energy used.

When looking at the possible areas for load shifting at cement plants, the largest electricity users have to be identified. In the cement production process both the raw mills and finishing mills are candidates for possible load shifting.

Raw milling requires that the kiln must run for 24 hours a day, seven days a week. This is achieved by ensuring that the silo feeding the kiln is never empty. In a finishing milling situation, cement must always be available in the silo to prevent packaging plant disruptions.

If the correct data for the simulations are used, and the various obstacles are overcome, the outputs of the simulation will show the cement plant what amount of load shifting potential and cost savings can be realised when DSM is implemented, and will assure the cement plant that the silo levels will be stable.

CHAPTER 3

DEVELOPING THE NEW SIMULATION MODEL

3.1 INTRODUCTION

The simulation is a complex model that needs to be explained in detail. This chapter explains the strategy employed to develop the simulation model. An explanation of all the input parameters and their functions in the simulation is given. The results of the simulation and their significance are also discussed. In conclusion, a verification of the simulation is done to show that realistic solutions are obtained.

3.2 SIMULATION APPROACH

Load shifting opportunities at cement plants, were identified on the raw milling section before and the finish milling section after the kiln. The kiln is the slowest component in the cement production flow process, which implies that any stoppage of the kiln translates into a loss in production. For the kiln to run 24 hours a day, the raw meal silo must never run empty.

In the finishing mill situation, it is important for the packaging plant to meet the production figures each day. This basically means that the cement silos preceding the packaging plant should never run empty.

Silo levels are vital in the simulation to ensure that production will not be influenced. Because the raw milling and finishing milling sections are two different sections in the process, the simulation differs between the two sections. In the raw milling simulation, the raw material silo level between the raw mill and kiln is significant. If the raw material silo feeding the kiln is empty, the kiln will have to be stopped, resulting in a loss of production.

In the finishing milling section, the cement level in the silo between the finishing mill and the packaging plant is crucial. When the cement silo is empty, the packaging plant is forced to stop, because there will be no cement left to process.

The simulation must project the silo level over the period of a month because of fluctuations in the silo level during the month. Reasons for these fluctuations are provided below:

- The running hours of the mill on weekdays differ from the running hours on weekends.
- Monthly planned maintenance usually takes place in the same periods each month.

- Mill stoppages occur because of unforeseen circumstances.

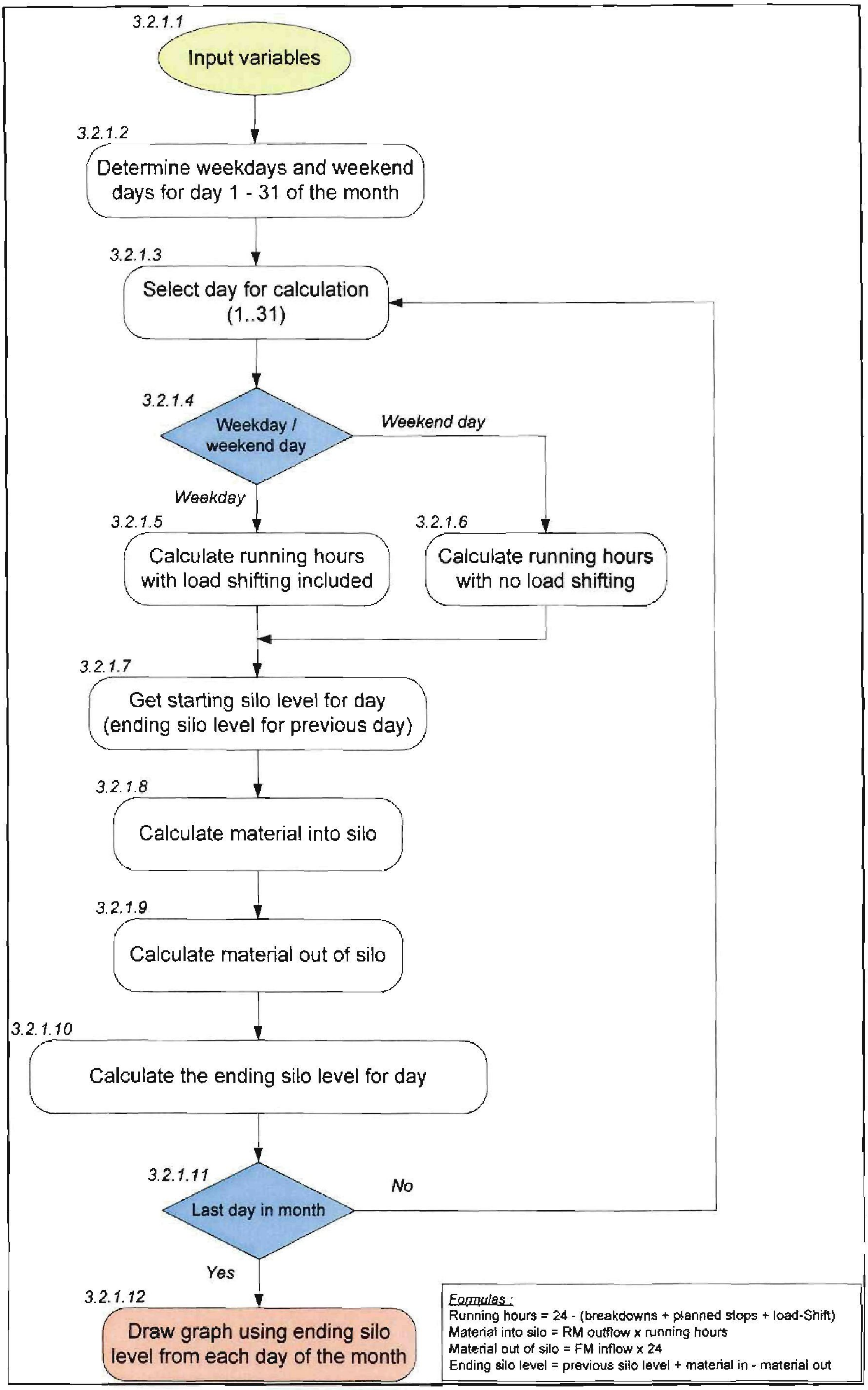
The simulation model consists of two parts. Firstly, the silo levels are simulated over a period of one month. The second part of the simulation requires the calculation of the optimised baseline, load shifting potential and annual cost savings that can be realised. This part is calculated using the mill running schedule from the silo level simulation.

3.2.1 Silo level simulation

To successfully predict the silo levels, the flow of material through the process needs to be determined for each day of the month. Table 3 depicts the input information needed for the silo level simulation. A detailed explanation of the inputs to the simulation is given in section 3.3.

Table 3 – Silo level simulation input parameters

Parameter
Raw mill outflow
Kiln inflow *(raw mill perspective)*
Daily PP production figure *(finishing mill perspective)*
Silo capacity
Silo starting level (%)
Silo maximum level (%)
Silo minimum level (%)
Date of calculations
Daily breakdown hours
Planned maintenance hours per week
Day of planned maintenance in week
Number of weeks planned maintenance per month
Hours load shift per day
Days load shift per week
Running hours on Saturday
Running hours on Sunday
Running capacity of mill



Formulas :
Running hours = 24 - (breakdowns + planned stops + load-Shift)
Material into silo = RM outflow x running hours
Material out of silo = FM inflow x 24
Ending silo level = previous silo level + material in - material out

Figure 28 – Flow diagram of the silo level simulation.

The functional flow diagram of the silo level simulation, as shown in Figure 28, is explained below.

3.2.1.1 Collect Input Variables

The required inputs are collected and read into the simulation. The inputs are listed and explained in detail in section 3.3.

3.2.1.2 Determine weekdays/weekend days for the month

Determine which days in the month are weekdays, and which days fall on weekends. The date input is used to do this calculation. There is no load shifting over the weekend.

3.2.1.3 Select day for calculation

Select the day to do the calculations on. This value starts at 1 and increments each time it is visited, until the last day of the month is reached.

3.2.1.4 Determine whether weekdays or weekend

Check if the selected day is a weekday or a weekend day. If it is a weekday, proceed to 3.2.1.5. If it is a weekend day, proceed to 3.2.1.6.

3.2.1.5 Calculate running hours with load shifting

Determine running hours for day by using equation 1.

$$\text{Running hours} = 24 - (\text{breakdowns} + \text{planned stops} + \text{load shifting}) \qquad (1)$$

3.2.1.6 Calculate running hours without load shifting

Determine running hours for the day by using equation 2.

$$\text{Running hours} = 24 - (\text{breakdowns} + \text{planned stops}) \qquad (2)$$

3.2.1.7 Determine Starting silo level of the day

Determine the starting silo level for the day by using the ending silo level of the previous day. The "starting silo level" input parameter should be used on the first day of the month.

3.2.1.8 Calculate amount of material going into the silo

Equation 3 is used to calculate the amount of material going into the silo per day. In a finishing mill scenario, the finishing mill outflow is used.

$$\text{Material into silo}(\mathit{tons}) = \text{RM outflow}(t/h) \times \text{running hours} \qquad (3)$$

3.2.1.9 Calculate material that left the silo

Determine the material that left the silo per day using equation 4. In a finishing mill scenario, the daily packaging plant production figure is used, which is the material that was subtracted from the cement silos each day.

$$\text{Material out of silo}(tons) = \text{kiln inflow } (t/h) \times \text{running hours} \qquad (4)$$

3.2.1.10 Calculate ending silo level

The ending silo level of the day is calculated by means of equation 5.

$$\text{Ending silo level} = \text{previous silo level} + \text{material in} - \text{material out} \qquad (5)$$

3.2.1.11 Check whether last day of month

Check whether it is the last day in the month. If it is, proceed to 3.2.1.12. If not, return to 3.2.1.3.

3.2.1.12 Draw graph

Draw a graph using the ending silo level for each day of the month, minimum silo level, maximum silo level and the total silo capacity. This displays the silo level throughout the whole month. An example of the graph is shown in Figure 29. Results of the silo level simulation are explained in more detail in section 3.4.1.

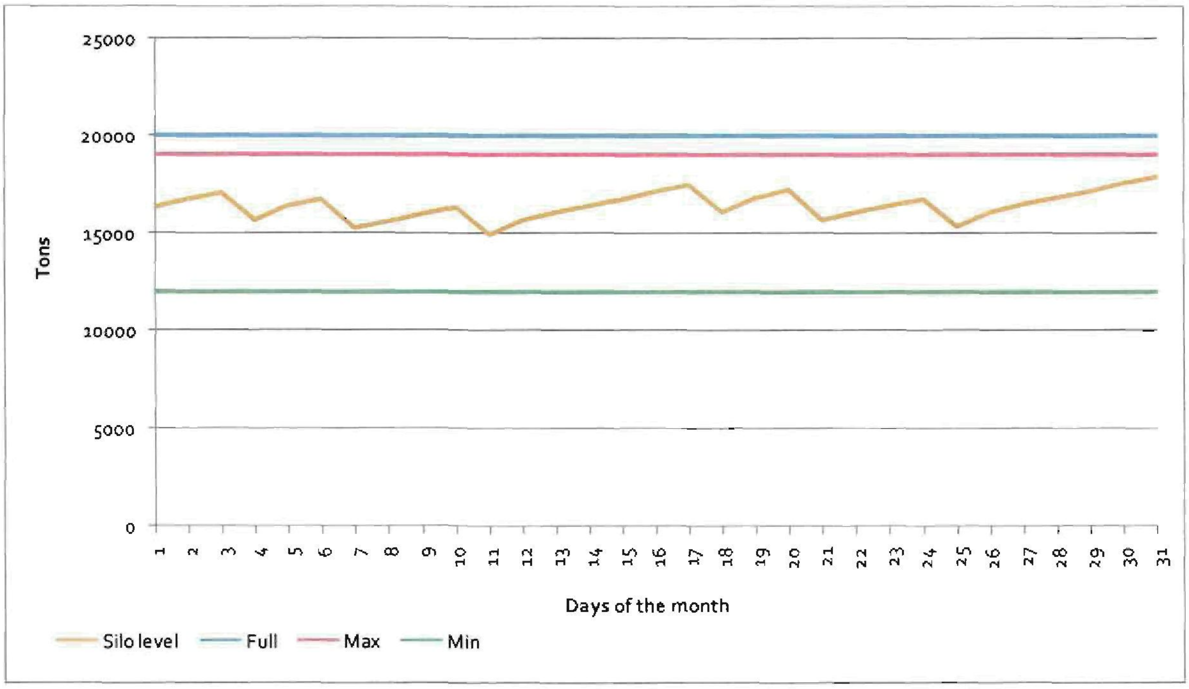
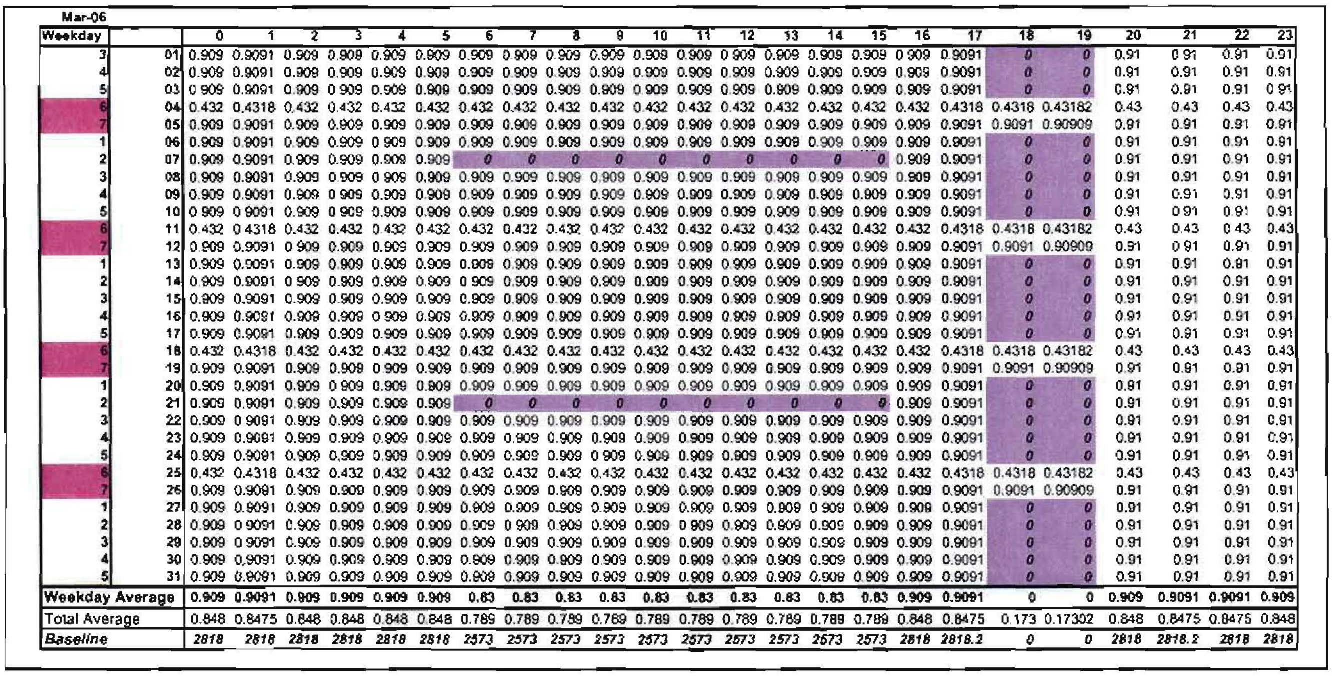


Figure 29 – Example of silo level simulation result

3.2.2 Optimised baseline and calculated savings

The first step in this part of the simulation is to calculate an optimised baseline using the mill running schedule from the silo level simulation. The optimised baseline is compared with the historical baseline. The load shifting potential and annual cost savings are calculated from this comparison.

The second part of the simulation combines all the hours stopped per day from part one of the simulation model into a matrix. The rows of the matrix represent the days of the month and the columns represent the hours of the day. An example of this matrix is provided in Figure 30.



Mar-06

Weekday		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3	01	0.909	0.9091	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.9091	0	0	0.91	0.91	0.91	0.91
4	02	0.909	0.9091	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.9091	0	0	0.91	0.91	0.91	0.91
5	03	0.909	0.9091	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.9091	0	0	0.91	0.91	0.91	0.91
6	04	0.432	0.4318	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.4318	0.4318	0.43182	0.43	0.43	0.43	0.43
7	05	0.909	0.9091	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.9091	0.9091	0.90909	0.91	0.91	0.91	0.91
1	06	0.909	0.9091	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.9091	0	0	0.91	0.91	0.91	0.91
2	07	0.909	0.9091	0.909	0.909	0.909	0.909	0	0	0	0	0	0	0	0	0	0	0.909	0.9091	0	0	0.91	0.91	0.91	0.91
3	08	0.909	0.9091	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.9091	0	0	0.91	0.91	0.91	0.91
4	09	0.909	0.9091	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.9091	0	0	0.91	0.91	0.91	0.91
5	10	0.909	0.9091	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.9091	0	0	0.91	0.91	0.91	0.91
6	11	0.432	0.4318	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.4318	0.4318	0.43182	0.43	0.43	0.43	0.43
7	12	0.909	0.9091	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.9091	0.9091	0.90909	0.91	0.91	0.91	0.91
1	13	0.909	0.9091	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.9091	0	0	0.91	0.91	0.91	0.91
2	14	0.909	0.9091	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.9091	0	0	0.91	0.91	0.91	0.91
3	15	0.909	0.9091	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.9091	0	0	0.91	0.91	0.91	0.91
4	16	0.909	0.9091	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.9091	0	0	0.91	0.91	0.91	0.91
5	17	0.909	0.9091	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.9091	0	0	0.91	0.91	0.91	0.91
6	18	0.432	0.4318	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.4318	0.4318	0.43182	0.43	0.43	0.43	0.43
7	19	0.909	0.9091	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.9091	0.9091	0.90909	0.91	0.91	0.91	0.91
1	20	0.909	0.9091	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.9091	0	0	0.91	0.91	0.91	0.91
2	21	0.909	0.9091	0.909	0.909	0.909	0.909	0	0	0	0	0	0	0	0	0	0	0.909	0.9091	0	0	0.91	0.91	0.91	0.91
3	22	0.909	0.9091	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.9091	0	0	0.91	0.91	0.91	0.91
4	23	0.909	0.9091	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.9091	0	0	0.91	0.91	0.91	0.91
5	24	0.909	0.9091	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.9091	0	0	0.91	0.91	0.91	0.91
6	25	0.432	0.4318	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.4318	0.4318	0.43182	0.43	0.43	0.43	0.43
7	26	0.909	0.9091	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.9091	0.9091	0.90909	0.91	0.91	0.91	0.91
1	27	0.909	0.9091	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.9091	0	0	0.91	0.91	0.91	0.91
2	28	0.909	0.9091	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.9091	0	0	0.91	0.91	0.91	0.91
3	29	0.909	0.9091	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.9091	0	0	0.91	0.91	0.91	0.91
4	30	0.909	0.9091	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.9091	0	0	0.91	0.91	0.91	0.91
5	31	0.909	0.9091	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.9091	0	0	0.91	0.91	0.91	0.91
Weekday Average		**0.909**	**0.9091**	**0.909**	**0.909**	**0.909**	**0.909**	**0.83**	**0.83**	**0.83**	**0.83**	**0.83**	**0.83**	**0.83**	**0.83**	**0.83**	**0.83**	**0.909**	**0.9091**	0	0	**0.909**	**0.9091**	**0.9091**	**0.909**
Total Average		0.848	0.8475	0.848	0.848	0.848	0.848	0.789	0.789	0.789	0.789	0.789	0.789	0.789	0.789	0.789	0.789	0.848	0.8475	0.173	0.17302	0.848	0.8475	0.8475	0.848
Baseline		*2818*	*2818*	*2818*	*2818*	*2818*	*2818*	*2573*	*2573*	*2573*	*2573*	*2573*	*2573*	*2573*	*2573*	*2573*	*2573*	*2818*	*2818.2*	*0*	*0*	*2818*	*2818.2*	*2818*	*2818*

Figure 30 – Example of the running hours optimised schedule matrix

The load shifting hours are placed in the correct peak hours depending on how much load has to be shifted. Note that load shifting does not take place over weekends.

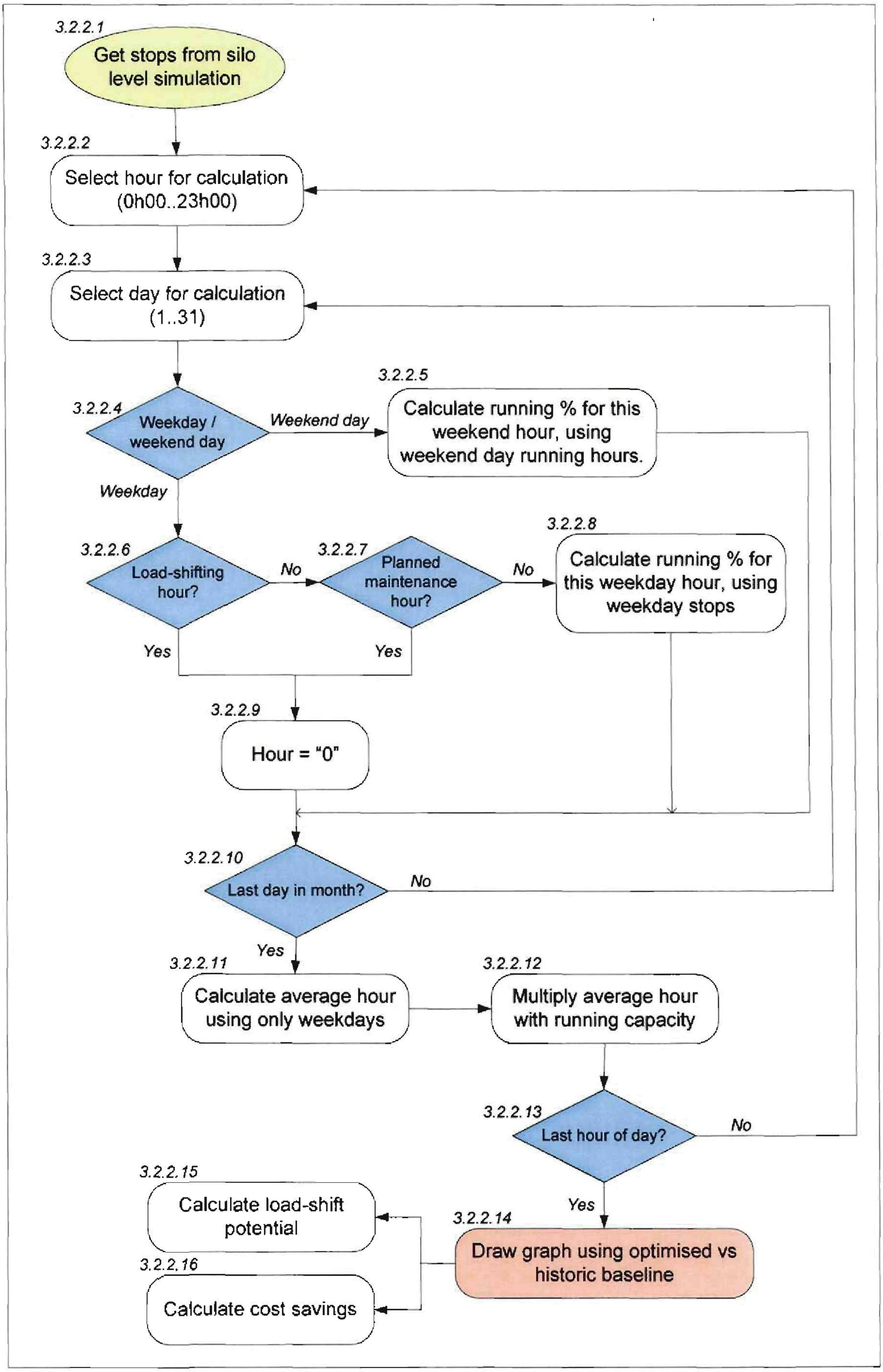


Figure 31 – Flow diagram of optimised baseline and cost savings part

Figure 31 is a flow diagram of the second part of the simulation model and is explained below.

3.2.2.1 Obtain stoppages from silo level simulation

The breakdown hours, planned maintenance hours, load shifting hours and weekend running hours are received from the first part of the simulation model.

3.2.2.2 Select hour for calculation

The correct hour in the day is selected for calculation. This value starts at 0:00 and increments every time it is revisited until 23:00.

3.2.2.3 Select day for calculation

Select the correct day in the month calculation. This value starts at 1 and increments every time it is revisited until 31.

3.2.2.4 Check whether weekday/weekend day

Check whether the day is a weekday of weekend day. If it is a weekday, proceed to 3.2.2.6; if not proceed to 3.2.2.5.

3.2.2.5 Calculate running percentage for hour (weekend)

The running percentage for an hour on a weekend day is calculated by means of equation 6. For example, if the mill is running for 18 hours in a 24-hour weekend day, it runs 75% per hour and stops 25% per hour on average. This technique is used to lower the optimised baseline evenly for the weekend day.

$$\text{Running } \%(weekend) = \left(\frac{\text{running hours on weekend day}}{24} \right) \times 100 \qquad (6)$$

3.2.2.6 Load shifting

Check whether the load shifting is done on this specific hour of this specific day. If load shifting is applied proceed to 3.2.2.9; if not proceed to 3.2.2.7.

3.2.2.7 Check for planned maintenance

Check whether the planned maintenance is scheduled for this specific hour of this specific day. If planned maintenance is scheduled, proceed to 3.2.2.9; if not proceed to 3.2.2.8. There is an input variable to indicate when planned maintenance should start on a planned maintenance day.

3.2.2.8 *Calculate running percentage for hour (weekday)*

The running percentage for an hour on a weekday is calculated by means of equation 7. This technique is used to apply the effect of breakdown hours, evenly over the weekday. For example, if two hours of load shifting are planned for the day, only 22 running hours are left. If there are four breakdown hours per day, the average time stopped because of breakdowns per hour is 18%. Thus the average time the mill is running per hour is 82%.

$$\text{Running } \%(weekday) = \left[1 - \left(\frac{\text{breakdown hours per day}}{24 - (\text{load shift hours for day} + \text{planned maintenance for day})}\right)\right] \times 100 \tag{7}$$

3.2.2.9 *Make zero*

If load shifting or planned maintenance is scheduled for this hour, the mill must be stopped for this hour. Hence the value for this hour is “0”.

3.2.2.10 *Check whether last day in month*

Check whether it is the last day in the month. If it is, proceed to 3.2.2.11; if not return to 3.2.2.3 and select the next day.

3.2.2.11 *Calculate average hour*

The average hour is calculated by dividing the running percentage of the current hour in each weekday, by the number of weekdays in the month.

3.2.2.12 *Multiply average hour by running capacity*

To obtain a value for the current hour of the optimised baseline, the current average hour is multiplied by the running capacity of the mill.

3.2.2.13 *Check whether last hour of day*

Check whether it is the last hour in the day. If it is, proceed to 3.2.2.14; if not return to 3.2.2.2 and select the next hour.

3.2.2.14 *Draw graph*

Draw a graph using the using the historical baseline and the optimised baseline. An example of the output is provided in Figure 32. The results of the silo level simulation are explained in more detail in section 3.4.2.

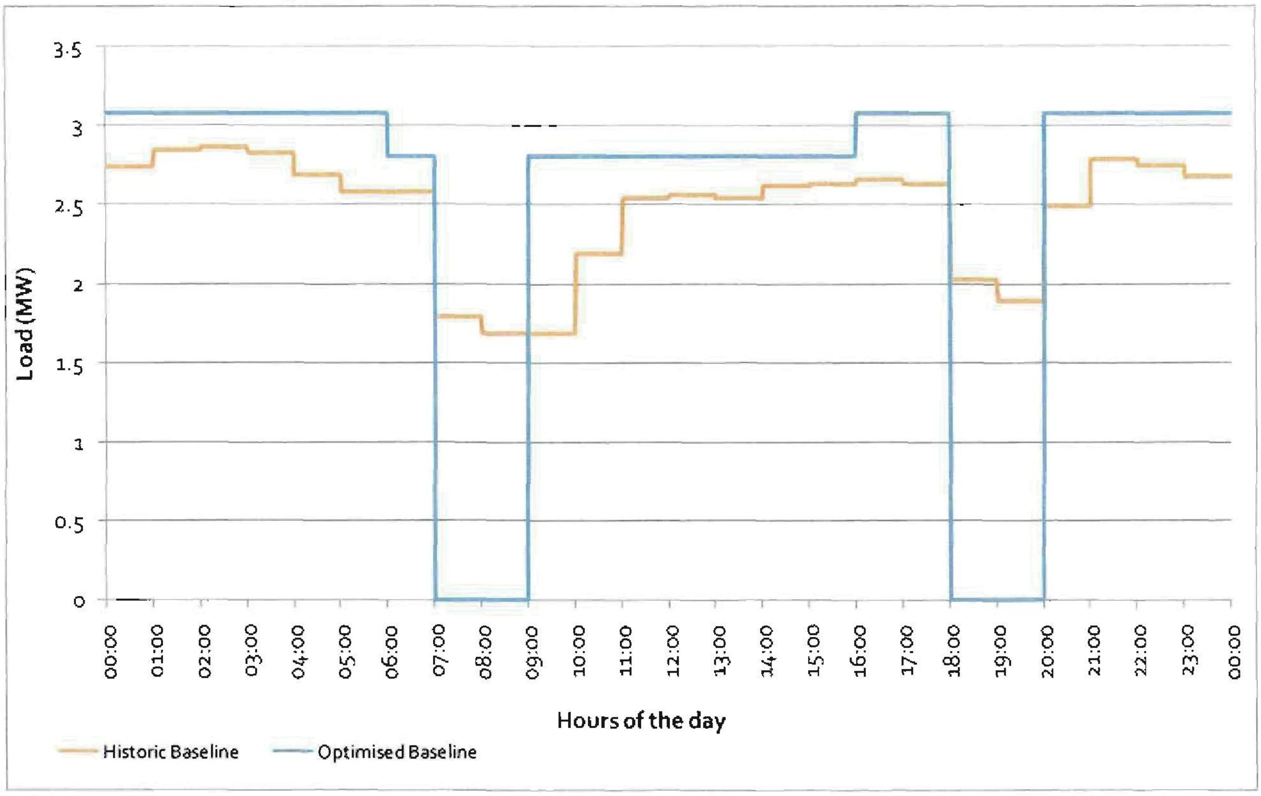


Figure 32 – Historical baseline versus optimised baseline.

3.2.2.15 Calculate load shifting potential

The load shifting potential is determined by using the optimised and historical baselines. The morning peak and evening peak load shifting potential are calculated by means of equation 8.

$$
\begin{aligned}
&\textit{Load shifting per day} = \left[\frac{X}{Z}\right] - \left[\frac{Y}{Z}\right] \\
&\textit{where:} \\
&\quad X = \textit{total load of optimised baseline peak hours} \qquad (8) \\
&\quad Y = \textit{total load of historical baseline peak hours} \\
&\quad Z = \textit{number of peak hours}
\end{aligned}
$$

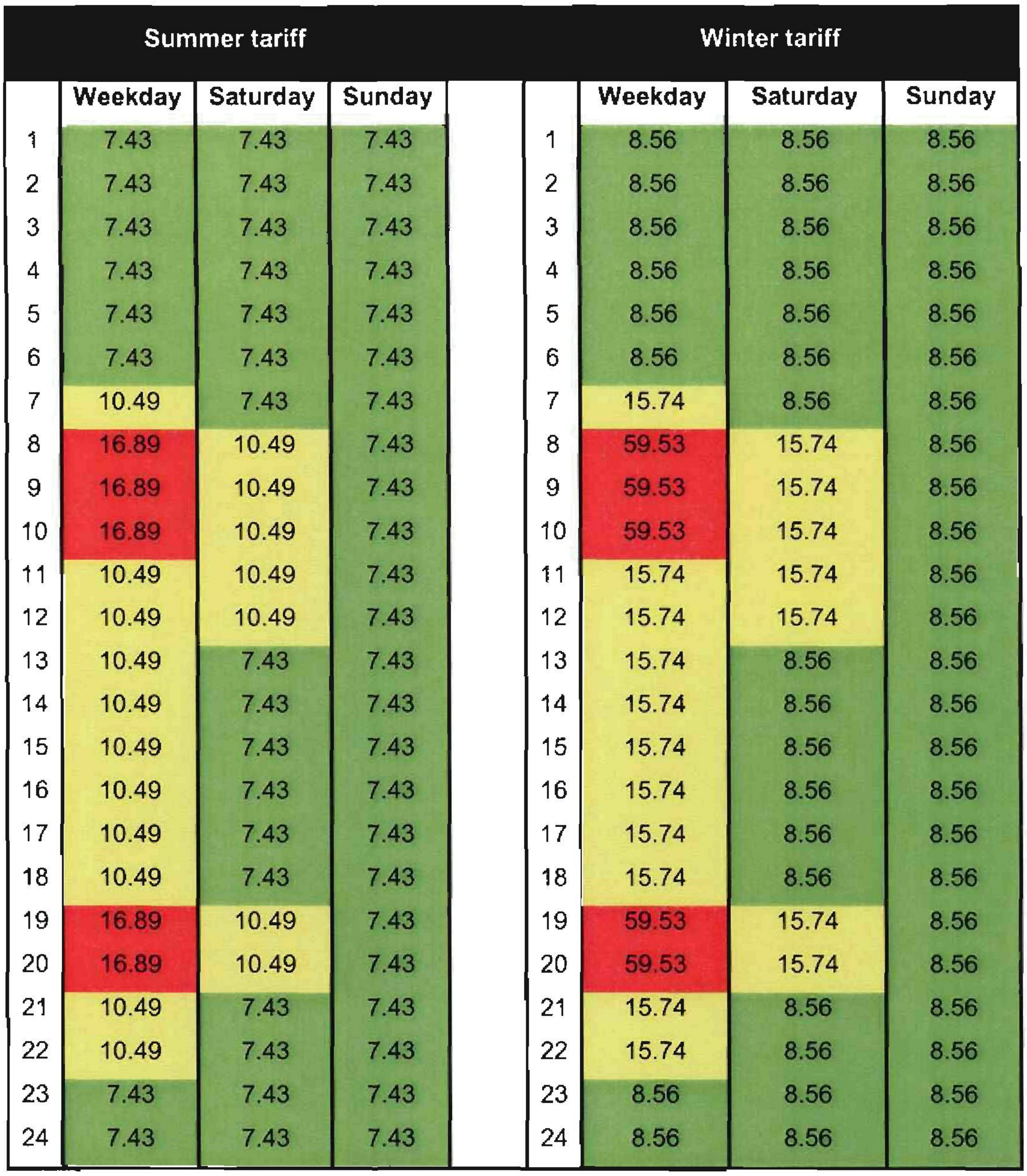
The result is the load shifting potential in both morning peaks and evening peaks.

3.2.2.16 Calculate cost savings

The annual cost saving is calculated using the optimised and historical baselines. Table *4* indicates the winter and summer Eskom electricity tariffs.

When the annual cost saving is calculated, the pricing of the different seasons has to be taken into account. There are no high peak times on weekends.

Table 4 – Eskom megaflex winter and summer tariffs



	Summer tariff				Winter tariff		
	Weekday	Saturday	Sunday		Weekday	Saturday	Sunday
1	7.43	7.43	7.43	1	8.56	8.56	8.56
2	7.43	7.43	7.43	2	8.56	8.56	8.56
3	7.43	7.43	7.43	3	8.56	8.56	8.56
4	7.43	7.43	7.43	4	8.56	8.56	8.56
5	7.43	7.43	7.43	5	8.56	8.56	8.56
6	7.43	7.43	7.43	6	8.56	8.56	8.56
7	10.49	7.43	7.43	7	15.74	8.56	8.56
8	16.89	10.49	7.43	8	59.53	15.74	8.56
9	16.89	10.49	7.43	9	59.53	15.74	8.56
10	16.89	10.49	7.43	10	59.53	15.74	8.56
11	10.49	10.49	7.43	11	15.74	15.74	8.56
12	10.49	10.49	7.43	12	15.74	15.74	8.56
13	10.49	7.43	7.43	13	15.74	8.56	8.56
14	10.49	7.43	7.43	14	15.74	8.56	8.56
15	10.49	7.43	7.43	15	15.74	8.56	8.56
16	10.49	7.43	7.43	16	15.74	8.56	8.56
17	10.49	7.43	7.43	17	15.74	8.56	8.56
18	10.49	7.43	7.43	18	15.74	8.56	8.56
19	16.89	10.49	7.43	19	59.53	15.74	8.56
20	16.89	10.49	7.43	20	59.53	15.74	8.56
21	10.49	7.43	7.43	21	15.74	8.56	8.56
22	10.49	7.43	7.43	22	15.74	8.56	8.56
23	7.43	7.43	7.43	23	8.56	8.56	8.56
24	7.43	7.43	7.43	24	8.56	8.56	8.56

Figure 33 shows the summer megaflex tariffs. If the summer megaflex tariff is compared to the winter tariffs in Figure 34, the daily peak hours in winter are much more expensive than the peak hours in summer.

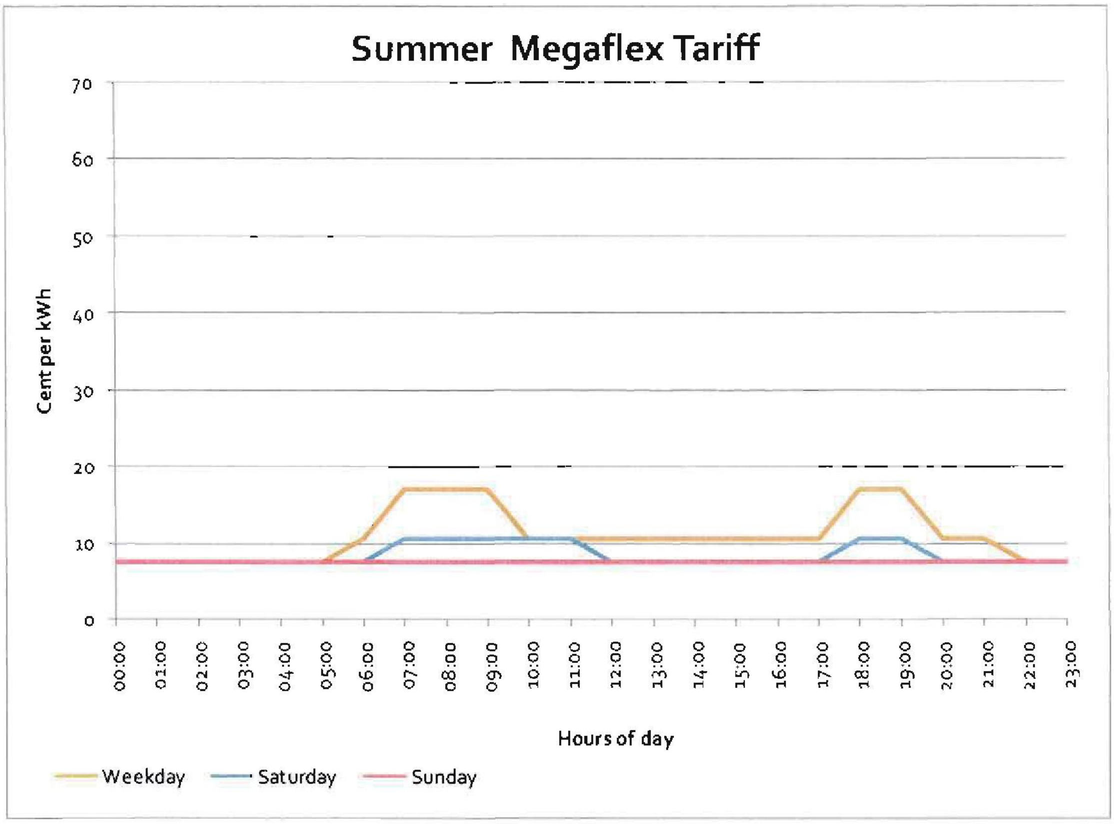


Figure 33 – Summer megaflex tariffs

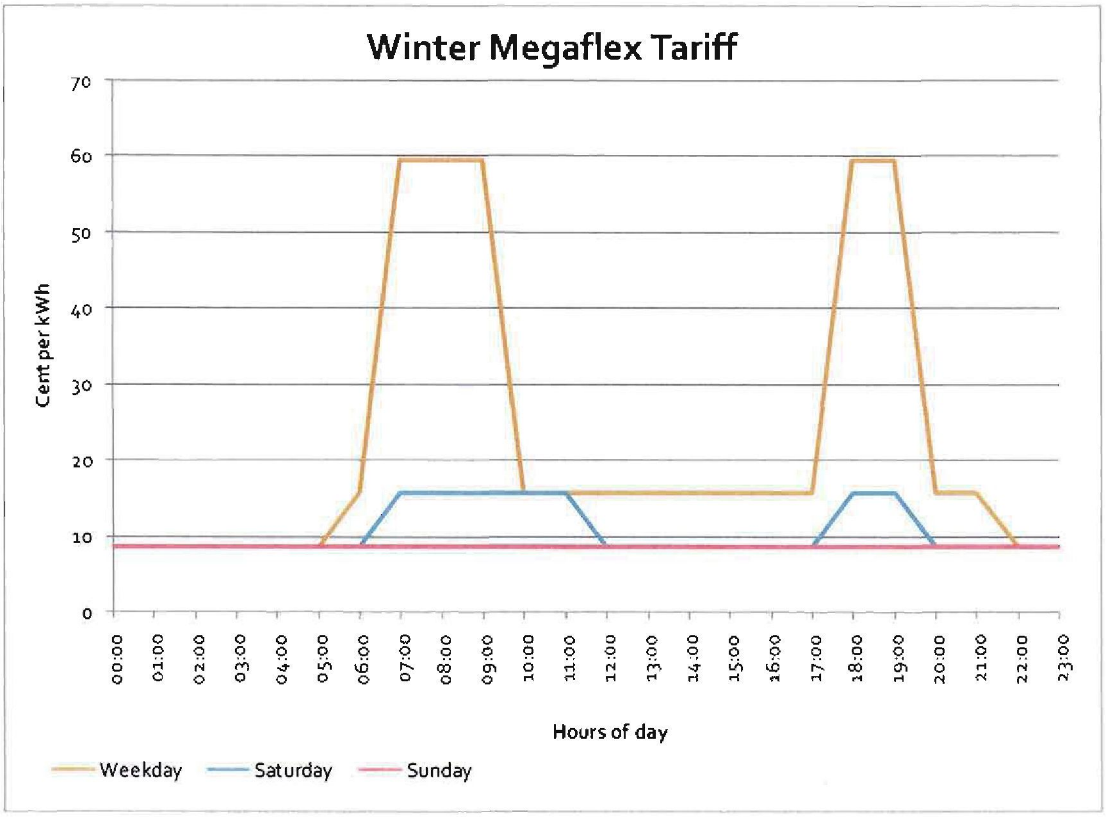


Figure 34 – Winter megaflex tariffs

The winter month costs apply to June, July and August of each year. Summer megaflex tariffs apply to the rest of the year. The total monthly electricity cost for each month is calculated by determining the savings for a weekday, Saturday and Sunday, according to the difference between the baselines.

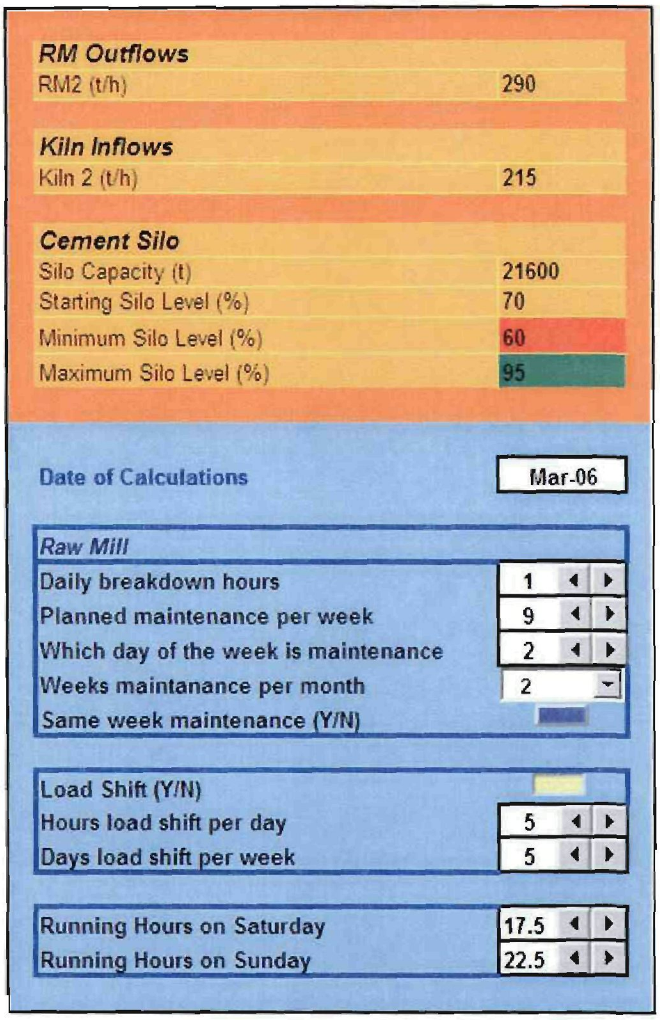
The electricity cost for a weekday, Saturday and Sunday is multiplied by the number of weekdays, Saturdays and Sundays respectively in each month. These three totals are added to obtain the cost saving for each specific month in the year. The 12 months of the year are added up to calculate the annual electricity cost saving.

3.3 SIMULATION MODEL INPUTS

In this subsection, the different input parameters and their functions in the simulation model are explained. The difference between a parameter in the raw milling and finishing milling sections is explained in separate subsections. Figure 35 shows the parameter input of the first part of the simulation model.

3.3.1 Historical baseline

The historical baseline is the average load profile of a component calculated with historical data. The hourly power measurement is used for the calculation. A minimum of six months of data has to be used. The data are captured by a SCADA system on the cement plant. To determine the average daily baseline, an average is calculated for each hour of the day for the period of the data available. This will result in an average 0:00, 1:00 up to an average 23:00. It is necessary to compare the area beneath the historical baseline and the optimised baseline, to verify that they are within an acceptable margin of each other.



RM Outflows
RM2 (t/h) 290

Kiln Inflows
Kiln 2 (t/h) 215

Cement Silo
Silo Capacity (t) 21600
Starting Silo Level (%) 70
Minimum Silo Level (%) 60
Maximum Silo Level (%) 95

Date of Calculations Mar-06

Raw Mill
Daily breakdown hours 1
Planned maintenance per week 9
Which day of the week is maintenance 2
Weeks maintanance per month 2
Same week maintenance (Y/N)

Load Shift (Y/N)
Hours load shift per day 5
Days load shift per week 5

Running Hours on Saturday 17.5
Running Hours on Sunday 22.5

Figure 35 – Inputs to the RM silo simulation

3.3.2 Mill flow rate

The mill flow is the rate of material flow through the mill per hour and is a vital parameter in the simulation model. A faster material flow through the mill enhances the opportunity for load shifting in peak hours. This can lead to a larger build-up of material in the mill if the inflow of the kiln remains the same. The mill flow rate can be determined by means of equation 9.

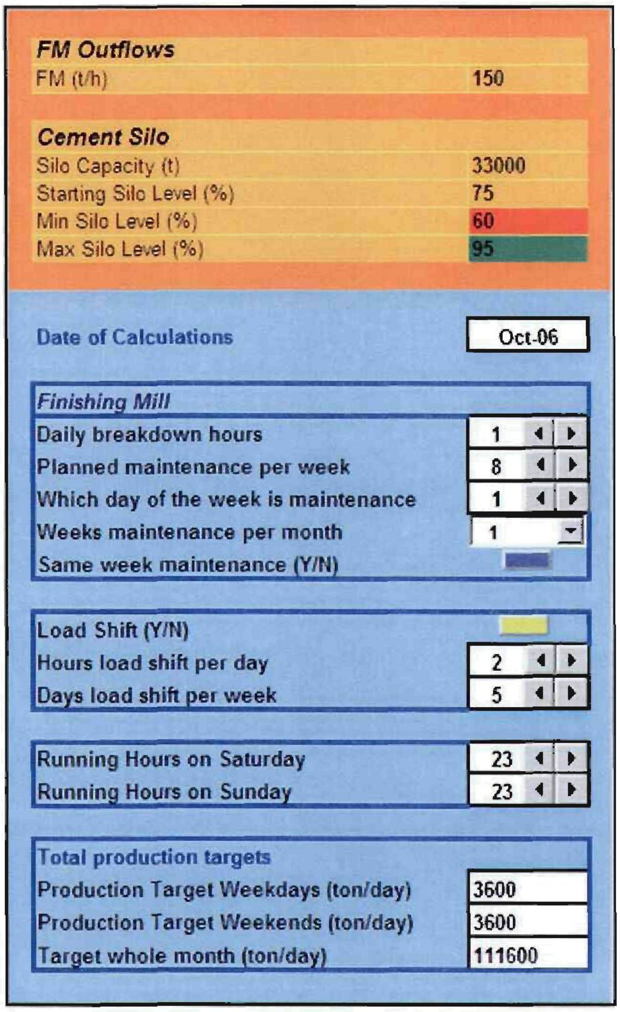
$$\text{Average flow rate } (t/h) = \frac{\text{Daily material produced } (tons)}{\text{Daily running hours}} \qquad (9)$$

The flow data are obtained either from a SCADA system or logbooks. The SCADA system logs data in short time intervals in an electronic format. Plant operators record the data in logbooks. These data are not updated as frequently as the electronic data. When this information is not obtainable, the daily material coming from or feeding into the machine can be measured. If it is still not possible to obtain the flow rate, employees on the plant can be consulted.

3.3.3 Kiln flow rate

The kiln obtains material from the raw material silo, processes it and provides clinker to the clinker silo. As stated previously the kiln flow rate is the slowest component in the cement process. The kiln's running hours are directly linked to production each month. Each hour stopped means that the process did not produce clinker for that hour, and this means a loss in production.

The difference between the mill and the kiln flow rates indicates the viability for load shifting. If the difference in flow rate is large the raw material silo will fill up requiring the raw mill to be stopped for more hours during the month. These stoppage hours can be scheduled in peak hours.



FM Outflows	
FM (t/h)	150
Cement Silo	
Silo Capacity (t)	33000
Starting Silo Level (%)	75
Min Silo Level (%)	60
Max Silo Level (%)	95
Date of Calculations	Oct-06
Finishing Mill	
Daily breakdown hours	1
Planned maintenance per week	8
Which day of the week is maintenance	1
Weeks maintenance per month	1
Same week maintenance (Y/N)	🟦
Load Shift (Y/N)	🟨
Hours load shift per day	2
Days load shift per week	5
Running Hours on Saturday	23
Running Hours on Sunday	23
Total production targets	
Production Target Weekdays (ton/day)	3600
Production Target Weekends (ton/day)	3600
Target whole month (ton/day)	111600

Figure 36 – Inputs to the finishing mill silo simulation

3.3.4 Daily production target

The daily production target is the amount of cement the packaging plant has to package per day. Figure 36 provides an example of the daily production target input. This input variable only applies to the finishing mill simulation.

3.3.5 Silo capacity

The material silos are between the raw mill and the kiln. The silo capacity is the total storage after the mill. The cement silos which store the cement produced by the finishing mill are between the finishing mill and the packaging plant.

The silos provide a buffer between the raw mills and the kiln or the finishing mills and the packaging plant. The larger the buffer the easier it will be to stop in scheduled peak times. Storage capacities range from 10,000 tons to 25,000 tons per section. If for example the raw mill keeps the silo level near full and the supply line is stopped for the five peak hours of the day, there will be sufficient material in the silo for the kiln to continue operation for these five hours. This information can be obtained by viewing the plant schematics or the SCADA system.

3.3.6 Starting silo level

The starting level of the silo is important. It provides a reference to work from at the beginning of the month. From here the difference between the material entering the silo and material leaving the silo per day, will be added to the starting silo level. This enables the current month's simulation to carry on from the end of the previous month's silo level. By linking the simulations for each month, the silo level for a whole year can be obtained.

3.3.7 Minimum and maximum silo levels

The plant operators specify the minimum and maximum permitted silo level. The material in the silo must remain between these levels. In the simulation the silo level must be kept between these two constraints in order to gain approval for a DSM project.

The maximum and minimum silo levels are expressed in percentages of the total silo capacity. The maximum and minimum levels specified by the plant are usually close to these values between 85 and 40% respectively.

3.3.8 Date of simulation

The date of the simulation is inserted because the number of days and hours of plant operation in a month varies from month to month and even from year to year. The weekdays, Saturdays and Sundays in each month also differ from one year to the next. The simulation can therefore be done for any specific month of a specific year.

3.3.9 Daily breakdown hours

Breakdown hours are unscheduled unexpected stops of the mill due to a breakdown of one or more of the components directly or indirectly linked to the mill. The SCADA system usually logs the historical breakdowns of a specific plant. The reason for the breakdown, duration and which components were stopped because of this breakdown are included in this information.

The average daily breakdown number of hours can be calculated from the historic breakdown data over the period of a few months. Breakdowns must be integrated into the simulation to account for real life situations. The average daily breakdown hours are included in the total stopped hours of the day.

3.3.10 Planned maintenance

Planned maintenance is a predetermined stop during which maintenance is performed on the mill and its components. This can occur between one and four times per month, for up to 10 hours per maintenance stop.

Each plant has its own schedule for planned maintenance, and there may also be differences between the raw milling and the finishing milling sections. An example of planned maintenance could be the relining the raw mill. Planned maintenance should also be included in the daily stopped hours when it occurs.

3.3.11 Load shifting per day

Load shifting involves the number of hours stopped during the peak electricity tariff per day. The morning peak hours range from 07:00 to 10:00 and the evening peak from 18:00 to 20:00. This allows for a total of five hours that can be stopped per day for load shifting.

The evening peak hours are the most important. If there is only scope to stop two hours per day for load shifting, the mill will be stopped in the two evening peak hours, because the evening peak on the Eskom baseline is much higher than the morning peak, as shown in Figure 11.

When there is an opportunity to stop the mills for more than two hours per day, the hours during the morning peak can be used. The total number of hours stopped for load shifting are also added to the total number of stopped hours per day.

3.3.12 Days of load shifting per week

This input specifies the number of weekdays available for load shifting in each week. The silo level can be improved in the month if extra running hours can be added to the milling hours each week. This occurs when one or two hours of load shifting each weekday have a negative influence on the silo level over the period of a month.

3.3.13 Running hours on weekends

Over weekends, the material capacity, lost during the week on account of load shifting, can be gained. There are no peak hours on Saturdays and Sundays. This affords the mills an opportunity to run the maximum number of hours possible during the weekend. This will be 48 hours minus the average number of breakdown hours for the two days.

3.3.14 Running capacity of mill

The running capacity of the mill can be defined as the electricity usage of a specific mill when running at under normal circumstances. The running capacity is usually less than the installed capacity of the mill motors. This variable is obtained by calculating the average electricity used by the specific mill per running hour over the period of a month or a year.

3.3.15 Eskom megaflex electricity tariffs

The Eskom electricity tariffs are obtained from the Eskom website. The megaflex tariff structure is usually used by cement plants in South Africa. In the megaflex tariff structure, the peak hours during weekdays are very expensive as shown in Figure 12, Figure 33 and Figure 34.

The daily cost saving is calculated by multiplying the number of hours stopped for the load shifting and the tariff for those hours. As can be seen in Figure 33 and Figure 34, there is a difference in electricity costs between summer and winter seasons. When the annual savings are calculated, this must also be taken into account.

When all the relevant inputs have been obtained and fed into the simulation, the simulation model will calculate and generate the required outputs. Simulation results are discussed in detail in the following section.

3.4 SIMULATION RESULTS

The simulation model produces several results that are used to determine the viability of load shifting for a cement plant. These results are used to motivate the implementation of a DSM project. A list of the results produced by the simulation is provided below:

- silo level projected over the period of a month
- silo throughput tonnage per month
- average silo ton throughput per day
- optimised baseline versus the historic baseline
- morning load shifting potential
- evening load shifting potential
- annual electricity cost saving

These results produced by the simulation model are explained in detail in the sections below.

3.4.1 Silo level simulation

The output of the silo level simulation model provides an estimation of what the silo level will look like for each day in a specific month, with all the factors of the above inputs having their own impact on the outcome.

The silo levels of both the silos are a key factor in the cement production process. If a silo is empty, the production of critical components following the silos is forced to stop. This may influence production negatively.

As explained earlier, it the silos should never be empty. When DSM is applied to the milling section, the impact of the new load shifting schedule on the silo level is of importance. A small alteration in the number of load shifting hours per day can easily drive the silo to empty or to overflow.

The simulation of the silo level is done over the period of a month because of the fluctuations experienced as a result of planned maintenance occurring one to four times each month, and the difference in milling schedules between weekdays and weekends. Using this model, a silo level can also be done for each specific month of the year and added up to acquire a proposed silo level for an entire year.

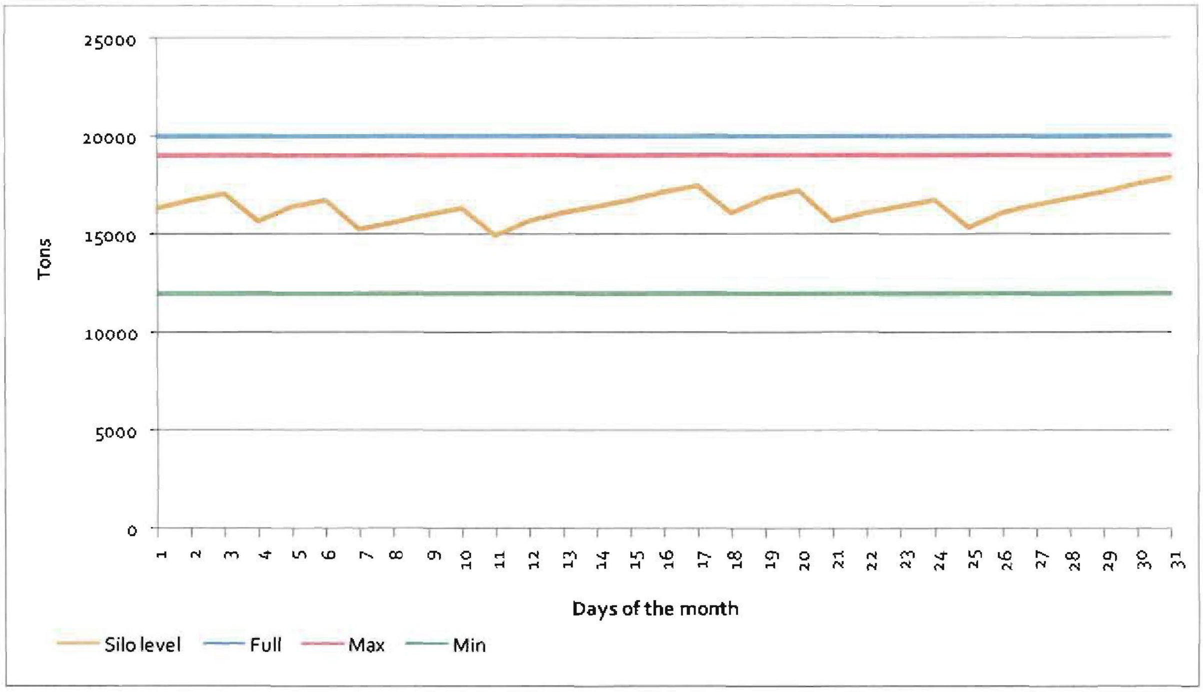


Figure 37 – Raw mill silo simulation

Figure 37 shows the silo level output of the silo simulation model. The X-axis represents the number of tons in the silo. The Y-axis is the days of the month. The blue line represents the silo's maximum capacity. The red and green levels show the maximum and minimum permissible levels of the silo specified by the cement plant operators. The silo level should remain between these two levels. The yellow line represents the simulated silo level for each day of the month.

The starting level of the silo on day one is obtained from the level on the last day of the previous month. From there, the difference in tons left in the silo each day is calculated and added to the previous day. The new silo level can be obtained from this calculation.

Figure 38 is an example of a silo level, which falls below the minimum required level on the sixth day of the month. If the trend is allowed to continue the silo will become empty by the following month.

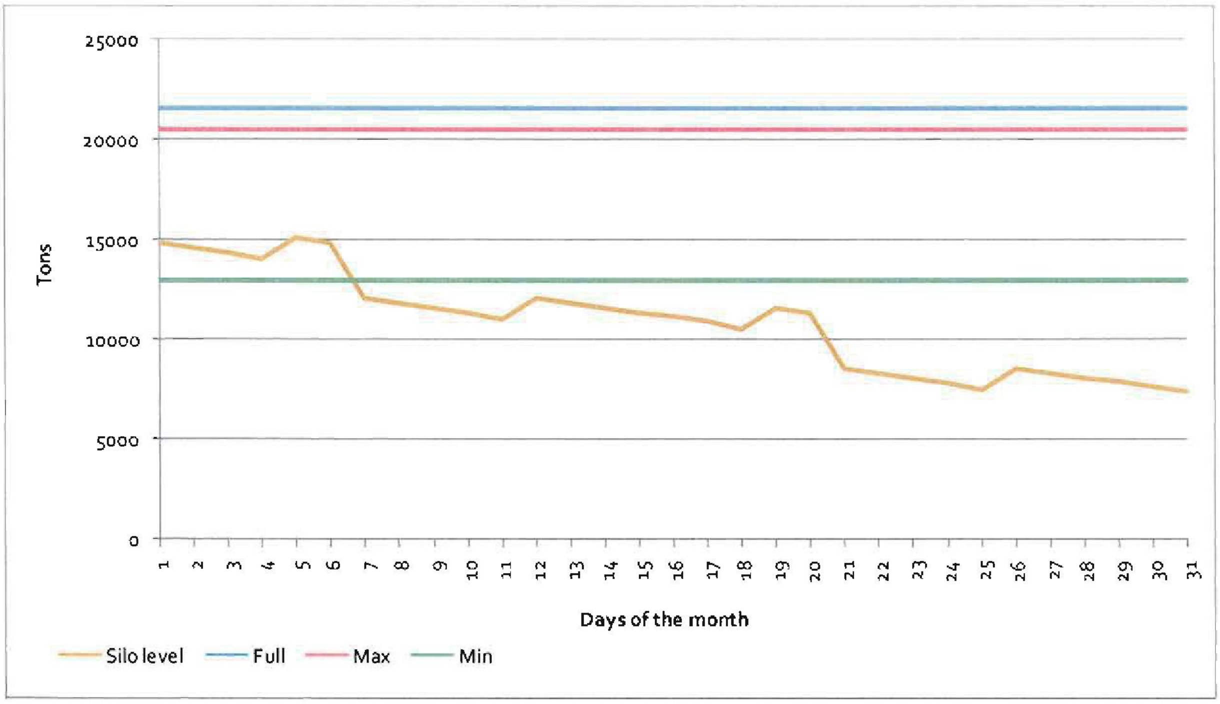


Figure 38 – Falling raw material silo level

Figure 39 is an example of a silo level that reaches a maximum silo level on the twelfth day of the month. If this occurs, the raw mill must be stopped. In this case there is ample opportunity to stop the mill during peak hours for load shifting.

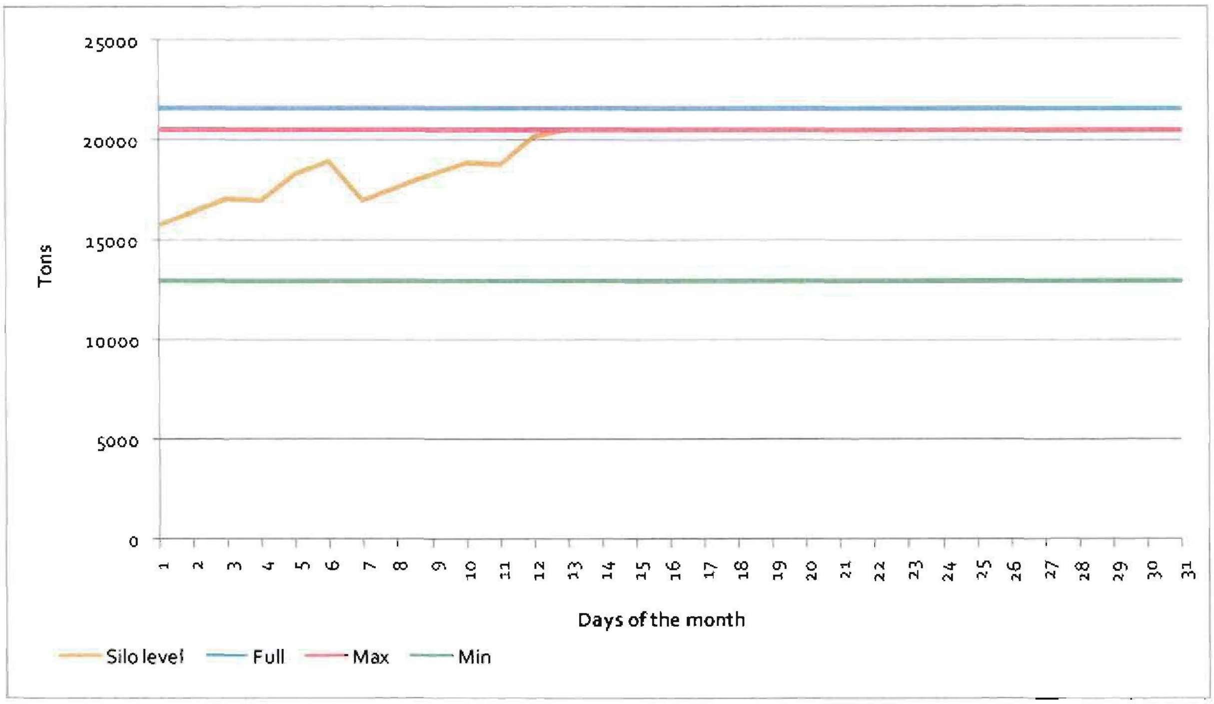


Figure 39 – Rising silo level to full capacity

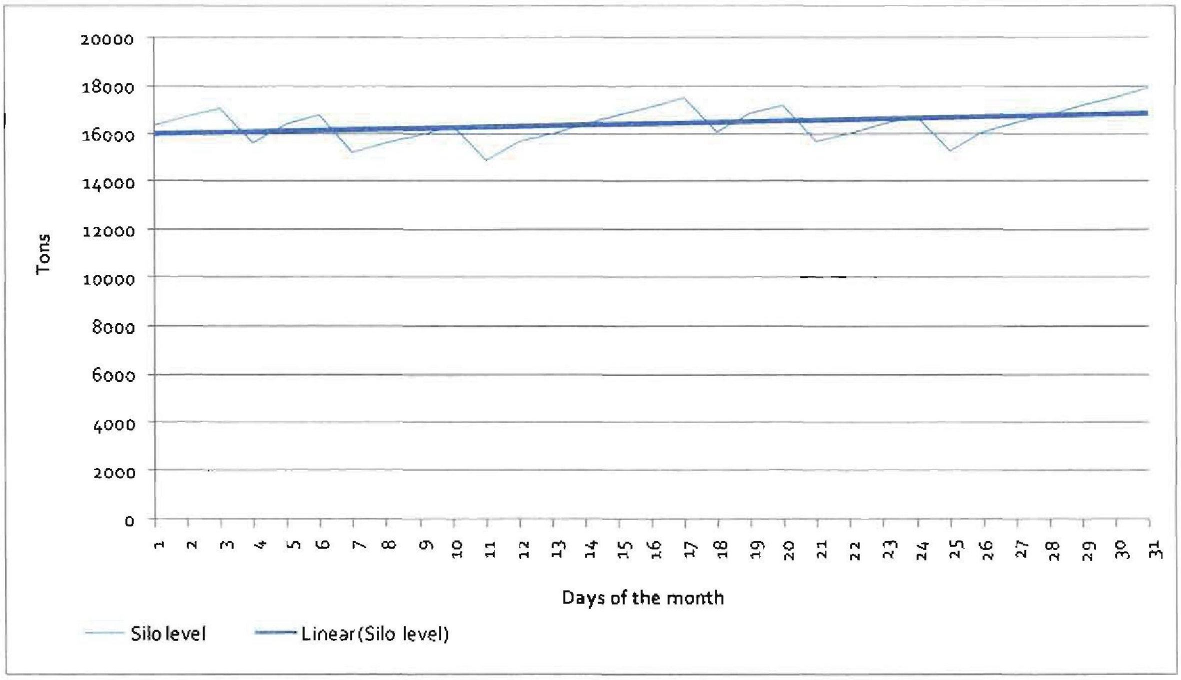


Figure 40 – Silo level trend line.

Figure 40 shows a trend line of the proposed silo level for the specific month. The trend line is ideal when its gradient is greater than 0. In both milling sections, it is safe if the trend line rises in the same way as the example in Figure 40. If the trend line rises sharply, there is an opportunity for more load shifting capability. The same principles can be applied to the finishing mill simulation.

Other outputs received in this part of the simulation are the total tonnage passing through the silo in that month, and the average ton throughput per day. These can be compared with the existing tonnage throughput of the silos to calculate whether there will be any loss in production.

3.4.2 Optimised baseline and calculated savings

Outputs of the second part of the simulation are the historical baseline versus optimised baseline, as depicted in Figure 41. The load shifting potential and the annual cost savings that can be realised with this schedule are also part of this output data.

The historical baseline, calculated from actual mill running capacity data, shows the average electricity used by the mill during a typical weekday. The x-axis represents the hours of the day and the y-axis represents the electricity used by the mill.

The historical baseline is much lower than the mill's possible running capacity because of stoppages that occurred throughout the day, which were integrated into the average historical daily baseline. The average daily electricity power profile in the baseline indicates that this specific cement plant tried to implement load shifting manually. This is evident in the slightly lower baseline during the peak times of the day.

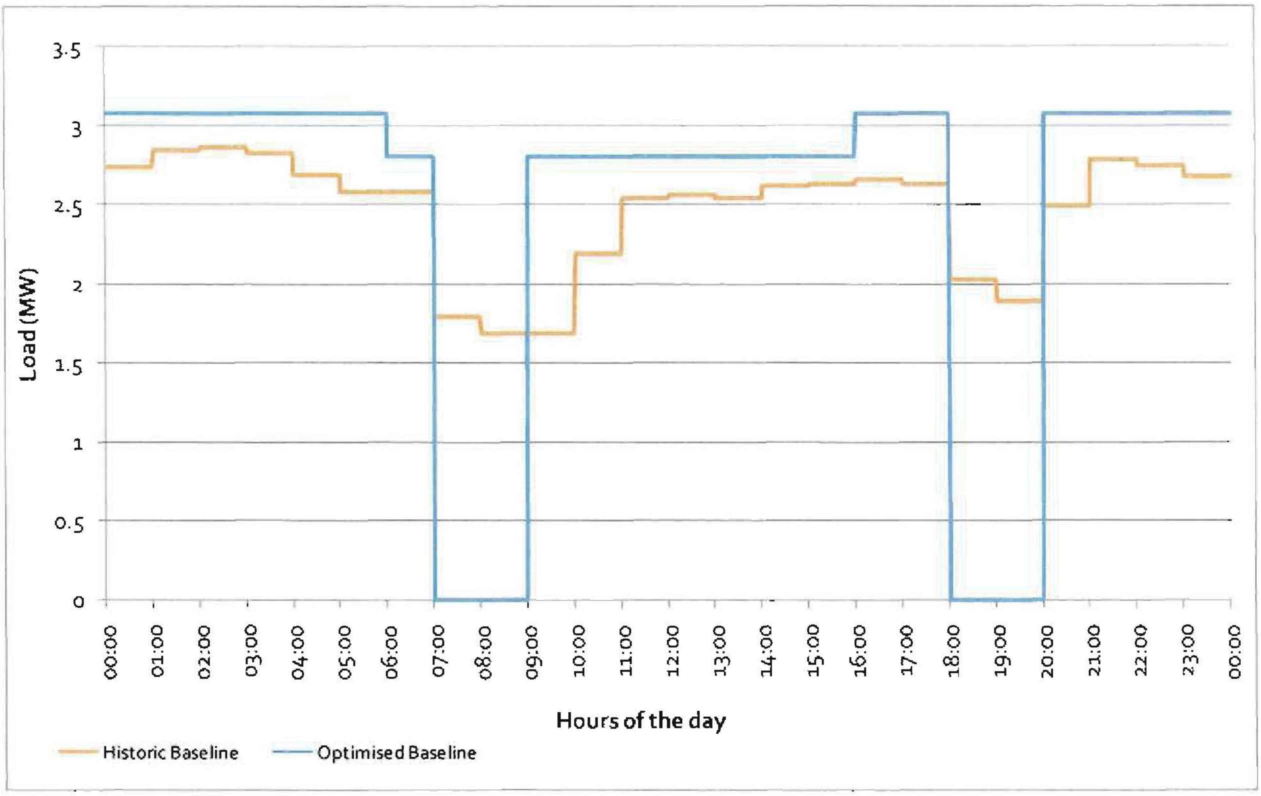


Figure 41 – Historical baseline versus optimised baseline

The optimised baseline illustrates an improved way in which the mill can be operated. Figure 41 shows that the optimised baseline during off-peak hours is much higher than the highest peak of the historical baseline. The sudden drop of the optimised baseline from 06:00 until 16:00 shows the 10 hours planned maintenance that occurs once each week. In the historical baseline, planned milling stops occurred during the day. These periods of planned stops can be scheduled for the peak hours when electricity is expensive.

To realise the opportunity for load shifting a new milling schedule, provided by the simulation model, will have to be implemented. The schedule is viable when the silo level is within the given constraints throughout the month, and the area beneath the historical baseline and optimised baseline is equal.

The area under each baseline represents the amount of work done by the mill. When the areas beneath these two baselines are the same, the mill processed an equal amount of material with both schedules. When the area under the optimised baseline is greater than the area under the historical baseline it implies that there was an increase in production. It is critical to the success of the project that the area under these two baselines is equal or that the area under the optimised baseline is greater to ensure that production is not influenced in a negative way.

The morning and evening load shifting potential is calculated by the average of the difference in MW between the two baselines for each hour of that specific peak period. The annual cost savings are calculated from the difference between the areas of the two baselines.

3.5 SIMULATION VERIFICATION

The simulation model must be verified to ensure that it delivers acceptable results, so that it can be used in the industry. The verification was done with the data from October 2005 of the raw milling section at a specific cement plant.

The silo level simulation, which is the main part of the simulation model, is verified by using actual historical data retrieved from the raw milling section on a cement plant. The actual silo level is not available because of constraints in measuring the silo level accurately on a constant basis. The detailed verification procedure is explained below. The following data were used in the verification:

- daily tonnage material produced by the raw mills
- daily clinker produced by the kilns
- stop logs from the raw mills and the kilns
- daily average output flow rate of the raw mills

Only the data from the first 28 days of October 2005 were used, because some of the data needed for verification were not logged on the last three days of the month. Figure 42 shows the basic layout of the raw milling section from which the data were retrieved.

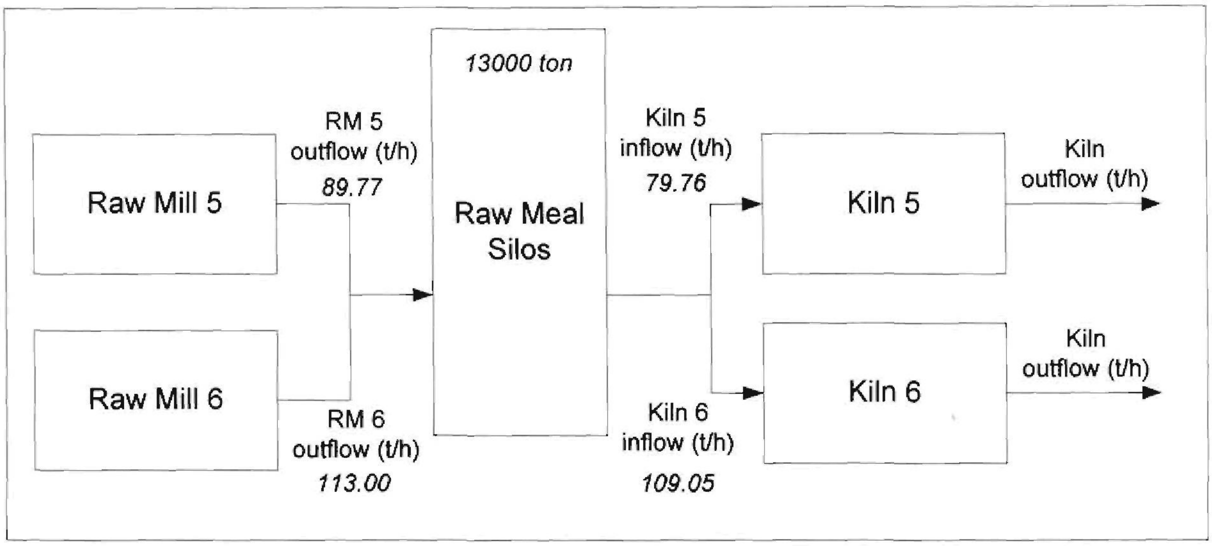


Figure 42 – Layout of the raw milling section

This raw milling section has two raw mills feeding material to common silos, and two kilns extracting material from the same silos. To apply the data to the simulation model, the section must be simplified as shown in Figure 43. The combined raw mill represents the effect of the two raw mills on the section, while the combined kiln represents the effect of both kilns on the section.

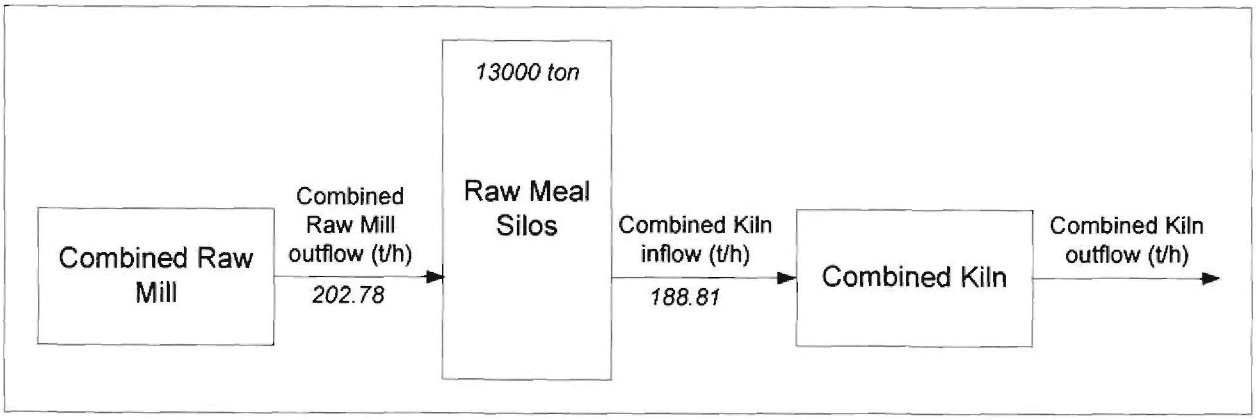


Figure 43 – Layout of the combined raw milling section

The stop logs are a database of all the stoppages that occurred during a month. This include both breakdowns and planned maintenance hours. The total number of hours stopped per day can be calculated by using the stop logs. In October 2005 the total number of stopped hours by the raw mills was 135.1. Both raw mills made the following planned maintenance stops:

Table 5 - Planned maintenance stops

Date	Hours stopped RM5	Hours stopped RM6	Weighted average combined RM
7 October 2005	*8.7*	*8.3*	*8.48*
13 October 2005	*9.3*	*9.3*	*9.30*
18 October 2005	*0*	*10.0*	*5.57*
25 October 2005	*10.0*	*10.0*	*10.0*

Table 5 shows the planned maintenance for both raw mills. To calculate the planned maintenance stops for the combined raw mill, the weighted average of the planned maintenance stops for each day is calculated. The average breakdown hours per day is needed for simulation input, and is calculated with a weighted average of the daily breakdown hours of both raw mills. The average breakdowns for the combined raw mill are 1.44 hours per day. The weights used for these averages are calculated by using the flow rates of both raw mills.

The outflow of the raw mills is calculated by taking an average of all the raw mill flow rates measured each day. The combined raw mill output flow rate is calculated by adding the average output flow rate of raw mill 5 to the average output flow rate of raw mill 6 output flow rate. The combined raw mill output flow rate low was 202.78 tons per hour. The clinker output by both kilns for each day was provided in the data received. To obtain the combined clinker produced per day, the clinker output of kiln 5 is added to the output of kiln 6. The clinker output of the kiln is approximately 66% of the material feeding the kiln.

$$\text{Kiln input}\,(tons) = \frac{\text{Daily kiln output}\,(tons)}{0.66} \qquad (10)$$

The daily kiln input tonnage is calculated by means of equation 10, and the average kiln inflow of the month is calculated by means of equation 11. The daily input tonnage of each kiln is calculated and then added together to determine the daily input tonnage of the combined kiln. The input flow rate of kiln 5 is 79.76 tons per hour and kiln 6 109.05 tons per hour. Hence the combined silo input difference in flow rates between the combined raw mill and combined kiln was -13.96 tons per hour, indicating a decline in material in the silo.

$$\text{Kiln inflow } (t/h) = \frac{\text{average daily kiln input } (tons)}{24} \quad (11)$$

The following parameters, calculated by using the historical data, are then applied as inputs to the simulation model:

Table 6 – Input parameters to the simulation for verification

Parameter	Value
Combined raw mill output flow rate (t/h)	*202.78*
Combined kiln input flow rate (t/h)	*188.81*
Silo capacity (tons)	*13000*
Silo starting level (%)	*70*
Date of calculations	*Oct '05*
Daily breakdown hours	*1.44*
Planned maintenance week 1	*8.48*
Planned maintenance week 2	*9.30*
Planned maintenance week 3	*5.57*
Planned maintenance week 4	*10.0*
Load shifting	*None*

The simulation calculates the simulated ending silo level of each day of the month. This simulated silo level must be compared with the historical silo level for the same month. The historical silo level for each day was calculated by means of equation 12, using the historical data.

$$\begin{aligned}\text{Ending silo level}(tons) = {} & \text{silo level of previous day} + \text{tons produced by combined RM} \\ & - \text{tons consumed by combined kiln}\end{aligned} \quad (12)$$

The result is the historical ending silo level for each day of the month.

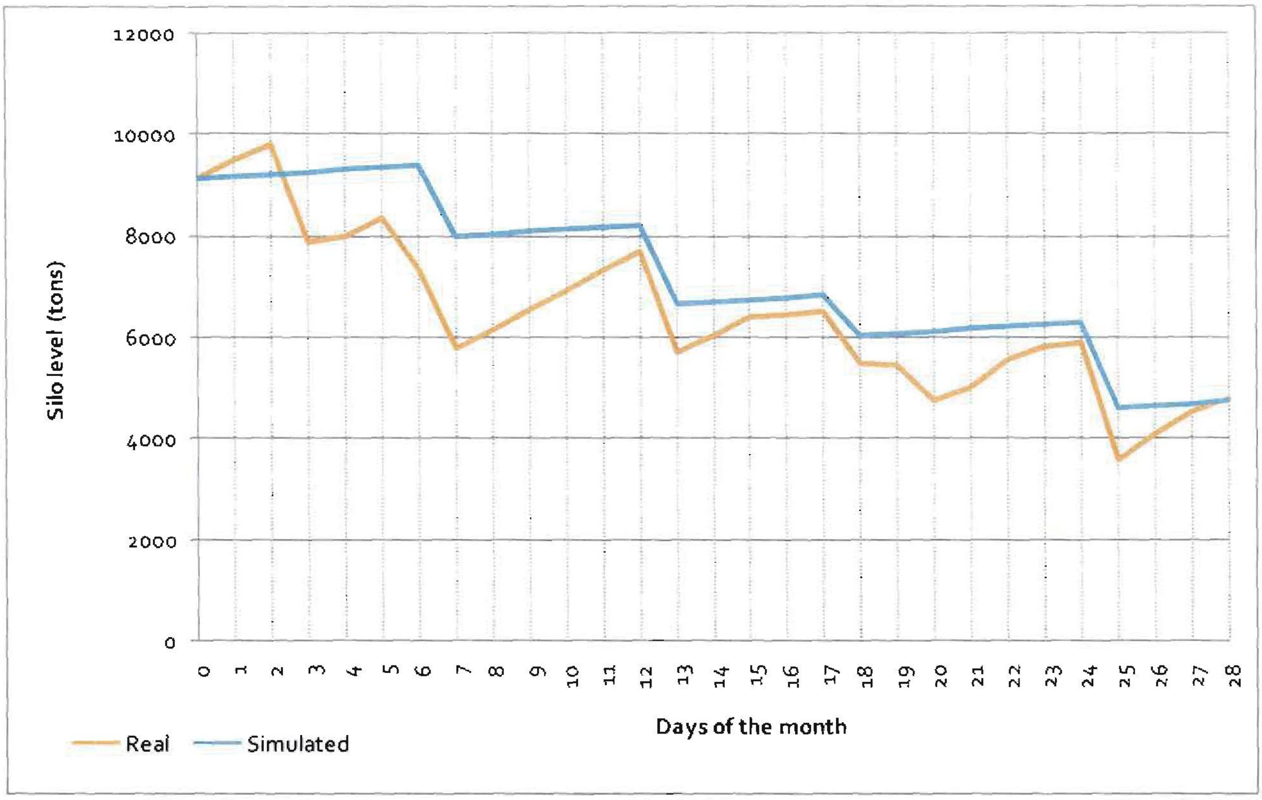


Figure 44 – Historical versus simulated silo levels

Although there is no scope for a DSM load shifting project on this raw milling section, it is still a suitable situation on which to verify the simulation.

The results of the verification are shown in Figure 44. The actual historical silo level and the simulated silo level end within a 1.4% margin of each other, which is acceptable for the purpose of the simulation model. The sharp decline in the silo level four times a month on the simulated silo level can be compared with the four sharp drops in the actual silo level. This is a result of the monthly planned maintenance schedule.

In Figure 45 the trendlines of both the actual historical silo level and the simulation silo level are compared. The gradient of the silo level trendlines shows that the silo levels are decreasing. The gradients are within acceptable limits of each other.

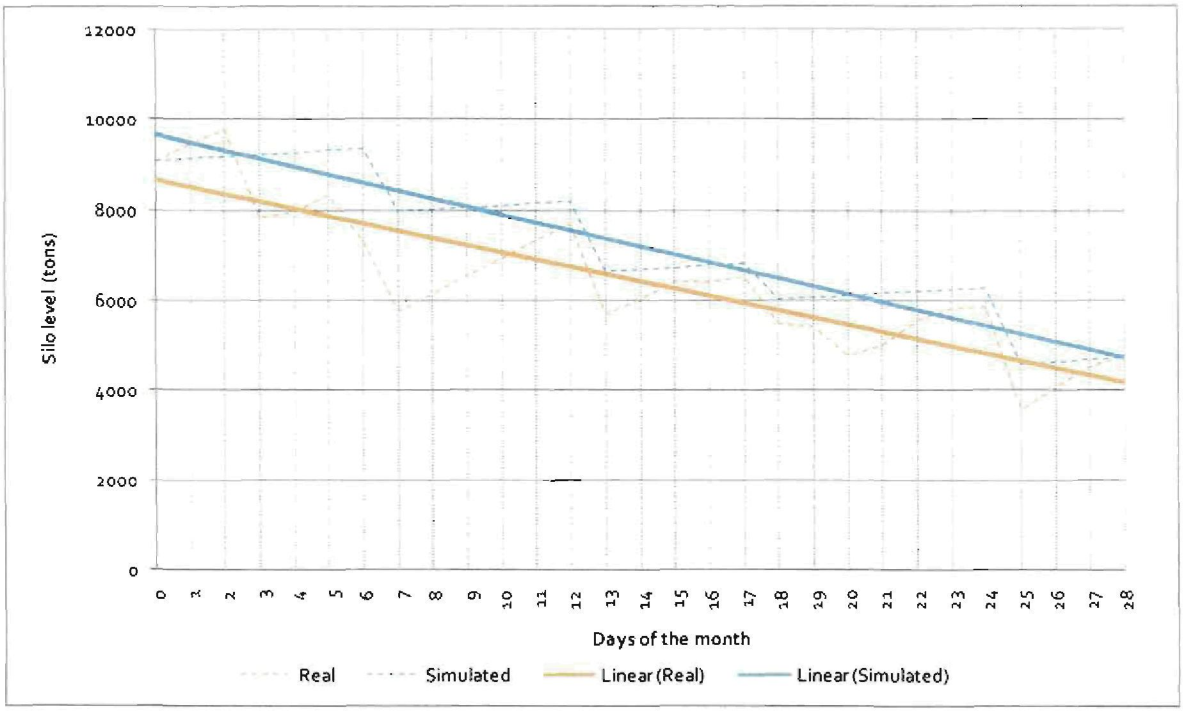


Figure 45 – Historical versus simulated silo level trendlines

Comparing the simulated tons of material produced and the actual tons of material produced by the raw mills is a second technique to verify the simulation. In October 2005, the actual historical tons produced by raw mill 5 was 54,984 and raw mill 6 67,580. This is a total of 122,564 tons for October. The simulated monthly tons produced by the combined raw mills are 122,497. These two values are within 0.05% of each other, which is acceptable for this simulation model.

The verification of this simulation model shows that the simulation gives an acceptable representation of the silo level. If all input parameters are accurate, the model will simulate the levels of the silo accurately, and the effects of load-shifting on the silo level can accurately be determined.

3.6 CONCLUSION

The simulation model provides an accurate simulated silo level with load shifting potential and annual cost savings as an output. For the simulation to calculate this output a set of information obtained from the specific cement plant is used. The credibility of this information is of vital importance for a correct simulation output.

The verification of the simulation shows that the simulation is accurate. The simulated silo level, load shifting potential and annual cost savings will confirm whether or not a DSM project is viable at a specific cement plant.

CHAPTER 4

CASE STUDIES: APPLYING THE SIMULATION MODEL

4.1 INTRODUCTION

In this chapter, the simulation model is applied to different cement plants across South Africa. The case studies are divided into two sections. The first set of case studies is applied to the raw milling sections of different plants, and the second set on different finishing milling sections.

For confidentiality purposes the names and particulars of the different cement plants may not be disclosed. The different cement plants will be referred to as Plant A, Plant B, Plant C and Plant D.

4.2 CASE STUDIES: RAW MILLS

In the raw milling section, the simulation model is applied to two plants. The specific input values to the simulation are given, and the results of the simulation are explained in detail.

4.2.1 Plant A

This simulation model was applied to a raw mill of Plant A. The parameters used as input to the simulation are listed in Table 7.

Table 7 – Raw mill case study 1: parameters

Parameter	Value
Raw mill outflow (t/h)	*290*
Kiln inflow (t/h)	*215*
Silo capacity (tons)	*21,600*
Silo starting level (%)	*70*
Silo maximum level (%)	*95*
Silo minimum level (%)	*60*
Date of calculations	*March '06*
Daily breakdown hours	*1*
Planned maintenance hours per week	*9*

Day of planned maintenance in week	*Tuesday*
Number of weeks planned maintenance per month	*2*
Hours load shift per day	*5*
Days load shift per week	*5*
Running hours on Saturday	*17.5*
Running hours on Sunday	*22.5*
Running capacity of mill	*3.1 MW*

Figure 46 shows the simulated silo level for Plant A. The silo level rises slowly and remains within the maximum and minimum silo levels specified by the plant operators. At this plant, there is a full five hours of load shifting potential per weekday without having a negative effect on production.

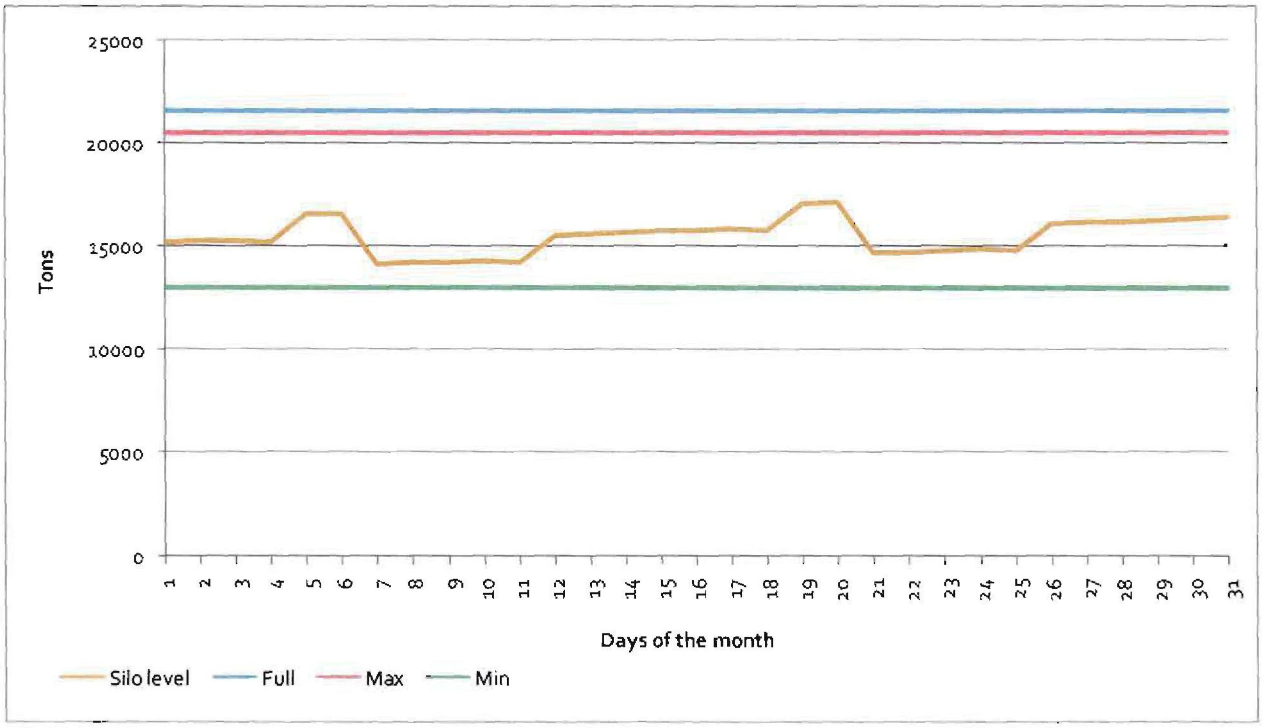
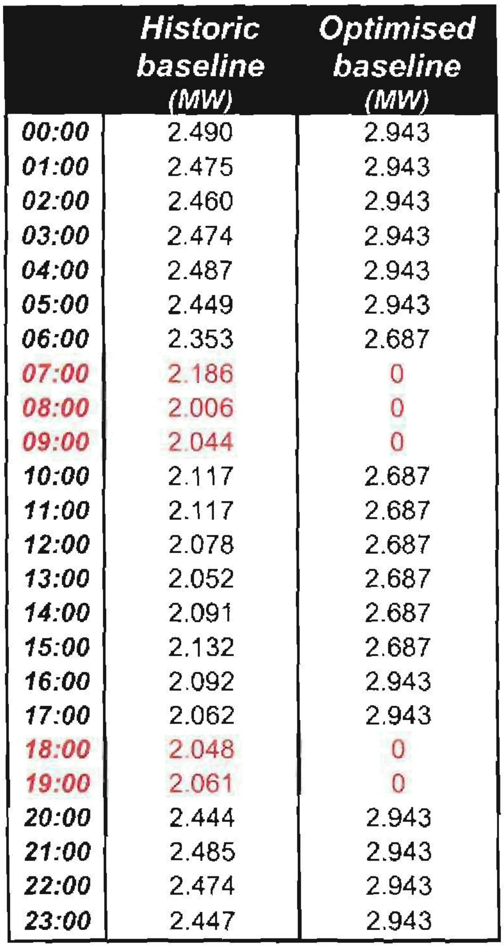


Figure 46 – Plant A raw mill silo simulation

The increasing trend in this silo level allowed for three of the load shifting hours in the morning peak between 07:00 and 10:00, and two hours in the evening peak between 18:00 and 20:00.

Table 8 – Plant A raw mill baseline comparison



	Historic baseline (MW)	Optimised baseline (MW)
00:00	2.490	2.943
01:00	2.475	2.943
02:00	2.460	2.943
03:00	2.474	2.943
04:00	2.487	2.943
05:00	2.449	2.943
06:00	2.353	2.687
07:00	2.186	0
08:00	2.006	0
09:00	2.044	0
10:00	2.117	2.687
11:00	2.117	2.687
12:00	2.078	2.687
13:00	2.052	2.687
14:00	2.091	2.687
15:00	2.132	2.687
16:00	2.092	2.943
17:00	2.062	2.943
18:00	2.048	0
19:00	2.061	0
20:00	2.444	2.943
21:00	2.485	2.943
22:00	2.474	2.943
23:00	2.447	2.943

Table 8 shows the results obtained from the second part of the simulation model. It also shows the historical baseline calculated from actual data. The red highlighted values in Table 8 indicate where load shifting is applied.

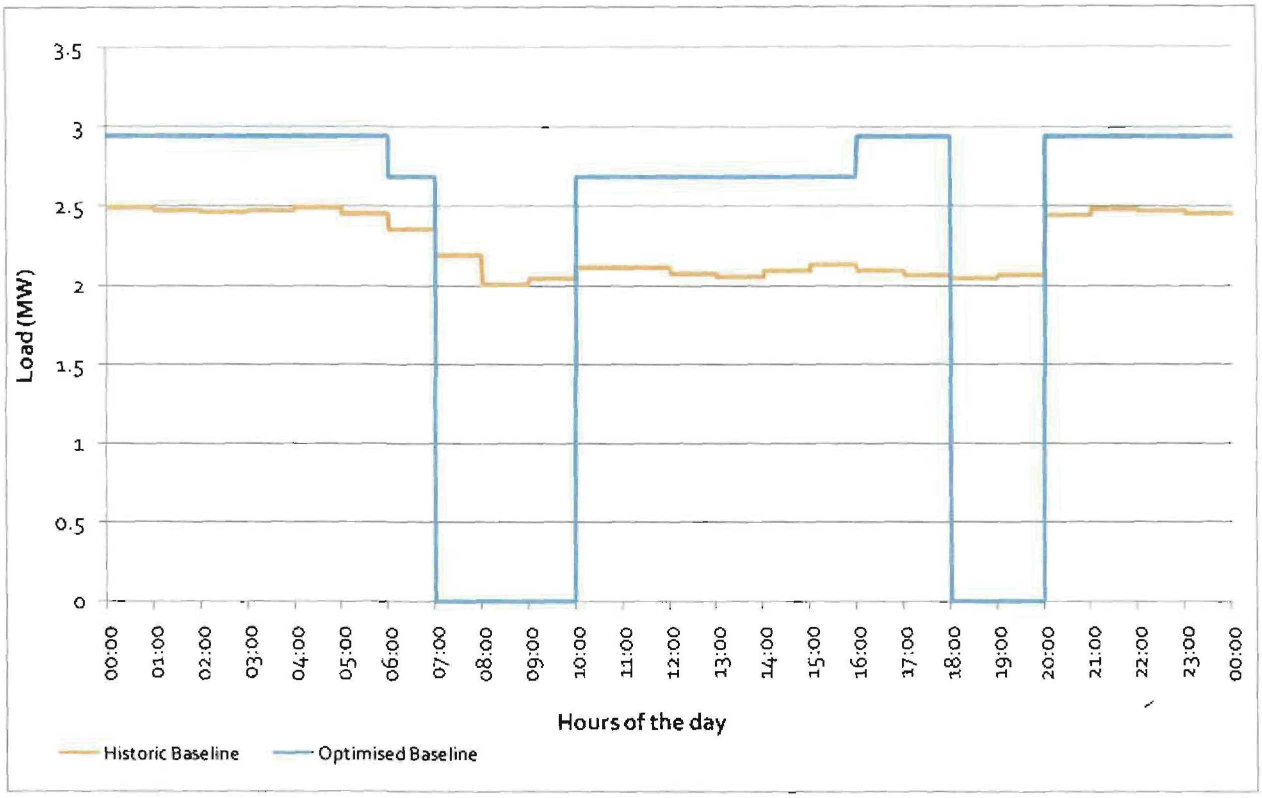


Figure 47 – Plant A raw mill baseline comparison

Figure 47 provides a graphical representation of Table 8. The yellow line represents the historical baseline and the blue line the potential new baseline when load shifting is applied. The maximum average of the optimised baseline is below the mill's 3.11 MW running capacity.

Table 9 summarises the morning and evening load shifting potential as well as the annual cost savings that can be realised on Plant A.

Table 9 – Plant A load shifting potential and annual cost savings

Load shifting : morning peak	Load shifting : evening peak	Annual cost saving
2.08 MW	2.05 MW	R474,341

4.2.2 Plant B

The simulation model was applied to the raw mill of Plant B. The parameters used as input to the simulation are listed in Table 10.

Table 10 – Raw mill case study 2: parameters

Parameter	Value
Raw mill outflow (t/h)	*200*
Kiln inflow (t/h)	*154*
Silo capacity (tons)	*20,000*
Silo starting level (%)	*75*
Silo maximum level (%)	*95*
Silo minimum level (%)	*60*
Date of calculations	*Mar '06*
Daily breakdown hours	*2*
Planned maintenance hours per week	*9*
Day of planned maintenance in week	*Tuesday*
Number of weeks planned maintenance per month	*2*
Hours load shift per day	*4*
Days load shift per week	*5*
Running hours on Saturday	*22.0*
Running hours on Sunday	*22.0*
Running capacity of mill	*3.4 MW*

Figure 48 shows the simulated silo level of Plant B. The silo level is rising slowly and remains within the maximum and minimum silo levels specified by the plant operators. At this plant, there are two hours morning and two hours evening load shifting potential every weekday.

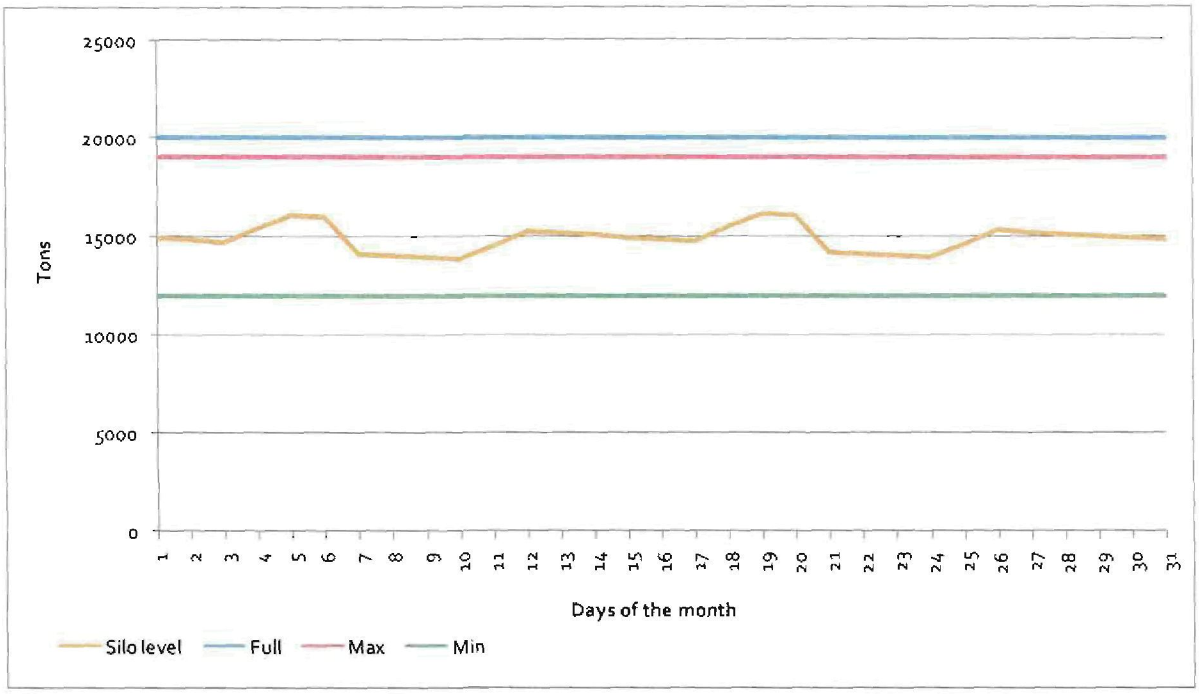


Figure 48 – Plant B raw mill silo simulation

The stable trend in this silo level allowed for two of the load shifting hours in the morning peak between 07:00 and 10:00, and two hours in the evening peak between 18:00 and 20:00.

Table 11 shows the results obtained from the second part of the simulation model. It also contains the historical baseline calculated from the historical data. The red highlighted values in Table 11 indicate where load shifting is applied.

Table 11 – Plant B raw mill baseline comparison

	Historic baseline (MW)	Optimised baseline (MW)
00:00	2.736	3.073
01:00	2.843	3.073
02:00	2.866	3.073
03:00	2.827	3.073
04:00	2.693	3.073
05:00	2.586	3.073
06:00	2.579	2.806
07:00	1.792	0
08:00	1.695	0
09:00	1.690	2.806
10:00	2.197	2.806
11:00	2.549	2.806
12:00	2.568	2.806
13:00	2.550	2.806
14:00	2.624	2.806
15:00	2.633	2.806
16:00	2.665	3.073
17:00	2.634	3.073
18:00	2.031	0
19:00	1.896	0
20:00	2.494	3.073
21:00	2.791	3.073
22:00	2.754	3.073
23:00	2.682	3.073

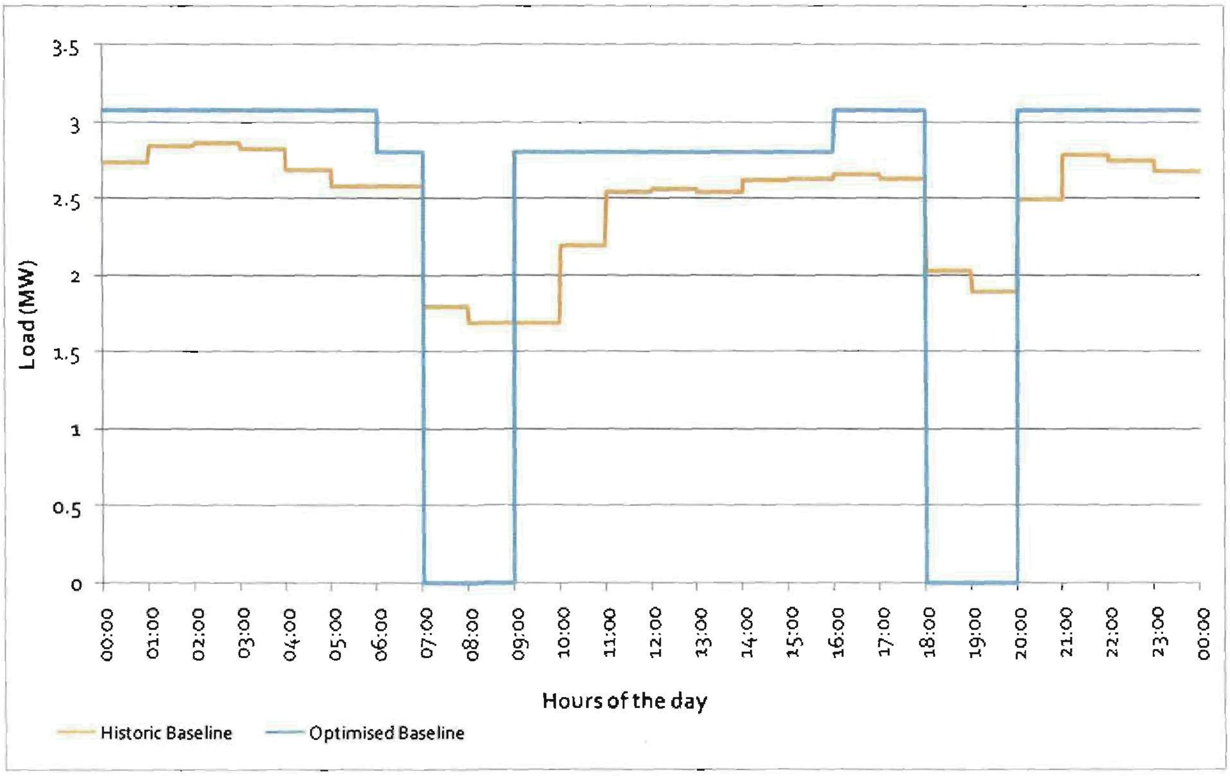


Figure 49 – Plant B raw mill baseline comparison

Figure 49 provides a graphical representation of Table 11. The yellow line represents the historical baseline and the blue line the potential new baseline when load shifting is applied. The maximum of the optimised baseline is below the mill's 3.4 MW running capacity. The historic baseline Figure 49 shows that Plant B already manually applied load shifting on the raw mill during peak hours. Due to this the load shifting potential lowered as shown in Table 12.

Table 12 summarises the morning and evening load shifting potential as well as the annual cost savings that can be realised on Plant B.

Table 12 – Plant B Load shifting potential and annual cost savings

Load shifting : morning peak	Load shifting : evening peak	Annual cost saving
0.79 MW	1.96 MW	R293,149

4.3 CASE STUDIES: FINISHING MILLS

In the following section, case studies are evaluated on the finishing mill section of two different cement plants.

4.3.1 Plant C

The simulation model was applied to the finishing mill section at this specific plant. The parameters used as input to the simulation are listed in Table 13.

Table 13 – Finishing mill case study 1: parameters

Parameter	Value
Finishing mill outflow (t/h)	*110*
Production target for weekdays (ton)	*1,950*
Production target for weekends (ton)	*1,950*
Silo capacity (tons)	*24,000*
Silo starting level (%)	*75*
Silo maximum level (%)	*95*
Silo minimum level (%)	*60*

Date of calculations	*March '06*
Daily breakdown hours	*1*
Planned maintenance hours per week	*13*
Day of planned maintenance in week	*Monday*
Number of weeks planned maintenance per month	*2*
Hours load shift per day	*5*
Days load shift per week	*5*
Running hours on Saturday	*21*
Running hours on Sunday	*20*
Running capacity of mill	*5.75 MW*

Figure 50 shows the simulated silo level for Plant C. The silo level rises slowly and remains within the maximum and minimum silo levels specified by the plant operators. At this plant, there are five hours of load shifting potential per weekday, without having a negative effect on production.

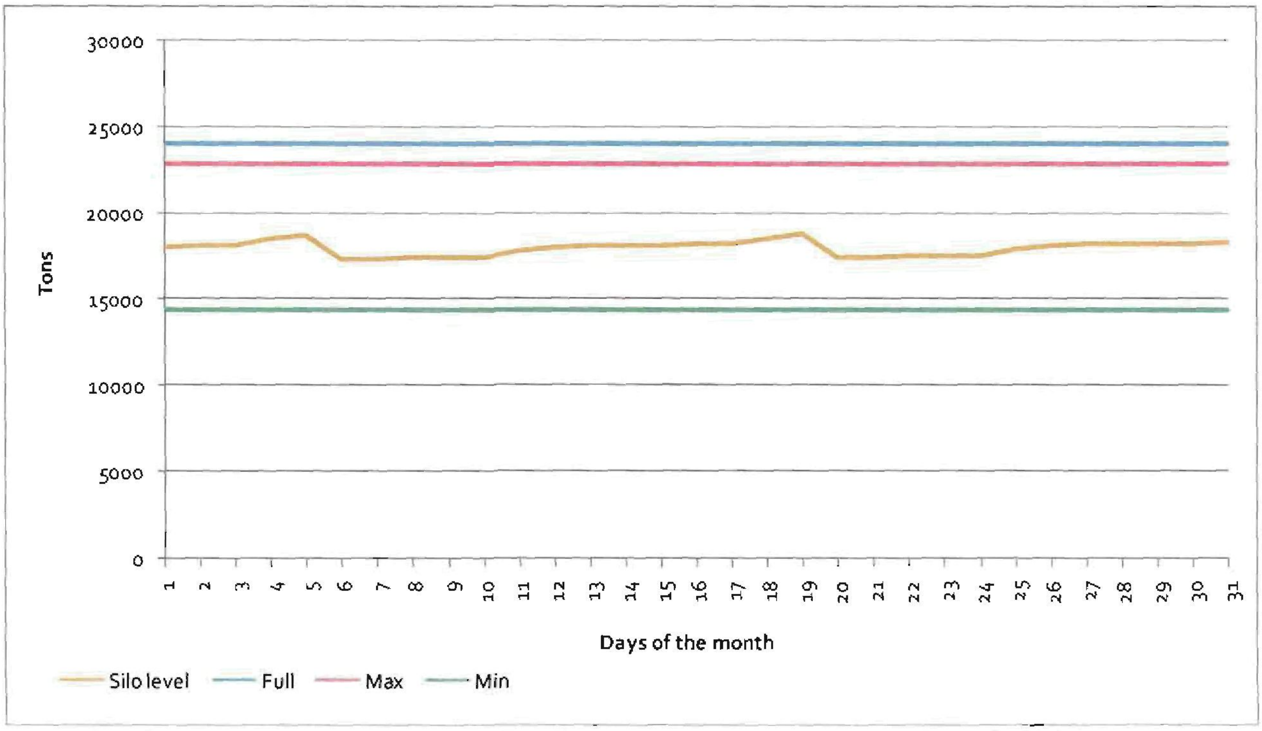


Figure 50 – Plant C finishing mill silo simulation

Two hours of load shifting are scheduled in the evening peak between 18:00 and 20:00 and three hours in the morning peak between 07:00 and 10:00. A maximum load shifting application is possible at this finishing mill.

Table 14 – Plant C finishing mill baseline comparison

	Historic baseline (MW)	Optimised baseline (MW)
00:00	4.776	5.447
01:00	4.767	5.447
02:00	4.709	5.447
03:00	4.777	5.447
04:00	4.715	5.447
05:00	4.593	5.447
06:00	4.376	4.974
07:00	3.593	0
08:00	3.472	0
09:00	3.482	0
10:00	3.695	4.974
11:00	3.961	4.974
12:00	4.075	4.974
13:00	4.149	4.974
14:00	4.076	4.974
15:00	3.895	4.974
16:00	3.940	4.974
17:00	4.026	4.974
18:00	3.873	0
19:00	3.946	0
20:00	4.343	5.447
21:00	4.523	5.447
22:00	4.700	5.447
23:00	4.757	5.447

Table 14 shows the results obtained from the second part of the simulation model. It also contains the historical baseline calculated from the historical data. The red highlighted values in Table 14 indicate where load shifting is applied.

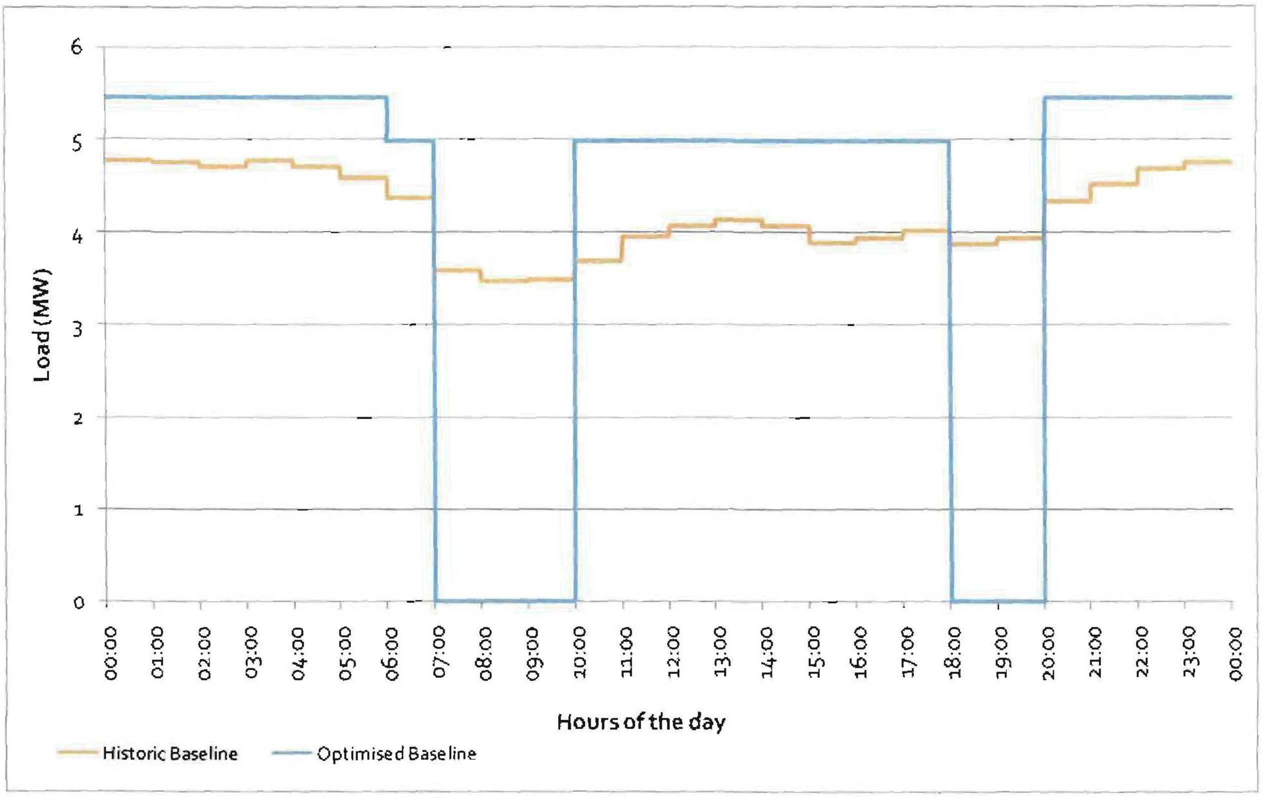


Figure 51 – Plant C finishing mill baseline comparison

Figure 51 provides a graphical representation of Table 14. The blue line represents the historical baseline and the red line the proposed new baseline with load shifting incorporated. Note that the maximum of the optimised baseline is below the mill's 5.75 MW running capacity.

Table 15 summarises the morning and evening load shifting potential as well as the annual cost savings that can be realised on Plant C. The relatively low annual cost saving is due to the absence of load shifting during the morning peak period.

Table 15 – Plant C load shifting potential & annual cost savings

Load shifting : morning peak	Load shifting : evening peak	Annual cost saving
3.52 MW	3.91 MW	R898,839

4.3.2 Plant D

The simulation model was applied to the finishing mill section at Plant D. The parameters used as input to the simulation are listed in Table 16.

Table 16 – Finishing mill case study 2: parameters

Parameter	Value
Finishing mill outflow (t/h)	*150*
Production target for weekdays (ton)	*3,600*
Production target for weekends (ton)	*3,600*
Silo capacity (tons)	*33,333*
Silo starting level (%)	*75*
Silo maximum level (%)	*95*
Silo minimum level (%)	*60*
Date of calculations	*October '06*
Daily breakdown hours	*1*
Planned maintenance hours per week	*8*
Day of planned maintenance in week	*Monday*
Number of weeks planned maintenance per month	*1*
Hours load shift per day	*0*
Days load shift per week	*0*
Running hours on Saturday	*23*
Running hours on Sunday	*23*
Running capacity of mill	*5.0 MW*

Figure 52 shows the simulated cement silo level for Plant D. The silo level decreases sharply during the month and will result in the silo running empty later in the year. This is because the flow rate into the cement silo is less than the flow rate out of the silo feeding the packaging plant. The packaging plant processes more cement per hour than the mill can produce. When the silo is empty the packaging plant is stopped, which means the cement production is also stopped.

From a production perspective every running hour of the finishing mill is important. Every hour stopped due to breakdowns or load shifting results in 150 tons less that can be processed by the packaging plant. Thus every extra hour stopped equals an hour loss in production.

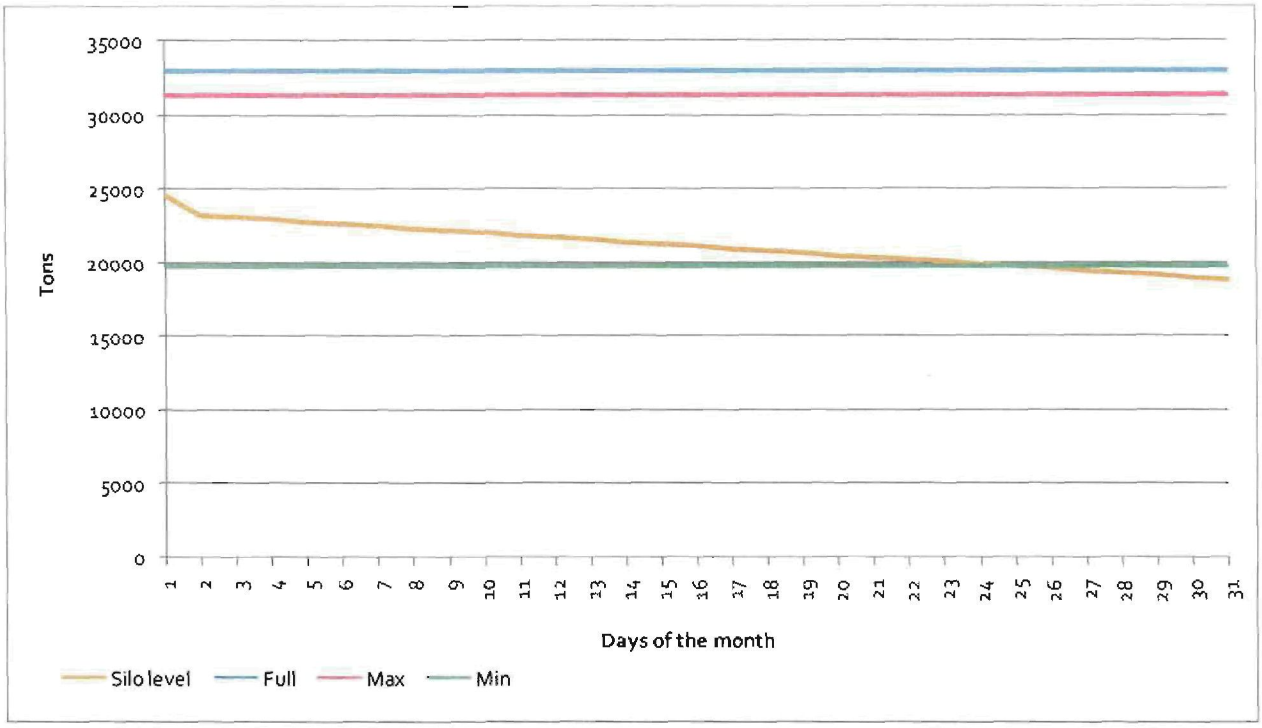


Figure 52 – Plant D finishing mill silo simulation.

The silo level part of the simulation shows there is no potential for a DSM project. The optimised baseline and savings can be discarded because it is already proven that load shifting is not viable in this specific scenario.

4.4 SUMMARY OF RESULTS

The results of the case studies are discussed in two subsections. The data from the four different plants that cooperated in this study was considered sufficient to provide meaningful results.

4.4.1 Raw milling results

The simulation was applied to the raw milling sections of cement plants A and B. Five hours of load shift per day are possible at the raw mill of Plant A. The silo level remained stable showing a small increasing trend over the observation period. The maximum and minimum silo levels remained well within the specified limits. A load shifting potential of 2.08 MW in morning and a

2.05 MW potential in evening peaks was possible. A total annual cost saving of R 474,341 can be realised.

On the raw mill of Plant B, four hours of load shifting can be realised each weekday. The silo level remained within the specified limits. A load shifting potential of 0.79 MW in morning and 1.96 MW potential in evening peaks was possible, realising an annual cost saving of R 293,149.

4.4.2 Finishing milling results

The finishing milling simulation was applied to the mills of plants C and D. The cement silo levels remained inside the specified maximum and minimum silo levels. At Plant C, five hours of load shifting were possible each weekday. A load shifting potential of 3.52 MW in the morning and 3.91 MW in the evening peak is possible realising an annual cost saving of R 898,839.

The finishing mill on Plant D was already running below the production rate needed from the cement milling section. This is due to the packaging plant being able to process the cement product in the silos faster than the finishing mill is able to produce the cement. Any extra hours stopped by the finishing mill will directly entail a decrease in production. There is no scope for a DSM project at this specific finishing mill.

4.5 EXPANDING DSM OPPORTUNITIES TO ALL CEMENT PLANTS

All the cement plants in South Africa have similar cement manufacturing processes as explained in section 2.3, which means this simulation model can be applied to any of these processes. The cement plants must be willing to supply input data needed for the simulation in order to provide information on DSM potential.

In the raw milling simulation case studies of plant A and B, there are opportunities for DSM in both cases. The results from these two simulations show implementation of DSM projects on the raw milling section will result in significant cost savings. In the two finishing milling case studies only one of the finishing mills showed the possibility for DSM potential.

The viability for load shifting may be smaller on the finishing milling sections, due to the different capacities of the finishing mills and packaging plants, but still provide viable DSM potential in certain cases. If for example more than one finishing mill is feeding the cement silos the inflow to the silos will increase. If the cement used by the packaging plant remains the same and the input flow rate to the cement will be higher than the output flow rate, the mills may have to stop preventing the silo from overflowing. In such a case load shifting might be possible.

There are currently 10 South African cement plants in operation. A total installed capacity of 67.6 MW was calculated from the data of seven cement plants in South Africa. The running capacity of the mills is approximately 75% of the installed capacity, which is a total of 50.7 MW for the seven cement plants. This value is possible load that can be shifted and is 33% of the annual DSM savings projected by NERSA.

These ten operational cement plants and several new plants in construction provide sufficient opportunity for DSM in the cement industry of South Africa.

4.6 CONCLUSION

Case studies of the simulation model were done on two raw mills and two finishing mills on different cement plants. In each study the input parameters used were provided. The following outputs were generated by the simulation:

- simulated silo level
- historical baseline versus simulated baseline
- morning and evening load shifting potential
- annual electricity cost savings

The results illustrate that DSM projects were viable on both the raw mill case studies and the finishing mill at Plant C. Five hours of load shifting per day were possible on two of these case studies. On the raw mill at Plant B load shifting could only be implemented for two morning peak hours and two evening peak hours of each day. Unfortunately, load shifting was not viable on the finishing mill at Plant D.

CHAPTER 5

CONCLUSION

5.1 SUMMARY

Applying the simulation model on data received from cement plants proved that there is potential to implement DSM in the raw milling and finishing milling sections of cement plants, and could contribute to the solution for Eskom's electricity supply problem.

The simulation model indicated DSM potential when the suggestion of load shifting is applied on the simulation model and the simulated silo level remains within the specified limits over a total month. This result shows that production will not be influenced negatively when load shifting is applied. The simulation model provided the load shifting and the annual cost savings that can be realised when the silo level remained within acceptable limits.

The simulation was applied to four case studies. In the first two case studies, the simulation model was applied to different raw milling sections of two different cement plants. The first plant showed that daily load shifting of five hours each weekday was possible. This gave a total load shifting potential of 2.08 MW in the morning peak and 2.05 MW in the evening peak, realising a R 474,341 cost saving per annum.

At the second cement plant, only four hours of load shifting could be applied to the raw milling section. Two hours are scheduled for the morning peak and the other two hours are scheduled for the evening peak. A load shifting potential of 0.79 MW in the morning peak and 1.96 MW in the evening peak could be realised. An R 293,149 annual cost saving can be realised in this case.

The last two case studies were done at the finishing milling section of two different cement plants. The first finishing milling simulation showed that five hours of load shifting were possible per weekday. This result in a reduction of 3.52 MW in morning peaks and 3.94 MW in evening peaks to the Eskom supply grid. A cost saving of R 898,839 per annum can be realised in the case study.

When the simulation was applied to the finishing milling section of plant D, the result showed that any load shifting would cause the silo level to fall below the specified limit. Production would be halted if any load shifting is applied on this section. There is no scope for a DSM project on the finishing milling section of the last cement plant.

It can be concluded that the simulation model provides accurate result in terms of the projected silo level, load shifting potential and annual cost savings. This study also shows that the model can be applied to different cement plants to determine the viability for a DSM project on the milling sections.

5.2 RECOMMENDATIONS FOR FUTURE WORK

In future studies, the diversity of different cement plants should be taken into account in the simulation model. There are various cement plants in which two or more mills work in parallel. This occurs in both the raw milling and finishing millings sections of cement plants. Often a cement plant would contain three smaller finishing mills instead of one larger finishing mill.

The simulation model could be extended to other industries in which similar equipment is used. This could be feasible where a material processing component with the adequate electricity consumption, according to Eskom's requirements, and sufficient storage capacity to store the material produced by the material processing component is present. Gold and sintering plants could be considered.

Additional components at cement plants that are highly energy intensive could be suitable for other load shifting and energy efficiency projects. Figure 16 shows that the kiln consumes approximately 90% of the energy used on a cement plant, and is usually the focus for energy efficiency and energy savings projects.

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