REAL-TIME ENERGY MANAGEMENT IN THE CEMENT INDUSTRY

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ABSTRACT

The purpose of this study was to investigate Demand-Side Management (DSM) opportunities in the South African cement industry. .

This was done by identifying four criteria that affect the DSM load shift process on a production facility. These criteria were used as benchmarks against which the viability of possible load shift projects on a cement factory was measured.

In order to test these criteria, procedures were developed for identifying viable load shift projects on a cement factory. These procedures include everything from the introduction to the plant management, through data gathering and refining, to the simulation of silo levels and material flows, and optimisation of these to result in an optimised load shift schedule for different plant systems.

These procedures were tested by means of a case study on a cement factory in the North-West Province of South Africa. The case study showed that it is possible to perform a viable load shift of approximately 9 megawatt (MW) on this factory, for an annual electricity cost saving of R 656,501.38.

Various concerns of the plant personnel have been identified, and possible solutions have been proposed in order to help overcome these concerns.

Even though there were some limitations preventing the full testing of these procedures, the study showed that it is definitely possible to find large viable load shift projects in the cement industry. It should be possible to expand the same principles to include other equipment on a cement factory, and should work for most similar cement factories.

SAMEVATTING

Die doel van hierdie studie was om "Demand-Side Management" (DSM)-moontlikhede te ondersoek in die Suid-Afrikaanse sementindustrie.

Dit is teweeg gebring deur vier riglyne te identifiseer wat die DSM-lasskuif proses op 'n produksie-aanleg kan beïnvloed. Hierdie riglyne is toe gebruik as verwysings waarteen die lewensvatbaarheid van 'n moontlike lasskuifprojek op 'n sementfabriek gemeet is.

Om genoemde riglyne te toets, is verskeie prosedures ontwikkel om te help met die identifisering van lewensvatbare lasskuifprojekte op 'n sementfabriek. Hierdie prosedures sluit alles in - van die eerste ontmoeting met die fabrieksbestuurders, tot die versameling en verwerking van data, die simulasie van silovlakke en materiaalvloei asook optimering van hierdie resultate. Die einddoel is 'n optimale lasskuifskedule vir verskillende masjiene of stelsels.

Hierdie prosedures is getoets deur middel van 'n gevallestudie wat gedoen is op 'n sementfabriek in die Noordwes Provinsie van Suid-Afrika. Die gevallestudie het getoon dat 'n realistiese skuif van ongeveer 9 megawatt (MW) moontlik is deur die rou meulens te herskeduleer in hierdie fabriek. Dit het die bykomende voordeel dat die fabriek ongeveer R 656,501.38 per jaar spaar aan elektrisisteitskoste.

Daar was wel verskeie bekommernisse van die fabriekspersoneel oor die new-effekte van 'n volhoubare lasskuif. Moontlike oplossings is bespreek en voorgestel om vrese te stil.

Alhoewel daar beperkte moontlikhede was om hierdie prosedures ten volle te toets op ander stelsels ook, het die resultate gewys dat dit definitief moontlik is om redelike groot lasskuifprojekte te vind in 'n sementfabriek. Verder behoort dit moontlik te wees om dieselfde beginsels en prosedures uit te brei om ander stelsels in te sluit.

ACKNOWLEDGEMENTS

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- Dr. Frik Geyser, in structuring the thesis.
- Mr. Dieter Krueger, in refining the thesis.

I would also like to thank my parents for encouraging me to always ask questions and seek knowledge, as well as encouraging me to complete this thesis.

This study is dedicated to the love of my life. Karin, thank you for all the evenings you had to sit alone at home while I was writing this thesis. You are the best. I love you.

Finally, my most sincere thanks to my God and Creator, who have blessed me with the talent that enabled me to complete my studies to this level. It was only possible through His love and blessings.

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INTRODUCTION TO THE STUDY

In this chapter, the background, problem statement, and objectives of the study are given. The most important contributions of the study are also listed. The section concludes with a brief summary of the remaining chapters.

1. INTRODUCTION TO THE STUDY

1.1 Background

Electricity consumption in South Africa

The United States Department of Energy predicts that the world primary energy consumption will increase by 59% over the period 1999 to 2020 [1], as shown in Figure 1:

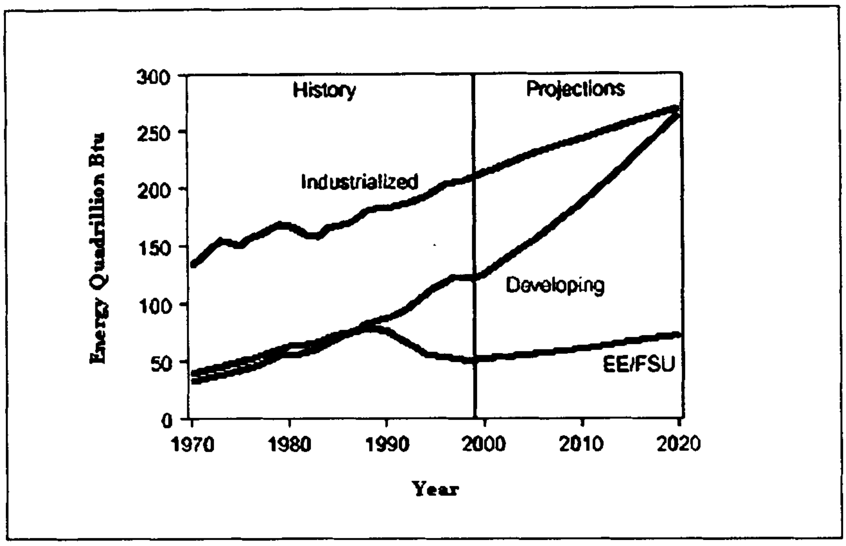


Figure 1: Prediction of world energy consumption.

From the figure, it can be seen that the highest growth is expected in developing countries. The electricity used in developing countries during the 1980's has grown by more than 11% per year [2].

South Africa is such a developing nation with rich deposits of minerals such as gold and platinum, as well as fossil fuels in the form of coal. As such, the economic development of the country has focused on the extraction and processing of these resources. These industries, by their very nature, are energy intensive [3]. As such, it was necessary to develop adequate electrification to sustain economic development [4].

According to Nortje [5] electricity consumption in South Africa is currently growing at approximately 1000 MW per annum. In the past, electricity demand in South Africa was addressed was addressed by the erection of large (3000 – 3600 MW) pulverised coal-fired power stations [6].

The use of coal was largely based on the fact that South Africa is one of the world's largest coal producers [7]. This growth still continues as the demand for coal for power stations is still on the increase. In support of this, the coal demand increase for the past few years were found to be the following: 8% in 2001 over 2000, 3,3% in 2002 over 2001, 1% in 2003 over 2002, and 7.1 % in 2004 over 2003 [8].

By the early 1990's, Eskom supplied 98% of the electricity in South Africa, with a nominal generating capacity of 39154 Megawatts from 20 power stations [9]. The other 2% was made up by a few mines and other industries that had their own generation capabilities.

By 1999 Eskom accounted for 95.7 % of generating capacity in South Africa, while some municipalities provided 1.5 %. The remaining 2.7 % was filled by private generators [10].

In the same year, the sales from this network had the following spread: Domestic (18%), Agriculture (3.3%), Mining (18.4%), Manufacturing (43.8%), Commercial (9.4%), Transport (2.6%) and General (4.6%) [10]. The mining, manufacturing and domestic sectors constitute almost 81 % of South Africa's total electricity sales.

According to a 2001 estimate of electricity generators in South Africa, the generation capacity in this country was still mainly supported by coal, followed by nuclear and hydro/pumped storage. Gas is the one source of generation that is very absent in South Africa if compared to the rest of the world [11].

The following figure provides a graphical presentation of this distribution of primary energy used for electricity generation:

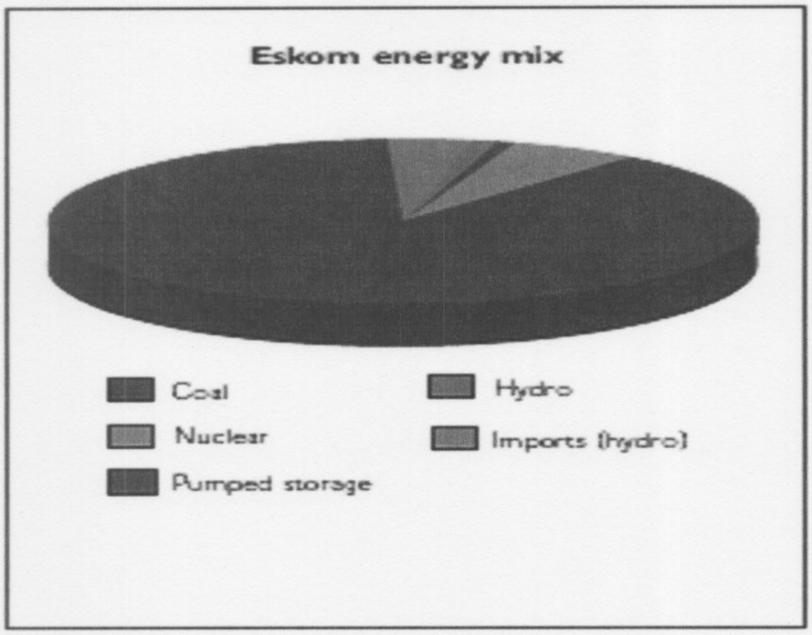


Figure 2: Distribution of electricity sources in South Africa.

Growing electricity demand

The South African government is currently implementing the national electrification programme in terms of the White Paper on Energy Policy. The goal is to provide at least basic electricity to every household in the country. These efforts are proving to be successful, as there has been an overall increase in electrified households from 50 % in 1995, to 69 % in 2003 [11].

This is mainly due to an increase in households with electricity in the rural areas, where the increase was from 21 % in 1995, to 54 % in 2003. In the urban areas, the growth was smaller, with 76 % having electricity in 1995, to 79 % in 2003 [11].

Because of this increase in electricity use in South Africa, there were some concerns that the current capacity of the electricity system might not be able to cope with the increase. As such, various studies have been done to predict the future of electricity demand in South Africa. One such study was done by R.M. Surtees [12].

Surtees compiled a simulated forecast model, and found that the electricity demand in South Africa was growing at such a rapid rate, that the current generating capacity would be overtaken by 2007 [12] [10]. The following graph illustrates this breakeven point:

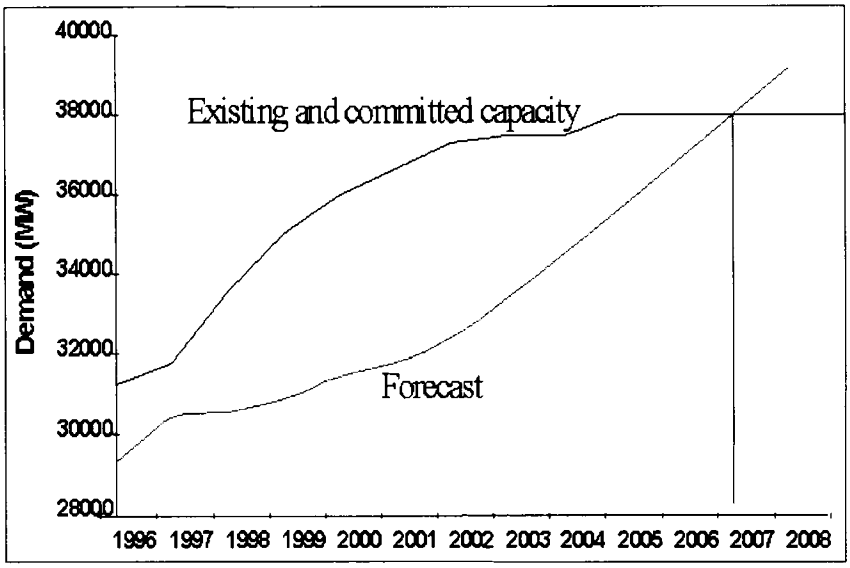


Figure 3: Forecast model of electricity demand in South Africa.

The expansion of the network to domestic users is a large driving force behind the formation of an electricity demand curve with two peaks per day, one in the morning between 07:00 and 10:00, and the other in the evening between 18:00 and 20:00 [13].

These are the times when most households with electricity use appliances such as stoves, lights and geysers. The time of year also plays a part in the forming of the peaks [13] for example; the peaks are higher in winter, because of an extra load due to domestic heating requirements [11] [14]. The following figure illustrates this demand curve:

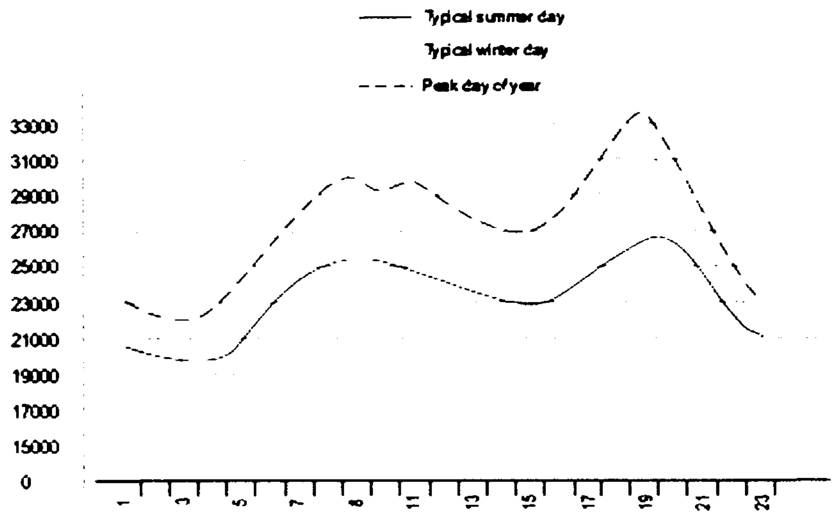


Figure 4: Typical daily electricity profile showing the two peaks.

Even though the peaks are greatly influenced by the growing level of domestic electrification, the increase in base load demand is largely influenced by an expanding economy and an increase in energy intensive electricity industries like mines for example [43].

The above peaks are also influenced by the type of day (weekday, Saturday or Sunday). It was found that the peaks are more pronounced during weekdays than on weekends [13].

The above figure clearly shows that the evening peak is much higher than the morning peak. It is this evening peak that produces the greatest problem for Eskom. Various strategies have been proposed to help reduce this load. These are all part of a large effort from Eskom to balance the generation capacity with the growing demand for electricity.

1.2 Corrective Measures taken by Eskom

Introduction

The two main focus areas for Eskom regarding the peak load problem, is Supply-Side Management (SSM) and Demand-Side Management (DSM) [15]. These approaches are part of Eskom's Integrated Strategic Electricity Planning (ISEP) process [12] [15].

This process is intended to provide the strategic framework for projections of supply-side and demand-side options that will need to be implemented to meet future energy needs [15]. The White Paper on the Energy Policy of the Republic of South Africa has been used as a guide for the ISEP process [16].

Alternative generation options: Supply-Side measures

On the supply side, the purposes of ISEP include the activities required to identify, evaluate, optimally select, implement and monitor options for the future generation of electricity to meet customer demand [15].

Various ways have been investigated to meet this customer demand. This includes the building of new power stations. However, erecting a new base-load power station of 4000 MW may cost up to R40 billion, and take a very long time to construct [17].

Eskom has also commissioned the return to service of three mothballed power stations, namely Camden in Ermelo(1600 MW), Grootvlei near Balfour(1200 MW) and Komati in Middelburg(1000 MW) [17] [18]. The cost of the refurbishment of these three plants will be about R 12 billion, and will provide a total of 3800 MW of power [17].

According to Etzinger [18], there are additional sources of electricity that can be used to augment the country's power supply in the future. These include new hydroelectric plants earmarked for development in Mozambique, DRC, Zimbabwe and Zambia.

There also are various renewable technologies such as bulk solar thermal, wind turbines, biomass generation and wave and tidal generation [18]. Gas is also a technology which might prove to be useful source of energy for electricity generation.

DSM: Demand-Side measures

Demand-Side Management also is part of the ISEP structure. It is an initiative launched by Eskom to focus on tariff-induced load shifting and potential quantification studies [15]. The term Demand-Side Management is used to describe the scheduling and implementation of different activities to influence the time, pattern and amount of electricity consumption in such a way that it produces a change in the load profile of the industry, while still maintaining customer satisfaction [19].

The options provided by Eskom include energy efficiency and load management/shift programmes within the residential, industrial and commercial sectors of South Africa. The following figures illustrate these two concepts:

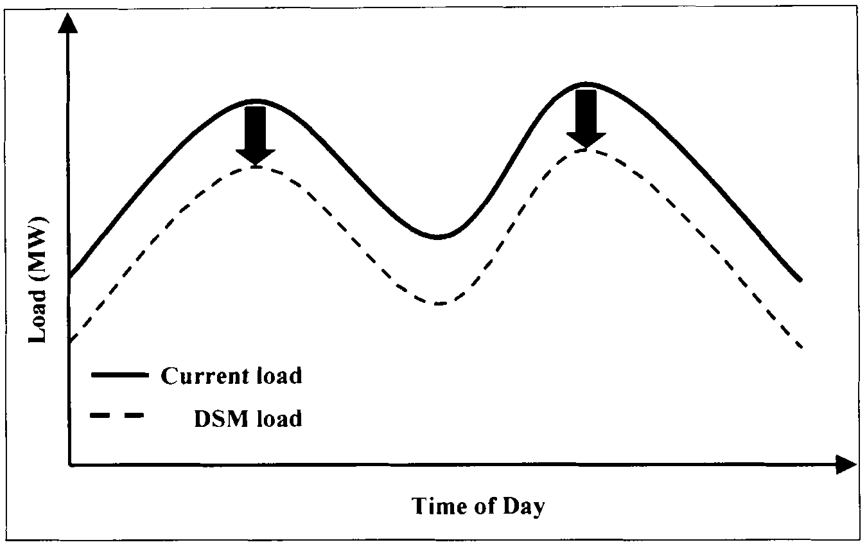


Figure 5: Representation of Energy Efficiency, showing a reduction in load.

As can be seen from Figure 5, energy efficiency entails the actual reduction of the load to a new, lower value.

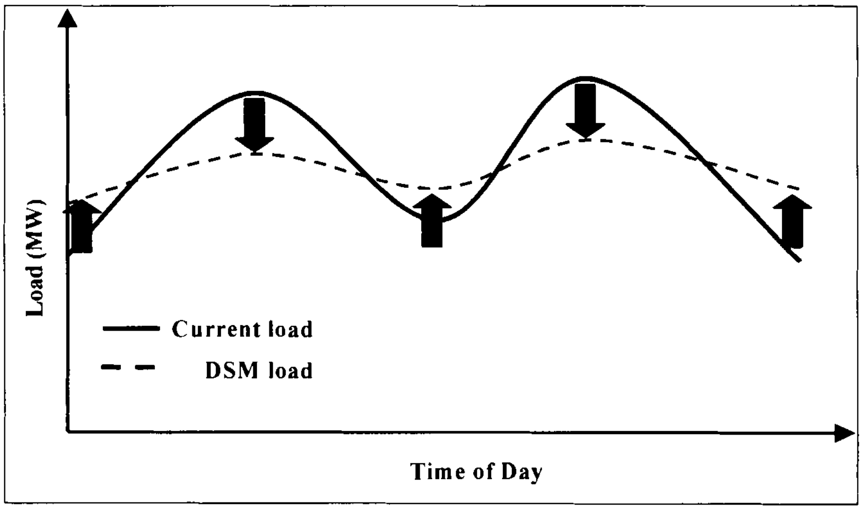


Figure 6: Representation of Load Shift from the peak times.

In Figure 6, it is shown that load management or load shifting entails the practice of dropping the peak energy consumption by shifting the consumption to other periods of the day.

Eskom planning suggests that load shift and energy efficiency aims to save about 150 MW per annum [5]. The estimated capital costs of these deferrals are in the order of R1.45 million per MW for load shift programmes alone [20]. This cost is low when compared to the cost of building a new power station, which is in the order of R10 million per MW [21].

One of the ways in which Eskom encourages the use of DSM is by introducing various pricing structures that are conducive to the intelligent use of electricity by large consumers [22]. The tariff structures used most often by larger consumers are the following: MegaFlex, NightSave and MiniFlex [23] [24] [25].

In the MegaFlex structure, the week is divided into three periods: Peak, Standard and Off-peak periods [13] [23]. The electricity is then simply billed according to these periods, with peak-time being the most expensive and off-peak the least expensive. The following figure illustrates the workings of the MegaFlex periods:

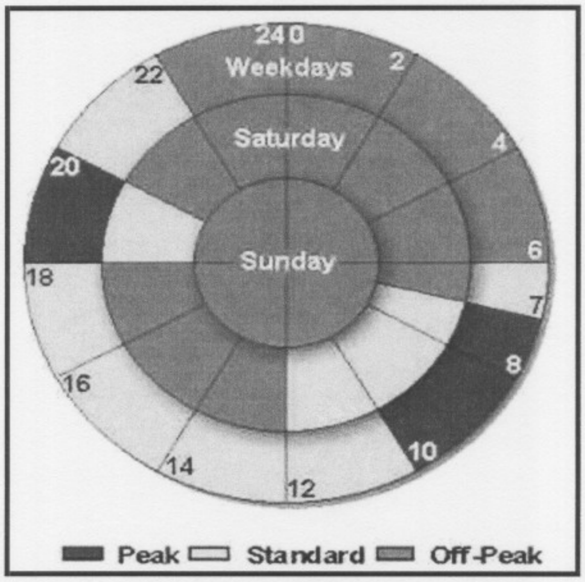


Figure 7: A Graphic representation of the MegaFlex times.

The MegaFlex structure also has different costs for different seasons of the year. The higher unit prices are billed during the winter months, June to August, due to the higher demand and more pronounced peaks. Conversely, the lower costs are associated with the summer months or the so-called low peak demand period from September to May [13].

The basic active energy charge for MegaFlex during different seasons can be seen in Table 1 [26]:

High-demand season (June – August)		**Low-demand season (September – May)**
50,44c + VAT = **57,50c/kWh**	**Peak**	15,45c + VAT = **17,61c/kWh**
14,56c + VAT = **16,59c/kWh**	**Standard**	10,23c + VAT = **11,66c/kWh**
8,63c + VAT = 9,84c/**kWh**	**Off-peak**	7,72c + VAT = 8,80c/**kWh**

Table 1: Current active energy costs of the MegaFlex structure.

NightSave is a tariff structured in such a way that it rewards those customers that are able to shift load in such a way that they work between 22:00 and 06:00 during the week [23] [25]. This time is then treated as an off-peak period by Eskom, and as such the electricity costs are lower. This allows the customer to take advantage of electricity cost savings by not working in the morning (07:00 – 10:00) - and evening peaks (18:00 – 20:00).

MiniFlex is used by medium sized customers that have different costs for different Time of Use (TOU) periods found in the different seasons [23] [24]. This system is very inflexible and is only really effective when the customer can shift load over extended periods of time.

Even though the basics of the above structures have remained the same since their inception, there have been some changes in the detail of the costing of each structure. These details have changed somewhat from year to year in an effort to find the optimum solution for both Eskom and the client [27].

There also are additional costs like service charges, network access charges, administration charges, etc, added to the customer's account. A detailed description of these can be found on the Eskom website [23]. However, these are not relevant to DSM activities.

Energy Services Companies (ESCO's)

In order to successfully implement DSM, Eskom makes use of Energy Services Companies (ESCOs). By definition, an ESCO is a company that develops, installs and finances projects designed to improve the energy efficiency and maintenance costs for facilities over a period of seven to ten years [13]. Since the beginning of the DSM program, 106 ESCOs have been established and 135 DSM projects have been registered [5].

In a typical Eskom DSM project, the ESCO is responsible for the success of the project. The ESCO does research on the specific electricity consumer in order to establish a base line to use as a benchmark for any savings that might be realised.

Any capital investment that is necessary for the implementation of such a DSM project, may qualify for capital investment from Eskom-DSM. Eskom-DSM currently provides funds for projects larger or equal than 500 KW. For Energy efficiency projects, the funding from Eskom is 50% of the total project cost, and for load shift projects, the funding from Eskom is 100 % of the total project cost.

Once these costs have been established, there is a contract that needs to be signed between the ESCO and Eskom. This contract includes the Megawatts (MW) that will be shifted during the evening peak by rescheduling the consumption of the customer [13]. Currently, Eskom only provides funding for load shifted during the evening peak, as this is much higher than the morning peak. It is possible that the programme might be expanded in future to provide funding for the morning peak as well.

With the above contract signed, the ESCO is tasked to shift the promised load. The ESCO is liable to pay penalties for any non-condonable reasons that the stipulated MW has not been delivered.

Up to date, various DSM projects have been implemented by ESCOs in South Africa. The following section will give a short description of some of these projects.

1.3 Current DSM Applications in South Africa

As proof of the success of the DSM campaign in South Africa, Eskom has published a few case studies that were verified by their auditors, Metering and Verification (M&V). The following table provides a summary of a few of these projects:

Project	Type of Project	Proposed Savings	Actual Savings	Ref.
Municipal water pump rescheduling	Load Shift	1.7 MW (Evening)	1.53 MW (evening)	[28]
Residential geyser load management project	Load Shift	0.693 MW (summer) 1.127 MW (winter)	1.10 MW (evening) 0.335 MW (morning)	[29]
Pump scheduling in the mining industry	Load Shift	3 MW (evening)	4.29 MW (evening)	[30]
Energy Efficient lighting retrofit	Energy Efficiency	R 219,254.35	R 212,217.98	[31]

Table 2: Summary of successful DSM projects In South Africa.

The projects summarised in Table 2 are just a few of the many that are currently running successfully in South Africa. The abovementioned projects are only included to show that the DSM programme in South Africa is well under way, even though it is a relatively new activity.

In summary, the literature survey showed that:

1. The electricity demand in South Africa has risen drastically in the previous 10 years, and will continue to do so in the future.
2. The supply for electricity in South Africa is going to be exceeded by demand in the near future.
3. Energy efficiency and load shift is going to play a large role in the energy policies of South Africa.
4. It is possible to perform successful DSM projects in the current South African economy.
5. The possibility for more DSM projects exists in South Africa.

Therefore, the need was established to find a new application for DSM in the industrial sector of South Africa. This application would preferably have a large savings potential and be easily repeatable for quick rollout in other places.

1.4 Objectives of this Study

The objective of this study was to identify Demand Side Management (DSM) opportunities in the South African cement industry. The main focus was the development of steps to identify load shift potential in a cement factory, as well as the testing of these steps.

The study was conducted on a cement factory in South Africa. The main focus was on the raw mills as potential candidates for load shift by using the MegaFlex tariff structure.

The end result is a revised proposed schedule for the use of the raw mills in the specific factory, so that the MegaFlex structure is used in an optimal manner. The anticipated problems with maintenance were addressed by proposing a change in the maintenance schedule of the factory, as well as the installation of new equipment.

1.5 Overview of the Thesis

A brief overview of each chapter is given below.

Chapter 1 serves as an introduction to the current electrical energy situation in South Africa, as well as the government's initiatives to help address the issues regarding base load and peak power generation. Typical successful projects that support these initiatives are also described.

Chapter 2 describes the cement industry in South Africa as a possible source of future large scale DSM projects. The workings of a typical cement factory are described in order to show how the different parts act together to produce cement products.

Chapter 3 describes the procedures developed during this study to find viable load shift projects on a cement factory. These procedures served as the basis for the study undertaken on a factory in the North-West province.

Chapter 4 is a case study of the theory that was developed in Chapter 3. The study was done on a South African cement factory. The name of this factory cannot be disclosed due to the sensitive nature of results published in this study. It will be known as "**the factory**" in any further references.

Chapter 5 is a conclusion of the results and ends with several suggestions for further work into the subject.

2

DSM POSSIBILITIES IN THE SOUTH AFRICAN CEMENT INDUSTRY

This chapter provides a background on the cement industry in South Africa, ranging from a general introduction to a product and market review. The operation of a typical cement factory is also described in order to provide the basis for further investigation into the subject. The chapter ends with a look at the possibility of finding a load shift project on a cement factory.

2 DSM POSSIBILITIES IN THE SOUTH AFRICAN CEMENT INDUSTRY

2.1 Introduction to the South African Cement Industry

South Africa currently has 22 cement industry facilities, 10 are production units and 12 are milling and blending units. The cement plants in South Africa vary in age from 3 years to some built in the early 1930's [32].

All South African cement plants produce Portland cement and other blended cement products like CEM I, CEM II and CEM III. Portland cement is a fine grey powder usually consisting of the following compounds: dicalcium silicate, tricalcium silicate, tricalcium aluminate, and tetracalcium alumino-ferrite, with the addition of 2-5% calcium sulphate (gypsum). Different types of Portland cement can be created depending on the application, as well as the chemical and physical properties desired [32].

The manufacturing of Portland cement is exacting by nature, and requires some 80 separate and continuous operations. These include the use of large-scale heavy machinery and large amounts of heat and energy (Normally 20-25 % of costs are attributed to energy consumption). To maintain the high levels of combustion in the kilns, large volumes of fossil fuels are used.

In the order of 15-16 tons of coal are burned for every 100 tons of cement clinker produced. The capital investment per worker in the cement industry is among the highest in all industries [32]. For this reason, reducing energy costs is an attractive proposition to most cement manufacturers.

Companies that dominate the cement industry in South Africa

Currently there are four companies that dominate the cement industry in South Africa. These are PPC Cement, Holcim (Formerly Alpha), Lafarge SA (Formerly Blue Circle) and Natal Portland Portland_Cement (NPC). In 2002, NPC (co-owned by the other three combined) was sold to Cimentos de Portugal (Cimpor).

The following table shows the ownership structures of the different manufacturers as of 2003 [32]:

Company	Holding company*
PPC Cement	100% PPC Company (Pty) Ltd (of which 68% is Barloworld owned)
Lafarge SA (Pty) Ltd	100% Lafarge South Africa (Pty) Ltd (part of Lafarge International)
Alpha (Pty) Ltd	54% Holcim, 46% Aveng
Natal Portland Cement	98% Cimentos de Portugal (Cimpor), 2% Employees' Trust Fund
Ash Resources	50% Lafarge SA, 25% Alpha, 25% Roshcon (subsidiary of Eskom)
Slagment	33% Alpha, 33% Lafarge, 33% PPC Cement

Table 3: Ownership structures of the largest South African cement manufacturers.

Production and market review

When the market shares of the different companies were compared, it was found to be the following. PPC is at the top of the list with a 35 % market share, secondly is Holcim and thirdly Lafarge SA. NPC holds more than 65 % of the market share in Kwazulu-Natal [32]. In terms of production for 2000, Lafarge SA produced 2600 Thousand Metric Tons of cement, Holcim Dudfield and Ulco produced 3445 Thousand Metric Tons combined and PPC produced 5500 Thousand Metric Tons combined [33].

The market for cement products in South Africa is divided into civil engineering and building sectors. There was a 0.4 % increase in the turnover of the civil sector during 2003. This can be compared to the 25 % increase of 2002. This indicates a temporary lull in spending on infrastructure during that period [34].

During the past few years however, there were a few projects that increased the short to medium term investment in the civil engineering industry. These included projects like the N4 Bakwena Platinum project, dam projects like the Baviaanspoort sewage works and the Mohale Dam, Harbour and waterfront projects in Durban, Richards Bay and Ngqura port, building projects such as the Cape Town Convention Centre and extensions to Johannesburg International Airport, as well as mass property developments [34].

In 2005, the per-capita consumption of cement in Gauteng alone is estimated to be close to that of the European Union (EU). Even the Western Cape falls just short of the consumption of a country like Mexico [35]. The following table illustrates the consumption rates of different countries and regions:

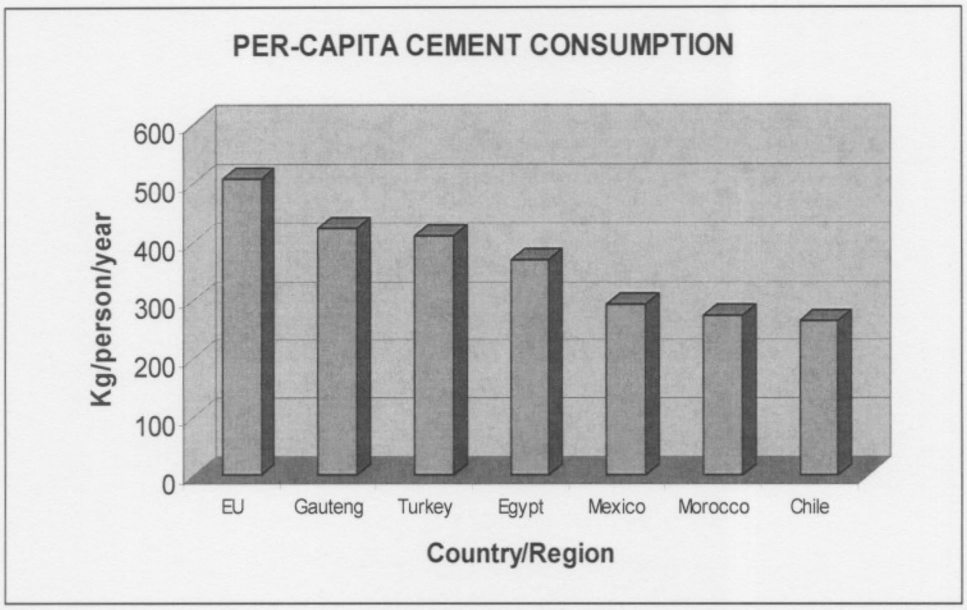


Figure 8: Per-Capita cement consumption of different regions.

The population of Gauteng is expected to increase by 40 % to 12 Million in 2010, therefore serving as a guarantee for growth in cement consumption in that province. There also are new projects underway to support this growth. This includes the new Gautrain, which is estimated to consume 300 000 tons of cement between 2005 and 2009 [35].

The government is busy with projects such as low-cost housing, schools, clinics and sewage works. There are several new stadiums for the 2010 soccer world cup that need to be constructed. There also is a tremendous explosion in the residential housing market. This has been the main driver behind the cement demand increase up to now [35].

It is therefore expected that the increased growth will put cement manufacturers under increased pressure to produce more cement in the foreseeable future. Large amounts of capital costs will be required for the expansion of existing cement factories.

Examples of this can be seen in cement plant upgrades that include advanced pre-heater kilns, pre-heater retrofits and additional pre-calciners. There are also water injection systems and bag filters instead of electrostatic precipitators and installation of grate coolers and kiln off-gas systems.

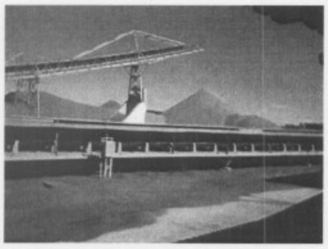
On the operational side there are new value-based management initiatives, supply chain optimisation, outsourcing of distribution logistics, uniform procurement systems, and increased automation through hardware and software upgrades, real-time statistical analysis and smart fleet management [34].

This suggests that it is now the correct time to find ways to implement cost saving initiatives like DSM on cement plants. The plant management have the benefit that DSM will cut operational costs, and also provide the factories with additional capital equipment that they might need in the quest for increased production. Typical examples of these are chemical analysers for better quality control on raw meal and final products.

2.2 Operation of a Typical Cement Factory

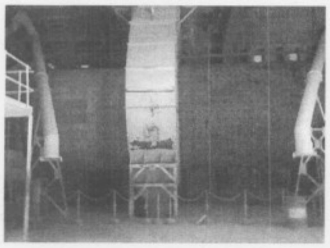
The nine steps in the production of Portland cement are included below [34]:

1. **Quarrying for raw material**



During this process, the quarry extracts mainly limestone from various deposits. These rocks are then crushed beforehand to sizes of about 19 mm in diameter or smaller. Quarry operations usually include drilling, blasting, excavating, loading, hauling, crushing, screening, stockpiling and storage.

2. **Raw milling**



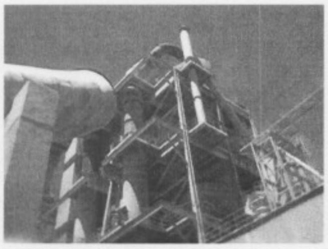
This involves grinding the raw material into a fine powder by means of horizontal ball mills or vertical roller mills. This is done to achieve the correct particle size for the properties needed in the final cement. This is a cyclical process that uses cyclones and separators to separate coarse and fine particles. The fines continue to the blending silos, while the coarse particles are re-inserted into the mill for further grinding.

3. **Blending**

The milled material needs to be blended according to a specific proportional scale in order to maintain the correct properties for the final product. To achieve this, the mills feed operations are being changed every few hours. When the silo is full, the meal will have the correct average composition.This homogenous blend is then transferred to a storage silo, known as the raw mill storage silo or the kiln feed silo.

4. **Calcining and clinkering**

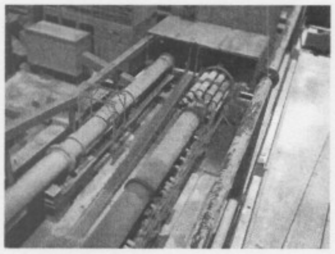
In the calcining process, the raw mix is heated to produce cement clinker. These are hard grey spherical nodules ranging in diameter from 0.32-5.0 cm. These are created from chemical reactions that occur in the kiln.



This process starts when cold raw mix is dropped into a pre-heater that uses kiln exhaust gases to heat up the meal. The pre-heater consists of a number of cyclones that serve to exchange heat between the hot air and the material. This pre-heating helps to reduce the total heat consumption in the burning process.

After pre-heating, the material enters the kiln at a temperature of 900-100°C. A flame is introduced in the kiln by burning coal. This allows clinker to form at temperatures of 1450 - 1500°C. All the kilns in South Africa are of the horizontal rotary type.

5. **Cooling of the clinker**

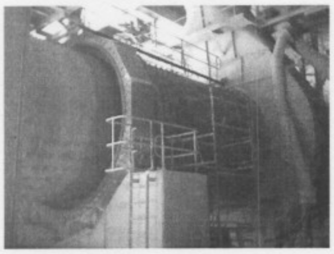


The clinkers exiting the kiln are cooled by means of planetary or grate coolers. This is to allow the clinker to be transported by means of conveyors to the clinker storage silo and also preserves the correct product qualities.

6. **Storage of the clinker**

The clinker is usually stored in clinker silos. The average plant in South Africa stores about two weeks worth production in the clinker silos.

7. **Finish milling**



During this process, the clinker is ground together with additives such as gypsum. The milling system is very similar to that of the raw mills. The final ground product is the finished cement powder.

8. **Advanced blending**

Additives used in the finish milling stages have been milled to various grades in order to produce different cement properties. The most evident additive is gypsum, as it controls the initial reaction with water and retards the setting time of the cement [36]. These are added in the post-production phase of clinker manufacture.

9. **Packing and loading**

After finish milling, the final product is transferred to cement storage silos for packing and dispatch. The product is sold in either bags or bulk.

2.3. Conclusion

By examining the cement industry in South Africa, it was found that currently there is a growing trend in the domestic cement demand. This is due to the numerous construction projects currently taking place or being planned for the near future.

In order to cope with this demand, the cement manufacturers in South Africa are currently expanding their existing facilities. This is very cost intensive. In conjunction with this, there are various large pieces of equipment on a cement factory that uses large amounts of energy, including electricity. Examples of these are the raw mills, kilns and finishing mills.

It is therefore beneficial to examine the possibilities of DSM on a cement factory. As such, the following chapter examines the different procedures developed as part of this study for the identification of cement plant equipment that was found to provide viable load shift possibilities.

3

DEVELOPING SOLUTIONS

Chapter 3 is concerned with developing procedures for finding viable load shift projects on a cement plant. This includes all the steps from the walkthrough audit, through the data gathering and simulations, to the final conclusion on the viability of a specific project. This chapter serves as the basis for the case study provided in chapter 4.

3 DEVELOPING SOLUTIONS

3.1 Introduction

Now that the process of cement manufacturing is outlined, the actual process of selecting the equipment that was used in this study can be highlighted. There are a few criteria that were chosen as benchmarks against which to measure the viability of a load shift project on a cement factory. These are the following:

- There must be enough storage capacity for production materials that can be used for storage during off-peak times.
- The equipment constraints must be taken into account.
- The quality of the products may not be influenced negatively.
- The downtime of the plant must not be increased because of the cost savings goal.

These criteria were developed by interviewing the plant personnel during the study.

In order to determine if a viable load shift project exists on a cement plant, there are a few procedures that have been developed as part of this study. These procedures use the above criteria as benchmark, and are used throughout the whole process, from the gathering of information, to simulations, to time studies, to the final conclusion about the viability of a specific piece of equipment for load shift.

This chapter describes these procedures in detail and concludes with the specific machines that were found to have the highest possibility of becoming a DSM project. These steps are an extension of the basic criteria for DSM project implementation as described by Metering and Verification (M&V) [37].

3.2 The steps in identifying viable load shift on a cement factory

The walkthrough audit

Get knowledgeable assistance

The first step in any audit is to communicate with the appropriate people. On a cement factory this is no different, and the production manager and engineering manager is the appropriate people to approach. They will be able to assign the appropriate plant personnel with enough relevant knowledge of the plant systems to be able to help with any questions asked.

It is important to keep at least these two managers in the process, as they will have the final say on the implementation of any possible load shift project that might arise. They are also responsible for the successful integration of load shift procedures into the plant operations.

Familiarization of the plant layout

At the start of every audit, it is helpful to be familiarised with the layout of the plant. This provides the bigger picture in which the possible DSM project will operate. Knowledge of the plant also serves the purpose of assisting the auditor in any questions that might arise from the audit. This will also point out any differences to similar types of plants, allowing incorrect assumptions about equipment or processes to be eliminated at an early stage.

Identify large electricity users

During the walkthrough, the large electricity consumers on the plant can easily be identified by questioning the person or persons serving as guide (usually an electrician). These machines are usually quite easy to spot by the presence of large motors. At this stage it is wise to gather any visible information on these equipment as it will save the time and trouble of returning later.

Typical information that must be gathered in this stage is the number of machines in question, as well as the installed capacities of each electrical motor. The auxiliaries like oil pumps and small fans connected to this equipment can also be noted.

Establish the storage potential

A load shift project requires that there be storage capacity for production materials that can be used during peak times, therefore it is also important to take note of any silos or stockpiles that are installed, as well as the systems that feed to and from them. The presence of a silo in a sub-system of the factory is usually a good sign for a potential load shift project.

On a cement plant there are usually three or four types of silos, namely: blending silos, raw mill (kiln feed) silos, clinker silos and final product silos. The blending silos and raw mill silos are sometimes combined. Therefore, the focus in terms of load shift must be on the equipment that uses storage silos.

Gathering information

Historical stop-and-start data

After the walkthrough has been completed, and the installed capacities of the relevant equipment has been gathered, it is necessary to find some kind of historical information on the daily operation of the selected equipment. This is either in the form of hand-written log sheets or computerised data usually stored in the control room.

For load shift purposes, the most relevant information would be those for the raw mills, kilns and finishing mills. Historical stop-start data for this equipment must be gathered for at least the previous three months, although longer periods could be beneficial in providing a more accurate picture of the actual consumption.

This information is used in conjunction with the installed capacities to calculate a baseline for the selected equipment.

Process flow information

It also is necessary to gather information on the product flow throughout the system. This is especially important for the milling circuits, as the main focus will lie with these circuits. The process data is used to simulate the silo levels at a later stage. This should conclude the actual site visit, as the rest of the procedure can be done off site.

Refining the information

Separating the data into hourly intervals

In order to get a clear picture of the actual daily electricity consumption of the selected equipment, it is necessary to develop a graph that shows the electrical load for each hour of an average day. This is known as the baseline. As such, the first step in refining the information is to separate the data so that hourly values can be extracted.

Establishing a baseline

A baseline is a daily load profile for a specific machine or system averaged over at least a three-month period. This is the most important piece of information necessary to conduct a DSM project, as it serves as the benchmark against which performance of the project is measured.

It is important to develop a baseline from at least three of the most resent consecutive months. This will give an accurate picture of the plant as it is run at present. Different baselines can be developed for weekdays, Saturdays and Sundays.

It is important to note that after the study was undertaken, it was found that the specific cement factory has a seasonal production demand. This will influence the baseline at different times of the year. For the purpose of this study, a constant demand throughout the year was assumed.

Preliminary saving simulation

Simulating the maximum savings

As a first step in determining the potential of a specific system, a simulation is done to compare the baseline electricity consumption to a new optimised profile that excludes use of the equipment during one or both of the peak times.

This means that the plant uses exactly the same amount of energy for production, but uses it during different times of the day, usually off-peak times. This is known as an energy neutral project and will provide a saving to the plant in terms of electricity cost, as well as provide Eskom with extra capacity during peak-times.

The fact that electricity is moved out of the peak time means that the consumption during other times of the day will rise. These new values must not exceed the installed capacity of the system and must preferably not surpass the current maximum demand.

Optimization models

Optimise the saving schedule by simulation the material flows and silo levels

If it has been determined that there may be a viable load shift project in a specific system by calculating the maximum cost saving, it is necessary to simulate the new fluctuating silo levels, as well as the material flows. This will determine if there is enough capacity in the silos to store enough material during off-peak times, so that the process can continue during peak time without the equipment in question.

Here the current material flows must be simulated as accurately as possible in order to keep to the production schedule of the plant. Normally the factory has a minimum and maximum level between which the silos must be kept for quality purposes, and these must be adhered to during the simulation.

Determine the time available to perform load shift

If it is has been determined that there is enough savings potential and storage capacity in the system, it is necessary to do a time study. The time study is a tool used to find the realistic amount of time available with which to perform a load shift.

The load shift may only occur in times that the factory is already stopping for maintenance or which is set aside for power planning. There are other reasons too, like full silos that may then also be utilised for load shift.

It may be necessary to change the maintenance schedule of the plant to accommodate the load shift. This can include doing opportunity maintenance on some equipment of the milling section during peak times, thereby reducing downtime at a later stage and possibly increasing production due to more reliable equipment.

This has to be cleared with the engineering and production managers, and the full details are not included in the scope of this study.

Identify possible problems

Isolate the problem

If the tests and simulations show that a specific piece of equipment or system will definitely be able to produce a load shift while still adhering to the criteria given at the beginning of this chapter, it is time to look at possible problems.

These problems include any concerns that the plant may have with stopping and starting their systems during peak-time every day. The most common concerns include the lifetime of the motors or shafts, or quality control of the cement raw meal product.

Develop possible solutions for the problem

In order to continue with the project, it is necessary to discuss the concerns with the factory management. It should be possible to reach a conclusion as to the type of solution that can be implemented. It was found that many of the concerns that the plant have could be addressed by installing specific equipment.

In some cases the correct equipment is already installed, but plant personnel may not fully understand the purpose of this equipment.

Conclusion

After all the above factors have been included in studies and simulations, it is necessary to measure the results against the criteria given at the beginning of this chapter. If a specific system or machine meets all the requirements, it will probably be a viable load shift project. If one or more of the criteria are broken, it may be difficult to provide long-term sustainability for the project.

3.3 Cement Equipment Amenable to Load Shift

As suggested in section 2.3 of this study, there are usually three systems on a cement factory that have storage capacity for a possible load shift project. These are the following:

- Raw mills
- Kilns
- Finishing mills

The case study in this thesis focussed only on the raw mills as a possible source of load shift potential. The reasons can be explained by using the following layout of a cement factory:

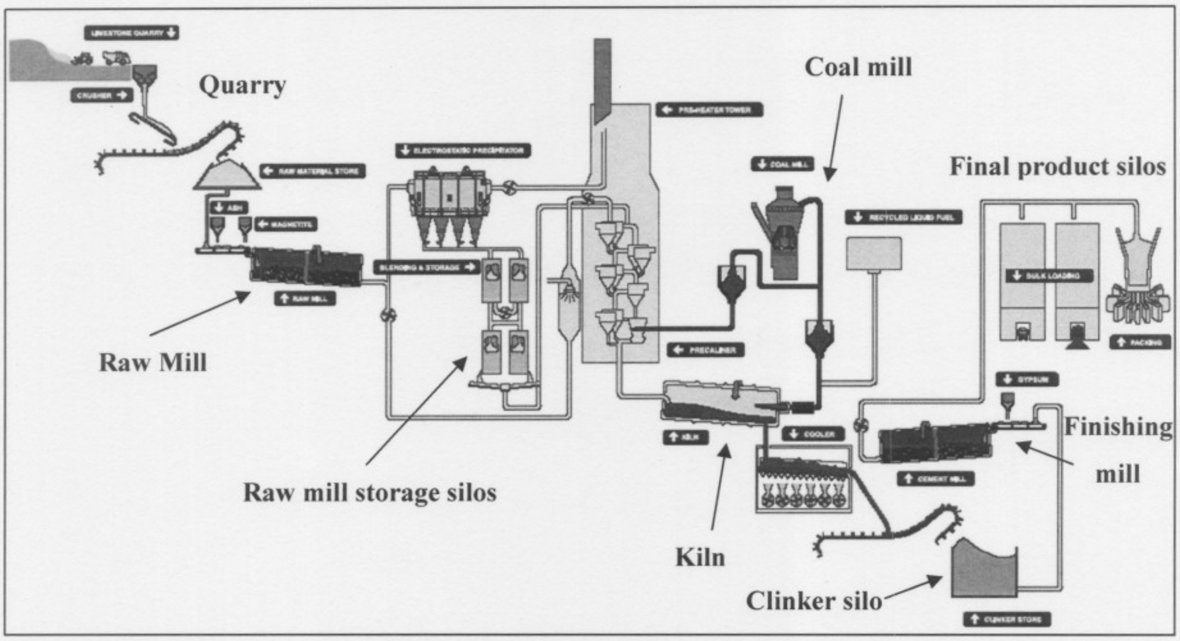


Figure 9: Simplified layout of a typical cement factory.

In Figure 9 the raw mill is situated between the quarry and a raw mill storage silo. The storage silo feeds the kiln through the pre-heater, which feeds into a clinker silo and into the finishing mills to the final product silos.

Even if the raw mill is stopped, the kiln will be able to produce clinker from the raw mill storage silos, which are normally huge enough to accommodate a breakdown of the raw mills. As such, **the factory** welcomed the idea of possible savings on the raw mills. The main focus of the study was therefore on the raw mills.

The kiln is not often stopped due to the large amounts of thermal energy involved and the complex chemistry and production tonnages that will be ruined if it is attempted. The coal mills feed the kiln with fuel, and as such must always be available for production.

Even though there are storage bins near the coal mills, the capacity of these is much too small for a viable load shift project. **The factory** was not very comfortable with the idea of stopping the kiln systems, therefore these were excluded from the study.

The finishing mills get material directly from the clinker silos and gypsum feeders. These mills are directly responsible for the final production of the plant. Anything they produce is sold in high volumes due to the large demand for cement in South Africa (See Chapter 2).

As such, the finishing mills are only stopped when absolutely necessary, excluding them from frequent stops over a long term. Due to this, **the factory** asked that the study be confined to the raw mills. The finishing mills were therefore excluded from this study.

3.4 Control Philosophy for Cement Applications

Now that it has been established that raw mills are the best equipment to use for a load shift project on a cement factory, it is useful to look at the control philosophy for such a project. The variables necessary for controlling the raw mills as a load shift project need to be investigated. One of the most important variables is definitely the electricity pricing structure, in this case MegaFlex.

If the MegaFlex tariff is examined (See Chapter 1), it becomes evident that the cost of electricity changes during different parts of the day, alternating between peak, off-peak and standard times, with peak times being the most expensive. The cost of electricity can therefore be used as one of the most important variables in determining a control philosophy.

The following figures show the real hourly effect of the MegaFlex structure:

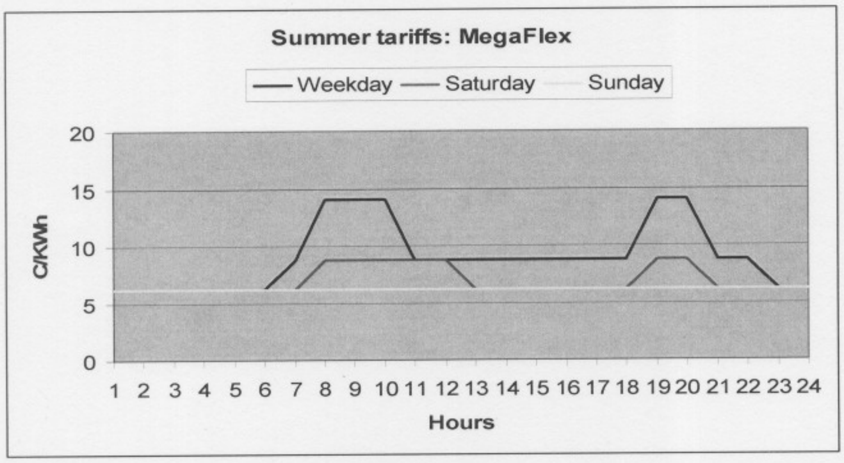


Figure 10: Graphical representation of the MegaFlex costs on a typical summer day.

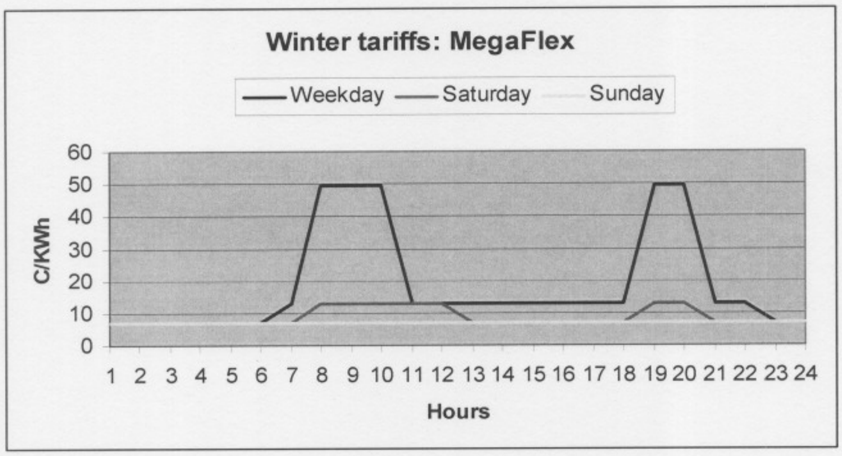


Figure 11: Graphical representation of the MegaFlex costs on a typical winter day.

The other variables that were found to be of importance on a cement factory are: Material flow, storage silo levels, availability of the mill, as well as mill start-up procedures. The values of these variables may differ from one cement plant to the next, but their application remains basically the same when doing a detailed simulation of the system.

In order to control the raw mill system accurately, it may be necessary to utilise the existing Supervisory Control and Data Acquisition (SCADA) system of the factory. By using this system, the ESCO doing the implementation will have the support of an expert software package, as well as the plant operators to manage the plant systems at predetermined set points.

By interfacing with the existing SCADA systems on the factory, the ESCO can receive critical information on the variables affecting the load shift by direct access to the SCADA tags.
An automatic dynamic simulation of the raw mill system can then be done by means of a simulation program. This same programme can then also employ an interface with the SCADA through which control signals can be sent to the relevant systems on the plant.

The following diagram illustrates a simplified control philosophy that might be used on a raw mill system:

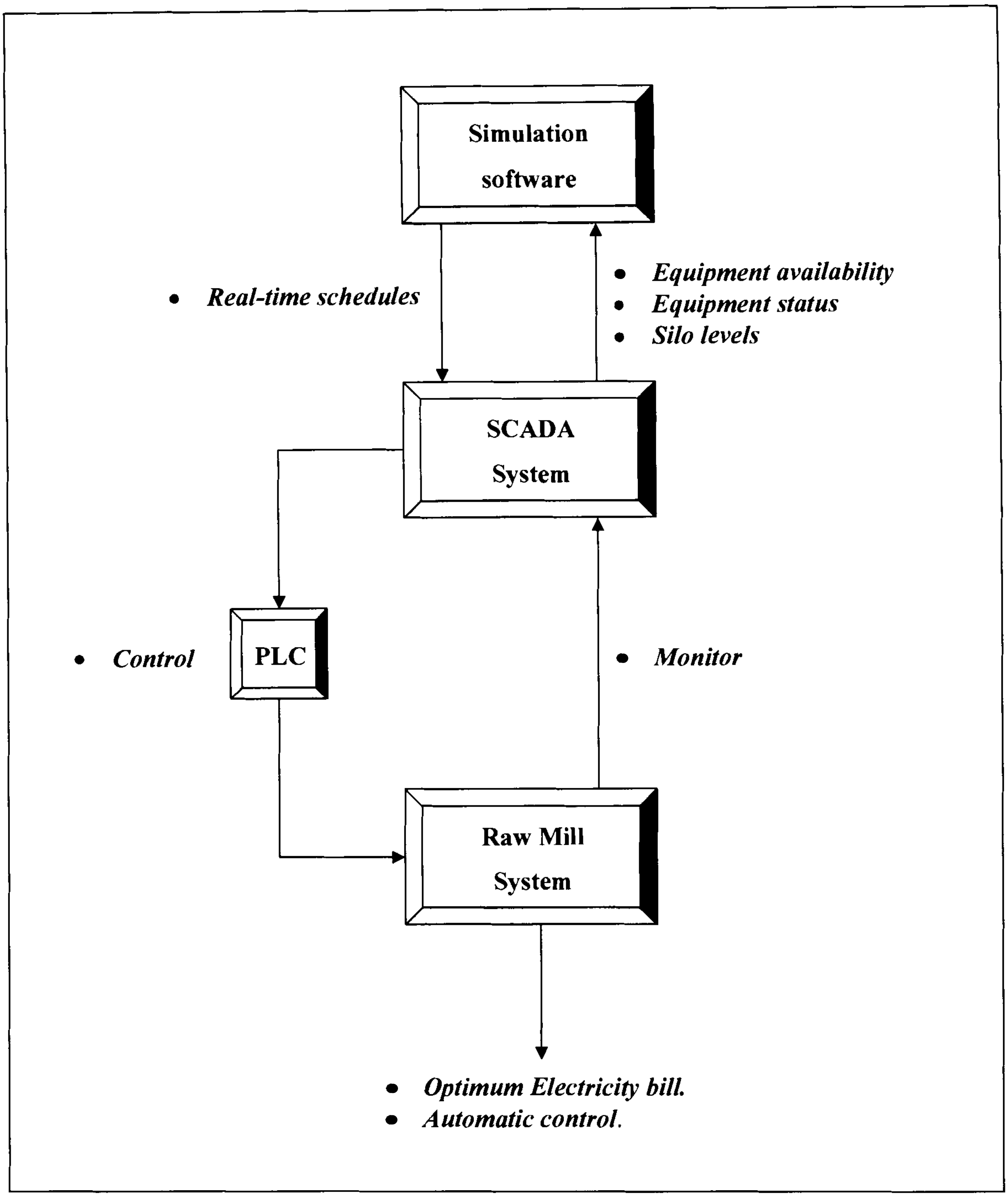


Figure 12: Control diagram for controlling equipment on a cement plant for load shift.

As most of the material flow systems to and from the raw mill are controlled automatically, it should be possible to monitor the levels of the raw mill storage silos to see if they are above the safety levels for shutdown during peak time. The plant control systems can then be used to switch the mill and its auxiliaries on or off at the required times.

3.5 Conclusion

This chapter described the procedures for identifying viable load shift projects on a cement factory, as developed by the author for the purpose of this study. These procedures originated from the basic criteria for DSM project implementation as produced by M&V.

The detailed steps were developed by the author during multiple visits to a cement factory. The following chapter is a case study of the experiences on this specific cement factory, and includes the results obtained by using the procedures developed in this chapter.

4

VERIFICATION OF PROCEDURES: A CASE STUDY

This chapter is a case study to verify the procedures developed in chapter 3. This case study was done on an actual cement plant in the North West Province of South Africa. All the steps developed are discussed in detail, and results are provided as verification. The chapter ends with a conclusion on the DSM viability of specific systems on a cement factory.

4 VERIFICATION OF PROCEDURES: A CASE STUDY

4.1 Introduction

A case study was done to test the procedures for the identification of viable load shift projects on a cement factory.

This case study was done in the same order as the test procedures in order to improve the logical flow of the process. A description for each stage is given, as well as results obtained using the prescribed methods. As the plant management was reluctant to allow studies on the kilns and finishing mills, the study will concentrate on the raw mills as possible load shift projects.

4.2 Case Study: the factory

4.2.1 Background on the factory

The Factory is a cement producer situated in the North West Province of South Africa. It receives most of its raw materials by train from a limestone quarry situated a few kilometres away. It is a large clinker producing facility, and produces clinker for use at blending and grinding plants in Limpopo, Gauteng, Mpumalanga and Kwazulu-Natal [32].

The Factory currently has two production lines: Line 2 and Line 3. Both of these lines are fitted with the normal equipment such as raw mills, silos, kilns, finishing mills and packing plants. Line 2 has hammer mill fitted in front of the raw mill, as the raw mill is of an older design than the mill on line 3.

Production is sustained 24 hours per day to satisfy the current high demand for cement in South Africa. It is currently running on the MegaFlex tariff. The following section will describe the factory in terms of the procedures developed in chapter 3, giving results where applicable.

4.2.2 The walkthrough audit

Get knowledgeable assistance

Before the walkthrough audit was conducted on **the factory**, the appropriate people were approached with the proposition to perform a study there. The proposed study was discussed with the both the Works- and Production Managers.

They both agreed to allow a study on the raw mill section, as this part can be run independently from the rest of the plant to a large extent. They assigned an electrician to act as guide during the audit. He was of tremendous help in describing the plant layout and locating the correct equipment for the study.

Familiarization of the plant layout

It was during this walkthrough that the cement process was described to the author and the purpose of all the major machines was discussed. Discussions were also arranged with the Raw Mill Engineer and a Plant Electrical Engineer. They were very helpful in providing layout drawings of the plant as well as answering all questions that arose as the audit progressed.

The following is a picture of **the factory**, as seen from a raw mill storage silo roof:

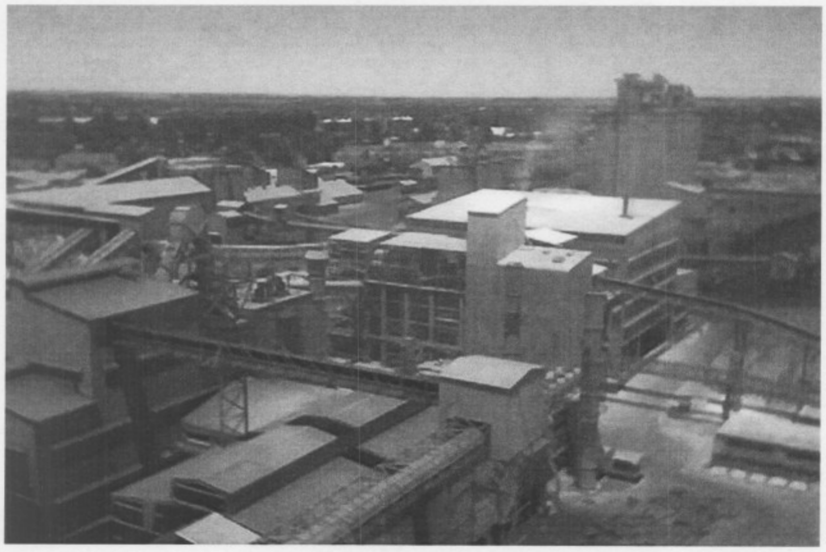


Figure 13: Picture of **the factory**.

The following diagram provides a simplified layout of the raw mill systems on **the factory:**

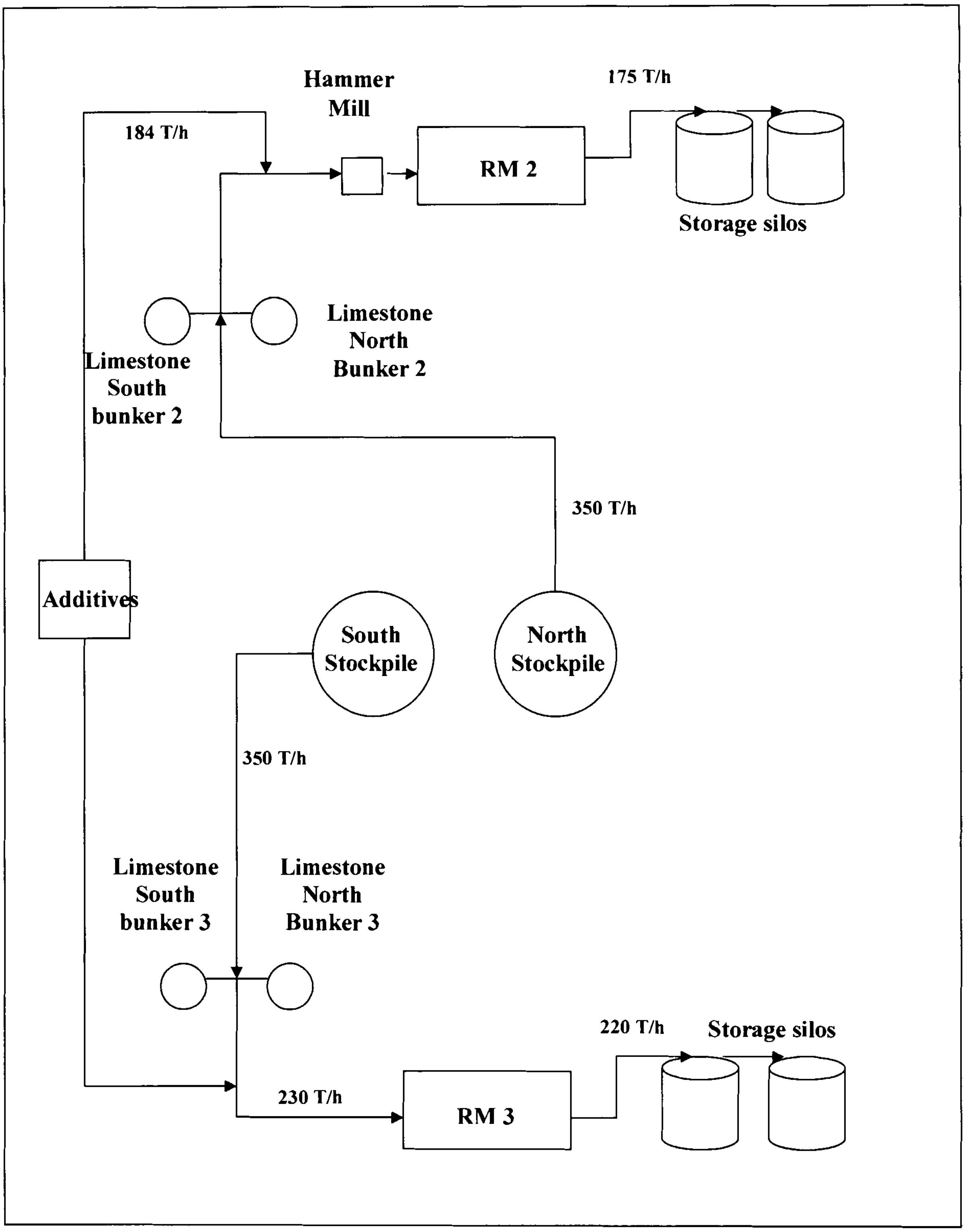


Figure 14: Simplified layout of the two raw mill systems examined in this study.

This figure helps to illustrate the independence of the raw mill section from the rest of the plant. This section is situated between the limestone bins being fed from the quarry, and the raw mill storage silos. These silos act as buffer in case of a mechanical breakdown on the mills, allowing the kiln to continue with production while repairs are being conducted on the mills.

In normal operation the limestone is transported by train from the quarry to the South and North stockpiles in the middle of the figure. These are stockpiles used for storage of limestone from the quarry. The limestone is then transported to the various limestone bins by means of conveyors. These bins are filled automatically if their levels get too low and their inputs are also stopped if they get too full, allowing the raw mills to empty them before continuing.

On the way to the raw mills, various additives are added to the limestone. These include sand, clay and iron ore [38]. It must be noted at this stage that raw mill 2 is of an older design than raw mill 3. Raw mill 2 is an air-swept ball mill [39] and also has a hammer mill in series to help with the crushing. Raw mill 3 is a more recently designed central discharge mill or double rotator mill [39]. This mill also has separators to help separate coarse materials from fine material.

In the raw mill cycle, the material is milled by means of steel balls known as media. The product is discharged from the mill and separated into course and fine material. Those particles of the right size continue on to the blending and storage silos, while the coarse particles are reintroduced into the mill for further milling. The dust is extracted by means of fans.

This is a continuous cycle where material is milled, separated and re-milled till it is the right size. The finished product is know as raw meal and is blended in the blending silos to the correct average chemical proportions. It is then stored in the raw mill storage silos or kiln feed silos, from where it is extracted to the kiln by way of the pre-heater tower.

Identify large electricity users

In this study, special attention was given to large electricity users. There are various other small motors such as oil pumps that were not taken into account. This is a very conservative approach, since the inclusion of these motors will only result in a bigger saving for both Eskom and the factory.

The following equipment was identified in the raw mill sections as being the largest electricity users:

Raw Mill 2		
Equipment	**No. of motors**	**Installed kW**
Mill main drive motors	2	3200
Hammer mill motor	1	680
Hammer mill fan motor	1	600
Main fan motor	1	1020
RM 2 Total installed capacity:		**5500**

Table 4: Equipment used in the study on raw mill 2.

Raw Mill 3		
Equipment	**No. of motors**	**Installed kW**
Mill main drive motors	2	3492
Separator fan motors	2	436
Main fan motor	1	1212
RM 3 Total installed capacity:		**5140**

Table 5: Equipment used in the study on raw mill 3.

The equipment on a specific line must all run together in order to produce raw meal, as it is a continuous process. This means that they will all stop together during shutdowns as well. All this is accomplished automatically in the correct sequence by means of interlocks.

This is very close to an ideal situation for load shift as it allows the stopping of a relatively large amount of electric motors at the same time, without the need to monitor all the systems. Tables 4 and 5 indicate the possibility of a very promising DSM project.

The following pictures show some of the equipment named in tables 4 and 5, as found on **the factory**:

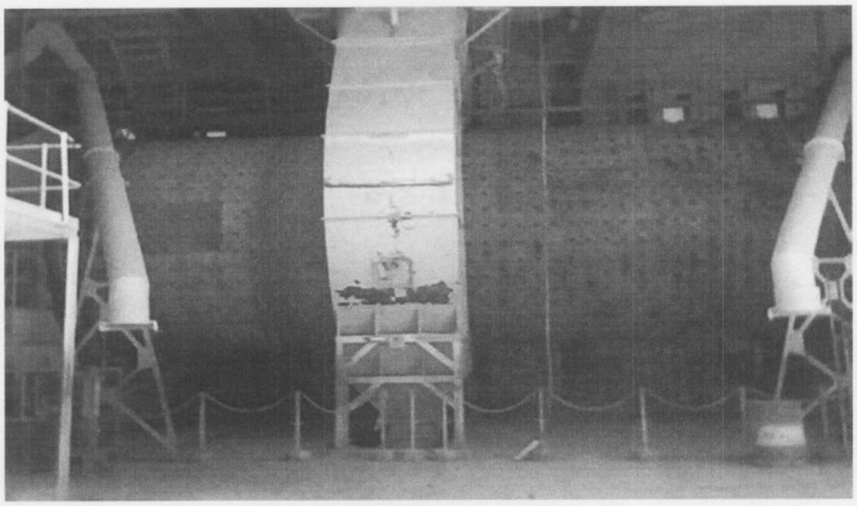


Figure 15: Raw Mill 3, Central discharge mill.

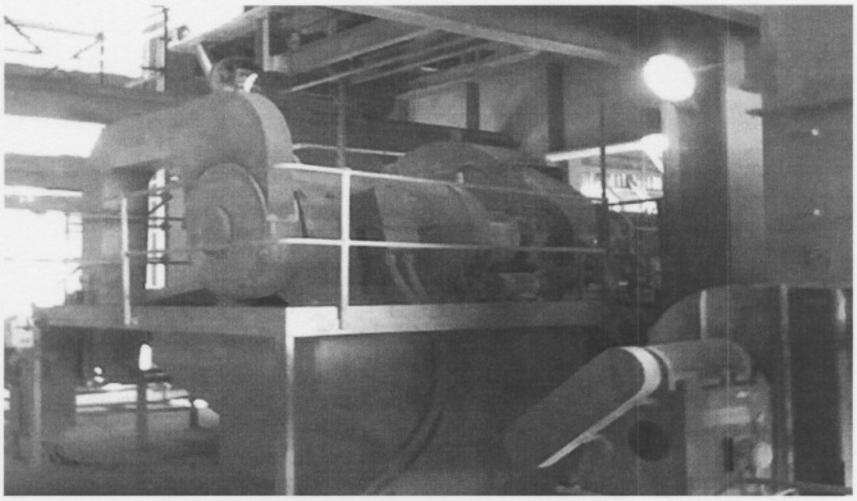


Figure 16: Raw Mill 2 drive motor.

Figure 17: Hammer mill on raw mill 2 line.

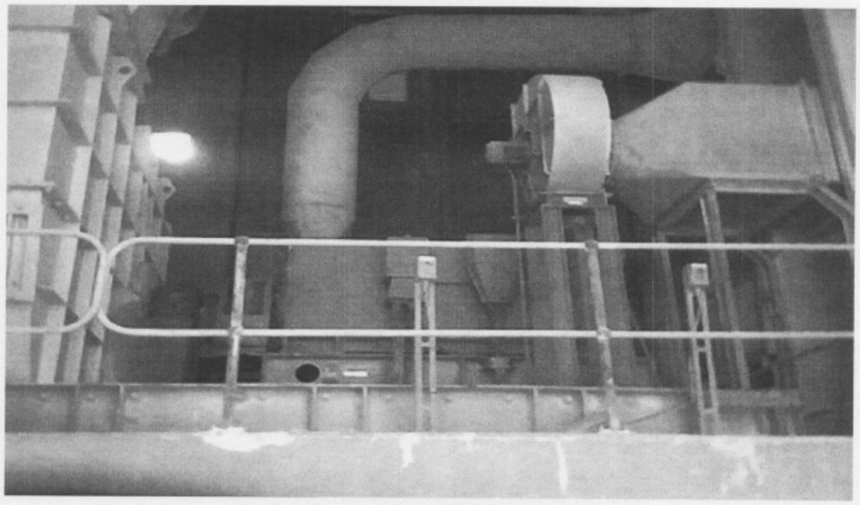


Figure 18: Raw mill fan motor on line 3.

Establish the storage potential

The number and size of the silos were also discussed with the Production Engineer. He provided a detailed explanation of the working of the blending mechanism, as well as the current use of the different raw mill storage silos. The following table provides information on the raw mill storage silos that were used for surge capacity in this study:

Mill	No. of storage silos	Capacity (Tons)	Total Capacity (Tons)
RM 2	3	1,530 t each	4,590 t
RM 3	2	7,200 t each	14,400 t

Table 6: Sizes of the raw mill storage silos on line 2 and 3.

These silos are quite large, which is once again a promising sign in terms of load shift potential

.

4.2.3 Gathering information

Historical stop-and-start data

In order to find historical stop-and-start data on the raw mills, the help of the Production Engineer was employed. He has all the historical information saved on a computer database as part of official company documentation.

The data was not available in terms of specific stop-and-start times, necessitating another approach. The control system is equipped with a computerised logging system that logs the hourly material flow from the limestone bins to the raw mills (see Figure 14, to see the location of the limestone bins).

As the raw mill will only receive material while running, the periods of very low flow readings can be regarded as times when the mills are standing. The following table shows a sample of one day of these log sheets for line 3:

Date	Time	Limestone South (Tons/hr)	Limestone North (Tons/hr)
01-Jun-04	00:00	111.1	111.6
	01:00	116.1	116.5
	02:00	115.9	116.4
	03:00	116.4	116.1
	04:00	115.8	116.2
	05:00	116.6	116.5
	06:00	110.1	109.6
	07:00	105.7	105.7
	08:00	115.8	116.1
	09:00	68.7	68.3
	10:00	0.5	0.5
	11:00	0.5	0.5
	12:00	0.5	0.5
	13:00	78.5	78.6
	14:00	111.0	110.7
	15:00	115.9	115.1
	16:00	115.4	115.9
	17:00	115.6	116.2
	18:00	115.7	115.5
	19:00	107.9	107.9
	20:00	116.1	116.1
	21:00	116.0	116.2
	22:00	116.1	116.0
	23:00	116.0	116.0

Table 7: Sample material flow log sheet for one day.

Data for line 2 is very similar. The numbers provided under the headings of "Limestone North" and "Limestone South" are the average hourly material flow (Tons/hour) flowing from the bins to the raw mills.

Process flow information

These logged values were used in conjunction with other material flow data discussed with the Production Engineer. This includes values like the material flow out of the raw mills and into the silos, as well as the material flow out of the silos and into the kilns. The relevant material flow values are given in Figure 14, the layout of the raw mill system.

4.2.4 Refining the information

Separating the data into hourly intervals

In this case, the values were already logged at hourly intervals, making the process of sorting much easier.

Establishing a baseline

In order to use the logged data to calculate a baseline, it is necessary to determine exactly when the mills and their auxiliaries were running or not. By using the average hourly flow value as an indication of a running system, the status could be determined. This was done as follows:

1. Calculate the average flow from the limestone bins for each hour.

Time	Limestone South (Tons/hr)	Limestone North (Tons/hr)	Average (Tons/hr)
00:00	111.1	111.6	111.4
01:00	116.1	116.5	116.3
02:00	115.9	116.4	116.1
03:00	116.4	116.1	116.3
04:00	115.8	116.2	116.0
05:00	116.6	116.5	116.5
06:00	110.1	109.6	109.9
07:00	105.7	105.7	105.7
08:00	115.8	116.1	115.9
09:00	68.7	68.3	68.5
10:00	0.5	0.5	0.5
11:00	0.5	0.5	0.5

Table 8: Sample average material flow calculated from log sheet data.

2. The highest average values are an indication of a running system, just as a low value indicates that the system is standing. In the following table, the green cells indicate a running system, while the red cells indicate a standing system:

Date	Time	Limestone South (Tons/hr)	Limestone North (Tons/hr)	Average (Tons/hr)
01-Jun-04	00:00	111.1	111.6	111.4
	01:00	116.1	116.5	116.3
	02:00	115.9	116.4	116.1
	03:00	116.4	116.1	116.3
	04:00	115.8	116.2	116.0
	05:00	116.6	116.5	116.5
	06:00	110.1	109.6	109.9
	07:00	105.7	105.7	105.7
	08:00	115.8	116.1	115.9
	09:00	68.7	68.3	68.5
	10:00	0.5	0.5	0.5
	11:00	0.5	0.5	0.5
	12:00	0.5	0.5	0.5
	13:00	78.5	78.6	78.6
	14:00	111.0	110.7	110.8
	15:00	115.9	115.1	115.5
	16:00	115.4	115.9	115.6
	17:00	115.6	116.2	115.9
	18:00	115.7	115.5	115.6
	19:00	107.9	107.9	107.9
	20:00	116.1	116.1	116.1
	21:00	116.0	116.2	116.1
	22:00	116.1	116.0	116.0
	23:00	116.0	116.0	116.0

Table 9: Indication of a running or standing raw mill system.

3. Calculate the hourly average status over a three-month period or longer.
4. Calculate hourly baseline values by using the following formula:

BASELINE VALUE = 3 MONTH AVERAGE STATUS X INSTALLED CAPACITY

5. The resulting answer is the baseline of the specific system. The baseline is an indication of the average hourly load that the raw mill systems consume.

The following figures provide the baselines for the two mill systems in graphic form:

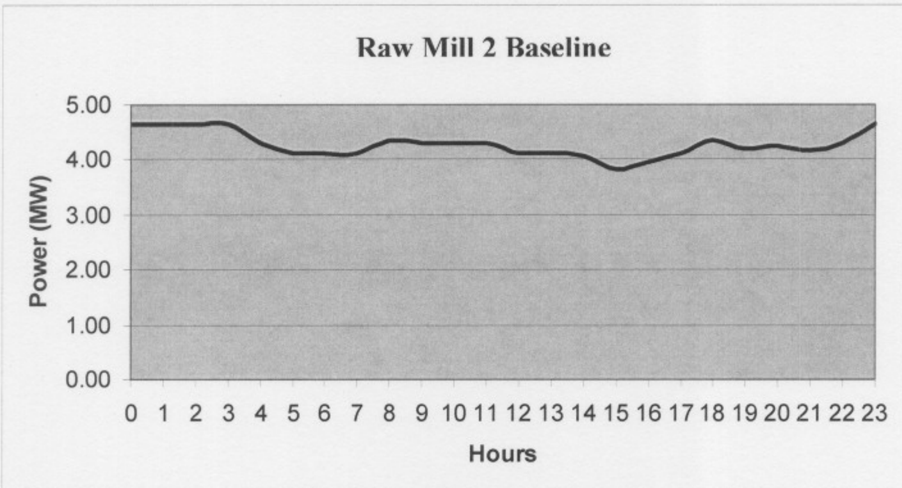


Figure 19: Baseline of the raw mill 2 system.

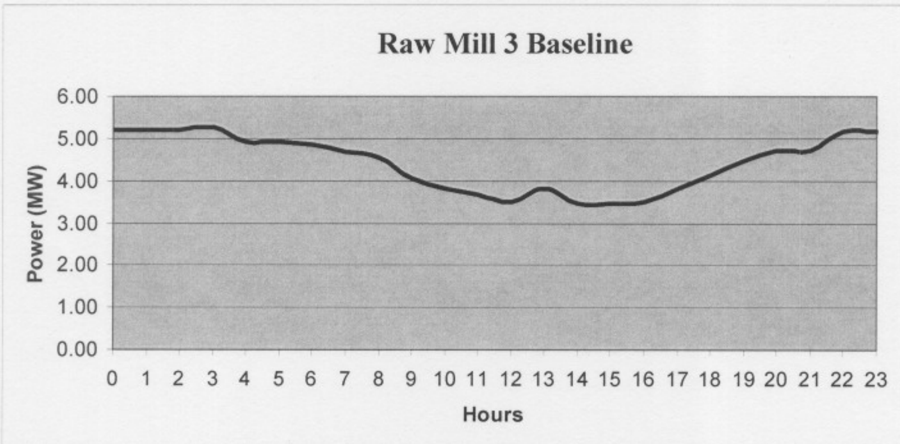


Figure 20: Baseline of the raw mill 3 system.

For the sake of simplification, the two graphs above were added together to form a single baseline representing both the systems of raw mill 2 and 3. This allows a single simulation to be done in order to find the maximum savings potential for the whole project. The following graph shows this single summed baseline:

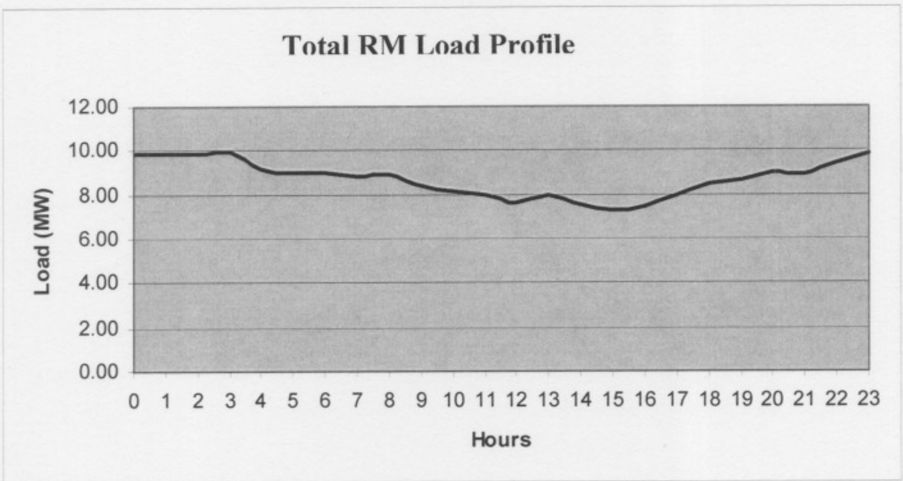


Figure 21: Combined baseline of raw mill 2 and 3 systems.

This baseline was now used as a benchmark for calculating the electricity savings potential for the two raw mill systems.

4.2.5 Preliminary saving simulation

Simulating the maximum savings

A computer program was used to simulate the electricity cost savings for the raw mill systems. This was done to provide the maximum saving scenario for the two systems. In order to be considered successful, the simulations have to comply with certain constraints. The constraints used for these simulations are the following:

- The Eskom MegaFlex tariffs must be used for the savings calculation.
- The electricity cost must be minimised during the peak times (07:00 – 10:00 and 18:00 – 20:00).
- The simulation must be energy neutral (The areas under the baseline and the simulated schedule must be the same) to ensure that the same amount of material is milled every day.
- The maximum electrical load cannot exceed the installed capacity.
- If possible the maximum demand must be kept at, or below, the current value.

These constraints were used to determine the maximum electricity cost savings, while not exceeding the energy capabilities of the mill systems.

The following table provides the new optimised MW values resulting from the simulations as compared to the combined baseline:

Hour of day	Measured electricity consumption on raw mills (MW)	Simulated electricity consumption on raw mills (MW)
00:00	9.9	11.1
01:00	9.9	11.1
02:00	9.9	11.1
03:00	9.9	11.1
04:00	9.2	11.1
05:00	9.0	11.1
06:00	9.0	9.8
07:00	8.8	0.0
08:00	8.9	0.0
09:00	8.4	0.0
10:00	8.1	11.1
11:00	8.0	11.1
12:00	7.6	11.1
13:00	7.9	11.1
14:00	7.5	11.1
15:00	7.3	11.1
16:00	7.5	11.1
17:00	8.0	11.1
18:00	8.5	0.0
19:00	8.7	0.0
20:00	9.0	11.1
21:00	8.9	11.1
22:00	9.5	11.1
23:00	9.8	11.1

Table 10: Baseline values of both systems compared to the newly proposed milling schedule.

The savings effect of the above proposed load profile could be better illustrated if compared in graphic form. (See Figure 22).

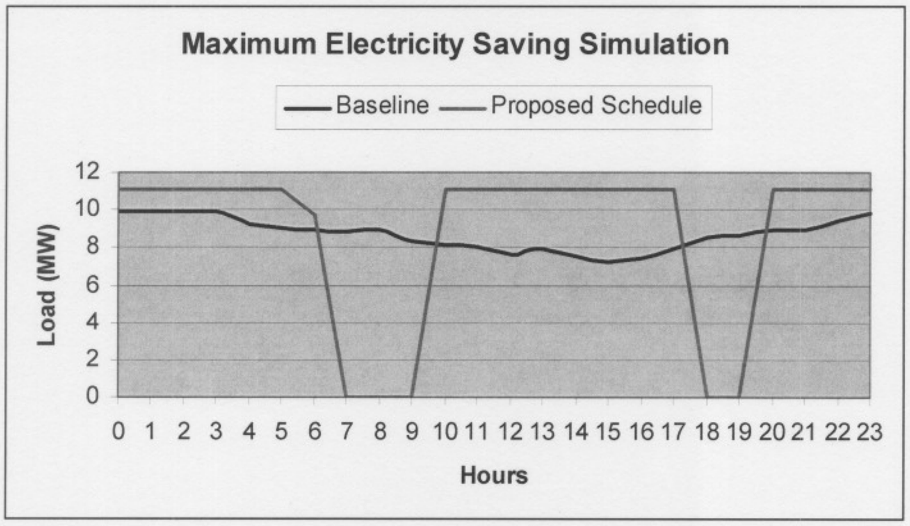


Figure 22: Graphical representation of the values provided in table 10.

As can be seen from Figure 22, there is a substantial saving to be gained from shutting down the raw mills during both the morning and evening peak. The load savings were calculated as the difference between the baseline and the new optimised profile averaged over the peak times.

It must be noted that these savings are the maximum that is possible with the MegaFlex tariff structure. The simulation only focussed on energy consumption and did not take into account any actual process flows.

Summary of maximum electricity cost savings

The maximum electricity cost saving was found to be the as follows, using the MegaFlex tariff structure:

Morning peak saving	Evening peak saving	Total MW saving	Annual cost saving
8.6 MW	9 MW	17.6 MW	R 1,600,000

Table 11: Maximum electricity cost saving using MegaFlex.

This is quite a substantial cost saving that can be achieved for the plant. These results need to be optimised to determine if it is truly possible. These simulation results are given in the following section:

4.2.6 Optimisation models

Optimise the saving schedule by simulation the material flows and silo levels

In order to optimise the simulation, it is first necessary to establish the actual values of material flow through the raw mill system. It is also necessary to know the correct silo volumes. All this information had been gathered in the first stages of the audit and was readily available to the author during the study.

In order to simulate the silo levels, the raw mill system was simplified as a control volume or so-called "black box". It was known what the inputs and outputs of the black box should be, and as such, the silo levels could be manipulated as a function of the material going in and out of the system.

The following figure shows a simplified concept diagram of the simulation model that was used to simulate the optimised milling schedule:

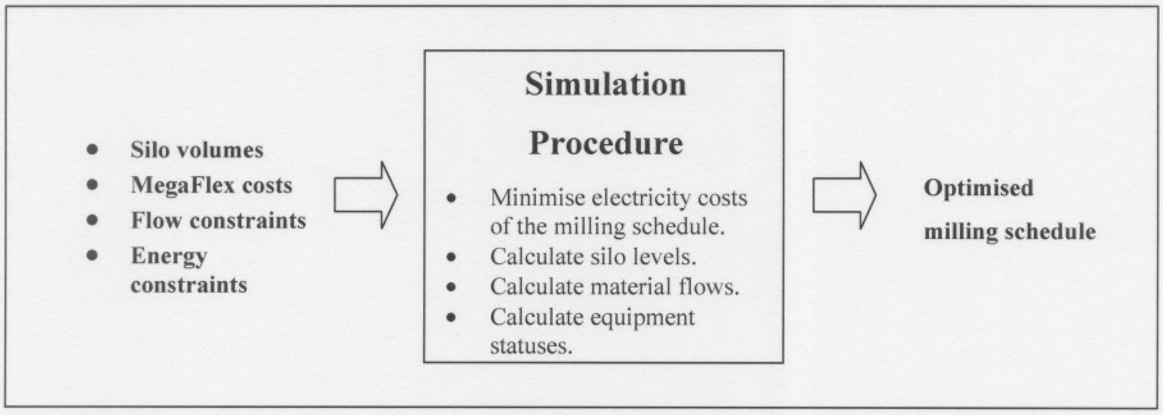


Figure 23: Simplified concept diagram of the simulation procedure.

This simplified method was used to simulate the material flow and silo levels by means of simulation software. This software allows the user to simulate a process or system by choosing to minimise or maximise a result by changing process values subject to user-defined constraints.

The results obtained by this simulation provide a more accurate description of the actual material flow through the raw mill systems than the energy simulation alone. As the two raw mill systems are fed from separate stockpiles and limestone bins, these simulations were done separately for each line.

Optimised simulation of raw mill 2

The first figure is the simulation of the raw mill 2 system:

Hour	Flow into mill	5% water reduction	Flow out of mill	Flow into silos	Silo tons	Silo %	Kiln flow	Baseline	shifter	Function	Simulated	Load shift
	T/h	T/h	T/h	T/h	Tons		T/h	MW			MW	
	177.81				2000.00		155.00					
1	177.81	8.89	168.92	168.92	2018.92	43.99	150.00	4.66	1.00	4.80	4.80	
2	177.81	8.89	168.92	168.92	2037.83	44.40	150.00	4.66	1.00	4.80	4.80	
3	177.81	8.89	168.92	168.92	2056.75	44.81	150.00	4.66	1.00	4.80	4.80	
4	177.81	8.89	168.92	168.92	2075.66	45.22	150.00	4.66	1.00	4.80	4.80	
5	177.81	8.89	168.92	168.92	2094.58	45.63	150.00	4.30	1.00	4.80	4.80	
6	177.81	8.89	168.92	168.92	2113.50	46.05	150.00	4.13	1.00	4.80	4.80	
7	177.81	8.89	168.92	168.92	2132.41	46.46	150.00	4.13	1.00	4.80	4.80	
8	177.81	8.89	168.92	168.92	2151.33	46.87	150.00	4.13	1.00	4.80	4.80	
9	90.88	4.54	86.33	86.33	2087.66	45.48	150.00	4.37	1.00	2.45	2.45	
10	159.99	8.00	151.99	151.99	2089.65	45.53	150.00	4.31	1.00	4.32	4.32	0.41 MW
11	177.81	8.89	168.92	168.92	2108.57	45.94	150.00	4.31	1.00	4.80	4.80	
12	177.81	8.89	168.92	168.92	2127.49	46.35	150.00	4.31	1.00	4.80	4.80	
13	177.81	8.89	168.92	168.92	2146.40	46.76	150.00	4.13	1.00	4.80	4.80	
14	177.81	8.89	168.92	168.92	2165.32	47.17	150.00	4.13	1.00	4.80	4.80	
15	177.81	8.89	168.92	168.92	2184.23	47.59	150.00	4.07	1.00	4.80	4.80	
16	177.81	8.89	168.92	168.92	2203.15	48.00	150.00	3.83	1.00	4.80	4.80	
17	177.81	8.89	168.92	168.92	2222.07	48.41	150.00	3.95	1.00	4.80	4.80	
18	177.81	8.89	168.92	168.92	2240.98	48.82	150.00	4.13	1.00	4.80	4.80	
19	0.00	0.00	0.00	0.00	2090.98	45.56	150.00	4.37	1000.00	0.00	0.00	
20	0.00	0.00	0.00	0.00	1940.98	42.29	150.00	4.19	1000.00	0.00	0.00	4.28 MW
21	177.81	8.89	168.92	168.92	1958.25	42.66	151.65	4.24	1.00	4.80	4.80	
22	177.81	8.89	168.92	168.92	1972.17	42.97	155.00	4.18	1.00	4.80	4.80	
23	177.81	8.89	168.92	168.92	1986.08	43.27	155.00	4.31	1.00	4.80	4.80	
24	177.81	8.89	168.92	168.92	2000.00	43.57	155.00	4.66	1.00	4.80	4.80	
								102.7889		102.7889	102.78889	

Table 12: Optimisation simulation of the raw mill 2 system.

- *Shifter* gives boundary values that are used to control the hours that load shift must take place.
- *Function* is calculated as *Shifter x Simulated MW* . The red total is the sum of these values and is the input that is minimised by the simulation program.

Optimised results for raw mill 2

The relevant results were plotted to provide a graphic representation of the simulation. The following graph provides the newly simulated electrical load for raw mill 2:

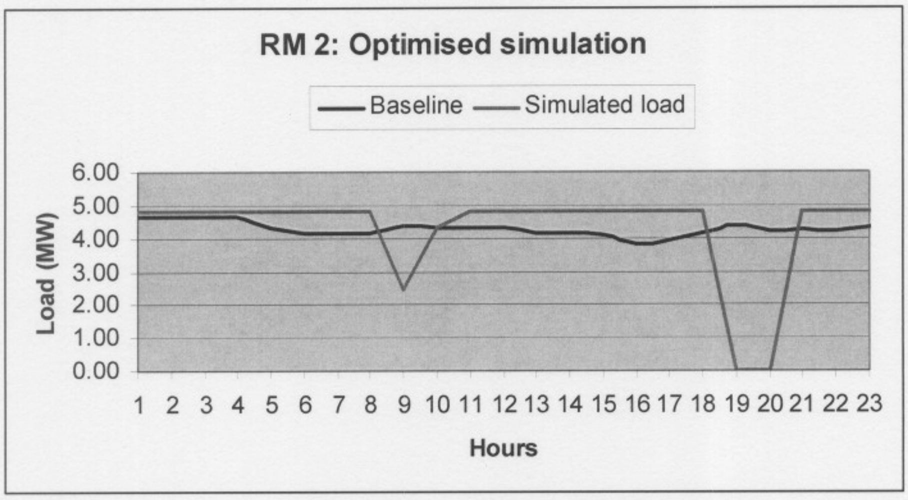


Figure 24: Optimised results for raw mill 2.

The simulated silo levels were also graphed. It is very important that the silo levels are kept in a relatively narrow range, as this allows the quality of the raw meal to be kept constant. These levels are given in Figure 25:

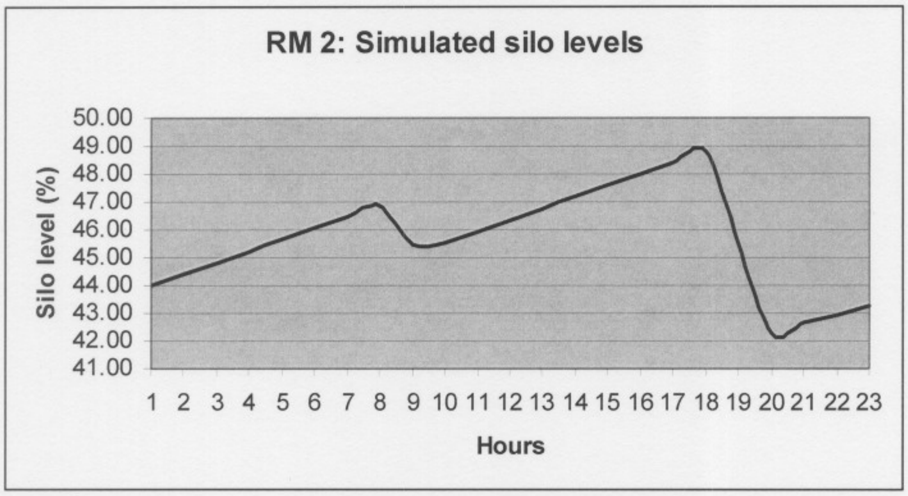


Figure 25: Simulated silo levels for the raw mill 2 system.

Optimised simulation of raw mill 3

The simulation of the raw mill 3 system was done in the same way as for raw mill 2. The following figures illustrate the results obtained:

Hour	Flow into mill	5% water reduction	Flow out of mill	Flow into silos	Silo tons	Silo %	Kiln flow	Baseline	shifter	Function	Simulated	Load shift
	T/h	T/h	T/h	T/h	Tons		T/h	MW			MW	
	230.00				10000.00		196.24					
1	230.00	11.50	218.50	218.50	10018.50	69.57	200.00	5.22	1.00	4.83	4.83	
2	215.16	10.76	204.41	204.41	10022.91	69.60	200.00	5.22	1.00	4.52	4.52	
3	230.00	11.50	218.50	218.50	10041.41	69.73	200.00	5.22	1.00	4.83	4.83	
4	230.00	11.50	218.50	218.50	10059.91	69.86	200.00	5.28	1.00	4.83	4.83	
5	229.10	11.45	217.64	217.64	10081.31	70.01	196.24	4.91	1.00	4.81	4.81	
6	229.10	11.45	217.64	217.64	10102.71	70.16	196.24	4.91	1.00	4.81	4.81	
7	229.10	11.45	217.64	217.64	10124.11	70.31	196.24	4.85	1.00	4.81	4.81	
8	226.73	11.34	215.39	215.39	10143.26	70.44	196.24	4.67	1000.00	4761.35	4.76	
9	226.73	11.34	215.39	215.39	10162.41	70.57	196.24	4.55	1000.00	4761.35	4.76	
10	226.73	11.34	215.39	215.39	10181.56	70.71	196.24	4.06	1000.00	4761.35	4.76	0.33 MW
11	226.73	11.34	215.39	215.39	10200.71	70.84	196.24	3.82	1.00	4.76	4.76	
12	226.73	11.34	215.39	215.39	10219.86	70.97	196.24	3.69	1.00	4.76	4.76	
13	226.73	11.34	215.39	215.39	10239.01	71.10	196.24	3.51	1.00	4.76	4.76	
14	226.73	11.34	215.39	215.39	10258.16	71.24	196.24	3.82	1.00	4.76	4.76	
15	226.73	11.34	215.39	215.39	10277.31	71.37	196.24	3.46	1.00	4.76	4.76	
16	226.73	11.34	215.39	215.39	10296.46	71.50	196.24	3.46	1.00	4.76	4.76	
17	226.73	11.34	215.39	215.39	10315.61	71.64	196.24	3.52	1.00	4.76	4.76	
18	226.73	11.34	215.39	215.39	10334.76	71.77	196.24	3.82	1.00	4.76	4.76	
19	0.00	0.00	0.00	0.00	10138.51	70.41	196.24	4.12	1000.00	0.00	0.00	
20	0.00	0.00	0.00	0.00	9942.27	69.04	196.24	4.48	1000.00	0.00	0.00	4.3 MW
21	226.73	11.34	215.39	215.39	9961.42	69.18	196.24	4.73	1.00	4.76	4.76	
22	215.16	10.76	204.41	204.41	9969.58	69.23	196.24	4.73	1.00	4.52	4.52	
23	215.16	10.76	204.41	204.41	9977.74	69.29	196.24	5.15	1.00	4.52	4.52	
24	230.00	11.50	218.50	218.50	10000.00	69.44	196.24	5.15	1.00	4.83	4.83	
								106.35		14374.2	104.444737	

Table 13: Optimisation simulation of the raw mill 3 system.

- *Shifter* gives boundary values that are used to control the hours that load shift must take place.
- *Function* is calculated as *Shifter x Simulated MW* . The red total is the sum of these values and is the input that is minimised by the simulation program.

Optimised results for raw mill 3

The newly simulated electrical load can be graphed as follows:

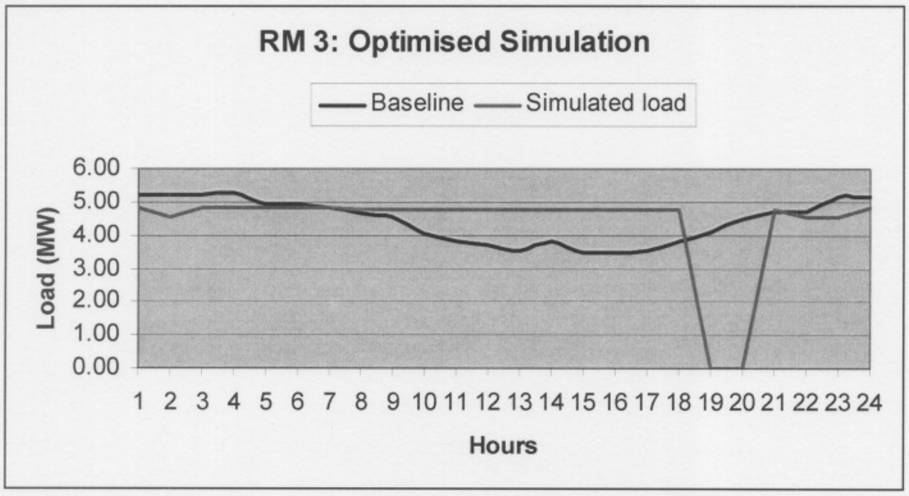


Figure 26: Optimised results for raw mill 3.

The silo levels were simulated as follows:

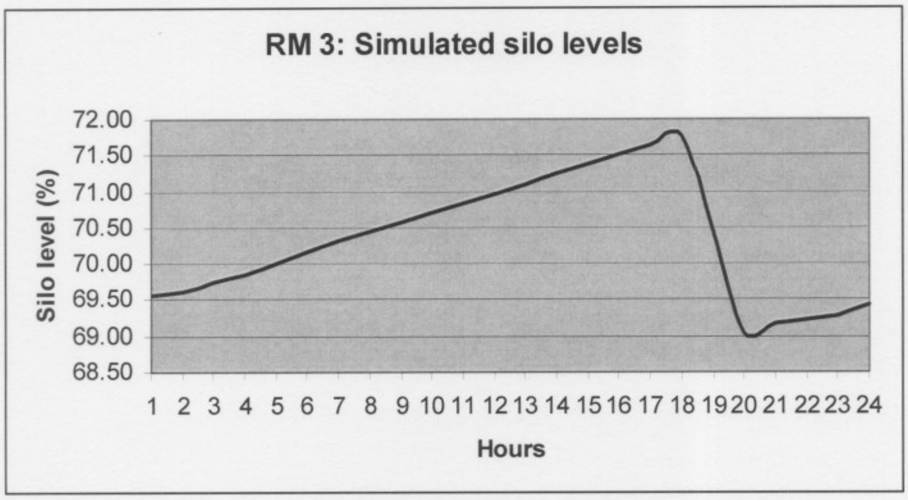


Figure 27: Simulated silo levels for the raw mill 3 system.

Summary of results obtained during the simulation

Because the electrical load shift illustrated in Figures 24 and 26 are performed in the off-peak times of the Megaflex pricing structure, there is an advantage to both Eskom and **the factory.**

Eskom has the advantage of having to produce less megawatts during the evening peak, while the factory will receive an electricity cost saving due to the evasion of high peak-time costs.

The following table is a summary of the MW savings as well as the electrical cost savings of **the factory:**

Mill	MW saving	Summer cost saving	Winter cost saving	Annual cost saving
Mill 2	4.7 MW	R 118,156.67	R 245,710.06	R 360,000
Mill 3	4.3 MW	R 103,678.62	R 188,956.03	R 290,000

Table 14: Optimised MW and electricity cost savings.

According to Table 14, the total optimum load shift on the combined raw mill systems of **the factory** is therefore 9 MW, and results in a total annual electricity cost saving of approximately R 656,000. On a month-to-month basis, the savings of **the factory** are calculated as follows for the two systems:

RM 2:	Avg. Monthly Savings		
summer	Jan		R 13,149
summer	Feb		R 12,565
summer	Mar		R 12,789
summer	Apr		R 13,014
summer	May		R 12,789
winter	Jun		R 80,665
winter	Jul		R 80,665
winter	Aug		R 84,381
summer	Sep		R 13,732
summer	Oct		R 13,373
summer	Nov		R 13,732
summer	Dec		R 13,014

Table 15: Monthly electricity cost saving for raw mill 2.

RM 3:	Avg. Monthly Savings		
summer	Jan		R 11,427
summer	Feb		R 10,933
summer	Mar		R 11,193
summer	Apr		R 11,454
summer	May		R 11,688
winter	Jun		R 62,038
winter	Jul		R 62,038
winter	Aug		R 64,880
summer	Sep		R 11,922
summer	Oct		R 11,686
summer	Nov		R 11,922
summer	Dec		R 11,454

Table 16: Monthly electricity cost saving of raw mill 3.

It can be seen from these results that the cost saving will be the largest during the three winter months of June, July and August.

Another result that is also relevant to the study is the silo levels. In order to have a continuous flow of material throughout the system, it is necessary to ascertain that the start and end values of the silo levels are the same. This shows that the plant operations will continue the following day exactly where it left off on the previous day.

The following table shows the difference between the start and end values of the silo levels, as well as the minimum and maximum simulated values

Mill	Max. silo level	Min. Silo level	Difference between start and end values
Mill 2	48.80%	42.30%	0.40%
Mill 3	71.80%	69%	0.10%

Table 17: Summary of the simulated silo levels.

The results in Table 17 show that the difference between the end of one day and the start of the following day is less than 0.4% and 0.1% respectively. This shows a minor difference, indicating a continuous flow from one day to the next.

As proof of the accuracy of the simulation, a comparison can also be made between the average simulated material flows when the plant is running, and the actual average flow values provided by plant personnel. If these values are similar, it can be said with confidence that the simulation is an accurate presentation of the actual systems. The following table shows the accuracy by comparing the simulated and actual flow values:

	Actual tons per hour	Simulated tons per hour
Raw mill 2		
Flow into the mill	184	178
Flow into the silo	175	169
Flow into the kiln	153	151
Raw mill 3		
Flow into the mill	230	226
Flow into the silo	220	215
Flow into the kiln	198	197

Table 18: Comparison between the average actual and simulated material flow values.

The similarity between these values, as well as the continuous silo levels, is an authoritative indication that the simulated result is an accurate representation of the actual plant systems. This leads to the conclusion that it is definitely possible to shift a substantial amount of load on the raw mill systems of **the factory**.

4.2.7 Determine the time available to perform load shift

Now that it has been determined that the silo levels will stay within the constraints set by the plant, and that the material flows will be close to the actual current values, it is necessary to determine the time available for load shift.

This is a very important part of the study, as it determines if the load shift will interfere with production time on the plant. If true, this will violate one of the criteria set in the beginning of Chapter 3 regarding load shift on a production plant.

In order to determine the time available for load shift, it is necessary to understand the production and maintenance schedules of the factory, as well as the breakdowns on the two raw mill systems. Information regarding this was gathered from the Raw Mill Engineer during the first stages of the audit. The following information is important for the time study:

- The production side of the factory works in shifts; thus producing cement 24 hours per day, 7 days a week.
- The raw mill system undergoes routine maintenance of approximately 8 to 12 hours every second week.
- There are various other unplanned events that cause the raw mills to stand.
- Long scheduled stops of the kilns also result in extended downtime periods for the raw mill, since the silos cannot be emptied.

The actual operational values of **the factory** were used to determine the relevant hours. It must be remembered that the time needed for load shift was fitted into the current unplanned stops. This is to ensure that the normal planned maintenance time is not reduced, and so that valuable production time does not suffer. This is in line with the criteria given at the beginning of Chapter 3.

A basic overview of the available hours was first developed as a starting point for the time study. A three-month period was used as basis to test the available hours. These results are given in the following tables.

RM2	Jun '04	Jul '04	Aug '04	Average
Hours operated	572	582	565	573
Hours available	720	744	744	736
Hours off	148	162	179	163

Table 19: Raw mill 2 available hours.

RM3	Jun '04	Jul '04	Aug '04	Average
Hours operated	561	575	539	529
Hours available	720	744	744	736
Hours off	159	169	205	178

Table 20: Raw mill 3 available hours.

These tables show that there are enough hours on average per month to perform load shift operations on **the factory** raw mill systems. It now remains to be determined how these hours must be allocated to accommodate the load shift as extra downtime.

The detailed time study was conducted for 10 months in 2004 as obtained during this study. The various stop categories were summarised for each month to see the actual allocation of each part making up the total. These results are given in the following tables:

[redacted]	Jan-04	Feb-04	Mar-04	Apr-04	May-04	Jun-04	Jul-04	Aug-04	Sep-04	Oct-04	Total	Avg	
Hours operated	580.66	254.18	302.31	613.91	514.62	551.86	555.39	518.03	244.17	313.32		445	
Hours available	744	696	744	720	744	720	744	720	744	720		730	
Hours off (Incidents)	4.36	6.77	72.24	11.7	21.74	28.22	16.39	20.42	4.75	48.55	235	24	
Hours off (Circumstantial)	130.45	57.28	9.07	70.31	177.86	110.93	139.5	152.03	484.4	351.44	1683	168	
Hours off (Planned)	28.53	377.77	360.38	24.08	29.78	28.99	32.72	29.52	10.68	6.69	929	93	
Hours off (Total)	**163.34**	**441.82**	**441.69**	**106.09**	**229.38**	**168.14**	**188.61**	**201.97**	**499.83**	**406.68**	**2441**	[redacted]	
[redacted]													
Hours (evening peak - 2 hours)												61	2 hrs/day
Hours (morning peak - 3 hours)												92	3 hrs/day
Planned stoppages (Hours)												93	
Hours off (Total)												[redacted]	hrs stopped
Balance left (Hours)												39	hrs in credit

Table 21: Detailed time study for raw mill 2.

[redacted]	Jan-04	Feb-04	Mar-04	Apr-04	May-04	Jun-04	Jul-04	Aug-04	Sep-04	Oct-04	Total	Avg	
Hours operated	430.22	522.41	517.46	361.62	177.88	556.64	583.19	516.42	565.14	441.27		467	
Hours available	744	696	744	720	744	720	744	720	744	720		730	
Hours off (Incidents)	53.31	65.64	184.42	36.41	13.69	18.17	53.53	19.96	67.3	15.45	528	53	
Hours off (Circumstantial)	247.45	65.43	9.64	79.55	31.77	88.66	44.1	118.64	62.24	219.95	967	97	
Hours off (Planned)	13.02	42.52	32.48	242.42	520.66	56.53	63.18	64.98	49.32	43.33	1128	113	
Hours off (Total)	**313.78**	**173.59**	**226.54**	**358.38**	**566.12**	**163.36**	**160.81**	**203.58**	**178.86**	**278.73**	**2624**	[redacted]	
[redacted]													
Hours (evening peak - 2 hours)												60	2 hrs/day
Hours (morning peak - 3 hours)												89	2.9 hrs/day
Planned stoppages (Hours)												113	
Hours off (Total)												[redacted]	hrs stopped
Balance left (Hours)												[redacted]	hrs in credit

Table 22: Detailed time study for raw mill 3.

These results show that, on average, it should have been possible to accommodate the load shift in the normal breakdown hours. There is also a surplus of available hours as the above time studies show that it should be possible to shift load for five hours per day, whereas the optimised potential simulation shows that it is realistic to shift two hours per day.

In the months where there are fewer hours, it was suggested that the planned maintenance schedule should be moved around in such a manner as to accommodate the relevant peak times as part of the downtime and during the winter.

Now that it has been determined that there are enough hours available to stop the raw mills during the evening peak, the attention can be shifted to other concerns that the personnel on **the factory** had with regards to the suggested rescheduling of the raw mills.

4.2.8 Identifying possible problems

Even though the studies showed that it is possible to reschedule the raw mills in order to save electricity cost during the evening peak, there were still concerns from some plant personnel.

The two main concerns were the following:

1) Some of the personnel responsible for the mechanical systems were concerned that the constant stopping and starting of the mills will result in large stresses on the drive shafts of the raw mills that might damage the said shafts.

2) The process personnel, including the production manager, were concerned that the constant stopping and starting of the mills will result in a drop in the quality of the cement raw meal.

Both of these are valid concerns and the author endeavoured to find solutions for both of them as part of this study. The following section will be devoted to the proposed solutions to these concerns.

Concern 1: Stresses in the mill drive shafts

A raw mill is a large piece of equipment with a high mass resulting from the materials used in its construction and use. Typical materials are the steel used as shell and grinding media, the magnetite liners and wear plates as well as the limestone in the process of being ground.

Raw mill 2 on **the factory** has an internal diameter of approximately 4.4 m and a length of about 9.9 m. The steel balls inside used for grinding weighs approximately 150 tons. Raw mill 3 also has an internal diameter of about 4.4 m and is divided into 2 chambers. Chamber one is 4.93 m in length and chamber 2 is 4.82 m in length. Each chamber holds about 80 tons of steel balls [40]. This results in a high moment of inertia, and a high torque necessary to start the mill from a standing position.

If a high torque is applied suddenly to a shaft connected to a raw mill, it is possible that the shaft may break. The start-up procedure will also produce a very high starting current, putting extra demands on the plant electrical systems. As such, the author first suggested that the mill be started in a gentler manner in order to reduce the loading on the drive shafts and electrical wiring. The author suggested the use of soft starters.

A soft starter is a form of reduced voltage starter for alternating current (AC) induction motors. It is connected in series with the supply to the motor. The soft starter employs solid state devices to control the current flow and therefore the voltage applied to the motor. This means that a soft starter will also reduce the starting torque available from the drive motors [41].

Where the requirement is for a gentle start at reduced torque, the soft starter will be beneficial. Unfortunately, a higher starting torque is required for a raw mill, therefore disqualifying this method [41] [42].

During one of the visits to **the factory**, the author contacted an engineer from a company that supplies drive systems for various types of industrial equipment. The problem of the sudden starting torque on the drive shafts was discussed with him, and the following conclusion was reached [42].

The raw mills at **the factory** are currently equipped with slip ring motors. Slip ring motors are employed for their ability to produce a very high torque across the entire speed range. The slip ring motor is able to do this at a very low start current. Another reason for the application of a slip ring motor is that it is able to offer a high degree of control.

Soft starters can be applied to many slip ring motors; however there are some situations where the application of a soft starter will **not** give satisfactory results.

If the slip ring motor is employed to give a very high start torque across the entire speed range, as in starting a raw mill, then the soft starter is not going to provide a satisfactory solution. This is because the application of a soft starter or any other primary starter is going to reduce the available torque.

Currently, the raw mill drive motors are started by means of a liquid starter; which applies a resistance to the rotors of the slip ring motors. This device has a tank with a resistive fluid such as a saline solution or caustic soda. This fluid acts as the resistor between the contacts.

Liquid resistors have a negative temperature coefficient and so consequently, as they heat up, their resistance reduces. The heat builds up in the resistors during start, and their temperature dependant resistance characteristics, make it essential that the resistors are allowed to fully cool down between starts. This restricts the starting frequency and the minimum time between the starts [42].

The use of liquid starters, as is currently the case, provide for an inherent soft start. This type of starter supplies the motor with a low starting current, as well as a high starting torque. This cannot be achieved with a conventional thyristor type soft starter. This is ideal for specific application on the raw mill, which has a high inertia that is more difficult to start.

The following pictures are of the soft starters on **the factory**:

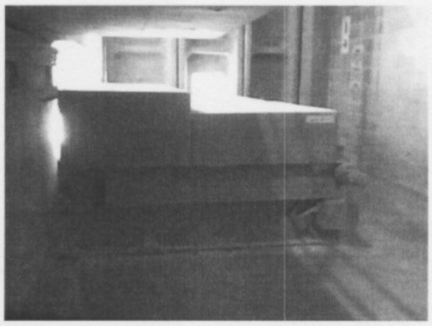


Figure 28: Soft starters installed on **the factory**.

Conclusion

It is recommended that the current drive systems on the raw mills be kept as is. The existence of the liquid starters already provides the benefit of soft starts. In addition to this, the proposed schedule does not stop and start the raw mills very often. This means that the liquid starters will have enough cooling time between switching operations.

Concern 2: The quality control of the raw meal

The Production Manager had concerns about the quality control of the raw meal because of the load shift schedule. The reason for this is that **the factory** currently has a manual method of determining the chemical properties of the raw meal. There are sampling points installed close to the raw mills, where a lab assistant will collect a sample every 45 minutes.

These samples are taken to the laboratory for analysis and once the results are known, the necessary adjustments are made to the material feeders to correct any difference in quality. Changes conducted in such a manner will take up to three hours to get through the system.

This is a very long lead-time during which the plant runs "blind" concerning production quality.

Any change in the system, such as stopping and starting a raw mill, results in a change in raw meal chemistry. This necessitates a way to analyse and adjust the chemistry at frequent intervals.

After talks with the Production Manager and Works Manager, they revealed that such a control is possible by means of a so-called online analyser. This is a machine that uses x-ray dispersive methods to determine the chemistry of the raw meal at short intervals (normally six to ten minutes).

The system is installed in line with the raw meal flow, allowing the material to pass directly through the machine. After analysing the chemistry, the system will automatically adjust the additive feeder to produce the correct chemistry at short intervals. The installation of such a machine will make it possible to stop and start the raw mills for load shift without loss of quality. The total quality management of **the factory** will also be upgraded.

The factory does not have such a system installed yet due to the high cost of acquisition and installation. However, it might be possible to obtain 100% of DSM funding for this system, since it is a necessary expense to achieve the load shift on the raw mill systems. (Appendix A is a more detailed description of such an online analyser system.)

4.2.9 Coming to a conclusion

Now that all the developed procedures have been followed and results have been obtained, it is possible to come to a conclusion as to the viability of load shift projects on the two raw mill systems of **the factory**. This follows a comparison with the criteria set for a viable DSM project in chapter 3. The following section describes the results obtained in the case study in terms of these criteria:

Guideline 1: Surge capacity

As was noted before in this study, the ability to store materials for use during peak times is a very important consideration for successful load shift. This could not be obtained by only looking at the silo tonnages (see Table 6). It was also necessary to simulate the silo levels.

This has been done successfully in this chapter and the silo level fluctuation can be readily observed in figures 25 and 27. A summary of these silo levels are also given in Table 17 As such it can be said with certainty that both raw mill 2 and 3 have sufficient surge capacity for successful load shift.

Guideline 2: Equipment constraints

There was a real concern from the personnel at **the factory** that the raw mill drive shafts will not be able to handle the repeated stops and starts required for sustainable load shift. This concern was addressed with an inquiry into the workings of the existing installed equipment. The investigation indicated that the currently installed liquid resistance starters, coupled with the slip ring drive motors, have been specifically designed to reduce any torque load on the drive shafts.

This has been confirmed by Mr. Will Law [42], a specialist engineer in the operation and installation of various motor drive systems. This led to the conclusion that the mill drive shafts will not be stressed beyond safe limits. As such, the go-ahead was given to this guideline.

Guideline 3: Quality of the product.

This was one of the main concerns aired by the production manager of **the factory**. As such, it is considered a very important guideline. The main concern was a possible drop in quality of the raw meal if the raw mills were stopped at regular intervals. This is a problem due to the slow response time of the current manual quality control methods employed at **the factory**.

This was discussed with the plant management and it was proposed that the installation of an online XRF analyser would make it possible for **the factory** to stop at regular intervals without compromising on quality. It was found that **the factory** has already installed such a system on the finish milling side, and was using it with great success.

The only reason why it has not been installed on the raw mills yet was the prohibitive costs of the complete systems, which included energy dispersive scanning, sample transport, sample milling and pressing as well as automatic adjustment of the feeders.

It was concluded that the installation of such a system would allow this guideline to be met successfully. A typical XRF system would cost in the order of R 2,500,000 according to ITECA (See Appendix A). This gives a payback period of approximately 3.8 years with the predicted savings.

Guideline 4: Current downtime must not be increased.
This is also a very important guideline, as the violation of it will result in a loss in production for **the factory**. This is especially disastrous in the current economic climate with a high demand for cement products.
In order to satisfy this guideline, a detailed time study was done on both raw mill systems. The results of these indicated that there is more than enough time to stop the mills for more than three hours per day, without stealing from active production time.

However, the implementation of such a strategy might require a reshuffle of the maintenance schedules of **the factory**. This has been discussed with the management and they feel confident that it should not be a problem. These changes will allow this guideline to be met successfully.

4.3 Conclusion

Now that the case study has been finished, it is possible to come to a conclusion as to the ability of the raw mill systems on **the factory** to serve as successful load shift projects. All the procedures developed in chapter three have been followed extensively in this case study, and many conclusive results have been obtained.

The results have been compared with the criteria set for a successful DSM project on a production plant. All the criteria have been met successfully, or have the ability to be met, with the installation of certain equipment or a change in the maintenance schedule.

It is therefore concluded that both the raw mill systems on **the factory** have the ability to become successful DSM projects, especially in terms of load shift from peak times. The following chapter highlights the limitations of the study as well as makes recommendations for further work into this subject.

5

CONCLUSIONS AND RECOMMENDATIONS

In this chapter, the limitations that were observed during the study are discussed. Possible solutions to these limitations are highlighted as inclusions in any further work on the subject.

5 CONCLUSION

5.1 Summary

The results obtained in this study lead to the following conclusions:

- Raw mill systems are large contributors to DSM on cement factories, especially load shift.

- The savings resulting from load shift on a raw mill system can be major, as illustrated by the 9 MW load shift and R 656,501.38 annual electricity cost saving.

- The procedures were simulated and tested successfully on the raw mill systems.

It can therefore be concluded that this study successfully achieved the main objective cited in Chapter 1, namely to investigate the DSM load shift possibilities on a cement factory.

5.2 Shortcomings and suggestions for further work.

Although the case study verified the success of the developed procedures, the study could not be developed even further due to some limitations. These are described below:

- The plant management only allowed testing on the raw mill systems. There are still various other large electricity users on a cement factory that can be examined in the same way. This includes the finishing mills, kilns, air compressors, coal mills and quarry.

- The procedures developed only allow for the identification of load shift projects on cement factories. It is not suitable as a tool for a complete DSM procedure including both load shift and energy efficiency.

- The fact that results of a similar study on a cement factory could not be found, made it impossible to verify the results obtained against other existing projects.

These problems hampered the complete development of the procedures for identifying viable load shift projects on a cement factory. In order to refine these procedures, the following suggestions for further work are made:

- Negotiate with the plant management to expand the procedures to the other large electricity users on the factory.

- Arrange controlled testing of the procedures in order to verify the accuracy of the simulated results.

- Test the procedure on multiple cement factories in order to gain a broader base of comparison for future use.

- Work in conjunction with an ESCO to develop a business case of such a load shift project that can be proposed to Eskom.

- A more in-depth study of the concerns that the factory personnel aired should be done in order to determine if the proposed solutions are the optimum ones for the existing problems.

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Appendix A

The operation of Online XRF-Analysers for use in chemical production facilities.

INTRODUCTION

The Online analyser is an automatic system designed to control on line the raw meal material. The X-Ray method is used to measure the most important element from a grinded and shaken sample.

Different elements can be measured by the system; the following are a few examples:

- Calcium
- Iron
- Silicon
- Aluminium

Other optional materials are the following:

- Magnesium
- Potassium
- Sulphur

The complete system (sampling + transport + analyser) can be installed on- line and on site or integrated in an automated laboratory (ROBOLAB).

The analyser gives the different results every 6 minutes for the Calcium, Iron, Silicon and Aluminium elements and every 7 minutes when the Magnesium element is measured.

ANALYSIS PRINCIPLE

The analysis principle is based on the principal of energy dispersive X-ray fluorescence (EDXRF) spectrometry to determine the concentration of various elements in a range of materials.

The analyser requires a Helium gas supply for optimum analytical performance if analysing for low atomic number elements, typically lower than chlorine in the periodic table, at low concentrations.

X-rays, which form a part of the electromagnetic spectrum, are generated when atoms of elements are stuck either by particles, such as electrons, or other higher energy radiation. The process of primary X-ray emission which takes place inside an X-ray tube can be considered simply as the release characteristics X-ray wavelengths of the tube anode element when it is irradiated by a beam of high energy.

X-ray analysis, as with other forms of spectroscopy, is a comparative technique. This means it is necessary to have a series of reference standards which cover the elements to be measured in the range of interest.

These are measured and the intensities for the elements to be analysed are recorded so that the calibrations of concentration versus intensity can be derived and stored in the data processing computer for future analysis of unknown samples of the same type.

OPERATING PRINCIPLE

Presentation

After being sampled, the samples are transported to the analyser through a hopper. The analyser will then proceed to the different operations, using a robot arm to handle the cell to the following positions:

- Sample volumetric dosing before grinding
- Grinding procedure with alcohol additive
- Volumetric dosing after the grinder
- Filling up of the specific measurement cell equipped with a special film.
- Preparation of the measurement surface using a vibrator for compaction.
- Sample introduction inside the analyser
- Measurement procedure

The following operations are also automated:

- Alcohol additive during grinding procedure.
- Cleaning of the grinder and analysis cabinet trough an external de-dusting unit.
- Cell cleaning after each cycle and control of the film cleanliness.
- Grinder cleaning.
- A storage system allows storage of up to up to 15 new cells.
- A control sample cell is stored inside the analysis cabinet and can be monitored frequently to control the calibration of the analyser.
- Recycled cell storage.

Communication

Operator - machine

The operator can read all the parameters on a control panel located in front of the analyser. The program is able to display all the information required by the different modes.

A historical list of the last measurement can be shown, as well as a historical list of the last 500 fault messages. It is also possible to adjust the parameters such as timers, limits or sampling frequency.

Control room

The analyser supplies the control room on a continuous basis with information such as results through the analogue outputs, status messages and failure information.

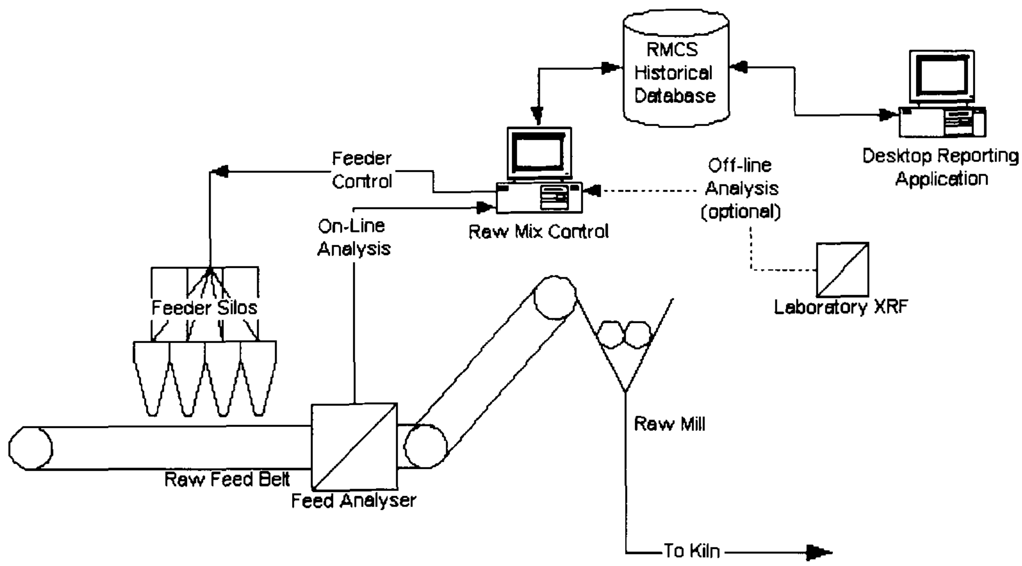
Raw Mix Control System

The analyzer requires a computerized control system to provide various services such as historical data storage, monitoring of quality values, application of constraint rules and correction factors and the control of the raw feeders.

The following key functional requirements for the lab system must be adhered to:

- Be simple and easy to use.
- Be trouble free and easy to maintain.
- Have support for analysis tools.
- Allow multiple concurrent accesses to records.

The following figure illustrates the interfacing of the control system with the plant equipment:



The above figure depicts a typical implementation of the Raw Mix Control system with four feeder silos. The on-line feed analyzer will provide elemental results for the current feed. The Raw Mix Control System will deduce calculated mineralogical results, and evaluate these based on rules entered by the process engineering staff. The resulting evaluation could cause a change in the feeder rates for any of the feeder silos. The analysis of the changes will in turn cause a re-evaluation of the feeder settings, providing a closed loop control of the raw feed.

The control algorithm provides two levels of control. The inner control adjusts the feeder settings based on frequent input analyses from an online analyzer and will make feeder adjustments to ensure the control values are within acceptable ranges. This frequent analysis does not take into account cost, variability or other constraints.

The outer control loop is done less frequently and typically obtains its analysis from the scheduled laboratory raw mix sample analysis. The outer control loop provides the same control as the inner loop, but in addition will take other control factors into account such as cost. When the outer loop computes its final feeder adjustments, the values are set as a new base level from which the inner loop will continue its control.

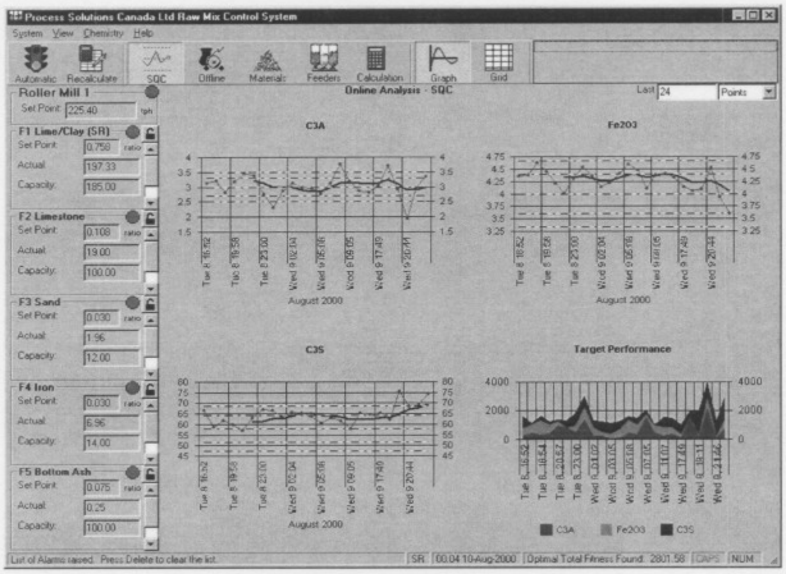
The benefits of using two loop control is that the inner loop provides frequent adjustments ensuring a more consistent raw mix, while the outer loop ensures that "ramping up" of expensive additives by the inner loop has been corrected to achieve secondary objectives such as cost.

Periodic correction of the on-line data stream is provided by fused bead or pressed powder analysis in the plant laboratory. A composite or point sample obtained from the raw mill exit stream will be analyzed and the results used to calculate correction factors to be applied to the instrument readings.

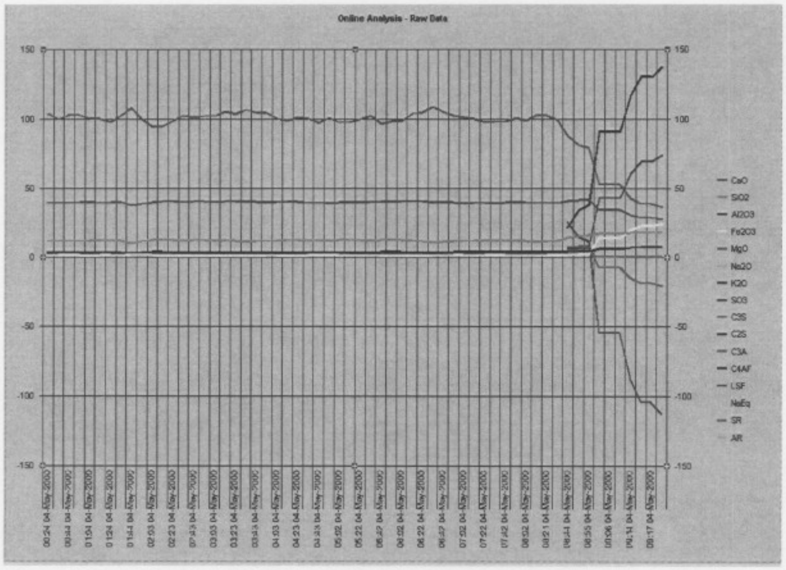
The on-line analyzer's results average will be obtained from the history database and adjusted in time to correlate with actual feeder tonnage results.

VIEWING DATA

The following figure illustrates a typical computer screen used in a raw mix control system:



Product chemistry can also be viewed on the computer system. A typical screen would look as follows:



In this way it is possible to gain an instantaneous insight into the chemistry of the process, making troubleshooting much easier.

Reporting

The Raw Mix Control system generates a record in a database with each analysis from the on-line analyzer. This database provides a historical snapshot of the quality and process parameters for each analysis. This source of historical information is invaluable to determine cause and effect of changes to the raw mix.

Feeder Control System

The feeder control system requires an interface communication program to retrieve feeder status and values and write the new feeder set points. Each installation is unique to the plant site and will be created and configured as necessary.

This Appendix has been adapted from documentation provided by ITECA SOCADEI SA.

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