Identifying demand market participation opportunities available in cement plants

ID Krüger

21063400

Dissertation submitted in fulfilment of the requirements for the degree *Magister in Mechanical Engineering* at the Potchefstroom Campus of the North-West University

Supervisor: Prof M Kleingeld

May 2014

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

It all starts here ™

ABSTRACT

TITLE: Identifying demand market participation opportunities available in cement plants

AUTHOR: Izak Krüger

PROMOTOR: Prof Marius Kleingeld

KEYWORDS: Demand market participation, cement plant, load reduction, cost saving, energy management

South African cement manufacturers are under financial pressure. Sales have declined due to the 2008 recession and electricity costs have tripled from 2005 to 2012. Electricity cost savings are therefore more important than ever. Unfortunately retrofitting highly energy-efficient equipment is not ideal. These installations are costly and take a long time to implement. Alternative strategies that can produce quick results in reducing electricity costs are needed. One such alternative is a programme called Demand Market Participation (DMP).

The DMP programme was implemented by Eskom, South Africa's national electricity utility, to reduce electricity demand during supply shortages. This programme offers potential cost savings for clients with excess production capacity. Clients such as cement plants can switch off non-essential production equipment in Eskom's peak demand periods for a financial incentive. To maximise the benefits for both the clients and Eskom, accurate electricity forecasting is needed, as are systems enabling a quick response to load reduction requests.

In this study DMP opportunities on typical cement plants were identified. A DMP strategy to assist cement plants was developed to achieve maximum cost savings without influencing production, quality and safety. An existing energy management system (EnMS) was adapted to incorporate the new DMP participation strategy. The new EnMS and DMP strategy were implemented at a South African cement plant, resulting in savings of R220 000 per month. This translates into an annual cost-saving potential of R2-million for the plant, and an R13-million cost-saving potential for the total South African cement industry.

PREFACE AND ACKNOWLEDGEMENTS

It is my hope that the findings and strategies of this study will help South African cement plants to successfully achieve cost savings and lower cement production costs. Best wishes for success to all who will use this research for implementation in the local cement industry.

I would like to thank my parents and family for their support, motivation and inspiring words which helped me through the tough times. A special thanks to Dr. Jan Vosloo, for his guidance throughout the study and to Riaan Swanepoel and Raynard Maneschijn who helped with the technical aspects of the research.

Thank you to Prof. Eddie Mathews, Prof. Marius Kleingeld and TEMM International for the opportunity and financial support to read my Master’s degree. Thanks to all the cement plant personnel for your cooperation during the case study. Lastly I want to thank the Lord for His strength and blessing. Without His help, I would not been able to overcome the many obstacles to finish the journey.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ASD	Adjustable speed drive
CBL	Customer baseline
CM	Cement mill
DMP	Demand Market Participation
DR	Demand Response
DSB	Demand Side Bidding
DSM	Demand Side Management
EnMS	Energy management system
ESCo	Energy service company
HMI	Human machine interface
IDM	Integrated Demand Management
LR	Load reduction
O&M	Observation and maintenance
OP	Off-peak
P	Peak
PC	Personal computer
PPC	Pretoria Portland Cement
PTB	Process toolbox
RM	Raw mill
S	Standard
SCADA	Supervisory control and data acquisition
TOU	Time-of-use
VFD	Variable frequency drive

VPS	Virtual Power Station
VRM	Vertical roller mill
VSD	Variable speed drive

UNITS

GWh	Gigawatt hour
h	Hour
Mta	Million ton per annum
MW	Megawatt
MWh	Megawatt hour
R/MW	Rand per Megawatt
R/MWh	Rand per Megawatt hour

CHAPTER 1: INTRODUCTION

1.1. Energy use in the cement industry

According to Avami, the cement industry is one of the most energy intensive industries in the world [1]. In Iran, cement production plants consumed up to 15% of the total industrial energy use for the year 2007 [1]. Energy costs can range from 40-60% of the total cement production cost [1, 2, 3] with thermal energy accounting for 20-25% [4] and electrical energy for 10-30% of the total production cost [5].

The modern cement plant has an electrical energy consumption of about 110-120 kWh per tonne of cement [1, 6, 7]. Electrical energy is mainly used for grinding processes but also for other auxiliary equipment such as kiln motors and process fans [7, 8, 9]. According to the International Energy Agency, one of the main challenges the cement industry faces is to increase energy efficiency [10].

In Figure 1 [11] Eskom's electricity tariff increases (actual and forecast) versus South African inflation is shown. Electricity costs have increased disproportionately to inflation from 2005 to 2012. Comparing the electricity tariffs of 2012 with the tariffs of 2005, an increase of approximately 330% occurred. With these rising electricity costs, it is becoming more and more important for local cement manufacturers to seek ways of reducing electrical consumption and cost.

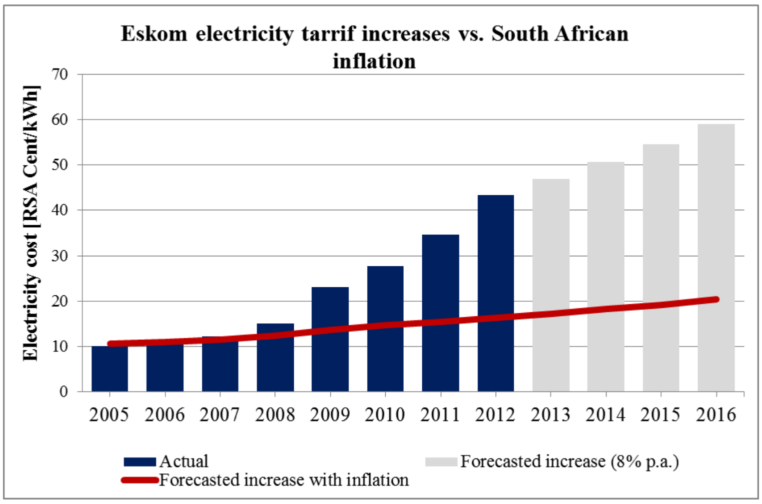

Figure 1: Eskom electricity tariff increases vs. South African inflation

1.2. The South African cement market

The major cement producers in South Africa are Pretoria Portland Cement (PPC), AfriSam, Lafarge and NPC-Cimpor. A summary of the cement production capacity is given in Table 1 [12].

Table 1: Cement production capacity in South Africa

Company	**No. of plants**	**Production capacity [Mta]**
Pretoria Portland Cement (PPC)	6 plants	7.50
AfriSam	3 plants	4.20
Lafarge	3 plants	3.50
NPC-Cimpor	3 plants	1.67
Sephako Cement - new entrant	*2 plants*	*2.20*
TOTAL	**18**	**19.1**

PPC is the largest producer with a total production capacity of 7.5 million tonne per annum (Mta). The second largest is AfriSam, with a production capacity of 4.2Mta. Lafarge is the third largest producer and NPC-Cimpor the smallest. In November 2013 a new producer, Sephako Cement, will enter the market and add an additional production capacity of 2.2Mta.

Figure 2 gives the South African cement sales from 2004 to 2012 and the local production capacity of 2012 [13, 14]. The market had a continuous positive growth from 2000 to 2007 where after sales decreased to a minimum in 2010. The economic recession in 2008 was the main cause of the cement sales decrease.

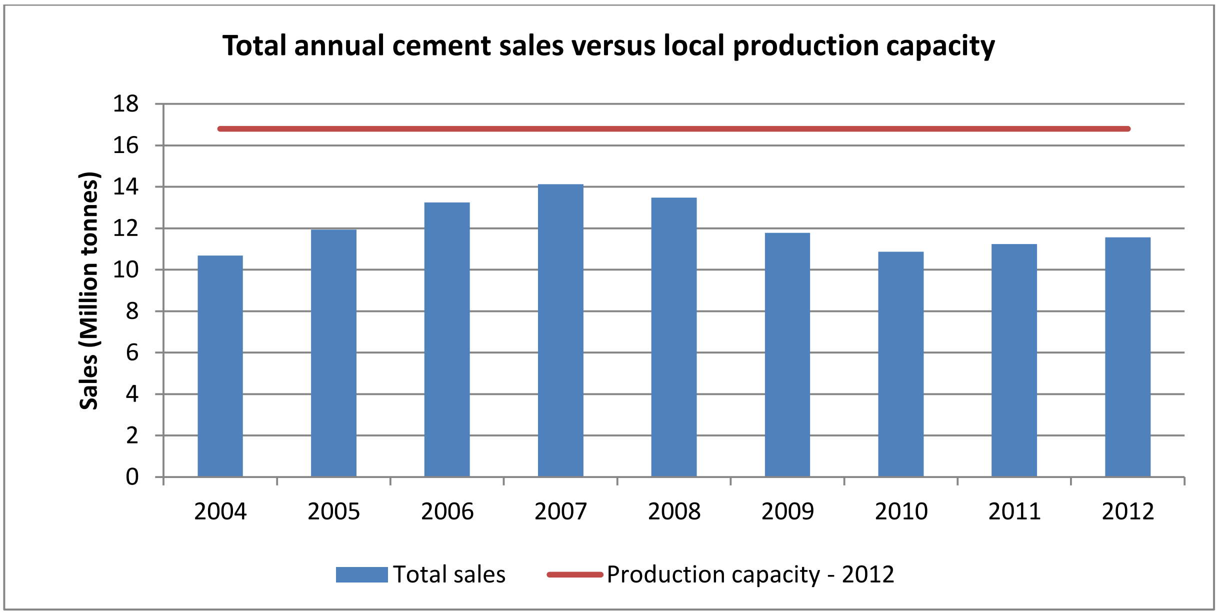

Figure 2: Total annual cement sales versus 2012 local production capacity

The total cement production capacity in South Africa was 16.9Mta in 2012 which will increase to 19.1Mta when the new production capacity of Sephako Cement is added at the end of 2013. The cement demand was still low in 2012 and the existing production capacity had an utilisation of approximately 69%. When the additional capacity is added, the utilisation may drop even lower.

The local cement market is becoming more competitive as production capacity is increased. The existing cement manufacturers are experiencing difficult economic conditions with high electricity costs and low cement sales. The cement sales of some of the current producers may also drop when the new entrant enters the market. Opportunities to lower production costs to improve profits must thus be utilised as far as possible.

1.3. South Africa’s electricity reserve margin

The South African economy experienced a period of fast growth from 2000 to 2007 with a resultant rapid growth in electricity demand. At times, the electricity supply could not meet the demand which lead to forced load shedding [15, 16] as a short term solution for the electricity supply challenge.

In 2007, Eskom had a total installed capacity of just less than 40,000MW [15]. The utility's electricity reserve margin has decreased from 25% in 2000 to approximately 8% in 2007 [15]. Studies recommended that it will be beneficial for Eskom to invest in projects to increase the supply capacity [15]. To this extent, Eskom invested in expansion projects to increase its base load capacity to a total of 80,000MW by 2026 [16].

These expansion projects included seven open cycle gas units, a pumping scheme and two state of the art coal-fired power stations [16]. However, these projects have long installation times that forced Eskom to also seek other solutions to overcome the supply shortage problem. Eskom then introduced Demand Market Participation (DMP), also known as Demand Response (DR) or Demand Side Bidding (DSB).

The DMP programme was developed to balance the electricity supply and demand [17]. When the national electricity supply cannot meet the demand, Eskom pays participants to reduce demand for a specified period which helps the utility to meet the peak demand. Large consumers are encouraged to participate in the programme by the cost savings or financial incentives that can be achieved when reducing their electrical load.

1.4. Problem statement & objectives

Problem statement

South African cement sales have dropped from 2007 to 2010 due to the economic recession of 2008. Electricity costs have also increased by more than 330% from 2005 till 2012. Energy accounts for 40-60% of the total production cost of cement and electricity alone accounts for 10-30% of the total production cost.

Reducing electricity consumption and the electricity costs have become very important for cement manufacturers. To this end, Eskom started with the Demand Market Participation (DMP) programme in 2007 to balance the electricity supply and demand. The programme offers financial incentives to participants which reduce the electricity demand upon instruction. It is these DMP opportunities that will be investigated in South African cement plants in this study.

Objectives

The objectives of the study are to:

a. Identify opportunities to implement Demand Market Participation in the cement industry.
b. Evaluate DMP as a saving measure in comparison to other saving measures.
c. Reduce the operating cost of cement plants by participating in the DMP programme.

1.5. Dissertation overview

Chapter 1: Introduction

In Chapter 1 the South African cement market is summarized and the trend of cement sales for the period 2004 to 2012 is illustrated. The use of energy and electricity in the cement industry is discussed and it is concluded that electricity is a high production expense for the local cement manufacturers. The electricity supply shortage problem in South Africa is sketched and an overview of the solutions implemented by Eskom is given. The problem and objectives for the study are then discussed.

Chapter 2: Literature review

In Chapter 2 the processes of a typical South African cement plant are analysed according to electricity consumption. The energy intensive processes are identified and investigated to identify the main electricity consuming components. Thereafter, the different methods available for electricity and electricity cost savings are discussed and evaluated according to feasibility. The opportunities to implement DMP at cement plants are identified and the requirements and theory of the programme are discussed.

Chapter 3: Methodology

A method to identify and analyse DMP potential on cement plants is described and thereafter the method to calculate a plant’s average load reduction. This method includes a mathematical model of the plant’s milling processes used to simulate mill stoppages. Lastly, a DMP participation strategy is specified that a typical South African cement plant can use to participate in the DMP programme.

Chapter 4: Case study

The method proposed in Chapter 3 is applied on a cement plant. The cement plant's DMP potential is identified and a mathematical model of the plant is built. The average load reduction of the plant is determined via a simulation of the different milling processes. Load reductions are then implemented on the cement plant, the results measured and compared with the simulation results. The results of participating in the DMP programme are then discussed.

Chapter 5: Conclusion

A conclusion of the DMP load reductions and cost savings that a South African cement plant achieved is presented. The benefit of the study is discussed and recommendations regarding the research are given.

CHAPTER 2: LITERATURE REVIEW

2.1 Preamble

Local cement sales have dropped since 2007 and the market is slowly recovering from that period of economic recession. In 2012, the utilisation of the cement production capacity was only 69% due to the low cement demand. This low demand and the increasing electricity costs placed cement manufacturers under financial pressure.

Reducing electricity costs have therefore become very important. The DMP programme previously described, offers cost-saving potential to consumers whilst helping Eskom meet the increasing electricity demand. In this study, opportunities to reduce the electrical load on South African cement plants will be investigated. Examples of these opportunities include shutting down electrical intensive equipment like mills and crushers.

The cement manufacturing process will be described first, followed by the available electricity and electricity cost-saving opportunities in the cement industry. The DMP programme's requirements, theory and cost-saving potential will be analysed and discussed lastly.

2.2 The cement manufacturing process

Cement plants in South Africa use the dry process for manufacturing cement, with coal and electricity as the primary sources of energy [18]. The dry process is 30% more energy efficient compared to the wet process [1, 8] and consumes up to 75% fossil fuel and 25% electrical energy [1]. The five main stages of the dry manufacturing process are:

a) raw material preparation,
b) kiln feed preparation,
c) clinker production or pyro-processing,
d) finish grinding and blending and,
e) packing and despatching.

The dry cement manufacturing process is given in Figure 3 [19, 20].

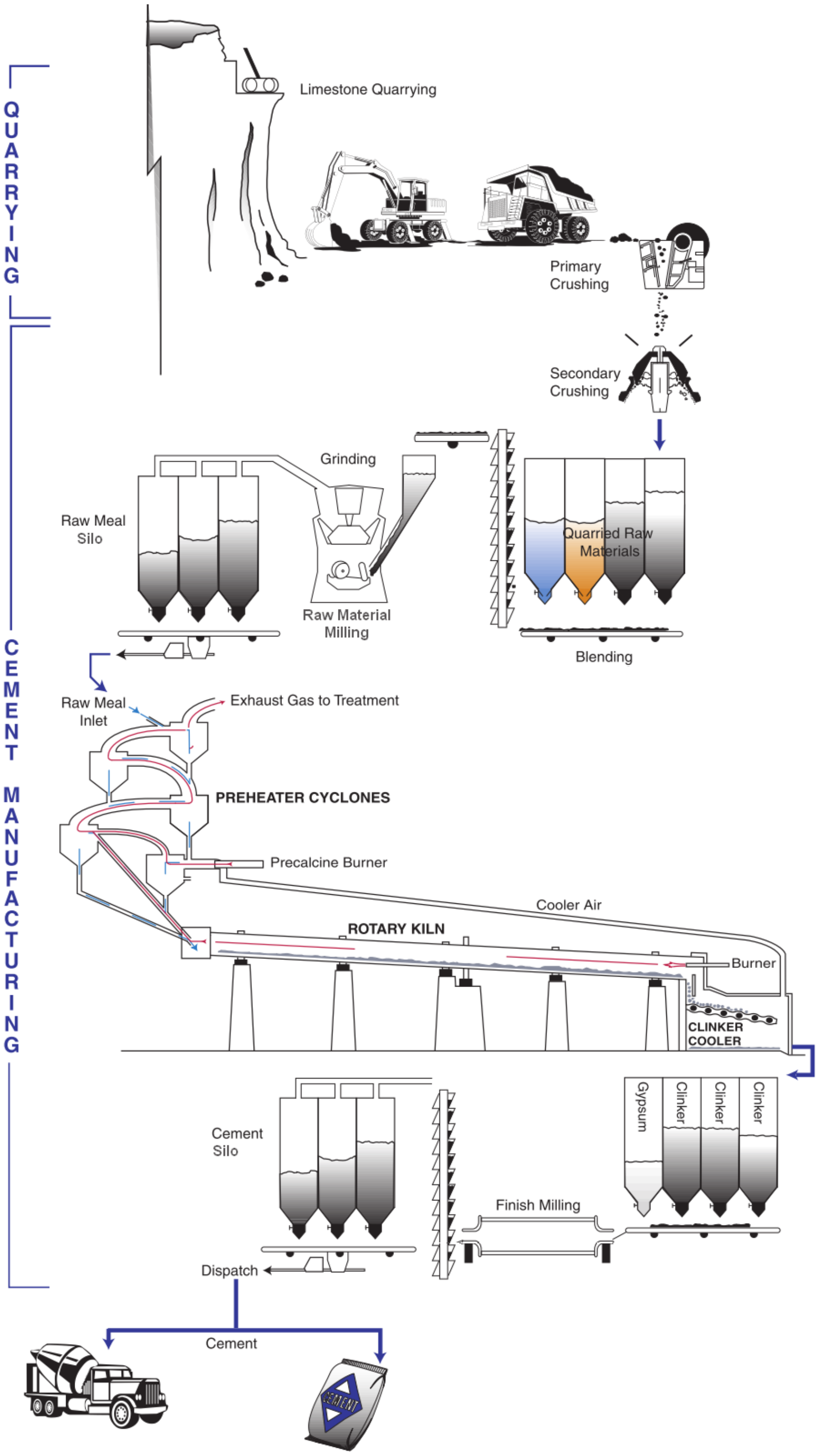

Figure 3: Dry cement manufacturing process [Lidbetter adapted the figure from Choate]

Raw material preparation

Limestone is the main raw material used to manufacture Portland cement and is mined in quarries [19]. Cement plants are located near the limestone quarries to minimize transport costs [18, 21]. The limestone reefs are blasted to break loose the limestone layers. Thereafter bulldozers load pick-up trucks to transport the limestone to the crusher plant.

The crusher plant is the first preparation facility, and uses jaw or cone crushers to break down the raw limestone material into smaller particles (25mm to 75mm). Usually primary and secondary crushers are connected in the process line [18, 22]. The secondary crusher has a classifier and operates in a closed loop. Particles which have not been crushed to a small enough size won’t pass the classifier and will be returned to be crushed again. A tertiary crusher can be added to the crushing line if needed [22].

The crushed raw material is stored on stock piles and homogenised before it is transported by rail or conveyer belts to the cement plant. The homogenising process is used to get a uniform limestone quality [18], which ensures efficient combustion in the kiln and that a qualitative product is manufactured [19]. At the cement plant, raw material stock is stored in blending silos or large warehouses. Other raw materials such as clay, chalk, shale, sand and iron ore, are blended with the limestone stock to ensure the product standard is met [23].

Kiln feed preparation

The raw material mixture is ground to a fine particle size by a raw mill. Most of the South African cement plants use vertical roller mills (VRM) or ball mills. A ball mill consists of a cylinder filled with steel balls that rotates horizontally [19] whilst a vertical roller mill uses vertical spindles or rollers to grind the raw material fine on a rotating table [19]. The crushed material mixture is called raw meal, and is stored in raw meal silos [18].

In South Africa, coal is mainly used as fuel for the pyro-process within the kilns. The coal is stored in stockpiles and ground fine by ball mills or vertical roller mills. During grinding, moisture is removed by hot air which is extracted through the mill. The dried, pulverised coal is then fed into the kiln. The hot gasses from the clinker cooler ignite the pulverised coal spontaneously, heating the kiln.

Three types of systems can be used for the coal feed into the kiln: direct firing, semi-direct firing and indirect firing. Most South African cement plants use direct or semi-direct firing. A direct firing system feeds coal directly after grinding into the kiln. This firing system has no storage bin for coal and a failure on the coal mill will cause a kiln stoppage [18].

A semi-direct firing system has a cyclone collector and a storage bin. The cyclone collector is used to remove most of the pulverised coal, which is then stored in the storage bin, which in turn feeds the kiln. The gas and particles that pass the cyclone collector are also fed into the kiln. Note that when the coal mill is not running, more pulverised coal is fed from the storage bin and the bin is emptied quicker [18]. As such, it is preferable not to stop the coal mills.

Pyro-processing or calcining

Modern dry process plants use preheaters and pre-calciners to increase the energy efficiency of the calcining process. The preheater and pre-calciner preheat the raw meal (raw material mixture) where after it is fed into the kiln.

The kiln is a long steel tube with a downward angle of five degrees from the horizontal [19]. Firebricks are mounted on the inside to protect the steel tube against the high temperatures. The preheated raw meal is fed into the top end of the kiln and coal at the bottom end. The coal ignites spontaneously in the hot kiln gasses.

The raw meal slowly runs downwards whilst the kiln is rotating. The kiln has the lowest feed rate, and determines the production capacity of the plant. The sintering process takes place in the hottest part of the kiln, at 1400-1450ºC. During sintering, the raw material melts and a complex succession of chemical reactions takes place to form clinker. After sintering, the clinker enters the grate cooler to be cooled down. Thereafter it is transported by conveyers or bucket elevators to be stored in the clinker silos.

Finish grinding or cement milling

Finish grinding is the final stage in the cement manufacturing process. South African cement plants use mostly ball finishing mills for this process. Vertical roller mills were not used historically due to the limitations caused by the narrow band of particle size reduction. The latest technology had overcome this problem and there is at least one vertical roller mill installed as a finishing mill in South Africa [18]. The advantage of a vertical roller mill is that it has lower electrical energy consumption.

The energy efficiency of the finish grinding process can be improved by inserting a pre-crushing stage in the process line, usually executed with a high-pressure roller press. The roller press improves both the efficiency and the production feed rate as it takes less energy to press clinker to fine particles than crushing it through collision. [18]

Hot air blowing through the mill is used to dehydrate additives and to separate the particles in the classifier. Fine particles will blow past the classifier, whilst bigger coarser particle will be reprocessed. The temperature in a cement mill has to be controlled carefully as cement produced at excessive temperatures will not harden during construction [24].

The initial strength of cement is determined by the fineness of the cement. Finer cement has a larger surface area and will harden quicker than coarser cement. In applications where initial strength is a requirement; finer cement is used. It must be noted that the production feed rate decreases considerably when cement fineness is increased and it takes much more energy to reduce the particle size. Cement must therefore not be ground too fine unnecessarily. [18]

Packaging and distribution

The fine cement powder is stored in cement silos. A bucket elevator or a pneumatic transport system is used to transport the cement to the silos. A pneumatic transport system is not as energy efficient as bucket elevators, which is therefore the preferred system.

Cement is either loaded in bulk or packed in bags. Bulk loads are transported to the client by road or railway containers. If the client prefers the cement in bags, the cement is transported from the cement silos to the packing plant where it is packed into bags and palletised to be transported to distributors and vendors by rail or road.

2.3 Electricity-saving opportunities on a cement plant

Large electric motors are used to drive crushers, mills and process fans, and consume about 81% of the plant's total electricity requirement [5]. In Figure 4, a cement plant's high electrical energy consuming processes are highlighted in red. Crushing, raw meal grinding, fuel preparation and cement grinding are the main electrical energy consuming processes [18].

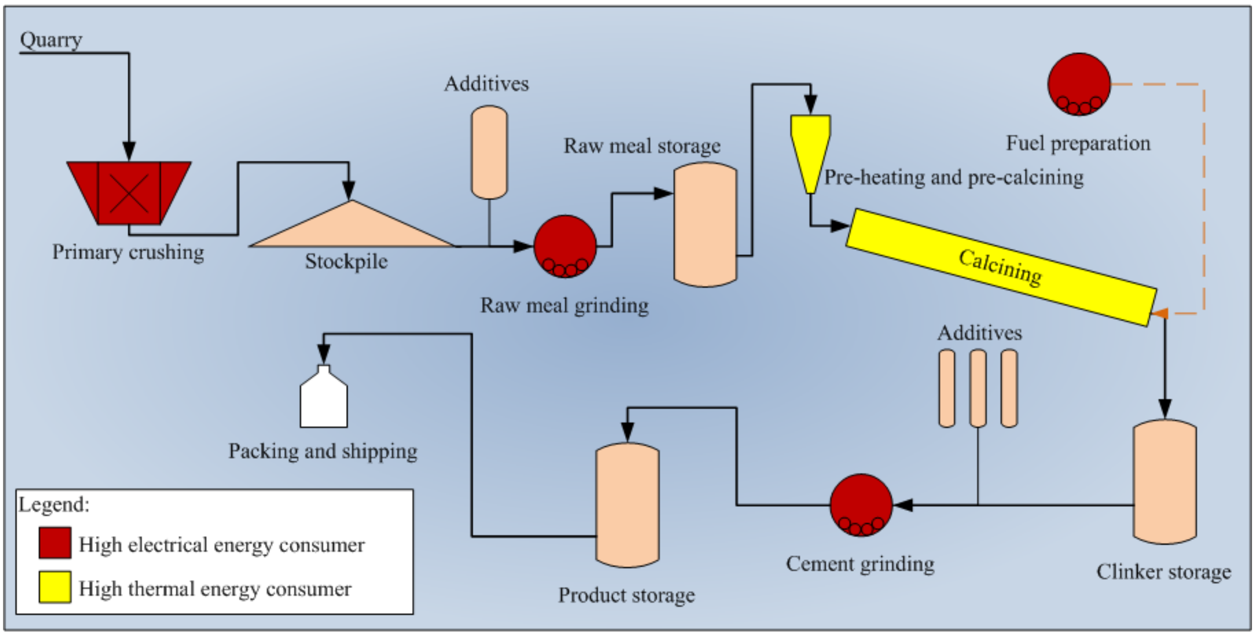

Figure 4: High electrical and thermal energy intensive processes

A study found that the typical electricity consumption for a dry process cement plant's raw mill is 35%, the cement mill 38%, the crusher 3% and the heater 24%, as shown in Figure 5 [1].

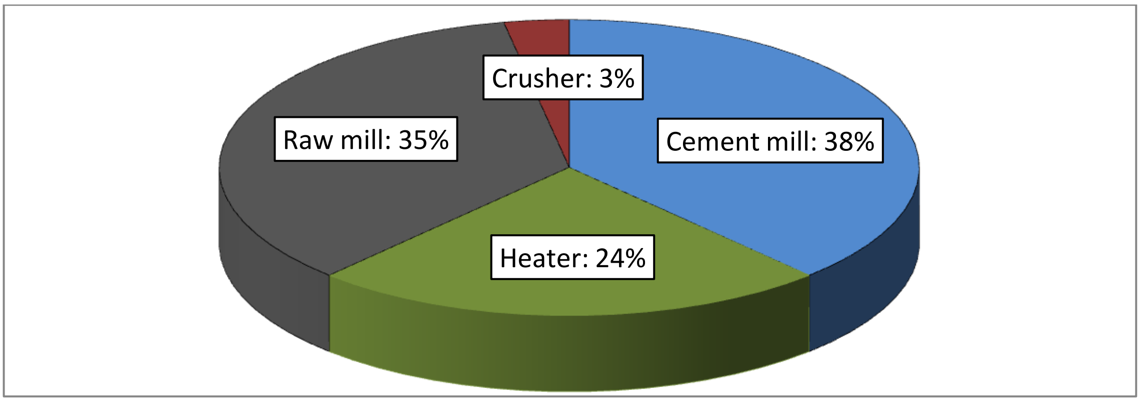

Figure 5: Typical electricity use of cement manufacturing equipment

Electricity-saving measures

Several international studies have been done to identify measures that can be implemented to save electricity. According to KEMA, electricity efficiency opportunities for the dry cement making process can be classified in three categories [1, 5]:

1. Installation of high-efficiency equipment,
2. Observation and maintenance,
3. Control and process management.

The different measures for each of these categories will be discussed next. First, some general examples and then a detailed list (Table 2 to Table 4) for each category's measures are given. Table 2 to Table 4 were compiled by Lidbetter from investigations on several cement plants, undertaken in different countries around the world [19].

Included in the tables are the saving potential for each measure and an estimated payback period for some of the measures. The potential savings were obtained from two case studies, one in Thailand [25], and the other in Shadong Province, China [26, 27]. The estimated payback period was obtained from a study completed by Worrell and Galitsky [28].

Note that the saving potential of a measure is dependent on several factors and it may vary from the actual savings that can be achieved in a certain cement plant. The payback periods were calculated on the basis of energy (electricity and fuel) savings alone and may be shorter if additional funds are received.

1. Installation of high-efficiency equipment/processes

Electricity-saving opportunities can be realised by replacing older, less efficient equipment with newer, more efficient equipment such as more efficient motors, fans, mills and classifiers. Older, less efficient technology can also be replaced with newer, more efficient technology. An example is the conversion from ball to vertical roller mills for raw material and clinker grinding. Another is to install an efficient transport system such as a bucket elevator rather than a pneumatic transport system. [19]

An extra component can also be installed in the process line to increase the efficiency of the process, for example to install a high-pressure roller press before the cement mill. Other examples are kiln upgrades and installing variable speed drives (VSDs) on the motor drives of large fans. VSDs, also referred to as variable frequency drives (VFDs) or adjustable speed drives (ASDs), are then used to control air flow via motor speed rather than the old, less efficient damper control systems. [19]

A list of the different high-efficiency equipment that can be installed on cement plants is given in Table 2.

Table 2: Electricity-saving technologies and measures [19]

Electricity-saving technologies and measures: High-efficiency equipment	**Annual electricity-saving potential [GWh]**	**Estimated payback period [years]**
Motors		
Adjustable speed drives	147.9	2-3
High-efficiency motors	53.0	<1
Efficient kiln drives	6.4	-
Variable frequency drive in cooler fan of grate cooler	1.8	-
Variable frequency drive in raw mill vent fan	6.1	-
Adjustable speed drive for kiln fan	26.7	-
Installation of variable frequency drive and replacement of coal mill bag dust collector’s fan	1.5	-
Fans		
Replacement of preheater fan with high-efficiency fan	5.0	-
High-efficiency fan for raw mill vent fan with inverter	7.2	-
Replacement of cement mill vent fan with high-efficiency fan	1.4	-
Fuel preparation		
Efficient coal separator for fuel preparation	2.2	-
Efficient roller mills for coal grinding	17.2	-
Grinding		
High-efficiency roller mill for raw material grinding	160.5	>10
High-efficiency classifiers for raw mill	24.4	>10
Improved finish grinding media for ball mills	11.7	8
Replacing a ball mill with vertical roller mill	68.5	-
High-pressure roller press as pre-grinding to ball mill	181.2	>10
High-efficiency classifiers for finish grinding	51.1	>10
Preheating		
Low pressure drop cyclone for suspension preheater	39.3	-
Transport		
Efficient mechanical transport system for raw material preparation	8.5	>10
Bucket elevator for raw meal transport from raw mill to homogenising silos	2.3	-
Bucket elevators for kiln feed	1.2	-
Power generation		
Low-temperature waste heat recovery power generation	56.1	3

2. Observation and maintenance (O&M)

This includes projects with the goal of keeping equipment in a good operational condition to ensure the equipment is operating efficiently. Examples are fan blade cleaning, fan wheel alignment, motor belt replacement, lubrication of motors and bearings and maintaining compressed air systems. The electricity saving that can be achieved by preventative maintenance is given in Table 3. [19]

Table 3: Electricity-saving technologies and measures [19]

Electricity-saving technologies and measures: Observation and maintenance	**Annual electricity-saving potential [GWh]**	**Estimated payback period [years]**
Preventative maintenance	13.3	<1

3. Control and process management

Electricity consumption can be reduced with improved control or process management in cement production. The electricity saving that can be achieved by implementing electricity management on the finish grinding process is given in Table 4. [19]

Table 4: Electricity-saving technologies and measures [19]

Electricity-saving technologies and measures: Control and process management	**Annual electricity-saving potential [GWh]**	**Estimated payback period [years]**
Grinding		
Energy management and process control in finish grinding	35.0	<1

Electricity costs can also be lowered by controlling the operating hours of intensive electricity consuming processes. An example is electrical load shifting which can be achieved by running the grinding mills during Eskom's less expensive off-peak periods rather than the expensive peak time periods. In the same way electricity tariffs are higher in winter months than summer months, so costs can be reduced by scheduling maintenance procedures for mills and other equipment during winter months. Stock building through higher production can be done in the summer months when electricity cost is lower. [18]

Another example of saving electricity and the related cost savings is to operate the kiln on a continual basis. During a kiln start-up, a large amount of paraffin is burnt to heat-up the kiln. This is a costly procedure and it is more efficient to operate the kiln continuously (twenty four hours a day, seven days a week) to minimise kiln start-ups.

There exist several electricity-saving measures that can be implemented on a cement plant. The feasibility of the saving measures is determined by business factors such as initial capital cost, plant factors such as layouts, initial installed equipment and production targets. Other important factors include the project duration, plant down time during installation, and the project's payback period.

Note that the estimated payback period is less than one year for control and process management systems, preventative maintenance and the installation of high-efficiency motors. The estimated payback period for the installation of VSDs and heat recovery is three years whereas the payback period for the installation of other high-efficiency equipment is eight or more years [28].

Key business factors

To gain insight into the goals, policies and priorities of cement companies, the key business factors have to be identified. This has been done by KEMA et al. in a study of five Californian cement plants [5]. The key business factors are indicated in Table 5, on the next page, where a score of 5 is the greatest priority business factor and 1 the lowest priority business factor.

Meeting regulatory requirements, production schedules/targets and maintaining product quality and consistency were ranked as the most important business factors. The implementation of cost-saving measures was ranked the least important. KEMA also noted that the priority of cost-saving measures varies from company to company.

Table 5: Key rated business factors [5]

Business factor	**Score (1 to 5)**
Meeting regulatory requirements	5
Meeting production schedule	4.5
Maintaining product quality and consistency	4.3
Keeping up with new and shifting market demands	3.3
Having reliable, high quality supply of electricity	3.3
Maintaining market niche	2.5
Keeping up technologically with competitors	2.3
Maintaining a happy and productive staff	2.3
Identifying and implementing cost-saving measures	1.3

According to KEMA [5] and Swanepoel et al. [29] companies do not implement cost-saving measures due to the following obstacles or limitations:

1. Limited capital – The availability of capital is a key concern as efficient equipment requires large capital investments.
2. Cost effectiveness and long payback periods - According to KEMA's study, only one of four companies considered projects with a payback longer than three years.
3. Production concerns and plant down time – For cement companies it is important not to disrupt production. New projects with long installation durations cause production delays and are generally not accepted.
4. Limited staff time – additional tasks are required when implementing saving measures. Existing staff do not have time for these tasks.
5. Information – Information of saving measures is readily available, but the decision making and investigation process is usually a time-consuming process which delays the implementation of these measures.
6. Inconvenience – If the saving potential is not substantial, the associated inconvenience of the project makes it not worth addressing.

Feasible electricity-saving measures for South African cement plants [19]

Lidbetter analysed a South African cement plant by using intuitive screening to identify electricity-efficient measures with feasible scope and which were not yet implemented by the plant. The different motives used to classify the saving measures are listed and described below:

1. Low inconvenience – To implement the saving measure causes little to no inconvenience for plant staff.
2. Improved control – When implemented, the saving measure will result in improved process control.
3. Lower capital expenditure – Lower capital is required to implement the saving measure.
4. Highly specialised – Specialised installation procedures are required to implement the saving measure, reducing feasibility.
5. Limited capital – Saving measures often cannot be implemented due to limited capital.
6. Production concerns – Production is delayed during the installation of the saving measures which causes production loss.

Table 6 gives the results of the investigated measures. The motives for each measure's classification are specified in the last column.

Table 6: Cost-effective electricity-saving measures for a South African cement plant [19]

Electricity-saving technologies and measures	**Feasible / Not feasible**	**Motive**
Adjustable speed drives	Feasible	Low in convenience with replacement of small motors
Variable frequency drive in raw mill vent fan	Feasible	Low inconvenience, improved control
High-efficiency fan for raw mill vent fan with inverter	Feasible	Low inconvenience, lower capital expenditure
Replacement of cement mill vent fan with high-efficiency fan	Feasible	Low inconvenience, lower capital expenditure
Energy management and process control in finish grinding	Feasible	Low inconvenience, lower capital expenditure
High-efficiency motors	Not feasible	Highly specialised, limited capital
Efficient kiln drives	Not feasible	Production concerns

Installation of Variable frequency drive and replacement of coal mill bag dust collector’s fan	Not feasible	Production concerns
Efficient coal separator for fuel preparation	Not feasible	Production concerns
High-efficiency roller mill for raw material grinding	Not feasible	Limited capital
Replacing a ball mill with vertical roller mill	Not feasible	Limited capital
Bucket elevator for raw meal transport from raw mill to homogenising silos	Not feasible	Limited capital, production concerns
Bucket elevators for kiln feed	Not feasible	Limited capital, production concerns
Low-temperature waste heat recovery power generation	Not feasible	Limited capital

Measures with a low inconvenience and lower capital expenditure were found to have a higher feasibility scope (Table 6). This includes the installation of VSDs, efficient fans and energy management and process control on the finishing mills. The measures that require high capital expenditure and cause production loss due to down time during installation were found to have no feasible scope.

2.4 Integrated Demand Management (IDM)

IDM is defined as the different processes implemented by Eskom to effectively manage the consumer's electricity use [30]. The programme aims to reduce the electricity demand on the national electricity grid thereby delaying the need for additional power generating capacity. It started in 2003 and was originally named Demand Side Management (DSM). There are three sectors, namely residential, commercial and industrial (Figure 6) [30, 31].

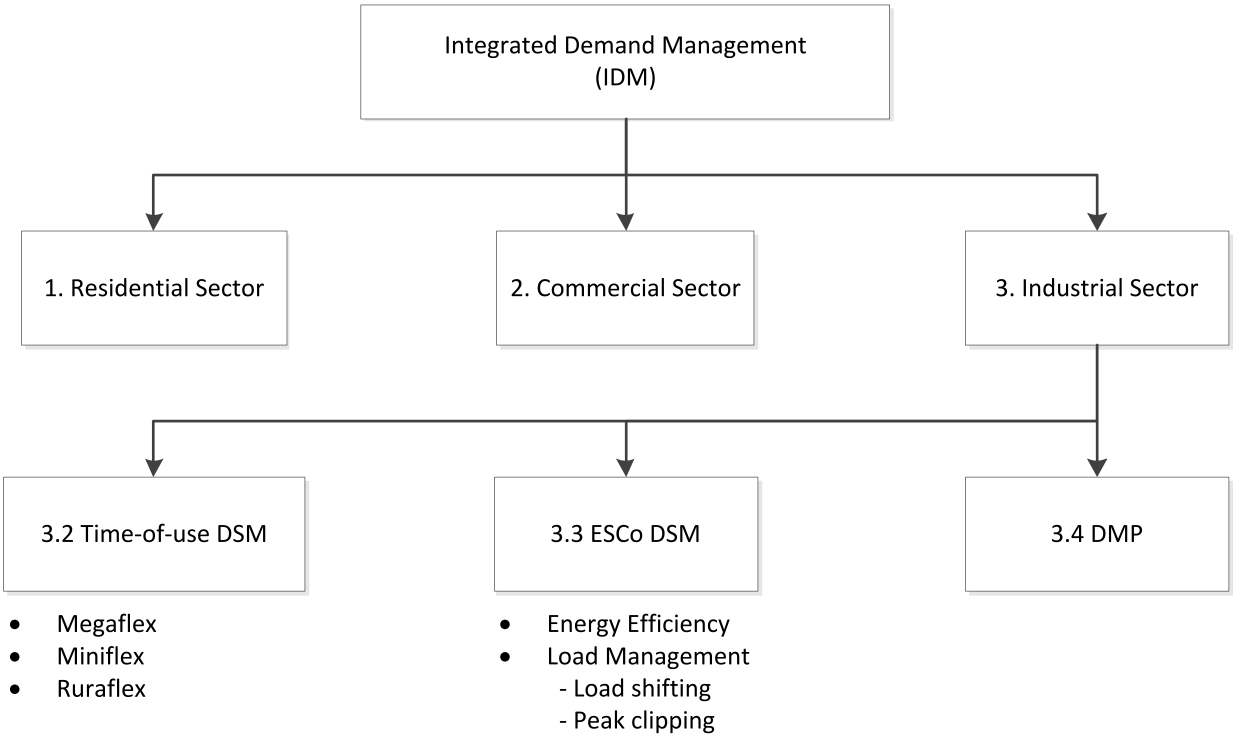

Figure 6: Integrated Demand Management (IDM) programmes

The residential and commercial sectors will not be discussed as the focus of this study is on cement plants, which fall in the industrial sector. The industrial sector is subdivided into time-of-use (TOU) DSM, Energy service company DSM (ESCo DSM) and DMP [31].

Time-of-use DSM

According to Grover, DSM is summarised as: “the planning and implementation of activities that are designed to influence the customer to use electricity in ways that will produce desired changes in the utility’s load shape” [32, 33, 34]. Time-of-use (TOU) DSM consists of different TOU tariff structures and promotes electricity consumption at lower usage times when electricity is charged at a cheaper rate [31].

The cost of electricity in peak periods is much more expensive than during standard and off-peak periods. This motivates mines, cement plants and other energy intensive industries to shift process loads out of the peak consumption periods. The three TOU tariff structures are Megaflex, Miniflex and Ruraflex.

ESCo DSM

Energy service companies implement DSM projects on different processes in mines, pump stations and other large industries. Energy efficiency, load shifting and peak clipping are the three types of projects that can be implemented. An energy efficiency project lowers the amount of electricity used; load shifting projects shift the load to less expensive periods, and peak clipping projects lower the demand at peak times. Load shifting and peak clipping is also known as load control [15].

ESCo DSM was developed to reduce the peak demand by shifting load to off-peak periods. The programme’s goal is to reduce the peak demand over the long term and is managed with a contractual target which must be achieved each year. The evening peak period, which is from 18:00 to 20:00, is the first priority while the morning peak periods are available for extra load shift potential. A load shift project is energy neutral and has no influence on the energy efficiency of a process.

The effect of a DSM project over a period of a month can be seen in the average power profile in Figure 7 [11]. The figure gives the power profile of a South African cement plant that implemented a DSM project.

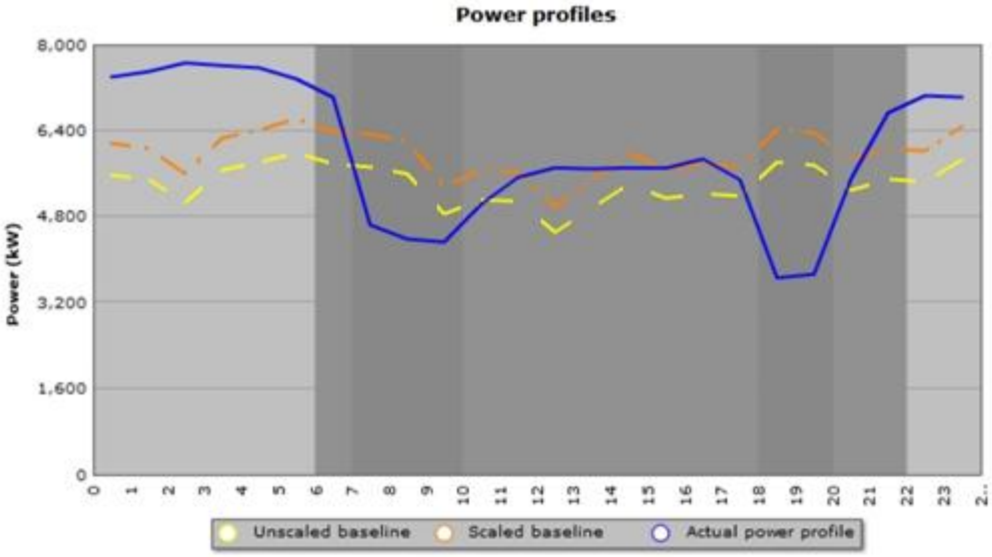

Figure 7: A South African cement plant's power profile

DSM potential in cement plants

In cement plants, DSM load shifting can be done on the raw and cement mills. Plant layout, equipment flow rates, silo capacity, planned maintenance, motor operating capacity, by-products, equipment reliability, DSM rules and operating hours over weekends are factors that determine the duration and availability/opportunity of the load shift. A typical layout of a cement plant is given in Figure 8 [19].

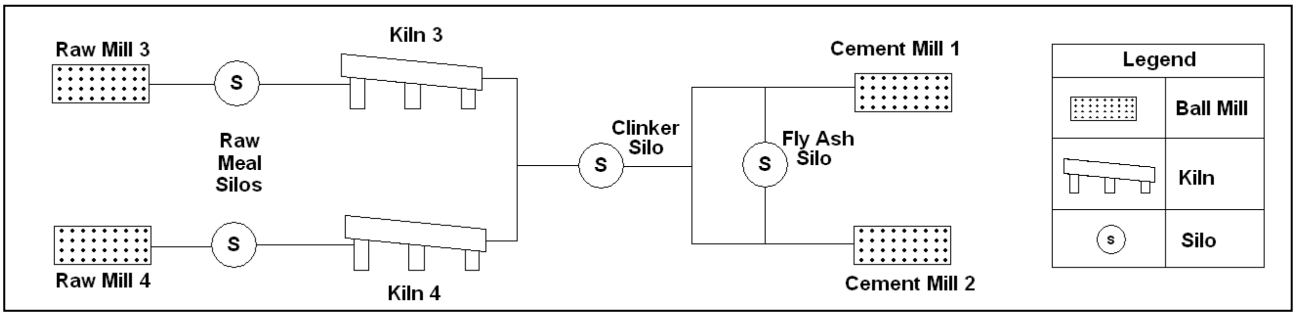

Figure 8: Typical cement plant

The raw milling process line has a raw material warehouse, a raw mill, a raw meal silo and a kiln. The raw mill's production rate is greater than the kiln's production rate which creates the load shift opportunity. The raw meal silo level is built up to an appropriate level, where after the mill is shut down for the load shift duration. The silo serves as a buffer supplying the kiln with raw meal.

A cement process line consists of clinker silos, a cement mill, and a packing plant. Bulk cement sales are loaded directly from the cement silos. If the cement silo's level is appropriate, the cement mill can be stopped for a load shift event.

Lidbetter proved with a pilot study on a raw mill that six hours of load could be shifted out of the peak to non-peak periods. As no load may be shifted to standard usage time (a DSM requirement), the total load shift potential is decreased to two hours. The study predicted that operating costs could be reduced by 2%. [19]

Swanepoel et al. implemented an energy management system (EnMS) on three South African cement plants. Cost savings of over R8.5 million were achieved over a five month period by managing the operational hours of raw and cement mills. [35]

Snyman et al. investigated the opportunity of implementing a load shift project on a crushing plant that is used to reduce the raw material particle size. The raw material from the quarry is transported by pickup truck to the crushing plant and is first crushed by a primary crusher, then by a secondary crusher and lastly by a tertiary crusher, if required (Figure 9). [22]

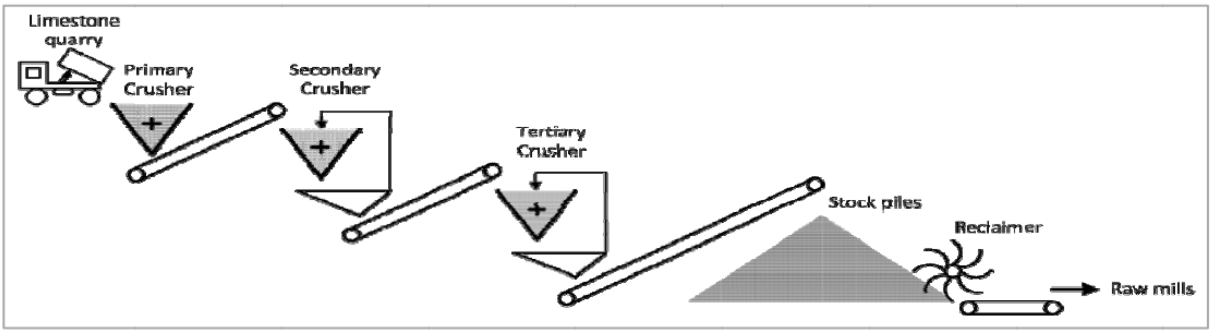

Figure 9: Crushing plant [22]

The case study was performed on a crushing plant of a South African cement plant. The operation schedule started at 08:00 in the morning and stopped the next morning at 02:00. The production targets and actual stock levels determine the operation schedule. The plant has two identical crushing lines, each having electric equipment with an installed capacity of 1.2MW. Optimised operating schedules were implemented to minimise electricity costs while meeting stock requirements. [22]

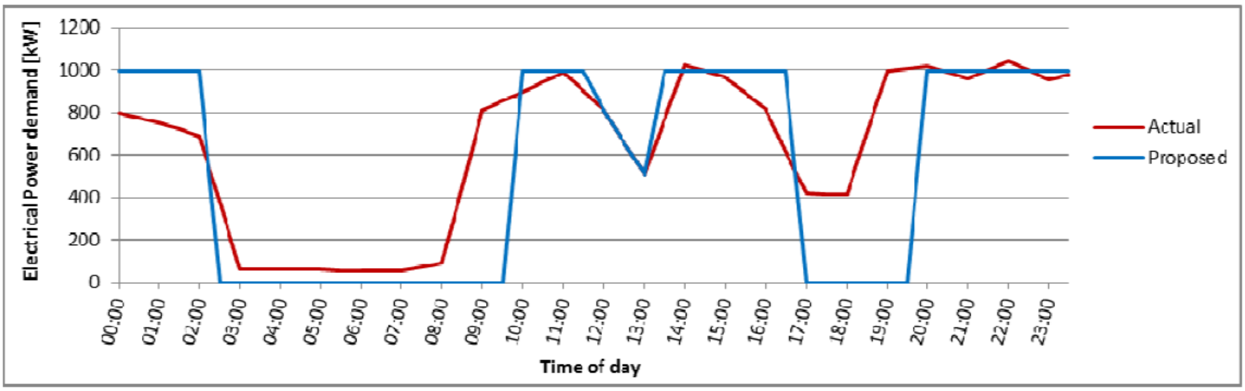

Figure 10: Load shift on a crushing plant [22]

The total proposed load shift was not met (Figure 10). Plant management was not willing to alter the production schedules to maximise load shift savings and unexpected breakdowns on the crushing lines further reduced the achieved savings.

Safety rules specify that crusher plants may not operate from 02:00 till 04:00 in the morning. During this time period, the probability of truck drivers falling asleep is high. However, as a crushing plant uses approximately only 3% of the total electricity consumption [1], a DSM load shifting project has not been implemented on a crusher plant of a South African cement plant.

By implementing a DSM project, the operating cost of the plant is lowered as less electricity is consumed during the peak time. To achieve this cost saving, the plant must be billed according to Eskom’s TOU tariff system. For a cement plant billed on Eskom’s Megaflex tariff, the cost saving is approximately R705/MWh calculated with the 2013/2014 tariffs.

Demand Market Participation (DMP)

The latest development is the DMP programme. Note that there is a distinct difference between Eskom's ESCo DSM programmes and DMP. The DMP programme is developed to balance the electricity supply and demand under peak conditions. Eskom buys a certain load capacity from the customer which the customer reduces for the specified time period. As supply shortages are experienced in the peak time periods, DMP events usually take place in Eskom's peak time periods.

The DMP programme, also referred to as Demand Response (DR), was originally designed with two types of programmes, the Energy Market and the Reserve Market [15, 17]. The Energy Market addresses capacity constraints for the following day by using bids that dedicate load for single-hour time slots whereas the Reserve Market obligates participants to shed load instantly.

There are three different Reserve Market programmes, each having a different notification time and load shed duration [15, 17]. The three Reserve Market programmes are:

i. The Instantaneous Reserve Market in which the participant is notified 10 seconds before load must be shed for a duration of at least 10 minutes,
ii. The Ten-minute Reserve Market in which the participant must shed load within 10 minutes for a duration of at least 2 hours, and
iii. The Supplemental Reserve Market in which the load must be shed within 30 minutes for a duration of 2 hours.

The 3 different Reserve Market programmes are summarised in Table 7 [15, 17].

Table 7: Different Reserve Market DMP programmes

Reserve Market programmes	**Notification time**	**Load shed duration**
Instantaneous Reserve Market	10 seconds	10 minutes
Ten-minute Reserve Market	10 minutes	2 hours
Supplemental Reserve Market	30 minutes	2 hours

To manage DMP programmes, Eskom created what they call a Virtual Power Station (VPS) that serves as a power generation unit for the system operator. The difference is that the VPS does not generate electricity but reduces electricity demand on the grid. The VPS is dependent on the load submitted by DMP participants and is dispatched when the utility experiences supply shortages. The VPS is used to manage DMP events or load reductions on a daily basis.

According to Surtees, managing director of Enerweb, the Supplemental Reserve and the Instantaneous Reserve Market (see Table 7) are the two programmes that Eskom uses to operate the VPS. It seems that the operating strategy of the Energy Market has been used for the Supplemental Reserve Market as bid placements are used to manage the participants of this market [17].

DMP potential in cement plants

The aim of a DMP programme is to reduce the peak electricity demand when Eskom’s power supply cannot meet this demand [36]. High peak demands or supply shortages reduce the stability of the grid and increase the cost to supply electricity. The cement industry was identified by the California’s Industrial Demand Response Team as an industry with significant potential for demand response (note that demand response is similar to DMP) [37].

All the electrical equipment that is not linked to the kiln and which will not interrupt the pyro-process may be used for the DMP programme [37]. These operations include raw material grinding, quarrying operations, fuel grinding, and clinker grinding [37]. The raw and cement mills can be used for the DMP programme as they do not have to operate continuously [37] and can be stopped and started in 15 to 20 minutes [according to cement plants’ control room operators].

Unfortunately it was found that crusher plants do not want to reschedule their operations for load shifting projects and therefore these operations will be excluded from DMP participation. The coal mills will also be excluded as most South African cement plants use direct or semi-direct firing for their kiln processes. Stopping a coal mill in these firing systems can cause a kiln stoppage, which is undesirable.

By participating in the DMP programme, customers are paid a financial benefit which consists of a standby capacity and an energy payment [38]. As DMP events occur during or around peak demand (mostly in Eskom's evening peak period), a participant will also achieve an operational cost savings as electricity is expensive at this time.

Automated DMP programmes are not favourable for a cement plant's critical production processes. Plant managers are not willing to commit these processes to external control as it may result in not meeting the cement demand. A production manager cannot afford that critical production processes, such as raw and cement mills are stopped automatically by the Virtual Power Station for a DMP event when the cement demand is high. Cement plant managers therefore prefer not to participate in Automated DMP programmes.

Another aspect that must be kept in mind is the safety hazard that is involved with the stopping and starting of large equipment. No plant personnel may be working in or on mill processes or in the particular substation when a mill is started. Equipment such as grinding mills may therefore not be started automatically.

Examples of cement plants participating in peak time demand reduction are an English and a French cement plant which reduced their peak load by 40-50% in 1977. The English plant reduced the peak demand for a period of 10 hours a day and the French plant for a period of 4 hours a day. New mills are typically designed to have either a 20 hour or a 16-18 hour daily operating capacity so that the mill will not be operated in peak demand periods. [37]

Olsen et al. recommended that the achievable magnitude, shape and response time of demand response in cement plants must be determined through manual tests. The practical opportunity available must be quantified and an implementation strategy must be developed. Successful methods and solutions that were used to overcome obstacles must be described. Lastly the financial value of demand response participation must be compared to other tariff structures. [37]

2.5 DMP requirements and theory [38]

As mentioned, plant managers are not willing to take part in automated DMP programmes such as Eskom's Instantaneous Reserve Market [37]. Therefore the only DMP programme that is applicable to the cement industry is the Supplemental Reserve Market.

The Supplemental Reserve Market makes use of bids to schedule DMP events. Participants have to place a bid on a daily basis to indicate to the VPS their standby capacity and duration for the next seven days. Note that the standby capacity and duration may alter per day and it is not required to have standby load available for each of the seven days. After bid placement, the VPS books the participant on standby a day ahead via a 'contract schedule' that is sent out at 15:00. On the day of the event, the VPS will instruct participants via an automated interactive voice response phone call to shed load if needed.

The Supplemental Reserve Market requirements are:

1. A participant is obligated to shed load when instructed by the VPS.
2. The maximum load reduction is once per day for a period of two consecutive hours.
3. The customer must be able to reduce load within 30 minutes of the notification time.
4. The VPS must be notified if the customer's load reduction will deviate by more than 10% or if the customer cannot shed load due to technical reasons.
5. The participant must have an automated meter that logs data in 30 minute time intervals.
6. A participant receives a financial benefit consisting of a standby capacity payment and an energy payment.
7. If the bid capacity is less than 90% of the certified capacity for more than five consecutive events, Eskom may reduce the certified capacity to equal the participant's average load reduction.

To apply as a new participant in the programme, Eskom requires proof of two successful load reduction events. For such proof, the VPS will notify the new participant of a DMP event where after the customer has to reduce his demand by the requested capacity and specified duration. If the load reduction was successful, the client may participate in the DMP programme.

The load reduction (LR) for a DMP event is calculated by subtracting the actual load from the customer's baseline power usage (CBL) (see formula 1). Thirty minute time intervals are used. The effective load reduction is equal to the sum of all the load reductions intervals. If the effective load reduction is negative, the event performance will be 0% with a zero megawatt hour load reduction.

$$LR = sum \left[\left(CBL\ (n) - Actual\ Load\ (n) \right) \ldots \ldots \left(CBL\ (m) - Actual\ Load\ (m) \right) \right] \qquad (1)$$

Parameter	Description
n:	first Integration Period of the Load Reduction request
m:	last Integration Period of the Load Reduction request

The customer's baseline is calculated from the electricity usage of three non-DMP days before the actual load reduction event. A non-DMP day is one on which there was no DMP event. The DMP programme also distinguishes between the days of a week, with the three categories being defined as a Weekday, Saturday or Sunday. For example, if a DMP event occurs on a Weekday, three non-DMP Weekdays will be used to calculate the CBL for that specific event.

The same applies for Saturdays and Sundays, and a public holiday is defined as either a Saturday or a Sunday in the public holiday definition table in Eskom's TOU tariff rates. Note that a day with planned or unplanned maintenance can be excluded to be not used as a CBL day. The customer must notify Eskom within three business days after the event report is received to exclude such days.

The CBL is scaled up or down so that the average electricity use in the reference period for the CBL and actual event day is equal. The reference period starts at three intervals before the event's start time and ends at one interval before the actual event start time. In Figure 11 [38] the reference period is illustrated by the point -3 and -2. The total duration of the reference period is one hour.

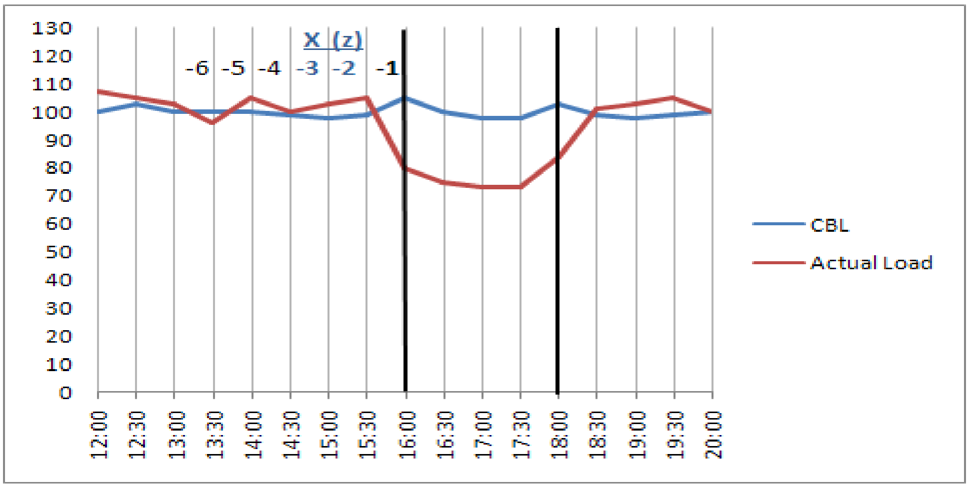

Figure 11: DMP load reduction calculation

If the reference period fell in a period of abnormal consumption for a certain event, the reference period may be shifted to a point of normal consumption. The reference period will be limited to the points (-1 & -2), (-3 &-4), (-4 &-5) or (-5 &-6). The same three business day notification time limit applies as for changing the CBL.

2.6 Conclusion

International studies have shown that electricity savings can be achieved by installing high-efficiency equipment on intensive electricity consuming processes or sub-processes. The reality is that most of this high-efficiency equipment is not installed by cement manufacturers due to limited capital resources, long payback periods, production concerns and possible plant down time.

VSD drives, efficient fans and energy management are three electricity-saving measures that have been found to have feasible scope in the South African cement industry. Unfortunately capital is required to install this more efficient technology, and cement plants therefore seek alternative strategies to reduce electricity costs.

Eskom’s DMP programme offers cost-saving potential to participating customers which reduce load upon instruction. According to the Industrial Demand Response Team of California the cement industry has significant potential for DMP. Cement plants can use their raw and cement mills to participate in load reductions events and consequently achieve cost savings without any expenses.

CHAPTER 3: METHODOLOGY

3.1 Preamble

A DMP participant receives a financial benefit when reducing load for a DMP event. The Supplemental Reserve Market requires that the load must be reduced within 30 minutes for a duration of 2 hours. Cement plants can participate in the programme by shutting down their raw and/or cement mills for such events.

To determine if a raw mill or a cement mill can be stopped, the specific silo storage level must be calculated as the silo must be controlled between specified minimum and maximum levels. If the silo level drops below the minimum, the specific mill feeding that silo may not be shut down as it could cause production loss, cement of lower quality or failure to meet the cement demand.

In this chapter, a strategy is proposed to determine the potential load that cement plants can use for DMP participation. This load will determine the financial benefits to the programme participant, while still maintaining the required product quality and production outputs. Lastly a strategy is formulated which cement plants can use to participate in the DMP programme.

The following sections will be discussed in this chapter:

Section	**Procedure**
3.2 DMP potential and capacity	Determine the DMP potential and capacity
3.3 Cost-saving potential	Calculate the cost benefit of the DMP programme
3.4 Modelling	Build mathematical models of the plant’s process lines
3.5 Simulation	Determine the average number of mill stoppages
3.6 Load reduction	Determine the load reduction of the plant
3.7 DMP participation strategy	Formulate the DMP participation strategy

3.2 DMP potential and capacity

Mill load profile

First the load profile of the cement plant's raw and cement mills is plotted. The load profile is used to identify load reduction potential and indicates the load consumption of the cement plant's mills over a 24 hour period. As the DMP programme distinguishes between events that take place on a Weekday, Saturday and Sunday, a profile for each day type must be plotted.

Two to three months' logged data has to be used to obtain an average load profile of the cement plant's mills. Data can be downloaded from the cement plant's SCADA or data loggers can be installed on the electrical metering panels. It is advised to download or log each milling process separately as the load reduction capacity per mill will be determined at a later stage.

In Figure 12 the Weekday load profiles of four South African cement plants' mills are given. The load profile is compiled over a three month period. The average of all the plants' load profiles indicates that the minimum load consumption is during the evening peak period.

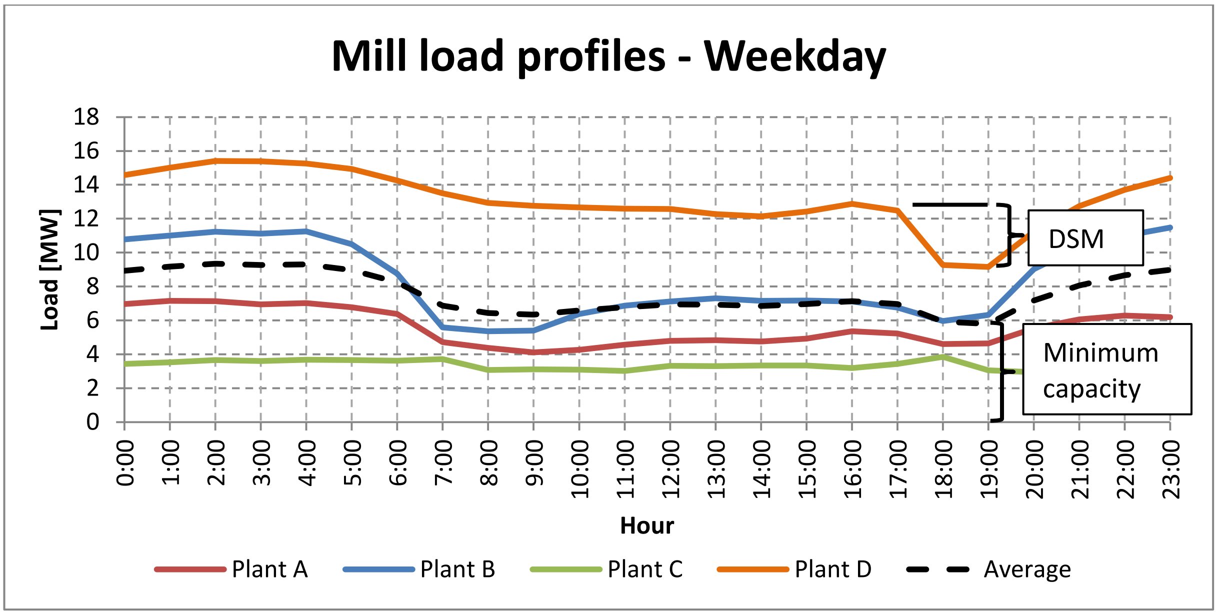

Figure 12: Mill load profiles

The clear dip during the evening and morning peak periods is due to stopping mills on a regular basis for DSM load shifting projects. These mills are scheduled so that the consumed load is shifted from the peak time periods to off-peak periods.

Load reduction capacity

The next step is to determine the load reduction capacity per mill. The total load of a mill consists of the running capacity of the mill's main drive, process fans, separator and other auxiliary equipment. In Figure 13, the different processes involved in a ball milling process are illustrated. The mill's main drive, process fans, separator and raw material feeders can only be stopped when a mill is stopped.

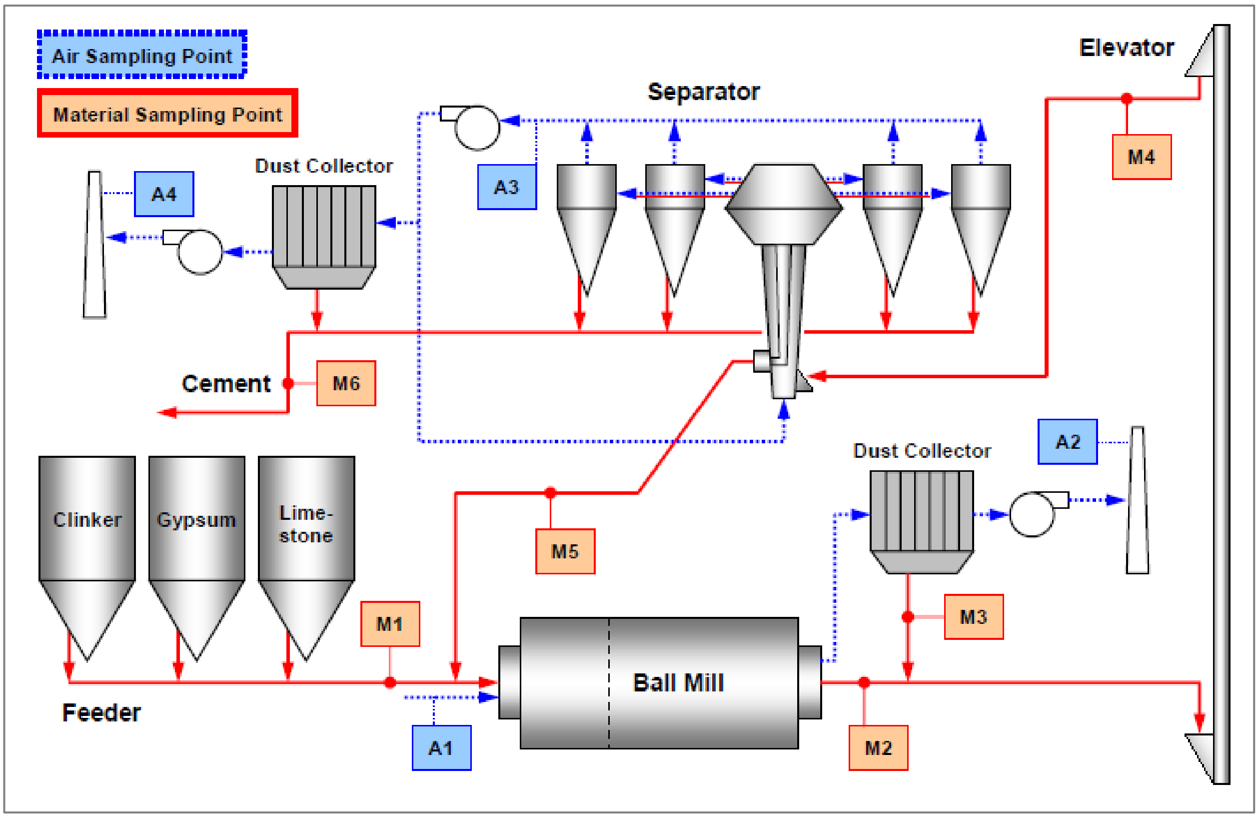

Figure 13: Milling circuit of a ball mill [6]

A set procedure is followed to stop a mill. First the raw material feeders must be stopped so that the mill can run empty. Thereafter the mill's main drive, process fans and separator are stopped. According to cement plant operators, the typical mill start-up and stop duration is 15-20 minutes.

Note that certain auxiliary equipment cannot be stopped, such as the oil pump of the mill's lubrication system which is important for mill start-up without delay. This minimum running load is referred to as the base load of the milling process.

The load reduction capacity for each mill is determined by subtracting the mill's base load from the mill's full load or total running capacity. In Figure 14 a mill load profile is given. The full load, base load and load reduction capacity are indicated.

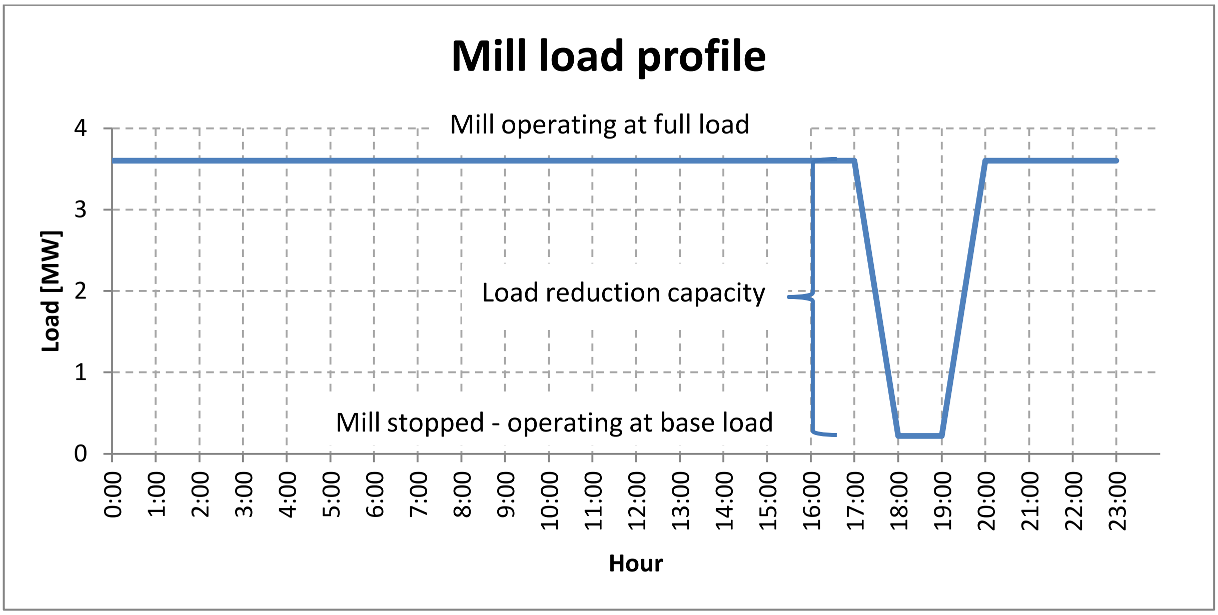

Figure 14: Mill load profile

If the average load for each day type and the load reduction capacity per mill are determined, the potential to implement load reductions on the different milling processes can be investigated. It can then be determined whether it is feasible to stop the different mills without delaying production.

Production target analysis

An analysis of the production targets for each process line is done to indicate in which months DMP load reductions can be implemented. The production targets, scheduled maintenance and mill reliability are used to calculate the total 'off time' that is available for each mill, when the mill is not scheduled for production.

Formula 2 is used to calculate the total off time available. The production time and maintenance time is subtracted from the total time to calculate the off time. The calculation is done per year, in monthly time intervals.

$$Off\ time = Total\ time - production\ time - maintenance \qquad (2)$$

The different variables or parameters that are used in formula 2 are described below. Note that the unit of all the parameters is the hour (h).

Parameter	**Description**
Off time:	The time that the mill can be stopped without affecting production.
Total time:	The total time in a month.
Production time:	The time needed to produce or manufacture the amount of product specified by the production target. The mill feed rate in tonne per hour, the production target in tonne and the reliability are parameters that will be used in this calculation.
Maintenance:	The time that is scheduled to service the specific mill.

The formulas to calculate each parameter are given below.

Parameter	**Formula**
Total time:	$Total\ time = Number\ of\ days\ per\ month\ \times\ 24$
Production time:	$Production\ time\ = \frac{Production\ target}{(Mill\ feed\ rate \times mill\ reliability)}$
Maintenance time:	$Maintenance\ time\ =\ Maintenance\ duration\ \times\ times\ per\ month$

In Figure 15 a typical raw mill's production, maintenance and total time are plotted. The off time for each month is equal to the blank space between the total time and the top of the column. The figure gives an overview of the production and maintenance times compared to the total time.

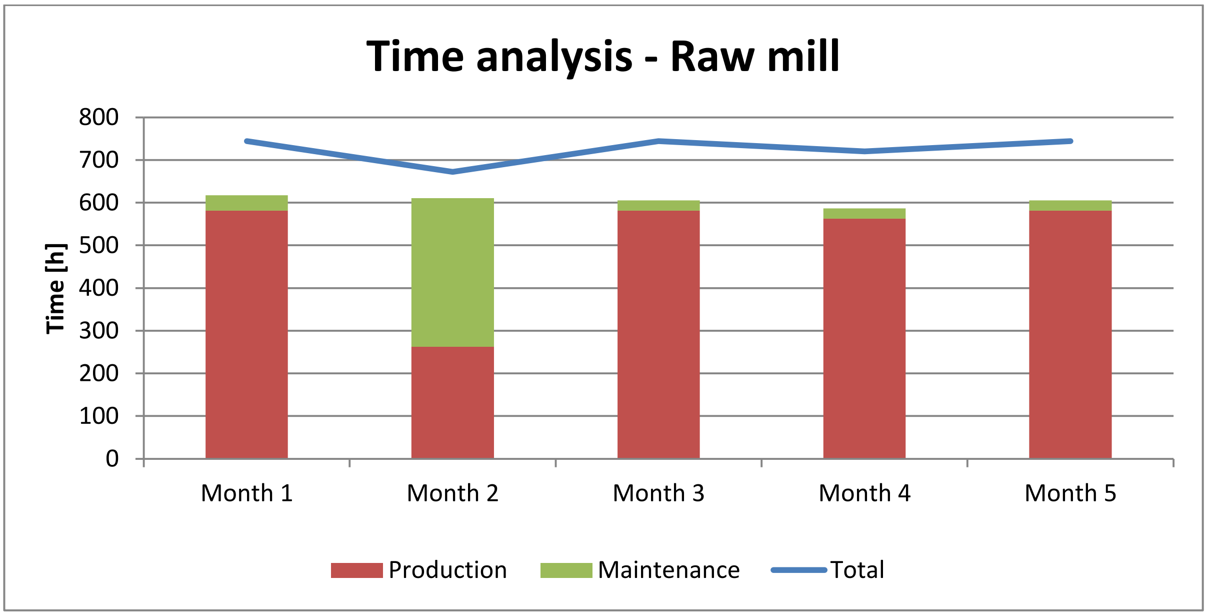

Figure 15: Production target analysis

When the sum of the production time and maintenance time is equal to, or almost equal to, the total time, there is little or no time for load reductions. If the sum is more than the total time, it indicates that there is no time to stop the mill for scheduled maintenance or that there is not enough time for production to meet the production target.

An estimated DMP time is calculated by assuming that a DMP event occurs on each day of the month. The DMP time is thus equal to the number of days in the month multiplied by the DMP event duration of 2 hours (formula 3).

$$DMP\ time\ =\ Number\ of\ days\ in\ month\ \times\ 2 \qquad (3)$$

In Figure 16 the DMP time is plotted on top of the production time and maintenance time. Note that the total time is more than the sum of the production, maintenance and DMP time. There is therefore enough time available to stop the mill for DMP events without affecting production. In month 2 the duration for scheduled maintenance is much longer than when compared to the other months. The potential to implement load reductions during this month will be limited as the mill will be off for a number of days to implement maintenance.

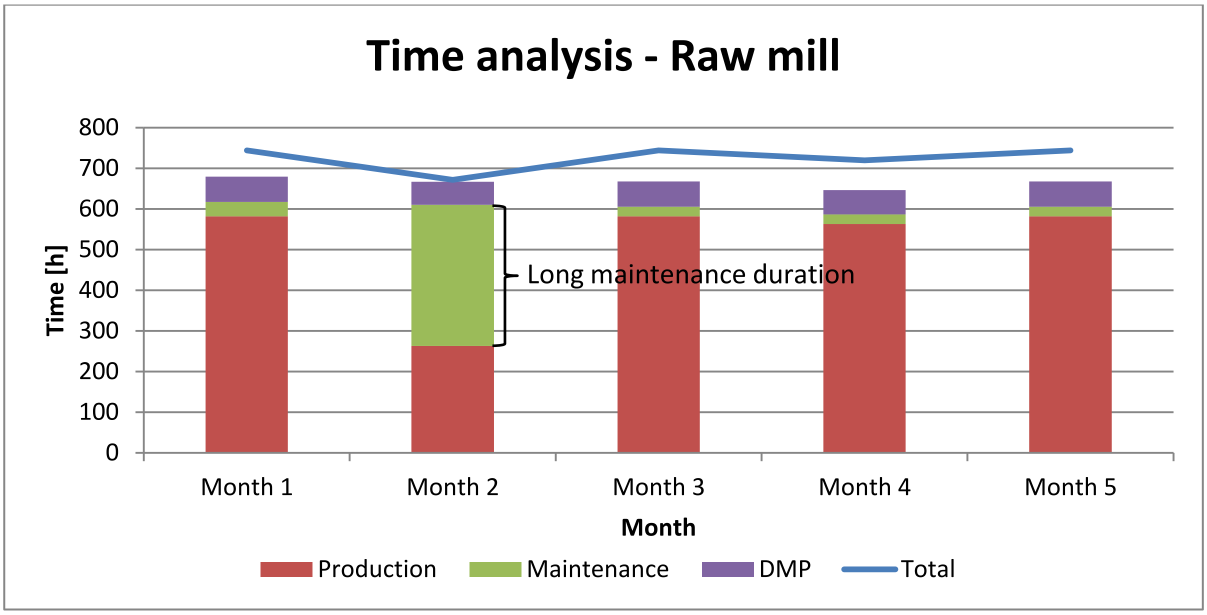

Figure 16: Production target analysis with DMP

3.3 Cost-saving potential

DMP payment

The cost benefits of the DMP programme will now be calculated and discussed. A DMP participant is paid by Eskom for reducing load. The DMP payment consists of a standby and an energy payment. The DMP payment per Megawatt hour is given in Table 8. The standby payment is R25.63/MWh for peak time and R10.76/MWh for other time periods. The energy payment is R1200/MWh for all time periods.

Table 8: DMP payment [38]

Payment type	Tariff period	Cost benefit	Unit
Standby	Peak	25.63	[R/MWh]
	Standard / Off-peak	10.76	[R/MWh]
Energy	All	1200.00	[R/MWh]

The maximum standby duration is from 06:00 in the morning until 22:00 in the evening. A cement plant can thus be scheduled for a maximum standby duration of 16 hours per day. In Table 9 the hours for a Weekday, Saturday and Sunday are grouped according to Eskom's Megaflex TOU tariff structure into peak, standard and off-peak periods. The Megaflex TOU tariff structure is used as most of the cement plants are billed according to this TOU tariff structure.

Table 9: DMP standby time grouped according to the Megaflex TOU tariff structure

Tariff period	Weekday	Saturday	Sunday	Unit
Off-peak	0	9	16	[h]
Standard	11	7	0	[h]
Peak	5	0	0	[h]
Total	**16**	**16**	**16**	**[h]**

In Table 10 the maximum standby duration and Eskom's Megaflex TOU tariff structure are indicated.

Table 10: TOU tariff structure

Hour	Weekday	Saturday	Sunday
06:00	Standard	Off-peak	Off-peak
07:00	Peak	Standard	Off-peak
08:00	Peak	Standard	Off-peak
09:00	Peak	Standard	Off-peak
10:00	Standard	Standard	Off-peak
11:00	Standard	Standard	Off-peak
12:00	Standard	Off-peak	Off-peak
13:00	Standard	Off-peak	Off-peak
14:00	Standard	Off-peak	Off-peak
15:00	Standard	Off-peak	Off-peak
16:00	Standard	Off-peak	Off-peak
17:00	Standard	Off-peak	Off-peak
18:00	Peak	Standard	Off-peak
19:00	Peak	Standard	Off-peak
20:00	Standard	Off-peak	Off-peak
21:00	Standard	Off-peak	Off-peak

The energy and maximum standby payments (16 hours) that can be achieved for a DMP event are given in Table 11. The maximum payment a plant can receive for a DMP event is thus R2647/MW for Weekdays and R2572/MW for Saturdays and Sundays. Note that the maximum standby payment accounts for only 9.31% of the total payment that can be achieved for Weekdays and 6.69% for Saturdays and Sundays.

Table 11: Total DMP payment

Payment type	Weekday	Saturday	Sunday	Unit
Standby	246.51	172.16	172.16	[R/MW]
Energy	2400.00	2400.00	2400.00	[R/MW]
Total	**2646.51**	**2572.16**	**2572.16**	**[R/MW]**

Operating / Electricity cost saving

An electricity cost saving is also achieved when the peak and/or standard load consumption is reduced, thus when the DMP event occurs during the peak and/or standard periods. The typical TOU tariff structure for the period 2013/2014 is given in Table 12 [39]. These tariffs have been selected for a typical cement plant that is billed according to Eskom's Megaflex TOU tariff structure with a transmission zone of 300-600km and a supply voltage of 0.5-66kV.

Table 12: Eskom Megaflex TOU tariff structure 2013/2014

Tariff period	Summer	Winter	Unit
Off-peak	289.60	334.50	[R/MWh]
Standard	456.50	610.60	[R/MWh]
Peak	663.40	2 033.40	[R/MWh]

The electricity cost saving (R/MW) is calculated by subtracting the cost to operate during off-peak (OP) time from the cost to operate during peak (P) or standard (S) time and multiplying it by the number of hours. Formulae 4 and 5 are used for the calculations.

$$Electricity\ cost\ saving_P = \left(P_{tariff} - \ OP_{tariff}\right) \times number\ of\ hours \tag{4}$$

$$Electricity\ cost\ saving_S = \left(S_{tariff} - \ OP_{tariff}\right) \times number\ of\ hours \tag{5}$$

In Table 13, the electricity cost saving is calculated for peak and standard time using the tariffs specified in Table 12. For the peak electricity cost saving, it is assumed the DMP event take place during two peak hours and for the standard cost saving, it is assumed that the DMP event take place during two standard hours.

Table 13: Electricity cost saving

Electricity cost saving	Summer	Winter	Unit
Peak time	747.60	3 397.80	[R/MW]
Standard time	333.80	552.20	[R/MW]

The peak electricity cost saving is R747.60/MW in summer and R3 397.80/MW in winter. The standard electricity cost saving is R333.80/MW in summer and R552.20/MW in winter. When the load is reduced during the off-peak time, an electricity cost saving is not achieved. The electricity cost saving can thus only be achieved for DMP events that take place on Weekdays and Saturdays, as Sundays do not have peak or standard time periods.

To ensure electricity costs for mill operations are kept low, it is important to verify that a stop for a DMP event during off-peak time won't implicate the mill to need to operate during peak time periods. If it is the case, the electricity cost will increase.

The maximum saving that can be achieved for Weekdays, Saturdays and Sundays is given in Table 14. The total DMP payment (Table 11) and the maximum electricity cost saving (Table 13) that can be achieved per day type are used, which is the peak cost saving for Weekdays and the standard cost saving for Saturdays.

Table 14: Maximum cost saving

Maximum cost saving	**Summer**	**Winter**	**Unit**
Weekday	3 394.11	6 044.31	[R/MW]
Saturday	2 905.96	3 124.36	[R/MW]
Sunday	2 572.16	2 572.16	[R/MW]

According to the average load profile in Figure 12, a cement plant has a minimum load reduction potential of approximately 6MW. If a cement plant reduces its load by 6MW for a Weekday DMP event, it can achieve a total cost saving of R20 346 in summer and R36 256 in winter. Using an example of there being 10 DMP events in a month, there is a potential monthly saving of either R203 460 or R362 560.

3.4 Modelling

The potential for implementing load reductions on the different milling processes has been identified and the cost-saving potential was calculated. The next step is to determine the average number of mill stoppages that can be implemented on the milling process, without affecting production targets or product quality.

The silo level of a milling process must be controlled within the minimum and maximum levels. When a mill is stopped, the silo level may not drop below the minimum level. A model of each milling process can be used to simulate the effect of a mill stoppage on the specific silo level. The number of mill stoppages can then be determined.

The DMP programme is developed to lower the peak demand, and therefore a DMP event has the highest probability of occurring around the evening or morning peak periods. Swanepoel et al. [35] designed a mathematical model with the objective of shifting load out of the peak periods. This model takes the different plant and process constraints into account and can be used to determine the number of mill stoppages that can be implemented on the milling process.

The maximum and minimum silo levels and the operational costs are used as the main constraints to compile a milling schedule. The different silo levels are controlled between the upper and lower limits. The operational cost is calculated according to the Eskom MegaFlex TOU tariff structure and is minimised by shifting run time out of the peak periods.

The plant’s production targets or cement sales are entered as inputs into the model. The operational hours required to meet the actual production target are given as the output. The effect of running according to the milling schedule is illustrated with predicted silo levels.

Building the mathematical model

For this study, the effect of stopping a raw mill or a cement mill will be simulated with the mathematical model. Each mill is part of a process line, and a model for each process line needs to be built. The effect of one process line on another will not be taken into account.

The number of process lines is determined by the plant layout. For example a plant may have two raw milling process lines and two cement milling process lines. In Figure 17 [36] a typical cement plant layout is given. This cement plant has one raw milling circuit and one cement milling circuit.

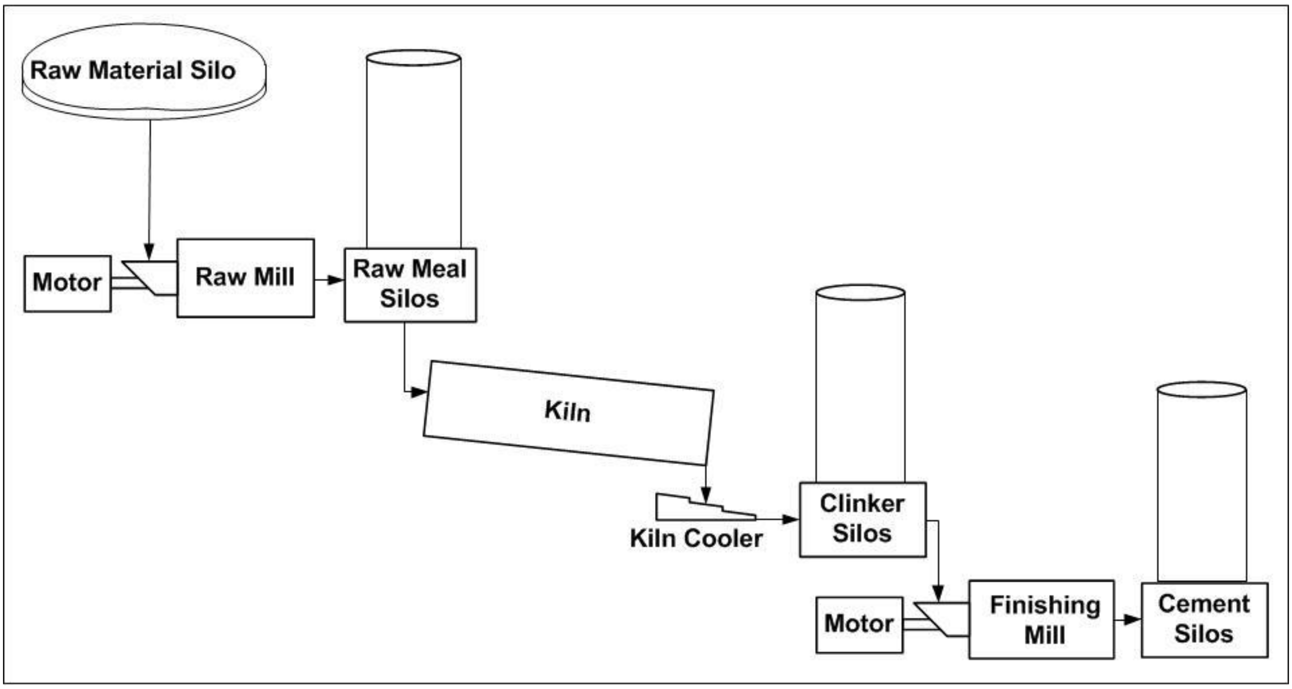

Figure 17: Cement plant layout

The raw and cement milling processes differ. A raw milling process line consists of a raw mill, raw meal silo and a kiln. The raw mill produces raw meal which is stored in the raw meal silo and the kiln extracts the raw meal from the silo. The raw milling process line is given in Figure 18.

Figure 18: Raw milling process line

A cement milling process line is formed by the cement mill, cement silos and cement exports. The cement exports are divided into bulk loads and bag loads. Bulk loads are extracted directly from the silo whilst bag loads are extracted from the packing plant. A cement milling process line is given in Figure 19.

Figure 19: Cement milling process line

In Table 15, the different components of raw and cement milling process lines are grouped according to the different model components. The mills, kilns and packing plants are the process components and the relevant silos are the storage components.

Table 15: Model components

Component	Raw milling process line	Cement milling process line
Process	Raw mill and kiln	Cement mill, packing plant and bulk sales
Storage	Raw meal silos	Cement silos

It is assumed that the availability or supply of the different raw materials to the relevant mills will not affect or determine the operation time of the milling process lines. Thus it is assumed that there is sufficient raw material supplying the raw and cement mills. This assumption is made to simplify the mathematical model.

Characteristics and operational specifications

The characteristics of the plant and its components must be entered into the model. The flow rates, the silo capacities, the scheduled maintenance and the reliability of the equipment are the component characteristics that need to be entered. A plant characteristic that needs to be entered is the operating hours of the facility.

Thereafter the operational specifications of the cement plant must be entered. These specifications form the constraints of the process line which will determine if the mill can be stopped or not.

A typical cement plant has the following specifications [37, 40]:

1. Produce good quality cement.
2. Meet the cement demand of clients (production targets).
3. Do not interrupt the pyro-process or any of the electrical equipment that is involved in the kiln process.
4. Control the kiln feed precisely.
5. Ensure that the levels of the raw meal silos do not drop below the minimum level.
6. Take the equipment constraints into account, for example the number of mill start-ups per day.

The number of mill start-ups and the minimum silo level of the raw meal silo or the cement silo must be built into the mathematical model. The other specifications will be met if the milling processes are controlled according these two specifications.

Take for example the raw milling circuit. If the raw meal silo level drops below the minimum level, the raw meal blending efficiency becomes too low which results in poor clinker formation, which in turn negatively affects the cement quality. From this, it is seen that the defined specification 1 could not be met because specification 5 was not met.

Another example is equipment constraints. If a mill is not operated according to the prescribed specifications, it may lead to a breakdown. This will lead to production loss which could result in not meeting the cement demand. Thus, as specification 6 was not met, specification 2 could not be met.

Now that the different process lines are built, the characteristics are entered and the constraints are specified, the framework of the model is created. The raw meal and cement targets must be entered as inputs whereafter each process line can be simulated.

3.5 Simulation

The model of the different process lines will be used to determine the average number of mill stoppages that can be implemented per milling process. This average will be used to calculate the average load reduction capacity for the specific milling process line. This capacity indicates what the average load reduction capacity is for that specific process line.

A mill's operating cycle consists of a *maintenance week* and a *no maintenance week.* A maintenance week has one day with scheduled maintenance on the mill. The maintenance procedure of a typical mill requires that the mill is stopped in the morning, usually at 5AM. The mill is serviced and started thereafter. The total mill down time is usually about 12 hours.

A no maintenance week has no scheduled maintenance. It must be noted that this maintenance and no-maintenance operational cycle of a mill may alter when long maintenance procedures must be done. The same applies for new installations or modifications on the process line of the mill. The mill may be stopped for a longer duration and the operation cycle will therefore alter from the normal operating cycle.

Under normal operating conditions the silo level is controlled between the minimum and maximum ranges. The average operating silo level will be used and can be calculated from two to three months logged data.

Note that a cement milling process line differs from a raw milling process line in the following ways: Different products are manufactured on cement mills, not only one product as on raw milling process lines. A cement milling process line can consists of a combination of mills to manufacture a certain number of products; for example, two cement mills can be used to manufacture three products or two mills can be used to manufacture four products. In a raw milling process line, there is only one mill per process line.

The minimum silo level is also lower for a cement milling process line than for a raw milling process line. In a cement milling process line, cement is extracted by the packing plant and by bulk loads. In a raw milling process line, it is only the kiln that extracts material from the process's silo.

Note that cement sales fluctuates on a daily basis and therefore the operation schedule of the cement mills will vary. For a raw milling process line, the kiln is operated continuously and a fixed material feed must be supplied. The operation schedule of a raw milling process will thus not differ as much as a cement milling process line.

A raw milling process line will be used as an example to discuss the simulation procedure. The same method that will be used to simulate mill stoppages on a raw milling process line will be used for a cement milling line. An example of the simulation of a cement milling process line will not be discussed as it is addressed in the case study.

Simulation analysis

A typical raw mill's average silo level is 77%. In Figure 20 to Figure 22 the milling schedules and predicted silo levels for a maintenance and no maintenance week are given in blue and green respectively.

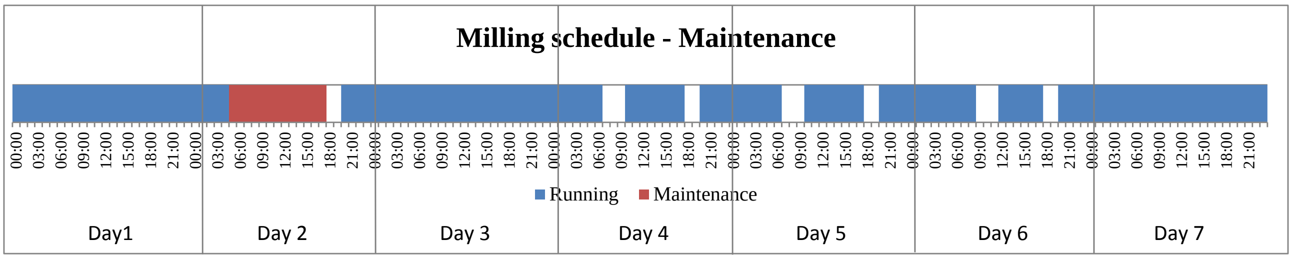

Figure 20: Milling schedule – Maintenance

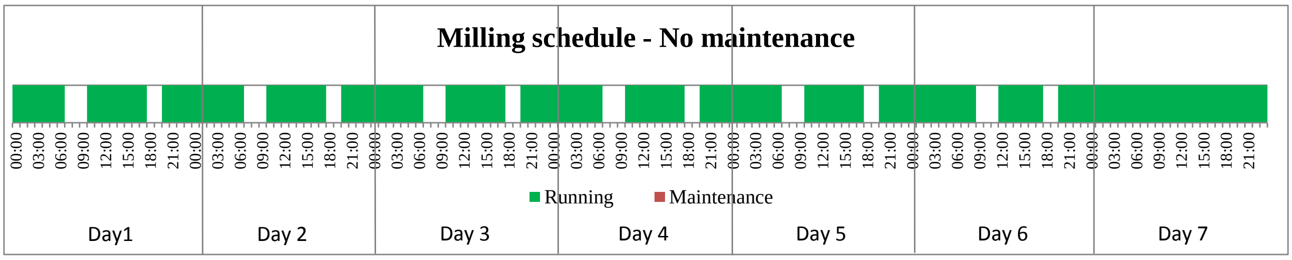

Figure 21: Milling schedule – No maintenance

In the figures, Day 1 on the milling schedule refers to a Monday. In the example the maintenance procedure is scheduled for a Tuesday (Day 2). Note that the mill is started at 20:00. This is to ensure that the mill start-up won't affect the load reduction if a DMP event occurs on that day. The effect of starting a mill before a DMP event will be discussed at the end of this section.

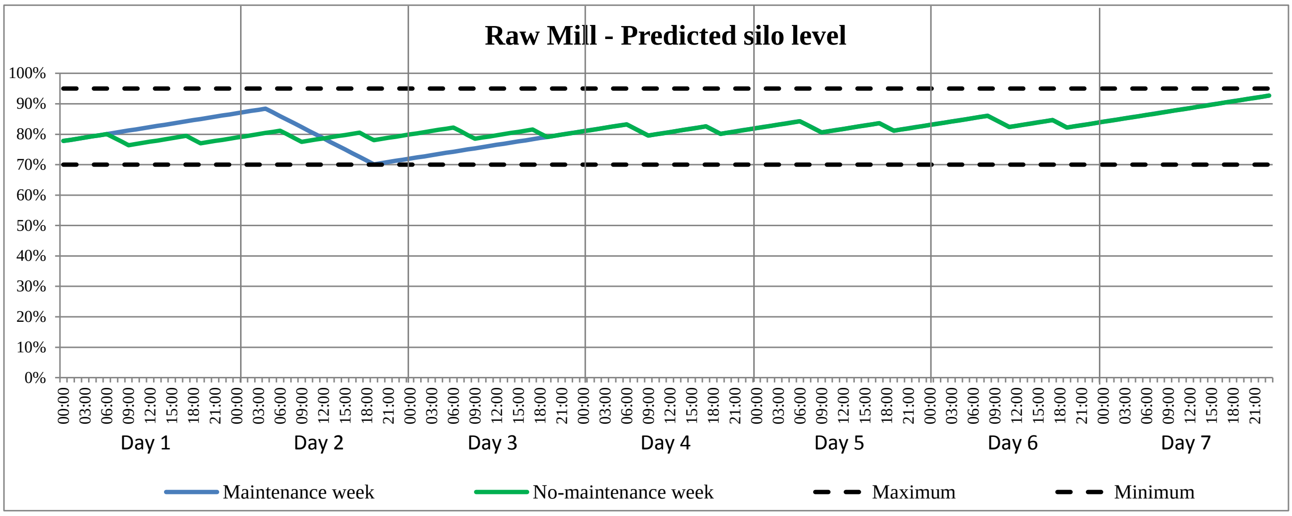

Figure 22: Predicted silo level – Maintenance and no maintenance week

The effect of stopping the mill is illustrated on the predicted silo levels. If the silo level is appropriate (that is, not dropping below the minimum level during a stoppage) a mill stoppage is indicated. The first priority is to stop the mill for the evening peak and then for the morning peak period. If the silo level is going to increase beyond the maximum level with the two peak stoppages, the stop duration is lengthened.

Note that the milling schedule does not indicate that the mill can be stopped on a Sunday. This is as the model is programmed to shift load out of the peak time periods. For a Weekday, load is shifted first out of the evening peak period and then out of the morning peak period. For a Saturday, load is shifted out of the evening standard period and then out of the morning standard period. A Sunday only has off-peak periods and therefore no mill stoppage is indicated.

The mill stoppages for both a maintenance and no maintenance week are tabulated in Table 16. The indicated number of mill stoppages for a Weekday morning and evening peak periods is tabulated in columns two and three respectively. The fourth column gives a summary of the maximum mill stoppages for Weekdays. Note that the maximum number of stoppages per day is calculated from only one DMP event taking place per day. The summary section therefore tabulates the maximum stoppages of either the morning or evening peak periods. For this example the morning and evening stoppages is equal.

Table 16: Summary of mill stoppages – Weekdays

	Morning	**Evening**	**Total**
Maintenance	2	2	2
No maintenance	5	5	5
Overall average			**3.5**

For this example the average mill stoppages per week are 3.5 times for Weekdays. By inspecting the predicted silo levels for a Sunday, it can be seen that the silo level is appropriate for a mill stoppage and the mill can be stopped on a Sunday if a DMP occurs.

The number of mill stoppages is then converted to a mill stop percentage for each day type. The mill stop percentage is calculated by dividing the maximum number of mill stoppages for a specific day type by the number of days in a week for that specific day type. The formula for the calculation is given below.

$$Mill\ stop\ percentage\ = \frac{Maximum\ \ number\ of\ mill\ stoppages}{Number\ of\ days} \qquad (6)$$

For this example the simulation predicted that the mill could be stopped 3.5 times on Weekdays. As there are 5 Weekdays in a week, the mill stop percentage is equal to 3.5 divided by 5. The mill stop percentage for Weekdays is thus 70%.

Effect of a mill start

Lastly, the effect of starting a mill an hour to half an hour before a DMP event will be discussed to determine how a mill start before or at the DMP event time must be tabulated if such a scenario occurs. For example, if a mill of 2MW must be started at 17:00 and a mill of 4MW can be stopped if a DMP event occurs at 18:00. The reference period for such an event is from 16:30 to 17:30 (see A in Figure 23) and the DMP event duration is from 18:00 to 20:00 (see B).

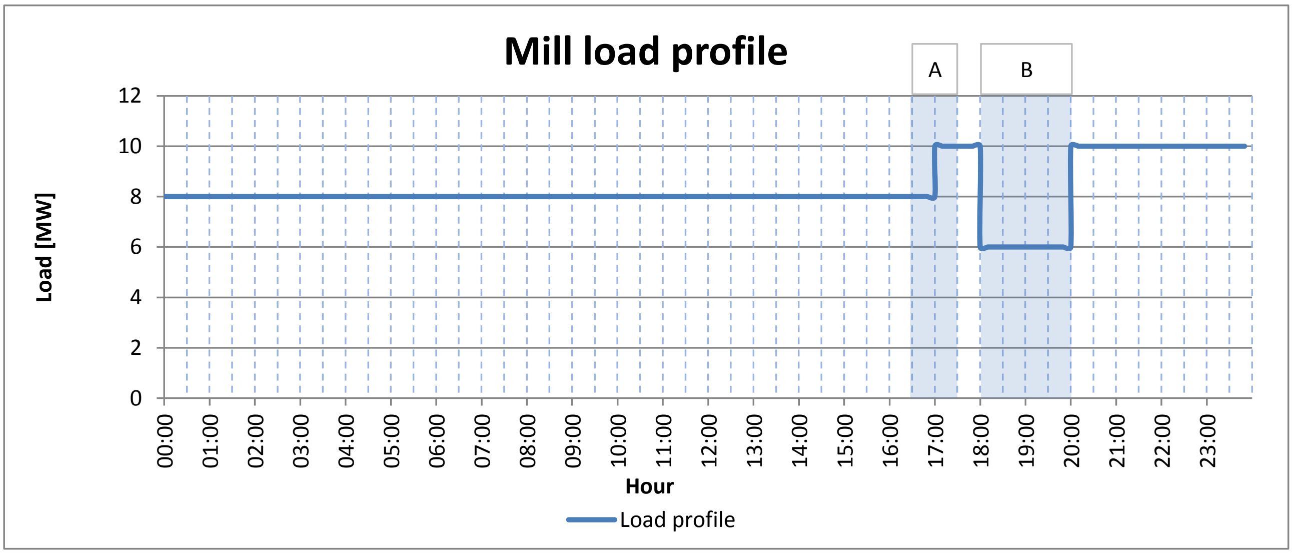

Figure 23: Mill load profile – DMP event at 18:00

The effective load reduction for such an event will be calculated as follows: The average load for the reference period is equal to the sum of the original load, which is 8MW for the full hour, and the load that was started, which is 2MW for half an hour. Thus the average load in the reference period is 9MW (8MW x 1 + 2MW x 0.5).

The reduced load is equal to 8MW (original load) plus the load of 2MW, which is due to the mill being started at 17:00, minus the load of 4MW, which is for the mill stopped at 18:00. In this case the reduced load is 6MW. The load reduction for the specific event is equal to the average load of the reference period minus the average load of the reduced load. For this scenario, it is 9MW minus 6MW which is equal to 3MW.

The effect on the load reduction when starting a mill of 2MW at 17:00, when a DMP event occurred at 18:00, is equal to -1MW. This is equal to -0.5 times 2MW. As the mill is started in the middle of the DMP event, the mill start at 17:00 had a -50% effect (-1MW) on the load reduction.

In Figure 24, the scenario is illustrated for a DMP event occurring at 17:30. Note that in this case the mill is started after the reference period and that the average load for the reference period is thus 8MW. The reduced load is still 6MW. The effective load reduction for this scenario is equal to 2MW (which is 8MW minus 6MW). As the mill is started after the reference period, the mill start at 17:00 had a -2MW effect on the effective load reduction. This is equal to -1 times 2MW.

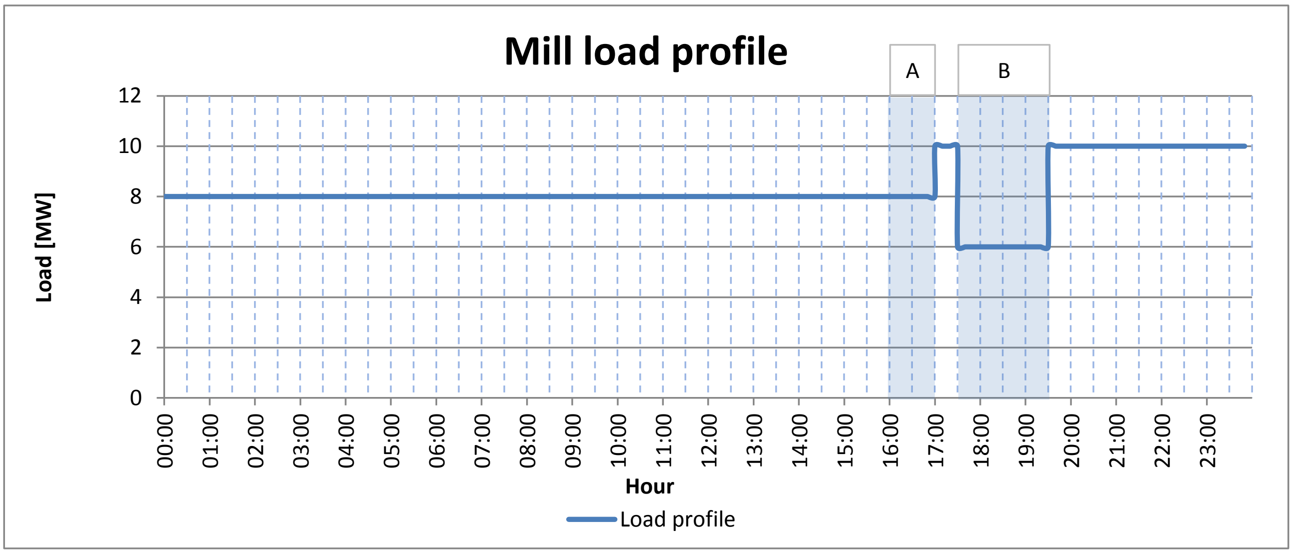

Figure 24: Mill load profile – DMP event at 17:30

When a mill is started an hour before a DMP event, the effect is -50%. If the mill is started half an hour before the DMP event, the effect is -100%. If such a scenario is simulated by the model, a start-up of an hour before a typical event must be taken as -0.5 times and a start-up of half an hour before the event must be taken as -1 times.

As the exact time of the DMP event is unknown, such a scenario will be noted by -1. By noting such a scenario with -1, the worst effect of the mill start-up is taken into consideration.

3.6 Load reduction

The mill stop percentage for each day type is calculated for the different process lines. The next step is to calculate the average load reduction capacity per process line whereafter the average load reduction of the cement plant can be calculated.

The average load reduction capacity of a process line is calculated by multiplying the mill stop percentage for the specific day type with the total load reduction capacity of the mill (calculated in section 3.2) and the mill utilisation. The formula for the calculation is given below.

$$Avg. LR\ capacity = mill\ stop\ percentage \times total\ LR\ capacity \times mill\ utilisation \qquad (7)$$

Once the average load reduction capacity per process is determined, the cement plant's average load reduction capacity is calculated by taking the sum of all the average load reduction capacities. Thereafter the average load reduction of the cement plant can be calculated.

A reduced load profile and a baseline load are required to calculate the plant's average load reduction. The reduced load profile gives the cement plant's average load profile for a typical DMP event and the baseline gives the average load profile of the cement plant for a non-DMP day.

The plant's average load reduction is calculated by subtracting the plant's reduced load profile from the plant's baseline. The formula to calculate the average load reduction is given below. Note that the baseline and the reduced load profile is scaled energy neutral at the reference point as discussed in section 2.5.

$$Average\ load\ reduction\ = baseline - \ reduced\ load\ profile \qquad (8)$$

The reduced load profile is obtained as follows. The baseline is taken as the basic running profile for the day. Thereafter the reduced load during the DMP event time is calculated by subtracting the cement plant's average load reduction capacity from the average load of the DMP reference period.

An example is given in Figure 25. The DMP event time is taken as 18:00. The reference period is thus from 16:30 till 17:30. The average load during this period is approximately 10.0MW and the cement plant's average load reduction capacity is taken as 6.0MW. The reduced load during the event time is thus equal to 10.0MW minus 6.0MW which is 4.0MW.

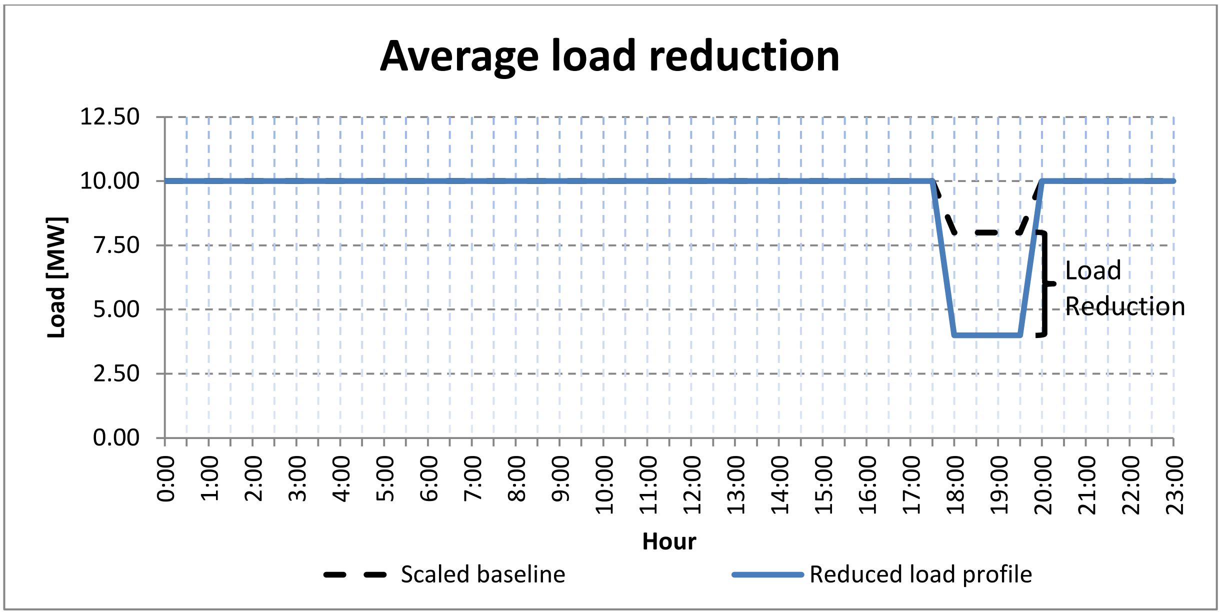

Figure 25: Average load reduction

The cement plant's load reduction is illustrated in Figure 25. Note the difference between the cement plant's average load reduction and the average load reduction capacity. This is due to the effect of the baseline. This calculation must be done for Weekdays, Saturdays and Sundays as the DMP programme distinguishes between each day type.

3.7 DMP participation strategy

DMP event proceedings

It must now be determined how the cement plant will participate in the DMP programme. First, the flow of proceedings for an actual DMP event will be discussed according to Table 17. Note that proceedings 1 and 2 must be completed a day before the actual DMP event (Day 0). If the plant is dispatched, proceedings 3-5 will take place on the day of the DMP event (Day 1).

Table 17: Flow of proceedings for a DMP event

No.	Proceedings	Day and time
1	Submit bid	Day 0 – Before 09:00
2	Receive standby schedule	Day 0 – at 15:00
3	Receive dispatch notification	Day 1 – 30min before event
4	Reduce load	Day 1 – at event start time
5	Restart load	Day 1 – at event stop time

A DMP bid must be emailed to the VPS before 09:00 in the morning (proceeding 1). The bid must indicate the capacity and duration of the standby load for the next seven days in single hour time slots. At approximately 15:00, the VPS will email a standby schedule to the plant that indicates the cement plant’s scheduled standby duration and load (proceeding 2).

If the cement plant is dispatched, the plant will be notified 30 minutes before the event start time via a telephone call. The event start time and load reduction capacity will be given whereafter the VPS will send a confirmation SMS. The cement plant must then reduce load at the event start time by shutting down one or more mills. After two hours, the event is over and the cement plant can restart their mills and continue with production.

Strategy

To implement this strategy of participating in the DMP programme, the different proceedings need to be assigned to the plant personnel. The proceedings will be fitted to the normal daily routine of a typical cement plant's personnel. Key personnel that will be involved are the production manager, production team members, shift managers and control room operators.

The production team of a cement plant manages the operational schedules of the mills. The production team consists of a production manager and several team members that work on a shift basis. The final mill operation is determined by the production manager.

Typically, the production team has a production meeting in the morning (usually 08:00 – 09:00). The daily milling operations and the production schedule for the week are discussed during this meeting. This meeting can be used to discuss the standby schedule for the specific day and the mills that are available that day should a DMP event occurs. The DMP bid for the next seven days can be drawn up and emailed to the VPS.

If a DMP event occurs, the production team will be notified. The team member on shift will then be responsible to ensure that the load reduction is implemented. Should there be a deviation in the planned mill operations, the production manager's advice can be sought.

The production team member will then inform the operational team which mills must be shut down and what the shutdown time is. The operational team's primary function is to control the different processes of the cement manufacturing process. The team consists of a shift manager and a number of operators. The shift manager is responsible for overseeing all the operators who control the different process lines. Usually an operator operates two process lines, for example a raw milling process line and a cement milling process line.

The operational team is then responsible to stop the mills when the DMP event starts. Once the DMP event is over, the mills can be restarted to continue with normal plant operation. When the DMP capacity cannot be met, the production team member on shift must retract or lower the DMP bid by sending an email to the VPS. In the case that the load specified by the contracted schedule cannot be reduced, due to an emergency or a technical breakdown, the VPS should be notified as a courtesy by the production team.

If the VPS has not informed the cement plant of a DMP event, the mills must not be shut down. If the mill has to shut down due to a high silo level or any other reason, the shutdown must occur an hour and a half before the usual DMP event start time or after the usual DMP event stop time. This will ensure that the customer baseline (CBL) is not lowered in the usual DMP event time. If the baseline is lowered, the actual DMP load reduction will be influenced negatively.

Resources

A resource that will help the production team is a milling schedule. The milling schedule must be compiled each morning before 08:00 and can be used to identify the mills that are available should a DMP event occur that day. The silo levels of the specific process line can be included in the schedule to see the effect of stopping the mill.

Swanepoel et al. designed an energy management system to optimise electricity usage on mills in cement plants. This system is called the Process Toolbox (PTB) which has a database, optimiser and reporting function. The system can be adapted and used to compile the weekly milling schedule.

Figure 26 is a schematic diagram of the EnMS system. The system is computer based and uses two servers. One server is installed at the plant and the other server is the common PTB server with the database, optimiser and reporting function. The PTB server is the brain of the EnMS.

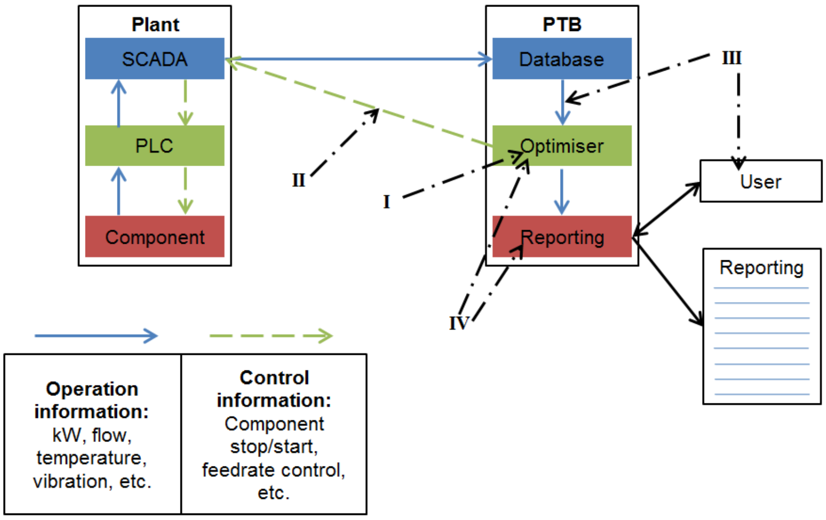

Figure 26: Schematic diagram of the operation of the energy management system [29]

The plant's server reads the required inputs from the SCADA. These logged inputs are sent to the PTB server via email. The PTB optimiser is used to compile the milling schedules by solving a mathematical model of the plant. A database is kept of all the milling schedules which are sent on a daily basis to the plant's server and relevant plant personnel. The logged input data is also stored in the database.

Note that the optimiser will use the mathematical model that was created in the modelling section. The primary design of the system will be used and no other alterations or modifications are required.

The hardware required is a PC station at the plant and the PC station at the central control point. Each PC station consists of a server and Human Machine Interface (HMI) devices, with their computer screens installed in the control room of the plant. Software programmes that need to be installed on both stations include a data logging programme, a communication programme and an optimiser programme on the central PTB server.

In the case where some of the critical inputs are not available on the plant's SCADA, the necessary sensors will have to be installed. An example is silo level measurement devices to read silo levels in real time.

To help with communication between the production team and the operation team, the mill run plan for the day can be displayed in the control room on the HMI screen. The shift manager and the control room operators can use this as a visual tool to interpret the instructions given by the production team member.

Lastly, all the plant personnel that are involved in the programme proceedings must be properly trained. The DMP theory and participation strategy must be explained to the production team for them to manage DMP according to the participation strategy. The shift managers and control room operators must be trained to follow and interpret the milling schedules on the screen.

3.8 Conclusion

Mill load profiles indicate if a cement plant has load to reduce for the DMP programme. If there is load reduction potential, the total load reduction capacity of each of the milling processes is calculated. The potential to implement these load reductions is determined by an analysis of the mill's total, production and maintenance time. The production target analysis gives an indication of which months of the year DMP load reductions can be implemented on the different process lines.

If a cement plant has load reduction potential, the cost-saving potential for the plant is calculated. The effect of stopping the plant's mills for DMP load reductions is simulated on a mathematical model to determine the average number of mill stoppages that can be implemented per process line. Thereafter the average load reduction capacity and the average load reduction of the plant are calculated.

A DMP participation strategy for a typical South African cement plant is discussed in the last section. This strategy can be used by cement plants to participate effectively in the DMP programme. The methodology discussed in this chapter can now be used to analyse a cement plant.

CHAPTER 4: VERIFICATION AND RESULTS

4.1 Preamble

In this chapter the procedure discussed in Chapter 3 is verified by implementing a case study on a cement plant. First the DMP potential and capacity is determined. Next, a mathematical model of the cement plant's different process lines is built, after which the number of mill stoppages is determined through simulation. Milling schedules are prepared and implemented for two weeks on the plant's process lines to determine what the plant's actual average load reduction per day type is. To conclude, the results of the cement plant participating in the DMP programme for a two month period are given.

The plant layout of the cement plant under investigation is given in Figure 27 (p. 76). The cement plant has three kilns and raw mills for clinker production and two cement mills for cement production. Only kilns 3 and 4 are used at the moment, whilst kiln 2 is mothballed. The two cement mills are used to manufacture four cement products which are stored in separate cement silos. The packing plant packs cement into bags after which it is palletised for bag dispatches. Bulk cement sales are loaded directly from the cement silos.

The two raw and two cement mills of the cement plant will be investigated for the DMP participation.

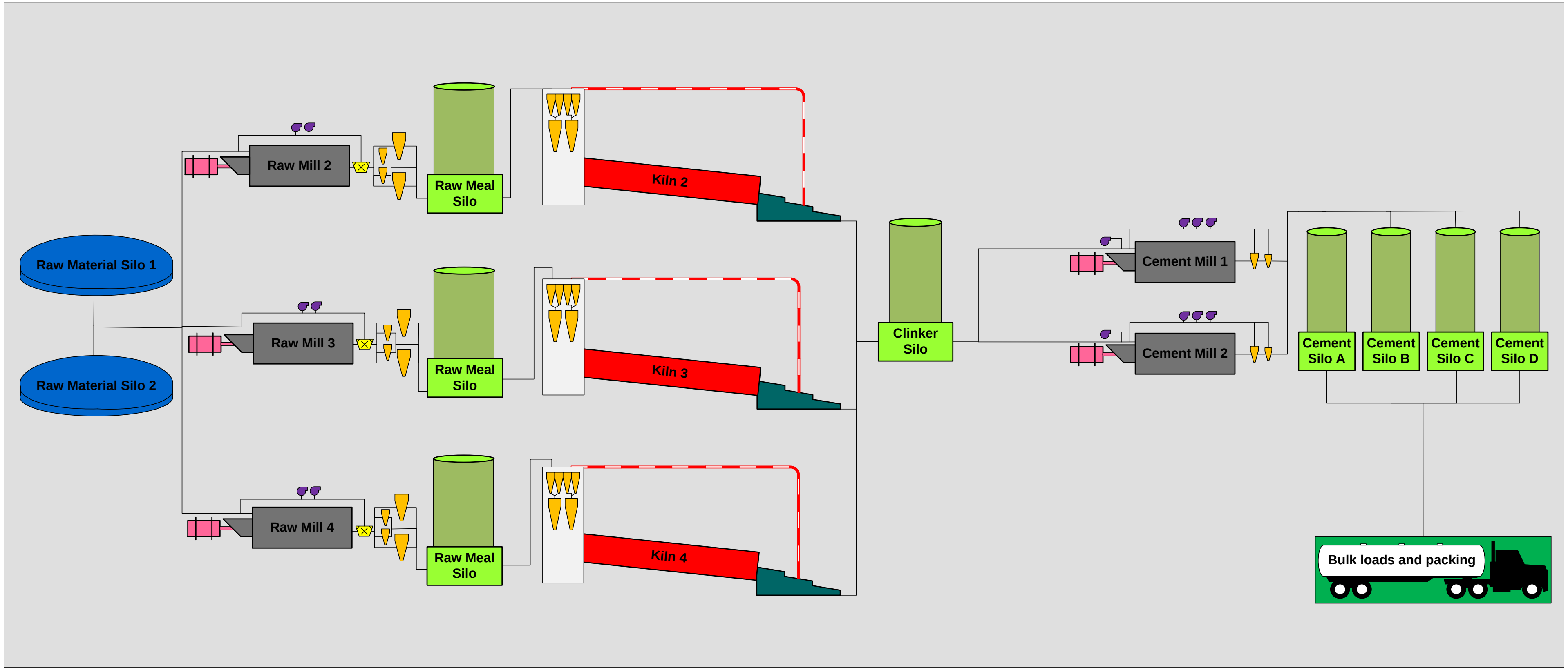

Figure 27: Plant layout

4.2 DMP potential and capacity

Mill load profiles

Logged data from November 2012 to January 2013 are obtained from the plant's SCADA and the combined capacity of the four mills is calculated. Weekday, Saturday and Sunday load profiles for each month are plotted, shown in Figure 28 to Figure 30.

In Figure 28, a clear dip can be seen from 18:00 until 20:00 in the Weekday load profile of each month. It is evident that a DSM project can be implemented on some of these mills. The minimum load reduction potential for the average Weekday load profile is 9.15MW.

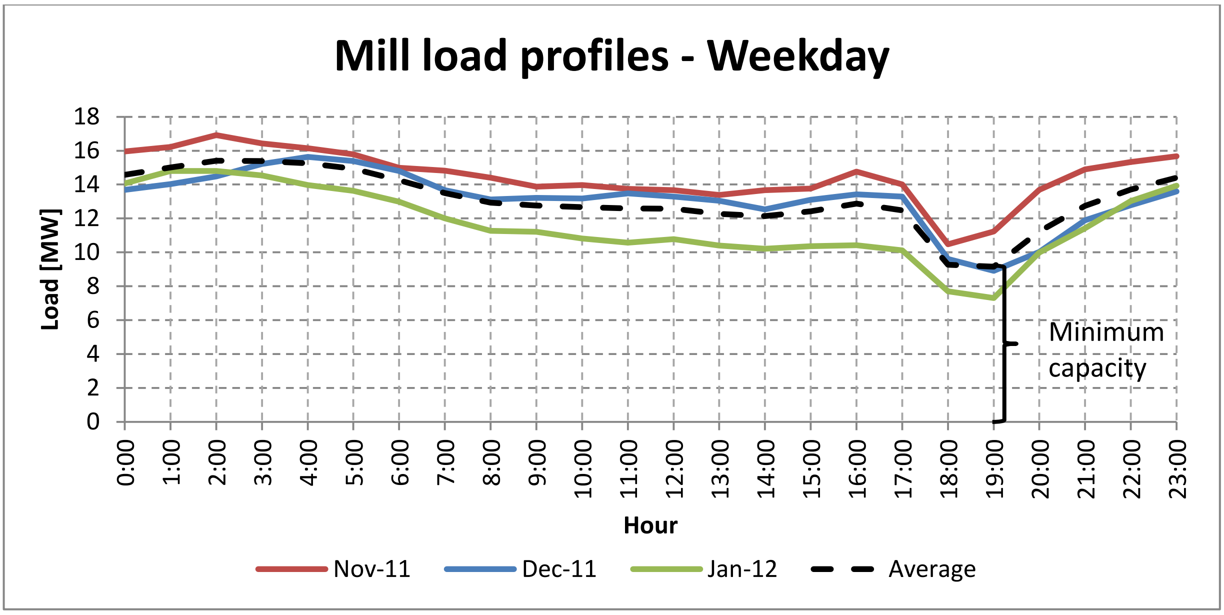

Figure 28: Weekday mill load profiles

Note that the load profiles for the different months differ. This is due to the fluctuation in each month's cement demand which causes the operation and utilisation of the mills to differ every month. The Saturday load profiles for the three months are plotted in Figure 29. The minimum load reduction potential for the average Saturday load profile is 9.63MW.

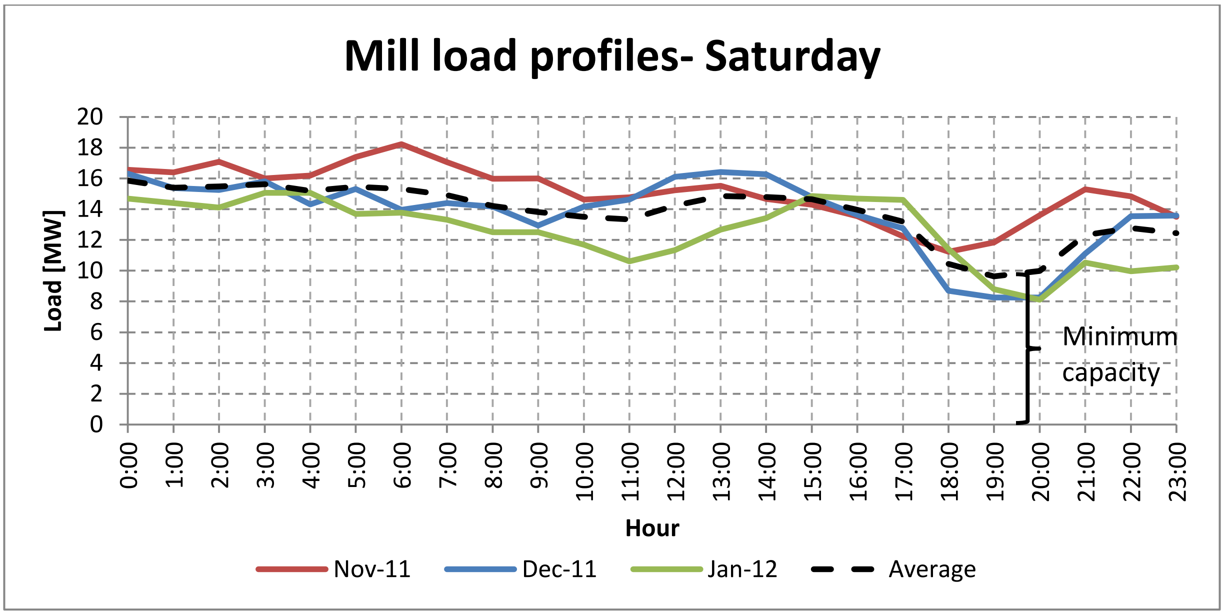

Figure 29: Saturday mill load profiles

The Sunday load profiles are plotted in Figure 30. The minimum load reduction potential for the average Sunday load profile is 11.2MW.

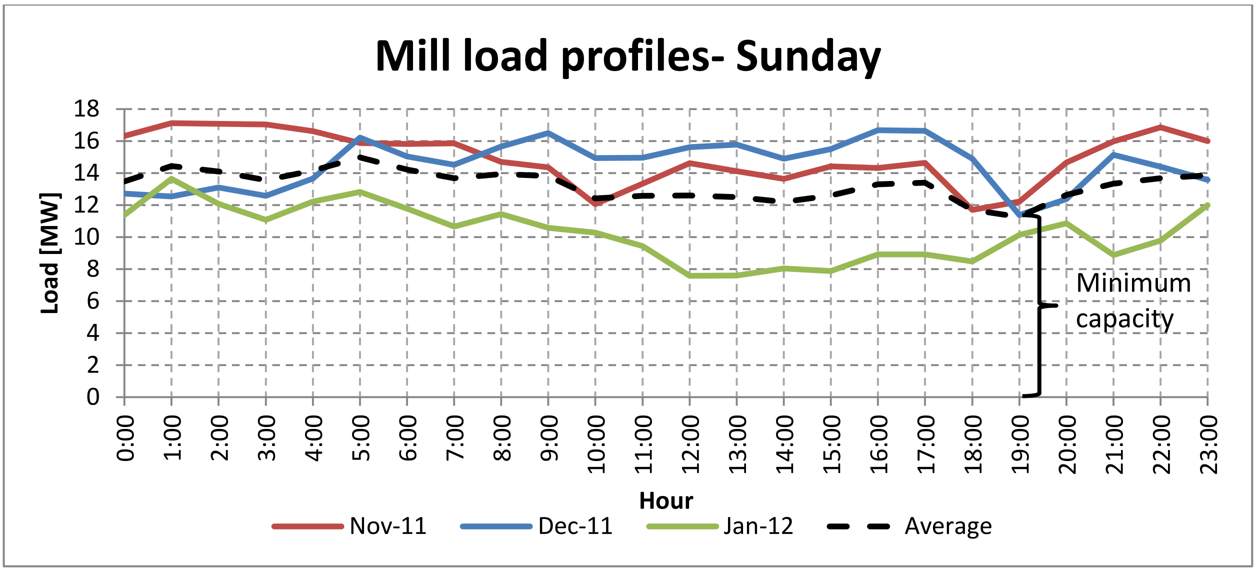

Figure 30: Sunday mill load profiles

A stacked graph of each mill's average load profile is plotted in Figure 31. This graph indicates the load reduction potential per mill for each day type (Weekday/Saturday/Sunday). The load profiles of cement mill 1 (CM1) and cement mill 2 (CM2) indicate that the cement mills are running consistently on Weekdays.

The Weekday load profiles (Figure 31) of raw mill 3 (RM3) and raw mill 4 (RM4) have a dip between 18:00 and 20:00. According to the plant, a DSM load shift project is implemented on raw mill 3 but not on raw mill 4. The aim of the DSM project is to shift the load in the evening peak to the off-peak periods to lower the load in the Weekday evening peak period.

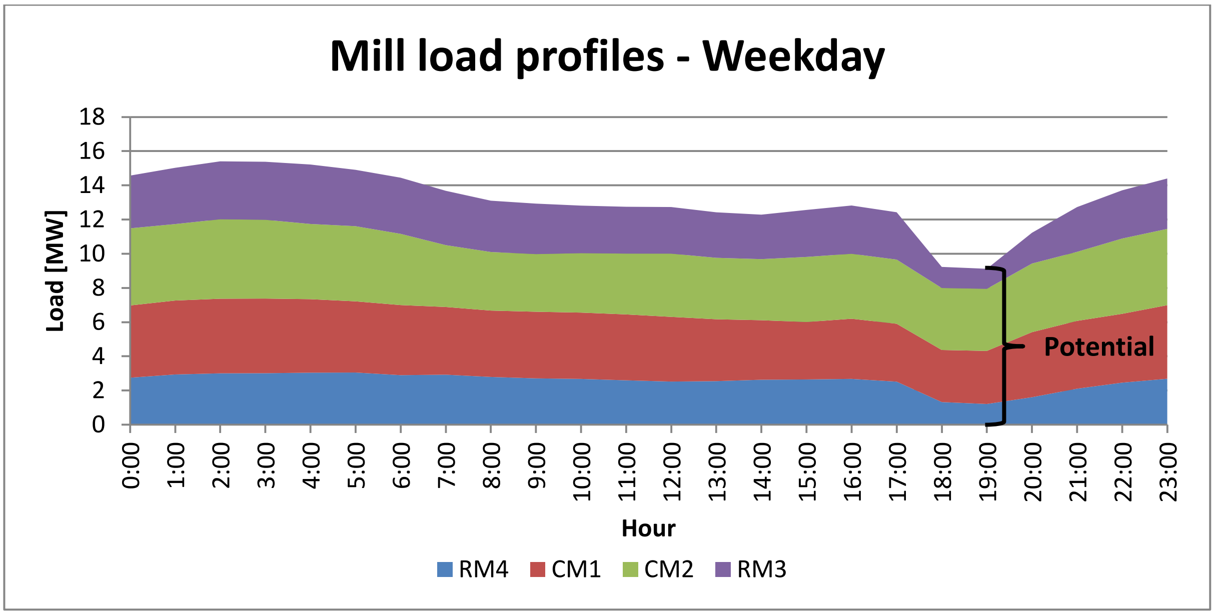

Figure 31: Weekday mill load profiles

Load reduction capacity

The total load that can be reduced per mill is determined next. In Table 18, the logged data obtained from the plant's SCADA is given. The green highlighted values indicate when the mill was running on full load and the maroon highlighted values indicate when the mill was off. The white highlighted cells indicate the period after the load reduction was implemented.

Table 18: Mill running and base loads, in MW[1]

Hour	RM4	CM1	CM2	RM3
00:00	3.62	5.41	5.24	5.18
01:00	3.62	5.43	5.23	5.20
02:00	3.62	5.43	5.25	5.18
03:00	3.63	5.44	5.26	5.18
04:00	3.61	5.43	5.22	5.15
05:00	3.60	5.44	5.22	5.20
06:00	3.61	5.47	5.24	5.17
07:00	3.65	5.47	5.24	5.15
08:00	3.67	5.46	5.24	5.18
09:00	3.65	5.47	5.28	5.18
10:00	3.67	5.45	5.21	5.16
11:00	3.68	5.44	5.23	5.15
12:00	3.66	5.45	5.24	5.13
13:00	3.67	5.44	5.22	5.15
14:00	3.64	5.43	5.20	5.14
15:00	3.66	5.43	5.20	5.13
16:00	3.64	5.44	5.20	5.14
17:00	3.50	5.32	5.21	4.63
18:00	0.24	0.14	0.68	0.57
19:00	0.25	0.09	0.28	0.53
20:00	0.58	4.18	3.21	4.16
21:00	0.60	5.41	5.17	5.18
22:00	1.23	5.43	5.19	5.18
23:00	3.62	5.44	5.22	5.17

From the logged data the total load reduction capacity is calculated. The load reduction capacity is calculated by subtracting the average load during the load reduction period (maroon highlighted cells) from the average load when the mill operated on full capacity (green highlighted cells).

---

[1] Verification: The plant's SCADA data corresponds within 3.8% with Eskom's meter readings.

The load reduction capacity for each mill is given in Table 19. The four mills have a total load reduction capacity of 18.0MW.

Table 19: Load reduction calculations

Mill	RM4	CM1	CM2	RM3	Total	Unit
Avg. running capacity	3.63	5.44	5.23	5.13	19.43	[MW]
Avg. base load	0.25	0.11	0.48	0.55	1.39	[MW]
Load reduction capacity	3.39	5.32	4.75	4.58	18.04	[MW]

In Figure 32, logged data are plotted to indicate the maximum load reduction for each mill.

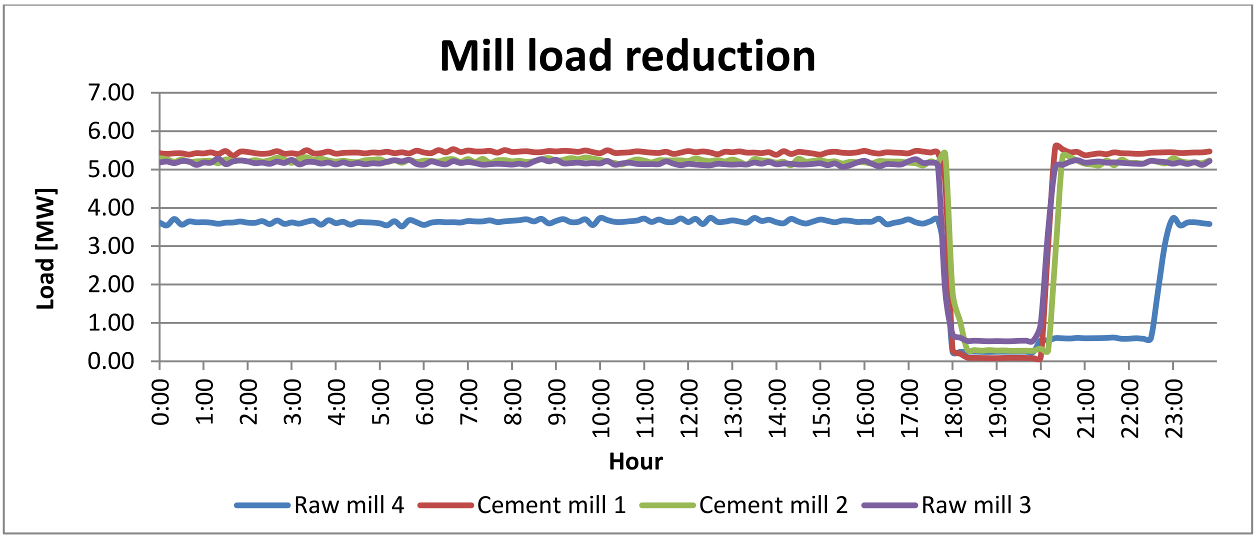

Figure 32: Mill load reduction

The next step is to analyse the production targets of each process line over a year to identify the months in which DMP load reductions can be implemented for each specific process line. The average number of mill stoppages is then determined through simulation, whereafter the average load reduction capacity per process line is calculated.

Production analysis

The raw meal and cement production targets, the mill and kiln production rates, maintenance duration, maintenance cycle or frequency and reliability are used for the production analysis. The cement production targets are obtained from the plant's production plan and the raw meal production targets are calculated.

Raw milling process lines

The raw meal production targets are equal to the kiln's production hours multiplied by the kiln's production rate and reliability. The kilns run continuously except for kiln shutdowns (Table 20). For each kiln, the first shutdown has a planned shutdown duration of 14 days, and the second of 7 days.

Table 20: Kiln shutdown dates for 2013

Kiln 3	Kiln 4
2013-02-01,12:00 to 2013-02-15, 12:00	2013-03-27, 12:00 to 2013-04-10, 12:00
2013-09-13, 12:00 to 2013-09-20, 12:00	2013-11-29, 12:00 to 2013-12-06, 12:00

The production rates in tonne per hour for the raw mills and the kilns are given in Table 21. Raw mills 3 and 4 have a production target of 260 and 181 tonne/h respectively. Kiln 3 and kiln 4 have a production rate of 195 and 161 tonne/h respectively.

Table 21: Production rates – Raw milling process lines

Component	Raw milling process line 3	Raw milling process line 4	Unit
Mill	260	181	[tonne/h]
Kiln	195	161	[tonne/h]

The raw mills are serviced on a two weekly cycle starting at 05:00 in the morning, with a total off time of 12 hours. The target reliability of the mills and the kilns are 98% and 99% respectively.

The calculated raw meal production targets for line 3 and 4 are given in Figure 33 (Values tabulated in the Appendix). The production targets of both raw milling lines are stable for each month, except for months with kiln shutdowns: February and September for line 3, and March, April, November and December for line 4.

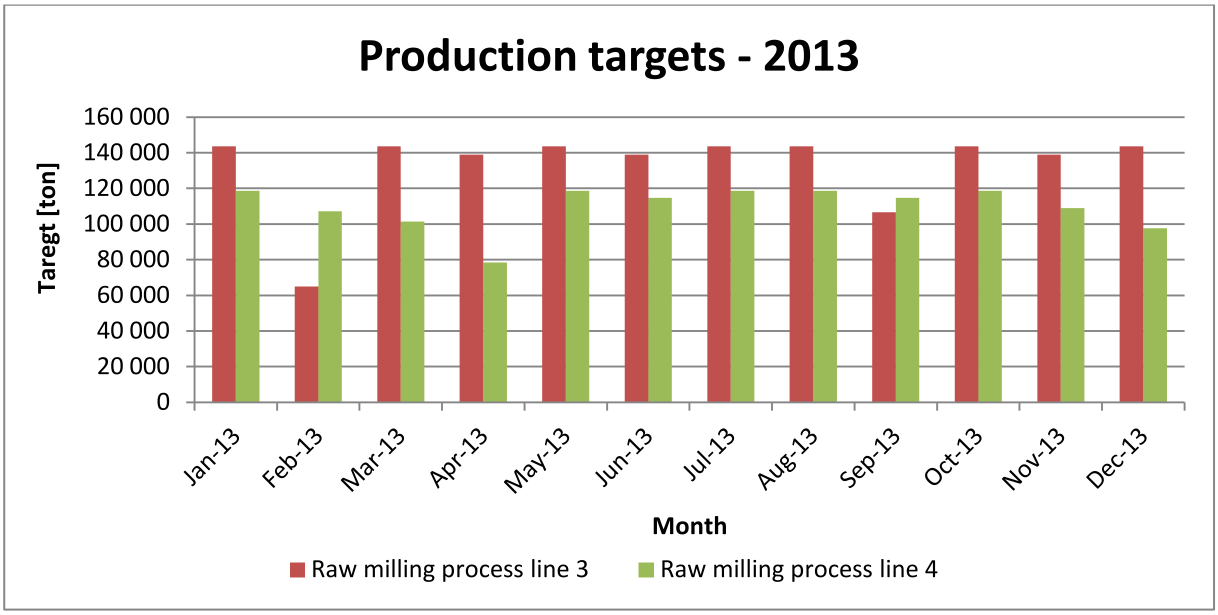

Figure 33: Production targets – Raw milling process lines

The production, maintenance, DMP and total time for the raw milling process line 3 are plotted in Figure 34. Note that the sum of the production, maintenance and DMP time is less than the total time. There is thus more than enough time available to stop the mill every day for DMP load reductions. Note that the potential for load reductions is limited in February and September due to the kiln shutdowns in these months.

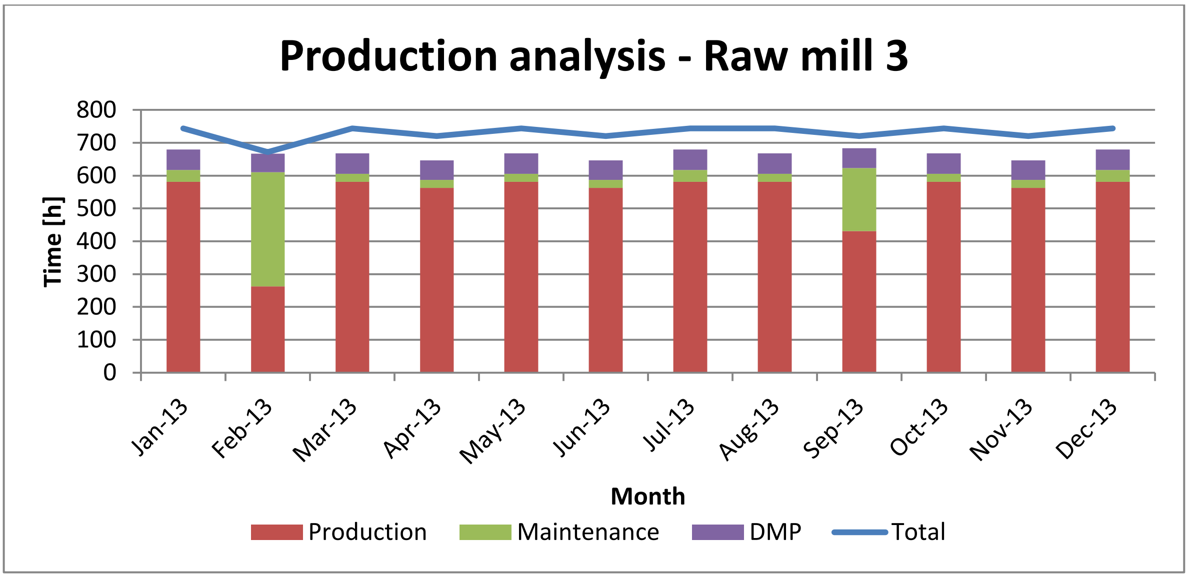

Figure 34: Production analysis – Raw milling process line 3

The production, maintenance, DMP and total time for raw milling process line 4 are plotted in Figure 35. The sum of the production, maintenance and DMP time are more or equal to the total time. The average off time available per day is one hour and there is thus not enough time to stop the mill every day for the full load reduction duration. However, although the off time available is limited, it will still be investigated for DMP participation. In April, March, November and December, there are scheduled kiln shutdowns and the potential for load reductions will be limited.

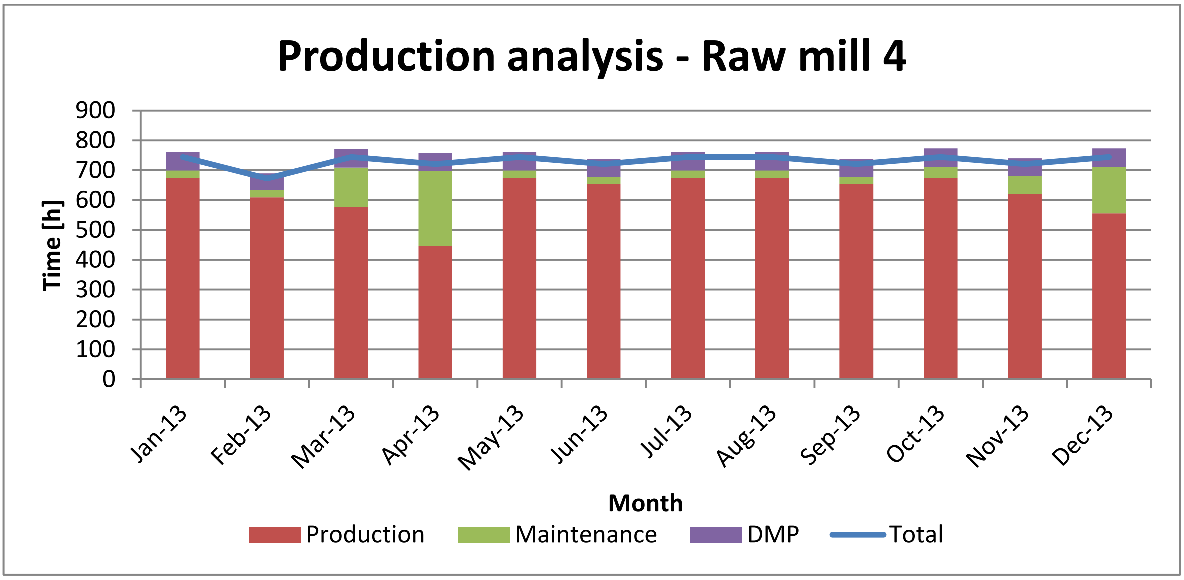

Figure 35: Production analysis – Raw milling process line 4

Cement milling process line

Each cement product has a unique production rate. The two cement mills are identical and have the same production rate for each product (Table 22). Cement mill 1 is usually used to manufacture products B and C, whilst cement mill 2 usually manufactures products A and D. Product D cannot be manufactured by cement mill 1.

Table 22: Production rates – Cement milling process lines

Component	**Cement milling process line 1**	**Cement milling process line 2**	**Unit**
Product A	170	170	[tonne/h]
Product B	130	130	[tonne/h]
Product C	90	90	[tonne/h]
Product D	-	150	[tonne/h]

The cement mills are serviced on a two weekly cycle. The maintenance procedure starts at 05:00 and has a total duration of 12 hours. The target reliability of the cement mills is 98%. The production targets for each cement product are plotted in Figure 36. The cement production targets for January to March are relatively low compared to April; from April to November the cement production targets are high.

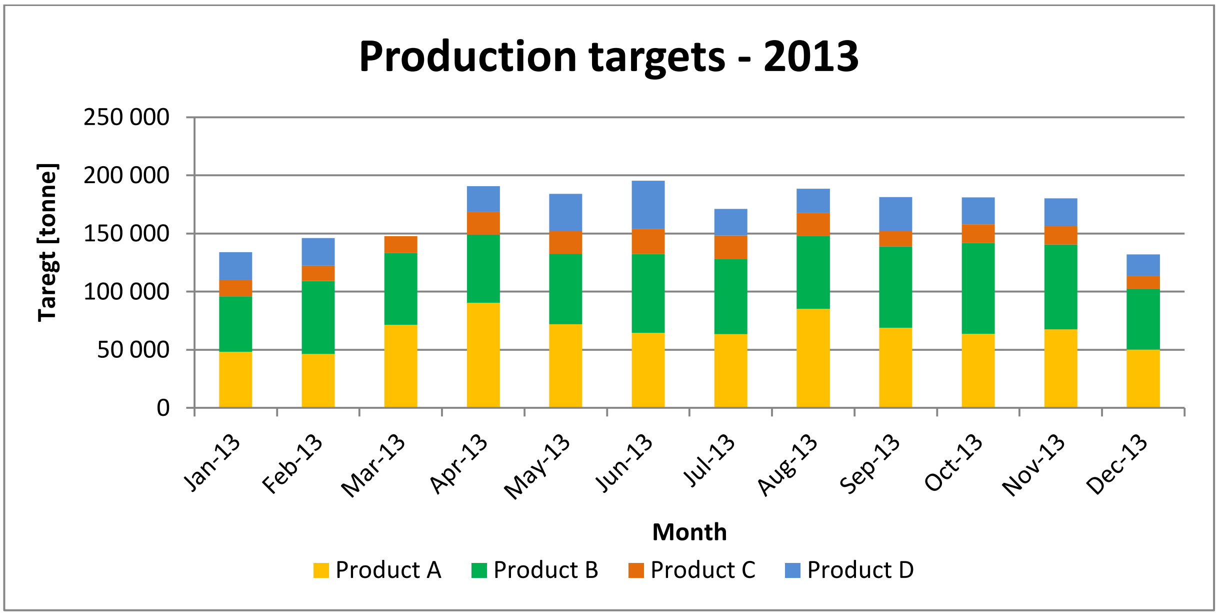

Figure 36: Production targets for 2013

The total, production, maintenance and DMP time for the cement milling line are plotted in Figure 37. From January to March there is enough time for DMP load reductions. In April and June, the potential for DMP load reductions is limited due to the high cement demand and scheduled maintenance in June. For the other months, there is the potential to stop both of the mills on a daily basis for DMP load reductions.

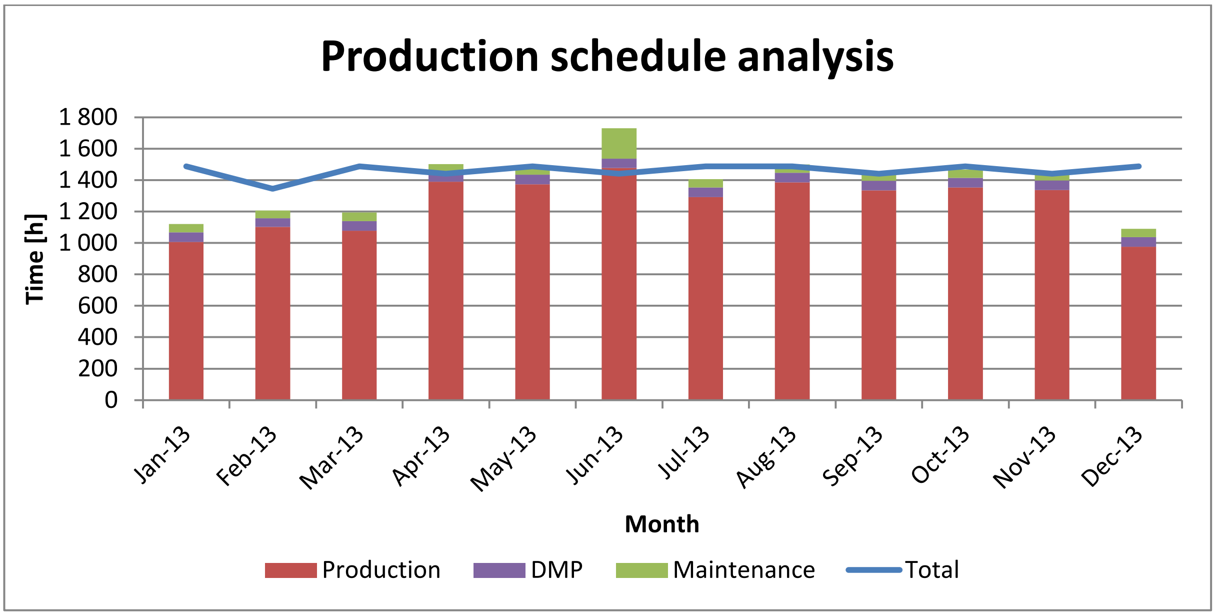

Figure 37: Production analysis – Cement milling process line

4.3 Mathematical models

The storage capacity, minimum and maximum levels for each raw meal silo are specified in Table 23. The minimum and maximum levels of the silos are 70% and 90% of the storage capacity respectively.

Table 23: Raw meal silo characteristics

Characteristic	**Raw meal silo 3**	**Raw meal silo 4**
Storage capacity	East silo: 8,000 tonne West silo: 8,000 tonne	2,400 tonne
Minimum level Maximum level	70% 95%	70% 95%

Table 24 gives the storage capacity and constraints for the different cement silos. Cement products A and B are stored in silos with a capacity of 12,000 tonne, with minimum and maximum levels of 16.7% and 86.6% respectively. Two 6,000 tonne silos are used to store products C and D. The minimum and maximum levels of these silos are 16.7% and 87.5% respectively.

Table 24: Cement silo characteristics

Cement Silo	**Silo A**	**Silo B**	**Silo C**	**Silo D**
Storage capacity	12,000 tonne	12,000 tonne	6,000 tonne	6,000 tonne
Minimum level Maximum level	16.7% 86.6%	16.7% 86.6%	16.7% 87.5%	16.7% 87.5%

The cement milling process line has a product switch procedure. To complete a product switch on a cement mill, the mill has to be stopped. The feeding line of the product that was manufactured is blocked, and the new product’s feeding line is opened. A flange is bolted into the feeding line to block the cement from entering the silo. A product change takes about 1 to 2 hours to complete.

Cement products A and D are mainly sold in bags. The packing plant extracts cement from Silo A and D and packs it into bags. The packing plant has a fixed production rate and extracts cement at a rate of 200 tonne/h. A schematic diagram of each of the plant's process lines is given in Figure 38 to Figure 40, in which the storage capacity and production rates are specified.

Figure 38: Raw milling process line 3

Figure 39: Raw milling process line 4

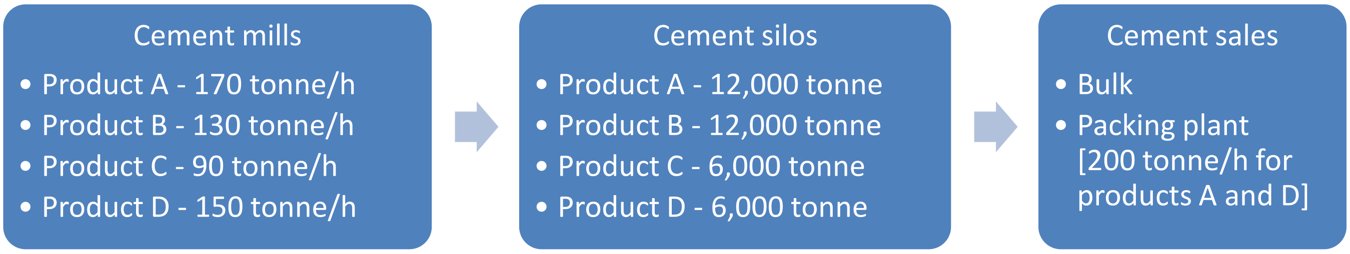

Figure 40: Cement milling process line

4.4 Simulation

Mill stoppages are simulated on the mathematical model of each process line. The milling schedule for a week with maintenance and a week with no maintenance is compiled whereafter the average number of mill stoppages is determined.

For model inputs, the average operating silo level is used as the start silo level. For the raw mill process lines, the average silo level is calculated from logged data. Unfortunately the cement silos do not have silo level measurement devices and log sheets with measured silo levels (measured manually each morning with a measuring line) are used to calculate the average silo levels for the cement milling process line.

Raw milling process line 3

RM3's milling schedules for a maintenance (blue) and no-maintenance (green) week are given in Figure 41. The maintenance procedure for RM3 is scheduled for Tuesdays from 05:00 to 17:00. Note that the simulation indicates to start the mill after the evening peak period and not at 17:00 for the maintenance day. The schedule indicates three evening and three morning stoppages for a maintenance week.

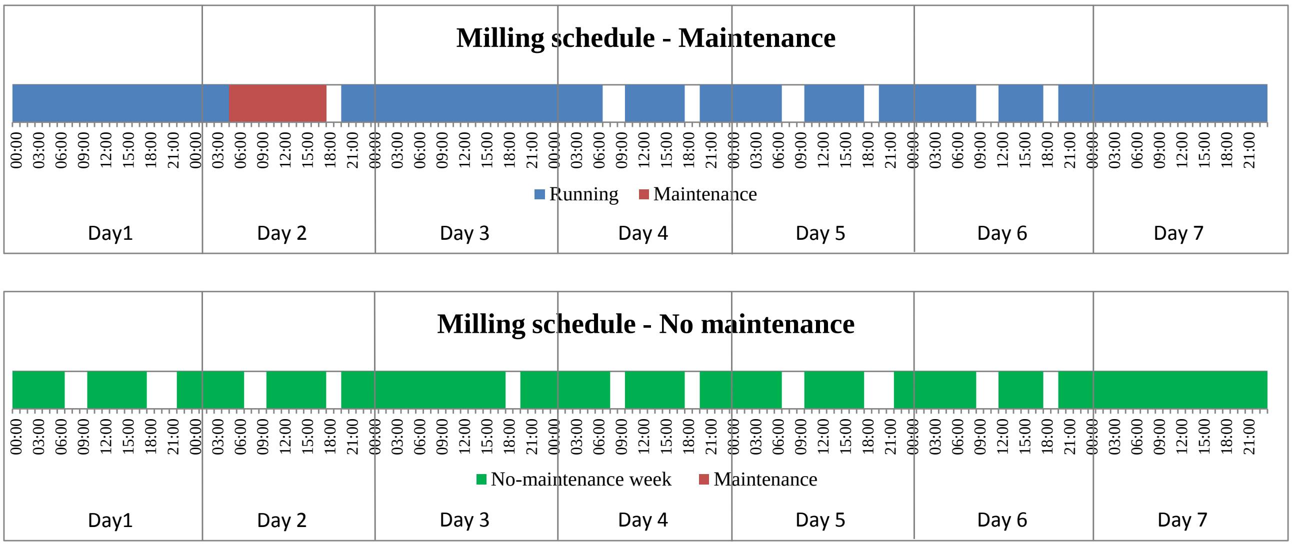

Figure 41: Milling schedules – Raw mill 3

For a week with no maintenance, there is a greater number of mill stoppages. The schedule indicates that the mill can stop for six evening and five morning peak periods. The predicted silo levels for a maintenance (blue) and no maintenance (green) week are given in Figure 42.

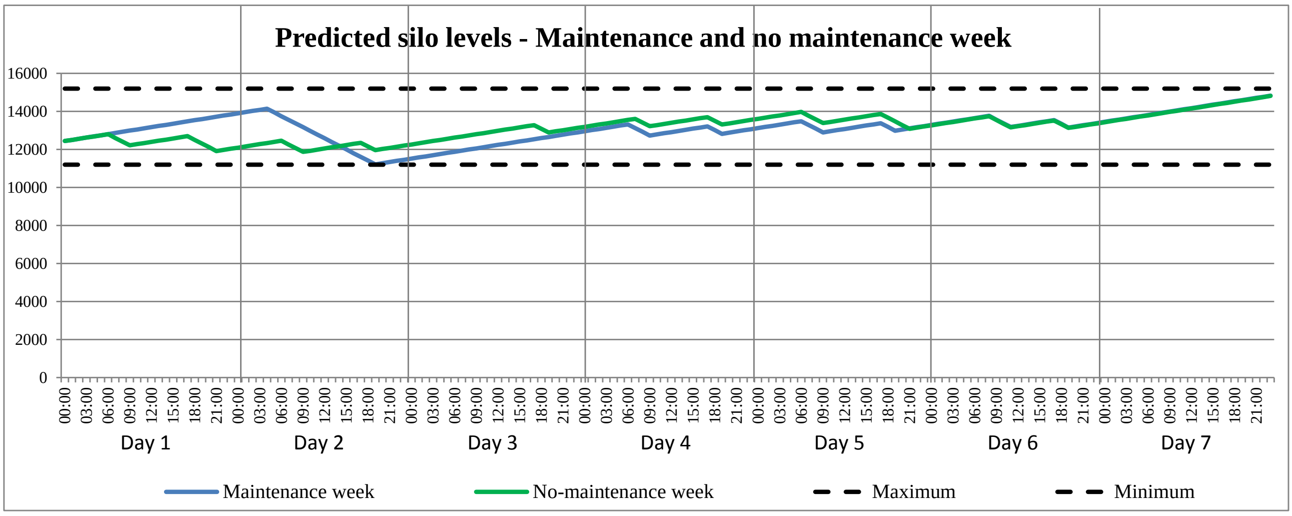

Figure 42: Predicted silo levels – Raw mill 3

A summary of the mill stoppages for both a maintenance and no maintenance week is given in Table 25. Note that only one DMP event can occur per day and that the maximum mill stoppages per day is therefore tabulated as one.

Table 25: Summary of mill stoppages

Day type	**Weekday**	**Saturday**
Maintenance	2	1
No maintenance	5	1
Average stoppages per week	**3.5**	**1**

For Weekdays, the mill can stop an average of 3.5 times (average calculated over the two week period). For Saturdays, the schedules indicate one mill stoppage and none for Sundays.

Raw milling process line 4

RM4’s milling schedules and predicted silo levels for a maintenance (blue) and no maintenance (green) week are given in Figure 43 and Figure 44. The schedule indicates that the mill can stop twice during a maintenance week. This is as the silo level drops far below the minimum level when the mill is off for maintenance. After the maintenance procedure, the silo level is very low and it is required to start the mill at 17:00. Such a start is tabulated as a -1 stoppage (see effect of mill start). For a week with no maintenance, the schedule indicates six evening and two morning stoppages.

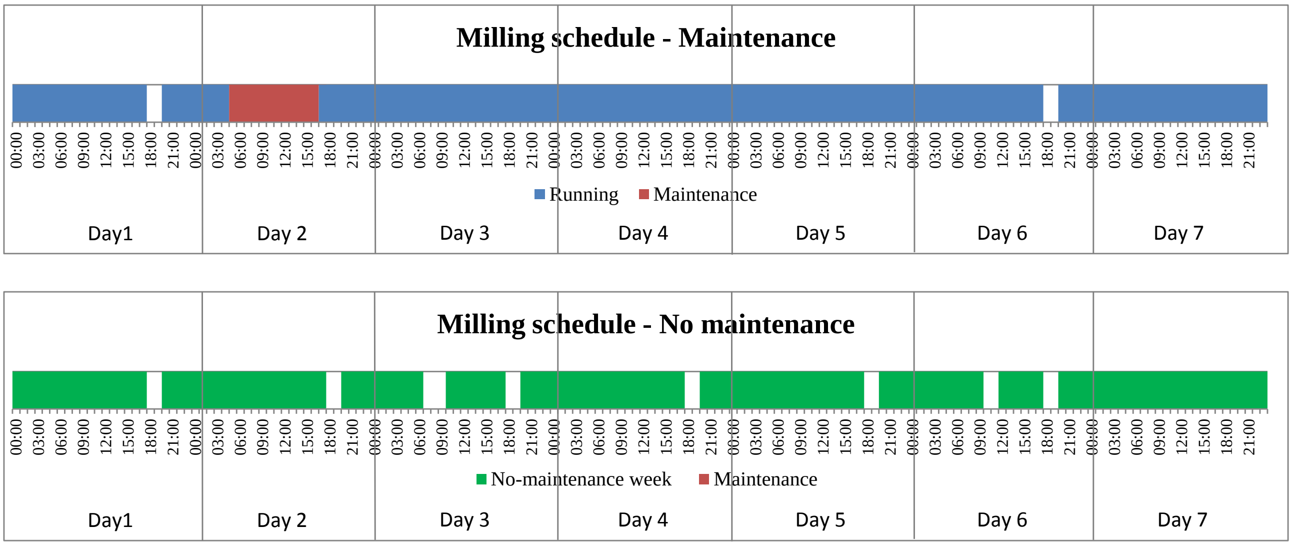

Figure 43: Milling schedules – Raw mill 4

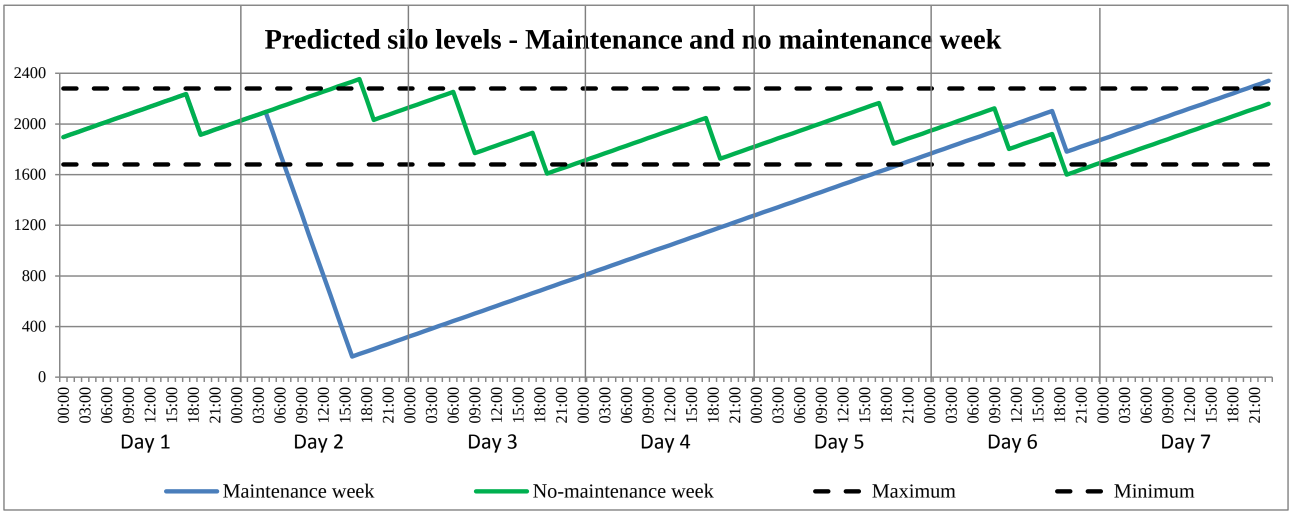

Figure 44: Predicted silo levels – Raw mill 4

A summary of the mill stoppages for a maintenance and no maintenance week is given in Table 26. Raw mill 4 can stop an average of three times for Weekdays and once for Saturdays. No stoppages are scheduled for Sundays.

Table 26: Summary of mill stoppages – Raw mill 4

Day type	Weekday	Saturday
Maintenance	0	1
No maintenance	5	1
Average stoppages per week	**2.5**	**1**

Cement milling process line

The production targets for the cement milling process line fluctuate from day to day and are not constant as with the raw milling process lines. It is therefore necessary to calculate the average cement production target for each day (day 1 to day 7) to compile the average milling schedule from which the average number of mill stoppages is determined.

Table 32 gives each product’s average production targets for each day of the week for the year 2013. Day 1 refers to Mondays and day 7 to Sundays.

Table 27: Average cement sales for each day of a week, in tonne

Day type	Product A	Product B	Product C	Product D
1	2,505	2,225	734	983
2	2,318	2,949	828	1,077
3	2,262	2,291	757	981
4	2,234	3,241	843	1,085
5	1,886	439	91	194
6	1,244	1,205	40	173
7	2,312	2,887	848	1,060

The average operational silo level of the cement silos is given in Table 28.

Table 28: Average cement silo levels, in tonne

Product A	Product B	Product C	Product D
2,803	2,856	3,441	2,952

The average cement sales per day and average cement silo level are used to simulate the average milling schedule. Note that the normal operating procedure for the cement mills requires that one cement mill is serviced per week. The average milling schedule and predicted silo levels for the two weeks are given in Figure 45 to Figure 49.

For the first week, maintenance is scheduled on cement mill 1. According to the plant’s routine, the maintenance is scheduled on the third day of the week. The milling schedules for the first week are given in Figure 45.

According to the schedule, cement mill 1 can stop twice in the evening. Cement mill 2 can stop five times in the evening and twice in the morning. Cement mill 1 is scheduled to start directly after the maintenance procedure, otherwise the silo level of product C drops below the required minimum level (see Figure 47). Note that such a start is tabulated as a -1 stoppage (see effect of mill start).

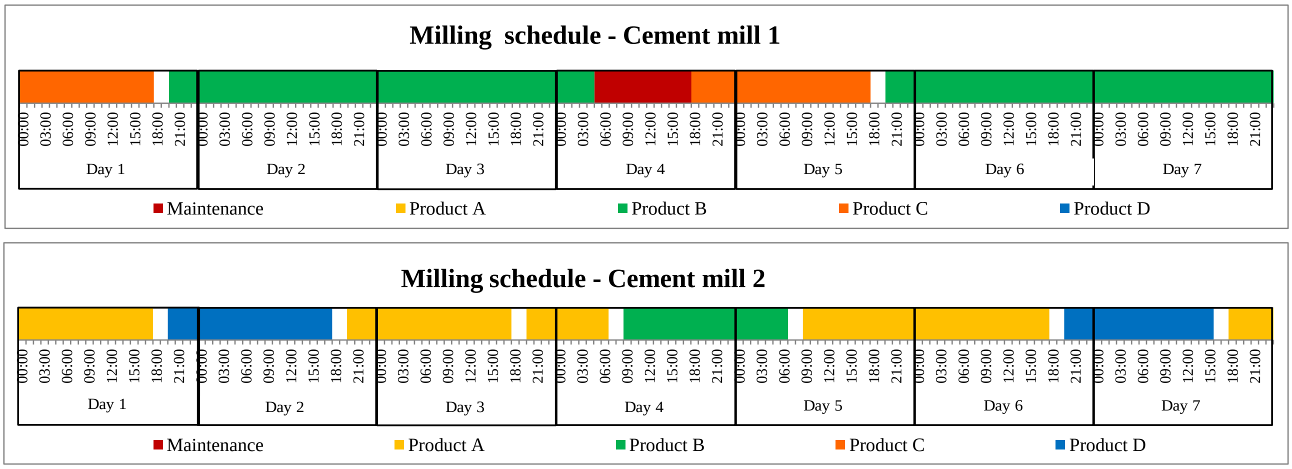

Figure 45: Cement milling schedules – Week 1

The predicted silo levels for products A and B are given in Figure 46 and products C and D in Figure 47. Note that the silo level for products A and B is low but still above the minimum level. This indicates that the average cement sales for these two products are high.

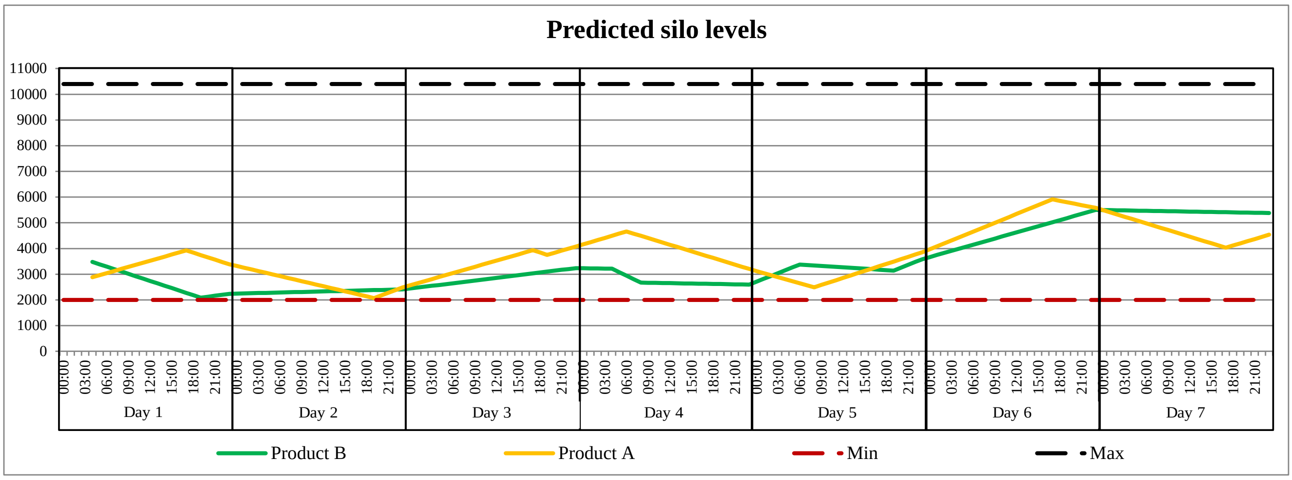

Figure 46: Predicted silo levels for week 1 – Cement products A and B

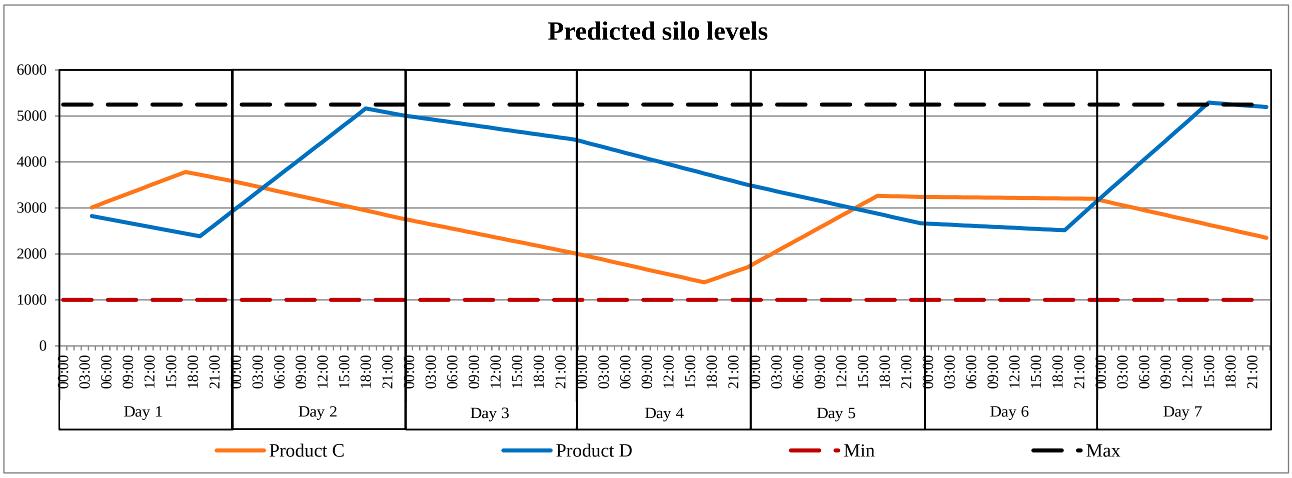

Figure 47: Predicted silo levels for week 1 – Cement products C and D

In the second week, cement mill 2 is scheduled for maintenance on the third day of the week. The milling schedules and the predicted silo levels are given in Figure 48 and Figure 49. The predicted silo levels for products C and D are given in the appendix (A.2).

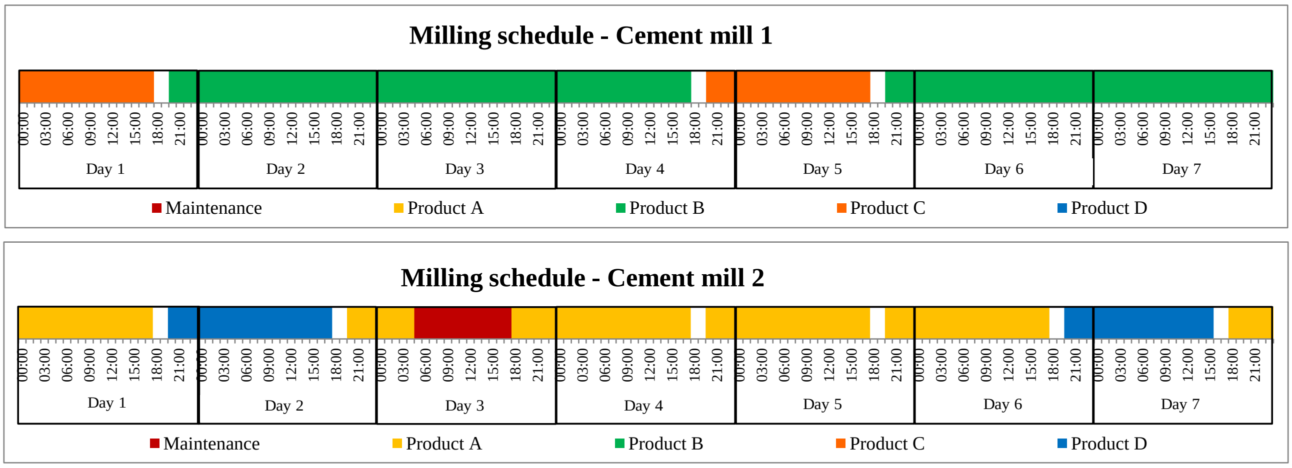

Figure 48: Cement milling schedules – Week 2

The milling schedules indicate that cement mill 1 can stop three times in the evening and cement mill 2 six times in the evening. Product A’s silo level drops just below the minimum level after the maintenance procedure on Day 3 and must therefore be started at 17:00. Note that such a start is tabulated as a -1 stoppage (see effect of mill start).

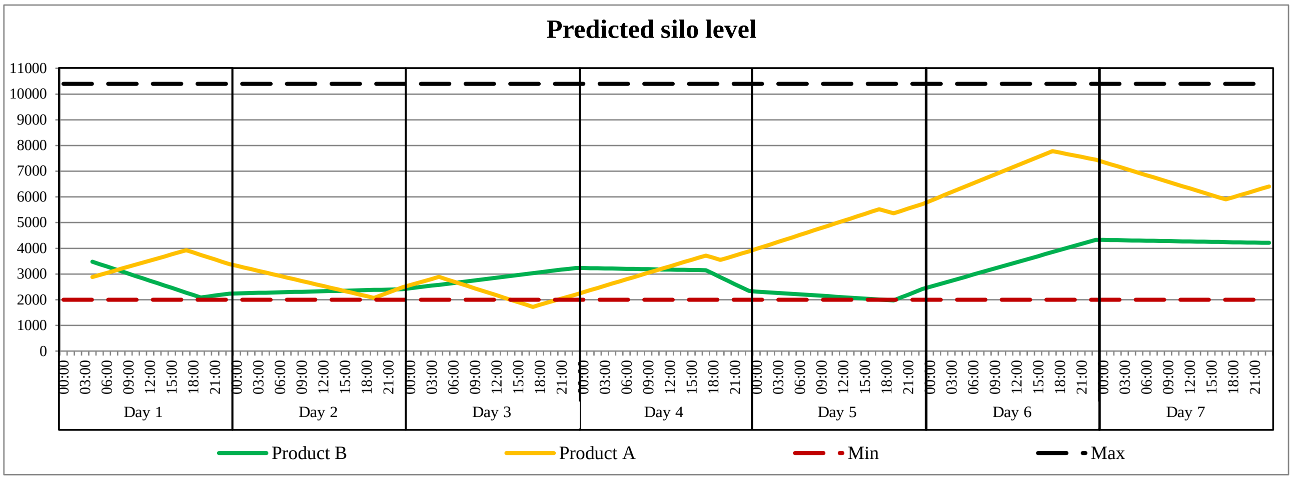

Figure 49: Predicted silo levels for week 2 – Cement products A and B

A summary of the stoppages for cement mills 1 and 2 is given in Table 29 and Table 30. Cement mill 1 can stop twice on Weekdays and never on Saturday and Sundays.

Table 29: Summary of mill stoppages – Cement mill 1

Day type	Weekday	Saturday	Sunday
Maintenance	1	0	0
No maintenance	3	0	0
Average stoppages per week	**2**	**0**	**0**

Cement mill 2 can stop three times on Weekdays and once on Saturdays and Sundays.

Table 30: Summary of mill stoppages – Cement mill 2

Day type	Weekday	Saturday	Sunday
No maintenance	3	1	1
Maintenance	3	1	1
Average stoppages per week	**3**	**1**	**1**

4.5 Implementation

The milling schedules were implemented on the cement plant over a period of two weeks of the 20th May 2013 to the 2nd of June 2013 and the number of scheduled and implemented mill stoppages was determined.

Raw milling process line 3

The milling schedule and actual operation with the predicted and actual silo levels for a maintenance week (week 1) are summarised in the Appendix (see A.3). The milling schedule (blue) and actual operation (green) for a no maintenance week (week 2) are given in Figure 50.

In the no maintenance week, the plant did not implement the morning stoppages but stopped the mill for longer durations in the evening. A breakdown on the fourth day caused a stoppage of eight hours (from 05:00 to 13:00) but as the silo level was above the required minimum level, the evening stoppage could still be implemented.

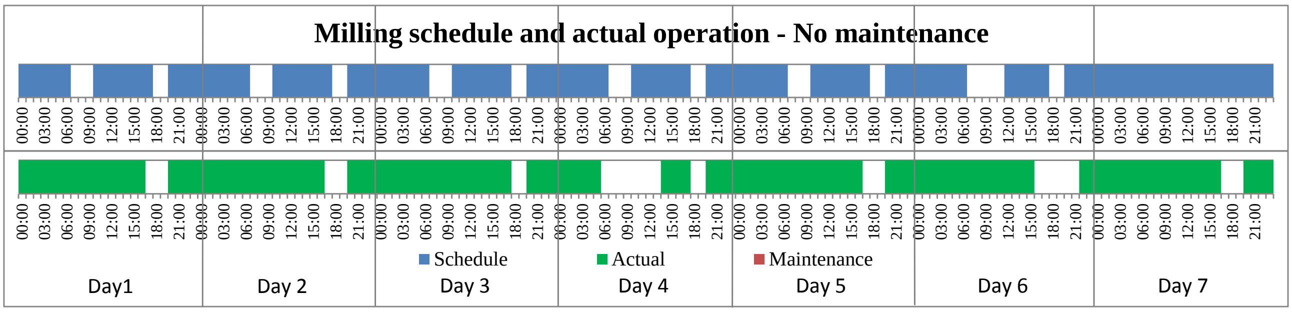

Figure 50: Milling schedule and actual operation for raw mill 3 – No maintenance

The predicted (blue) and actual (green) silo levels are given in Figure 51. For day 1 to 3 when the mill was not stopped in the morning, the end silo level was higher than predicted. On day 6, the mill had to stop much longer than predicted, as the morning stoppages of day 5 and 6 were not implemented. Note that the predicted and actual silo levels in Figure 51 compare which proves that the mathematical model simulates the actual process line accurately.

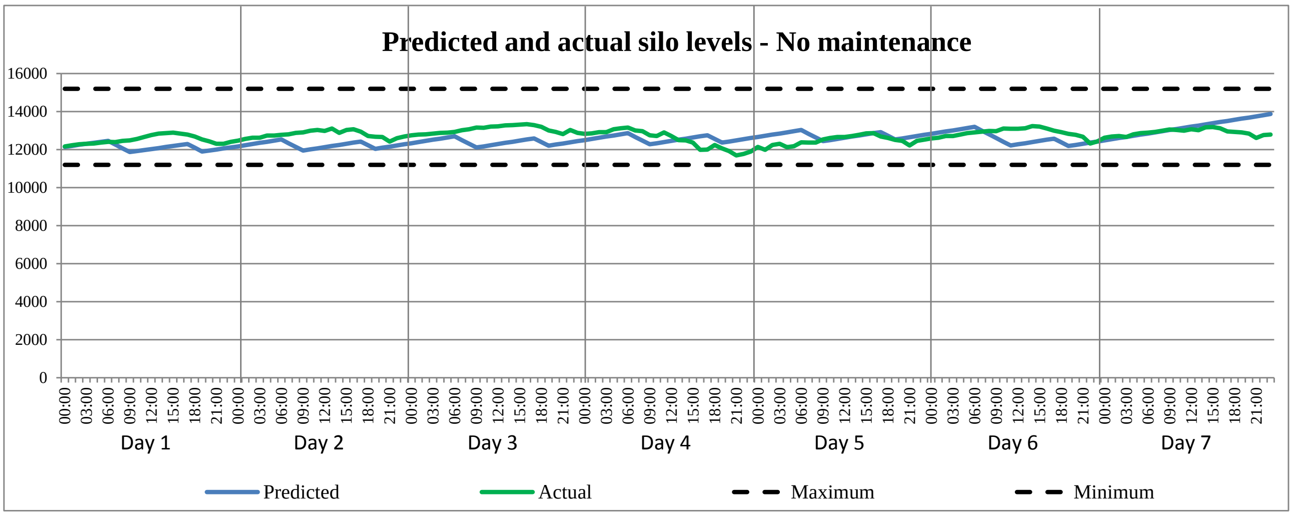

Figure 51: Predicted and actual silo levels for raw mill 3 – No maintenance

Table 31 gives the number of mill stoppages for the two week period for Weekdays, Saturdays and Sundays. The average scheduled and actual Weekday stoppages are 4.5 and 3.5 respectively. For Saturdays, it is 1 and 0.75 respectively, and for Sundays, it is 0 and 0.5 respectively.

Table 31: Summary of mill stoppages – Raw mill 3

	Weekday		Saturday		Sunday	
	Scheduled	Actual	Scheduled	Actual	Scheduled	Actual
Maintenance week	4	2	1	0.5	0	0
No maintenance week	5	5	1	1	0	1
Average week	**4.5**	**3.5**	**1**	**0.75**	**0**	**0.5**

The scheduled and actual mill stoppages differ due to breakdowns on the milling process, and the plant which did not follow the schedule accurately. The breakdowns caused unplanned downtime and limited the number of implemented stoppages (A.3). It was found that the plant did not stop the mill in the morning and evening as scheduled, but rather implemented a longer stoppage in the evening (no maintenance week). The mill was stopped on a Sunday as well, which differs from the schedule.

Raw milling process line 4

The milling schedule (blue) and actual operation (green) with the predicted and actual silo levels for a maintenance week are given in the Appendix (A.3). The milling schedule and actual operation for a no maintenance week are given in Figure 52. Note that there were short breakdowns of about an hour on the third, fourth and fifth day. The scheduled morning stoppages were not implemented but all the mill stoppages for the evening were implemented.

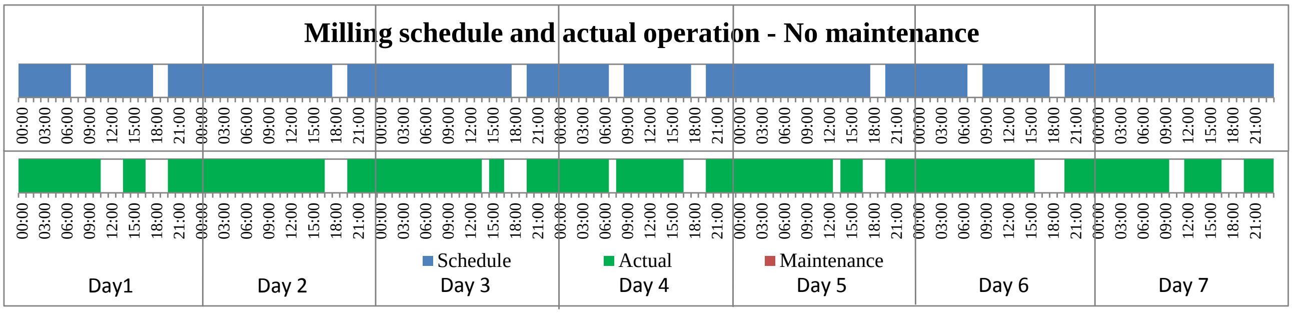

Figure 52: Milling schedule and actual operation for raw mill 4 – No maintenance

The predicted and actual silo levels are given in Figure 53. Note that the predicted and actual silo level at 20:00 of day 4 is the same. The predicted and actual silo level of day 2 is also comparable, although the mill was stopped for an extra hour. These days illustrate that the mathematical model simulates the actual process accurately.

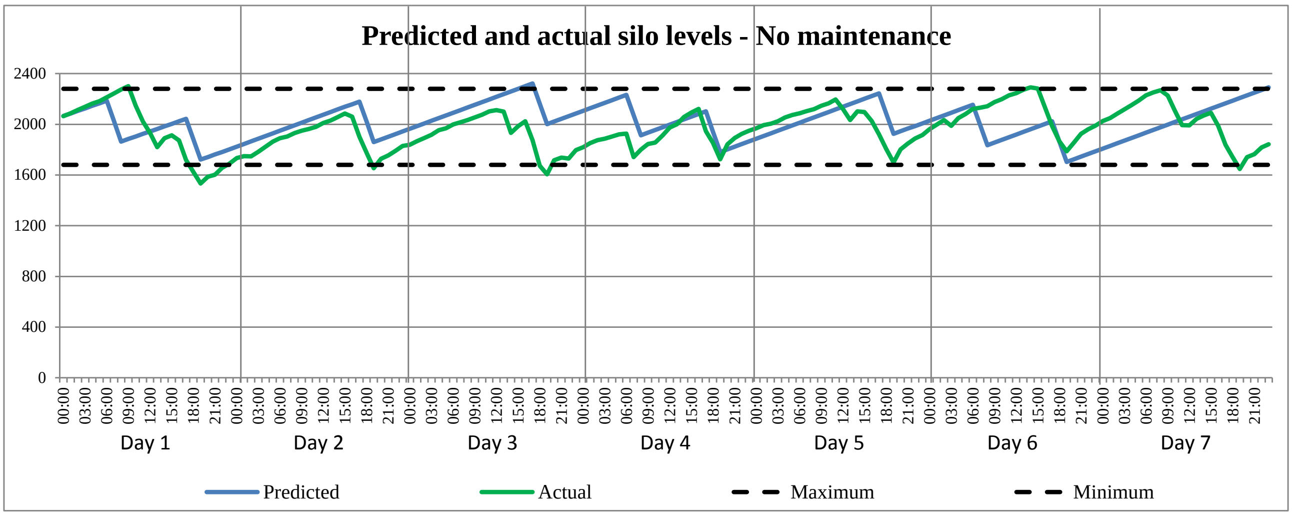

Figure 53: Predicted and actual silo levels for raw mill 4 – No maintenance

Table 32 gives the number of mill stoppages for the two week period for each day type. The milling schedule predicted 2.5 stoppages for Weekdays, one for a Saturday and one for a Sunday. The mill was stopped on average 4.5 times for Weekdays, once on a Saturday and once on a Sunday.

Table 32: Summary of mill stoppages – Raw mill 4

	Weekday		Saturday		Sunday	
	Scheduled	Actual	Scheduled	Actual	Scheduled	Actual
Maintenance week	0	4	1	1	1	1
No maintenance week	5	5	1	1	1	1
Average week	**2.5**	**4.5**	**1**	**1**	**1**	**1**

The scheduled and actual mill stoppages differ, due to the intended maintenance procedure which was not implemented (see A.3 for full details). As a result, more mill stoppages were implemented than planned in this week.

Cement milling process line

For the first week, cement mill 2 had scheduled maintenance and in the second week, both cement mills had scheduled maintenance procedures. This deviates from normal operation but the maintenance procedure of the second week required that both mills be stopped. The milling schedules and actual operation with the predicted and actual silo levels for the first week are given in the Appendix (A.3).

The milling schedules and predicted silo levels for the second week are given in Figure 54 to Figure 56. The schedules indicate two evening stoppages for cement mill 1, and five evening and two morning stoppages for cement mill 2.

The maintenance procedures are scheduled for the third day of the week. Cement mill 1 is scheduled to start directly after the maintenance procedure as the silo level is dropping, almost below the minimum level (Figure 55). Cement mill 2 is scheduled to start at 20:00 as the silo level for that specific product is still above the required minimum level (Figure 55).

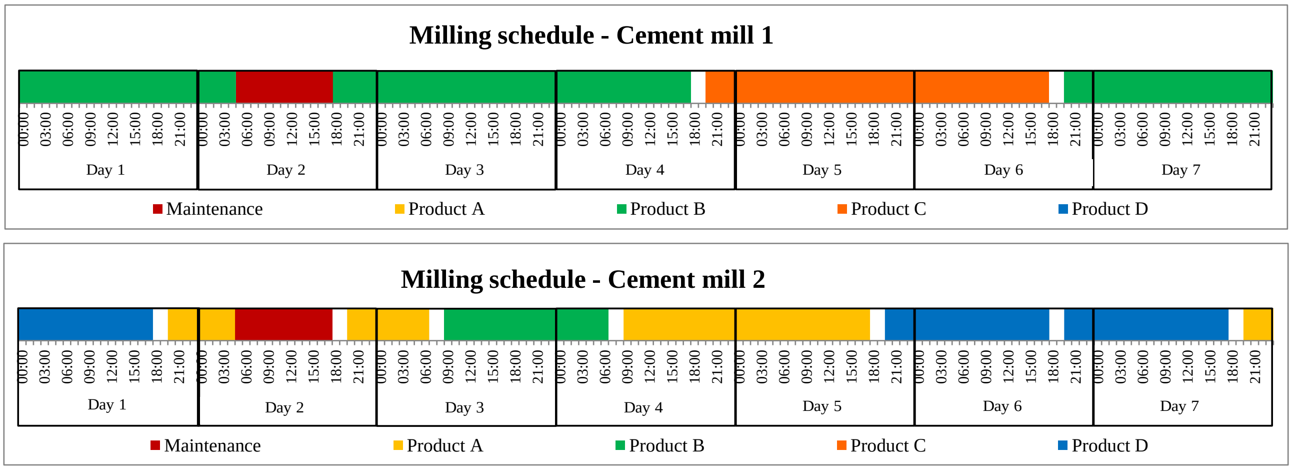

Figure 54: Cement milling schedule – Week 2

Figure 55 gives the predicted silo levels of products A and B and Figure 56 gives the predicted silo levels of products C and D.

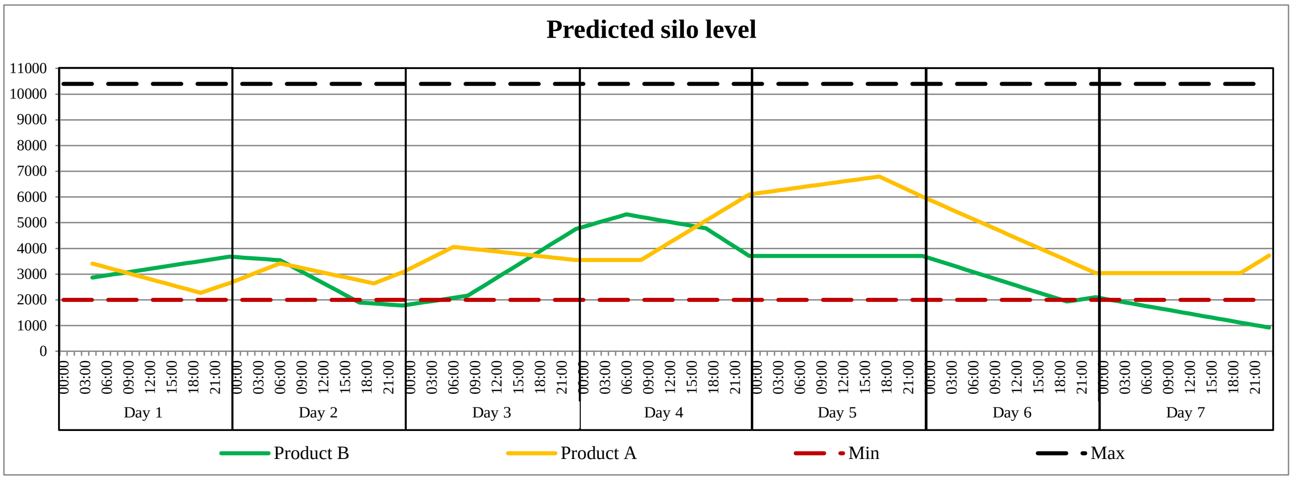

Figure 55: Predicted silo levels – Cement products A and B

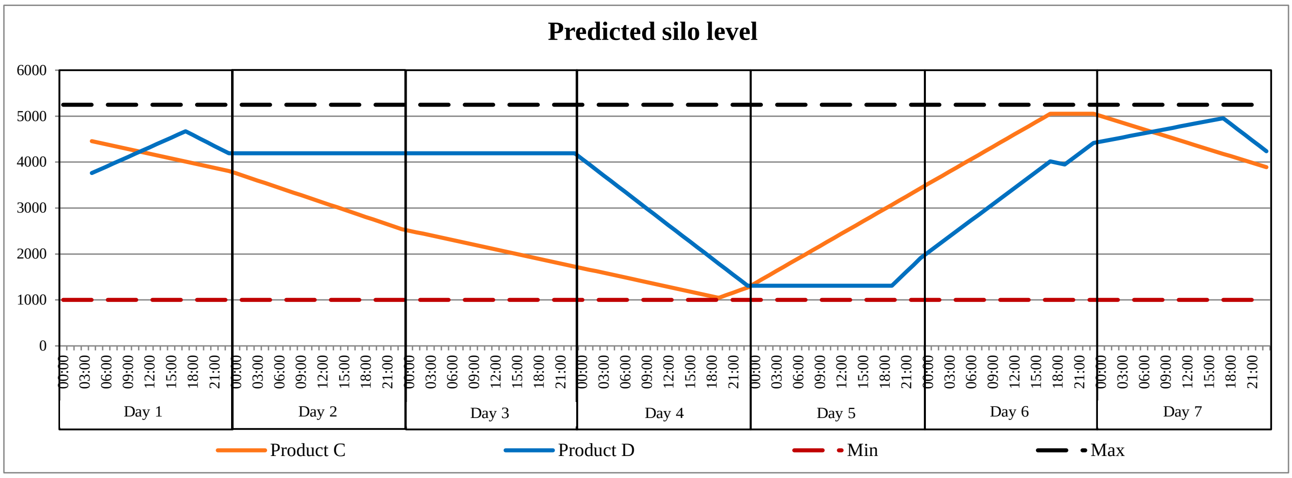

Figure 56: Predicted silo levels – Cement products C and D

The actual operation for cement mill 1 and 2 is given in Figure 57. Cement mill 1 was stopped twice in the evening peak, and on day 3, the mill was restarted at 20:00 and not at 17:00 as scheduled.

Cement mill 2 was stopped in the evening on day 1. The mill was started at approximately 19:00 after the maintenance procedure. This mill start affects the load reduction negatively (see effect of mill start p. 55) and is therefore tabulated as -0.5 for the number of mill stoppages for Weekdays. From day 4, the mill was not operated according to the schedule and the mill was not stopped in the evening peak for days 4, 5 and 7.

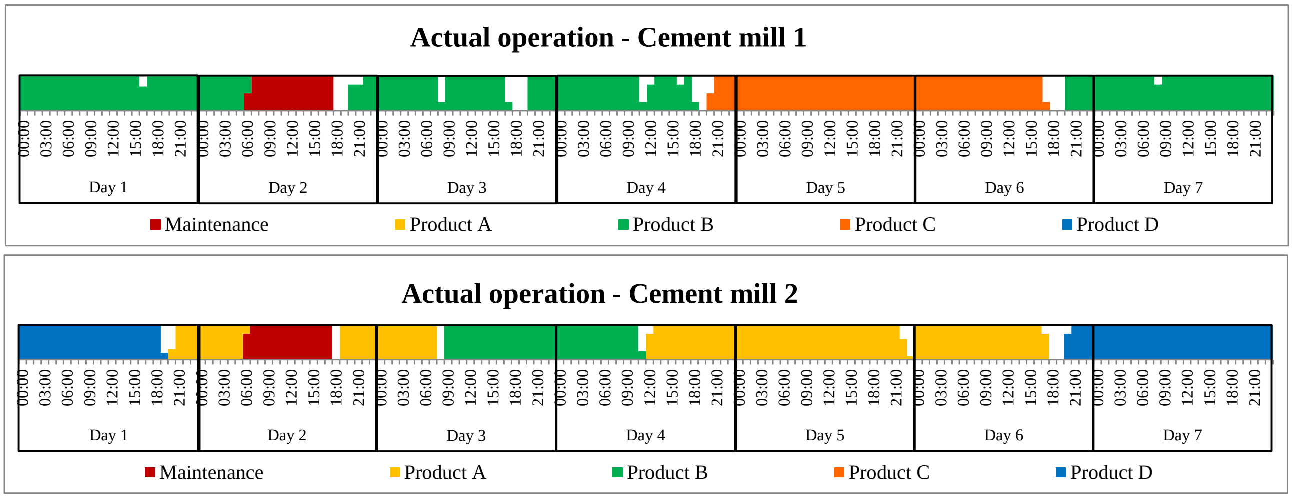

Figure 57: Actual cement mill operation – Week 2

Table 33 gives a summary for the number of mill stoppages for cement mill 1. The average scheduled and actual Weekday stoppages are 2 and 2.5 respectively. For Saturdays, the scheduled and actual stoppages are 0.5 and for Sundays, there were no stoppages scheduled or implemented.

Table 33: Summary of mill stoppages – Cement mill 1

	Weekday		**Saturday**	
	Scheduled	**Actual**	**Scheduled**	**Actual**
Week 1	4	3	0	0
Week 2	0	2	1	1
Average week	**2**	**2.5**	**0.5**	**0.5**

The difference in the Weekday mill stoppages is due to one scheduled mill stoppage that was not implemented in week 1 and two non-scheduled mill stoppages that were implemented in week 2. For Saturdays and Sundays, the mill stoppages implemented were as scheduled.

Table 34 summarises the number of scheduled and actual mill stoppages for cement mill 2. For Weekdays, the average scheduled and actual mill stoppages are 2.5 and 1 respectively. For Saturdays, both are 1 and for Sundays both are 0.5.

Table 34: Summary of mill stoppages – Cement mill 2

	Weekday		Saturday		Sunday	
	Scheduled	**Actual**	**Scheduled**	**Actual**	**Scheduled**	**Actual**
Week 1	3	1.5	1	1	0	1
Week 2	2	0.5	1	1	1	0
Average week	**2.5**	**1**	**1**	**1**	**0.5**	**0.5**

The scheduled and actual mill stoppages for Weekdays differs as the product changes were implemented on different times and the schedules were not followed accurately. The mill stoppages for the other Weekdays were the same for both of the cement mills. This proves that the schedules compiled by the mathematical model are predicting the cement mill stoppages accurately.

4.6 Load reduction

The load reductions for each day type are calculated in the Appendix (see A.4) for the mill schedules and actual operations. Table 35 gives the average load reductions for the different day types. The average scheduled and actual load reductions for the cement plant are 3.26MW and 2.97MW for Weekdays; 7.21MW and 6.41MW for Saturdays, and for Sundays: 2.08MW and 3.65MW, respectively.

Table 35: Summary of load reduction

	Weekday	Saturday	Sunday	Unit
Scheduled	3.26	7.21	2.08	[MW]
Actual	2.97	6.41	3.65	[MW]

The scheduled and actual load reductions differed by 8.9% for Weekdays, 11.1% for Saturdays and 75.4% for Sundays. The difference between the load reductions for Weekdays and Saturdays is due to breakdowns and the cement plant which did not always follow the schedules accurately. The large difference in the load reduction for Sundays is due to an unscheduled mill stoppage that was implemented by the plant. Note that the model only schedules mill stoppages on Sundays if the silo level will overflow without a mill stoppage, or if a product change must be implemented.

Lastly, the average of the implemented load reductions is calculated from the logged data according to the DMP load reduction theory. These load reductions are referred to as the measured load reductions and are compared with the actual load reductions. The actual and measured load reductions are given in Table 36.

Table 36: Load reductions – Actual and Measured

	Weekday	**Saturday**	**Sunday**	**Unit**
Actual	2.97	6.41	3.65	[MW]
Measured	3.26	6.45	3.82	[MW]

Note that with the operational load reductions, the assumption is made that the mill operates at a fixed capacity. In practice, the mill load may vary and therefore the actual and measured load reductions differ. For Weekdays, the average difference is 8.8%, 0.6% for Saturdays and 4.4% for Sundays. The load reduction methodology thus has an average accuracy of 95%.

4.7 DMP participation

The results for two months in which the cement plant participated in the DMP programme are given in Table 37. During the first month, the cement plant was trained to use the PTB energy management system and assisted to participate in the DMP programme. In the second month, the cement plant participated without assistance and used the EnMS and DMP strategy to manage DMP on a daily basis.

Table 37: DMP participation – Events for which the plant could not reduce load are omitted.

Date	Day type	Event time	Load reduction [MW]	Energy payment [R]	Electricity cost saving [R]
03-Jun-13	1	17:30	3.49	8,382	9,382
04-Jun-13	1	17:30	4.64	11,132	12,461
06-Jun-13	1	18:00	0.10	232	328
12-Jun-13	1	17:30	10.36	24,854	27,820
17-Jun-13	1	18:00	7.66	18,372	26,010
18-Jun-13	1	17:30	9.95	23,876	26,726
19-Jun-13	1	17:30	3.51	8,418	9,423
28-Jun-13	1	17:30	6.79	16,304	18,250
01-Jul-13	1	17:00	4.42	10,596	8,720
02-Jul-13	1	17:00	7.22	17,339	14,268
03-Jul-13	1	17:00	1.52	3,644	2,999
04-Jul-13	1	17:00	0.11	260	214
05-Jul-13	1	17:00	3.70	8,881	7,308
06-Jul-13	6	17:00	7.43	17,826	2,051
07-Jul-13	7	17:00	8.51	20,419	0
08-Jul-13	1	17:00	5.34	12,814	10,545
15-Jul-13	1	17:30	1.64	3,928	4,396
16-Jul-13	1	17:30	3.77	9,046	10,125
17-Jul-13	1	17:30	6.95	16,678	18,668
24-Jul-13	1	17:00	0.61	1,463	1,204
Total			**97.69**	**234,464**	**210,898**
Grand total					**445,362**

The total milling electricity cost for the two months was R7.91million. Over the two months, the cement plant reduced a total load of 97.69MW and achieved a total cost saving of R445,000. An average monthly saving of R223,000 was achieved and the demand was reduced with an average load reduction of 4.88 MW per DMP event. Over the two month period, the cement plant had reduced their electricity cost by 5.6%.

4.8 *Conclusion*

A DMP strategy was implemented on the raw and cement mills of the cement plant. According to the results achieved during implementation, the average load reduction for the cement plant was 3.26MW for Weekdays, 6.45MW for Saturdays and 3.82MW for Sundays. During DMP participation, the plant reduced electricity demand with an average of 4.8MW per DMP event. The study realised a total cost saving of R445,000 over 2 months and the plant's total milling electricity cost was reduced by 5.6%.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Electricity consumption can be reduced by installing high-efficiency equipment, implementing control and process management systems, or observation and maintenance. Installing VSDs and high-efficiency fans and implementing energy management systems and process control are all feasible saving measures for the South African cement industry. As the installation of this energy-efficient equipment requires large capital expenditure, South African cement plants are seeking alternative cost-saving measures. One such alternative is Eskom’s DMP programme.

A strategy to identify the potential load that a cement plant can use for the DMP programme is formalised in this study. The method to determine the average effective load reduction of a cement plant is described and a participation strategy is formulated according to the operation and management structure of South African cement plants.

Production targets, scheduled maintenance, mill reliability, mill utilisation and the cement plant’s baseline are the main factors that influence the effective load reduction for a DMP event. An energy management system such as PTB is therefore required to assist cement plant personnel to implement DMP load reductions effectively and meet their production targets successfully.

A South African cement plant was analysed in this study. The study found that the plant can reduce load by 3.26MW for Weekdays, 6.45MW for Saturdays and 3.82MW for Sundays. The cement plant participated in the DMP programme and achieved a total cost saving of R445,000 over a two month period, and reduced the mill electricity cost by 5.6%.

The main benefit of this study is that a cement plant’s potential load and load reduction for the DMP programme can now be calculated, as well as the estimated cost savings that can be achieved. Cement plants can effectively participate in the DMP programme by using the formulated DMP participation strategy. The study proved that the PTB system used to schedule and implement DMP load reductions on cement plants is accurate and that the PTB system can successfully be used to manage DMP on a daily basis.

5.2 Recommendations

Based on the achieved results, the analysed cement plant can reduce their mill electricity cost by R1.96-million per annum. This particular cement plant has a production capacity of 2.90Mta. If the saving is extrapolated to the South African cement industry of 19.1Mta, a potential annual cost saving of R12.9-million can be achieved if all South African cement plants participate effectively in the DMP programme.

It is therefore recommended that the different cement plants in South Africa be analysed to determine and identify cement plants with load reduction potential. Thereafter the different cement manufacturing companies can be informed about the estimated cost savings that can be achieved when reducing load for the DMP programme. This will help cement companies reduce their mill electricity cost and will help Eskom to sustain a reliable electricity supply.

To increase reliability and sustainability of DMP participation, the automation of the PTB system is recommended. To ease and simplify the daily management of DMP proceedings, bid placement, receiving and interpreting standby schedules and DMP dispatch notifications can be automated. Missed performances can also be eliminated if the system could be automated to control the plant’s mills according to their planned production schedule and DMP event dispatches.

The DMP participation strategy and methodology can also be adapted for application in gold plants and platinum concentrator plants, as both of these plants also use mills to reduce the ore particle size. The mills are seldom operated at full load and there may exist potential for DMP load reductions. However, as these plants use wet slurry based processes and equipment which are very sensitive to changes in operating parameters, detailed investigations are recommended.

REFERENCES

[1] A. Avami and S. Sattari, "Energy Conversion Opportunities: Cement Industry in Iran," *International Journal of Energy*, vol. 1, no. 3, pp. 65-71, 2007.

[2] D. Gielen and P. Taylor, "Indicators for industrial energy efficiency in India," *Energy*, vol. 34, pp. 962-969, Apr. 2009.

[3] J. Wang, Y. Dai and L. Gao, "Energy analyses and parametric optimizations for different cogeneration power plants in cement industry," *Applied Energy*, vol. 86, pp. 941-948, 2009.

[4] M.K. Singhi and R. Bhargava, "Sustainable Indian cement industry," *Workshop on International Comparison of Industrial Energy efficiency*, 2010.

[5] KEMA, "Industrial Case Study: The Cement Industry," KEMA Inc., Oakland., California, 2005.

[6] G.G Mejeoumov, "Improved cement quality and grinding efficiency by means of closed mill circuit modelling," PhD. Eng Thesis, A&M University, Texas, 2007.

[7] P. Alsop, *Cement plant operations handbook for dry process plants*, Portsmouth, UK: Tradeship Publications Ltd., 2001.

[8] N.A Madlool, R. Saidur, M.S. Hossain and N.A. Rahim, "A critical review on energy use and savings in the cement industries," *Renewable and Sustainable Energy Reviews*, vol. 15, pp. 2042-2060, Jan. 2011.

[9] S. Khurana, R. Banerjee and U. Gaitonde, "Energy balance and cogeneration for a cement plant," *Applied Thermal Engineering*, vol. 22, pp. 485-494, 2002.

[10] M. Schneider, M. Romer, M. Tschudin and H. Bolio, "Sustainable cement production – present and future," *Cement and Concrete Research*, vol 41, pp. 642-650, 2011.

[11] J.A. Swanepoel, R. Pelzer and G. Bolt, "Modelling for integrated energy optimisation in cement production," *Industrial and commercial use of energy*, Cape Town, no. 10, pp. 63-68, Aug. 2013.

[12] M. Bal, P. Bell, S. Fenwick, J. Fernandes, T. Amstrong and D. Hargreaves, *The global cement report*, 9th ed., Surrey, UK: Tradeship Publications Ltd., pp. 323-325, 2011.

[13] Cement and Concrete Institute of South Africa, "Industry Review 2008," CNCI, Lone Creek, Midrand., South Africa, 2008.

[14] Cement and Concrete Institute of South Africa, “Quarterly forecast for cementious sales,” CNCI, Lone Creek, Midrand, Apr. 2013.

[15] H.K. Grover and M.W. Pretorius, “The Technology Assessment of Demand Side Bidding within the South African context,” *South African Journal of Industrial Engineering*, vol.19, no.2, pp. 93-108, 2008.

[16] Eskom, “Capacity expansion,” Internet: www.eskom.co.za, 2013*, [Apr 13, 2013].

[17] R. Surtees and D. Blane, “SA’s Virtual power station 800MW and counting,” 23rd AMEU Technical Convention, 2011.

[18] R. Maneschijn, “The development of a system to optimise production costs around complex electricity tariffs,” M.Eng Dissertation, North-West University, Potchefstroom, 2012.

[19] R.T. Lidbetter, “Demand Side Manangement opportunities on a typical South African cement plant.” M.Eng dissertation, North-West University, Potchefstroom, 2010.

[20] W.T. Choate, “Energy and Emission Reduction Opportunities for the Cement Industry,” BCS Inc., Sterrett Place, Columbia, 2003.

[21] A. Kendall, S.E. Kesler and G.A. Keoleian, “Megaquarry versus decentralised mineral production: network analysis of cement production in the Great Lakes region, USA,” *Journal of Transport Geography*, no. 18, pp. 322-330, 2010.

[22] J. Snyman, J. Vosloo and G. Bolt, “Limestone crushing plant load management,” *Industrial and commercial use of energy*, Stellenbosch, no. 9, pp. 51-54, Aug. 2012.

[23] M.Y. Hassan, “Basalt rock as an alternative raw material in Portland cement manufacture,” *Materials Letters*, vol. 50, pp. 172-178, 2001.

[24] P. Alsop, H. Chen and H. Tseng, *Cement Plant Operations Handbook*, 5th ed., Surrey, UK: Tradeship Publications Ltd., 2007.

[25] A. Hasanbeigi, C. Menke and A. Therdyothin, “The use of conservation supply curves in energy policy and econcomic analysis: The case study of Thai cement industry,” *Energy policy*, vol. 38, pp. 392-405, 2010a.

[26] A. Hasanbeigi, L. Price, H. Lu and W. Lan, “Analysis of energy-efficiency opportunities for the cement industry in Shandong Province, China: A case study of 16 cement plants,” *Energy*, vol. 35, 3461-3473. 2010b.

[27] L. Price, A. Hasanbeigi and H. Lu, “Analysis of Energy-Efficiency Opportuniites for the Cement Industry in Shandong Province, China,” LBNL, Berkeley, California, 2009.

[28] E. Worrell, C. Galitsky and L. Price, “Energy Efficiency Improvements Opportunities for the Cement Industry,” LBNL, Berkeley, California, 2008a.

[29] R. Swanepoel, “Integrated energy optimisation models for the cement industry.” M.Eng Dissertation, North-West University, Potchefstroom, 2012.

[30] Eskom, “Integrated Demand Management,” Internet: www.eskomidm.co.za, 2013*, [Apr. 13, 2013].

[31] T. Matlala, “Industrial Demand Side Management in South Africa,” in *Industrial and Commercial Use of Energy Conference*, Cape Town, 2004.

[32] C.W. Gellings, “The concept of demand-side management for electric utilities,” *Proc. of IEEE*, vol. 73, no. 10 pp. 1468-1470, Oct. 1985.

[33] C.W. Gellings, “Then and now – the perspective of the man who coined the term ‘DSM’,” *Energy Policy Elsevier Science Ltd.*, vol. 24, no. 4, pp. 285-288, Apr. 1996.

[34] C.W. Gellings, and W.M. Smith, “Integrating Demand-Side Management into Utility Planning,” *Proc. of IEEE*, vol. 77, no. 6, pp. 908-918, June 1989.

[35] J.A. Swanepoel, R. Maneschijn and J.C. Vosloo, “Energy management using integrated energy optimisation models on industrial applications,” *International Conference on Applied Energy*, Pretoria, 2013.

[36] J. Vosloo, I. Kruger and J. v. Rensburg, “Demand Market Participation (DMP) on smaller energy users,” *Industrial and Commercial Use of Energy*, Stellenbosch, no. 9, pp. 21-25, Aug. 2012.

[37] D. Olsen, S. Goli, D. Faulkner and A. McKane, “Opportunities for energy efficiency and demand response in the California cement industry,” LBNL, Berkeley, California, 2010.

[38] Eskom, “Template of DMP contract,” Eskom, Megawatt Park, Sunninghill, 2013.

[39] Eskom, “Schedule of standard prices for 2013 to 2014,” Internet: www.eskom.co.za, 2013*, [April 13, 2013].

[40] N. Jordaan, “Real time energy management in the cement industry,” M.Eng Dissertation, North-West University, Potchefstroom, 2005.

APPENDIX:

A.1 DMP potential and capacity

Production targets

The calculated raw meal and cement production targets are given in Table 38 and Table 39 respectively.

Table 38: Estimated raw meal production targets for 2013, in hour

	Scheduled Maintenance		Production Hours		Production target	
	Kiln3	**Kiln 4**	**KIln3**	**Kiln 4**	**RM3**	**RM4**
Month	**Maintenance**	**Maintenance**	**Production**	**Production**	**Raw meal**	**Raw meal**
2013-01	0	0	744	744	143,629	118,586
2013-02	336	0	336	672	64,865	107,110
2013-03	0	108	744	636	143,629	101,372
2013-04	0	228	720	492	138,996	78,420
2013-05	0	0	744	744	143,629	118,586
2013-06	0	0	720	720	138,996	114,761
2013-07	0	0	744	744	143,629	118,586
2013-08	0	0	744	744	143,629	118,586
2013-09	168	0	552	720	106,564	114,761
2013-10	0	0	744	744	143,629	118,586
2013-11	0	36	720	684	138,996	109,023
2013-12	0	132	744	612	143,629	97,547

Table 39: Estimated cement production targets for 2013, in tonne

CEMENT	Product A	Product B	Product C	Product D	Total
2013-01	48,423	47,639	14,280	23,723	134,066
2013-02	46,291	62,966	13,225	23,707	146,189
2013-03	71,547	61,459	14,629	0	147,635
2013-04	90,518	58,601	19,216	22,404	190,739
2013-05	72,113	60,366	20,040	31,633	184,152
2013-06	64,552	67,791	21,766	41,125	195,234
2013-07	63,438	64,392	20,544	22,738	171,112
2013-08	85,327	62,597	19,830	20,680	188,434
2013-09	68,933	69,858	13,640	28,936	181,367
2013-10	63,786	78,254	15,965	23,016	181,021
2013-11	67,651	72,975	15,500	24,200	180,326
2013-12	50,130	52,421	10,695	18,768	132,014

Production analysis

Raw milling process line 3

The calculated values of the production target analysis are given in Table 40. The total, production, maintenance and off times for each month are calculated. An estimated time is calculated for DMP. The time is calculated by assuming that a DMP event will take place on each day of the month. The average off time per day is calculated in the last column.

Table 40: Production analysis – Raw milling process line 3, in hour[2]

Month	Total	Production	Maintenance	Off Time	DMP	Avg off time
2013-01	744	581	36	127	62	4
2013-02	672	263	348	61	56	2
2013-03	744	581	24	139	62	4
2013-04	720	563	24	133	60	4
2013-05	744	581	24	139	62	4
2013-06	720	563	24	133	60	4
2013-07	744	581	36	127	62	4
2013-08	744	581	24	139	62	4
2013-09	720	431	192	97	60	3
2013-10	744	581	24	139	62	4
2013-11	720	563	24	133	60	4
2013-12	744	581	36	127	62	4
Total hours	**3,624**	**2,570**	**456**	**598**	**302**	**4**
Percentage	**100%**	**70.9%**	**12.6%**	**16.5%**	**8.3%**	

The DMP time is less than the off time for each month. There will therefore be enough time to stop the mill on each day if a DMP event should occur each day.

---

[2] Total time = production time + maintenance time + off time, DMP time = days in month x 2

Raw milling process line 4

The same procedure is used to analyse raw milling process line 4. The calculated values of the production analysis are given in Table 41. Note that the average off time per day is 1 hour for the mill. This indicates that there is potential for DMP but the mill cannot be stopped every day for DMP.

Table 41: Production analysis – Raw milling process line 4, in hour[3]

Month	Total	Production	Maintenance	Off Time	DMP	Avg off time
2013-01	744	675	24	45	62	1
2013-02	672	609	24	39	56	1
2013-03	744	577	132	35	62	1
2013-04	720	446	252	22	60	1
2013-05	744	675	24	45	62	1
2013-06	720	653	24	43	60	1
2013-07	744	675	24	45	62	1
2013-08	744	675	24	45	62	1
2013-09	720	653	24	43	60	1
2013-10	744	675	36	33	62	1
2013-11	720	620	60	40	60	1
2013-12	744	555	156	33	62	1
Total hours	**3,624**	**2,982**	**456**	**186**	**302**	**1**
Percentage	**100%**	**82%**	**13%**	**5%**	**8%**	

---

[3] Total time = production time + maintenance time + off time, DMP time = days in month x 2

Cement milling process line

The production analysis for the cement mills is done in the same way as for the raw milling process lines except for the production time. The cement milling process line produces four cement products. The production time is equal to the sum of the production time of each of the products. In Table 42 the calculated values of the production analysis are given.

Table 42: Production analysis – Cement milling process line – 2013, in hour[4]

Month	Total	Production	Maintenance	Off time	DMP	Avg off time
2013-01	1,488	1,006	53	429	62	14
2013-02	1,344	1,101	48	195	56	7
2013-03	1,488	1,078	53	357	62	12
2013-04	1,440	1,391	51	-2	60	0
2013-05	1,488	1,373	53	62	62	2
2013-06	1,440	1,477	192	-229	60	-8
2013-07	1,488	1,291	53	144	62	5
2013-08	1,488	1,385	53	50	62	2
2013-09	1,440	1,335	51	53	60	2
2013-10	1,488	1,352	53	83	62	3
2013-11	1,440	1,338	51	51	60	2
2013-12	1,488	975	53	459	62	15
Total hours	**30,822**	**27,496**	**1,238**	**1,652**	**730**	**4**
Percentage	**100%**	**89%**	**4%**	**5%**	**2%**	

Note that for April and June the average off time is zero or less than zero. This indicates that the production is too high to stop the cement mills for DMP in the particular months.

---

[4] Total time = production time + maintenance time + off time, DMP time = days in month x 2

A.2 Simulation

The predicted silo levels (Product C and D) for week 2 of the cement mill simulation are given in Figure 58.

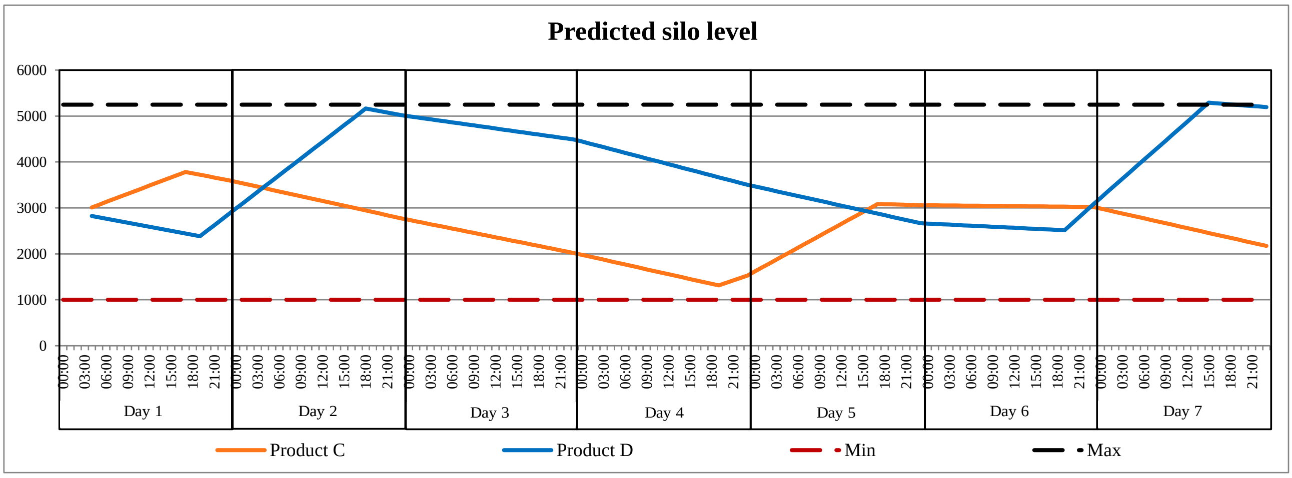

Figure 58: Predicted silo levels for week 2 – Cement product C and D

A.3 Implementation

Raw mill process line 3

The milling schedule and actual operation for the maintenance week are given in Figure 59. Note that there was a short breakdown of about an hour on the first day. On the third day the mill was shut down from 12:00 till 20:00 due to a technical problem.

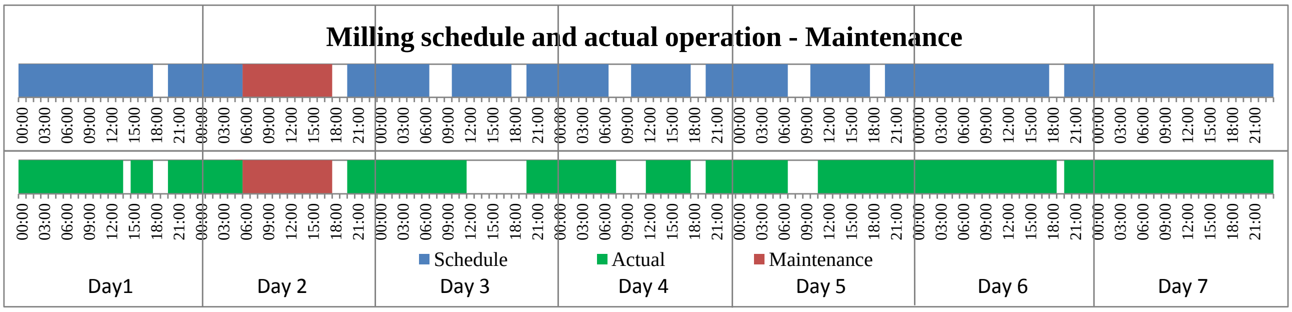

Figure 59: Milling schedule and actual operation for raw mill 3 – Maintenance

The predicted and actual silo levels are given in Figure 60. The drop in the silo level on day four (13:00) till five (07:00) is due to data loss on the plant’s SCADA.

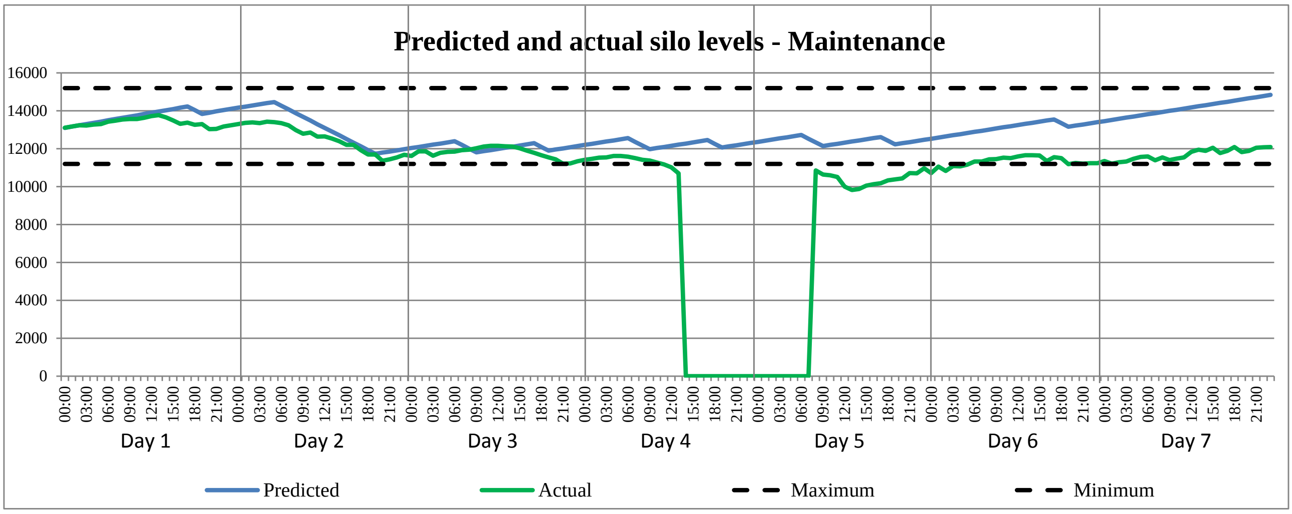

Figure 60: Predicted and actual silo levels for raw mill 3– Maintenance

Raw milling process line 4

The milling schedule and actual operation for a maintenance week are given in Figure 61. The predicted and actual silo levels are given in Figure 62.

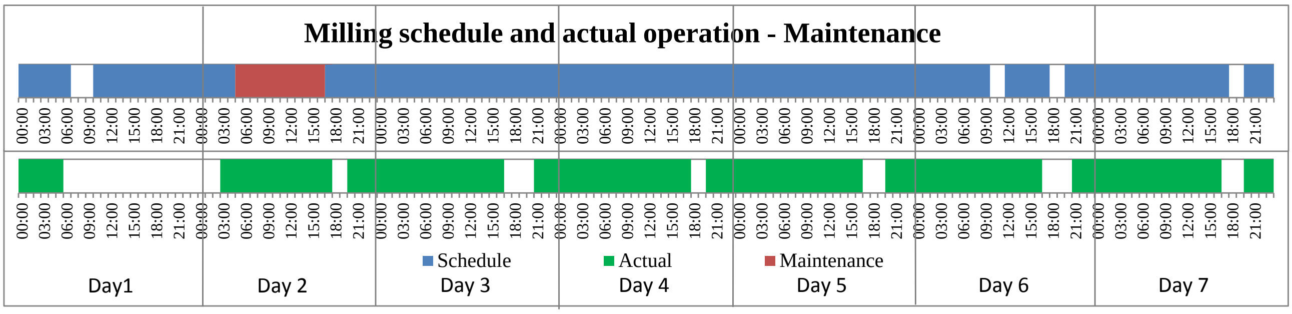

Figure 61: Milling schedule and actual operation for raw mill 4 – Maintenance

According to the milling schedule the mill could only be stopped on day 1 and day six. Note that the scheduled maintenance procedure on day 2 could not be implemented due to a breakdown and kiln stoppage on day 1. The silo level did not drop below the minimum level as predicted and the mill was stopped for every evening peak period for the rest of the week.

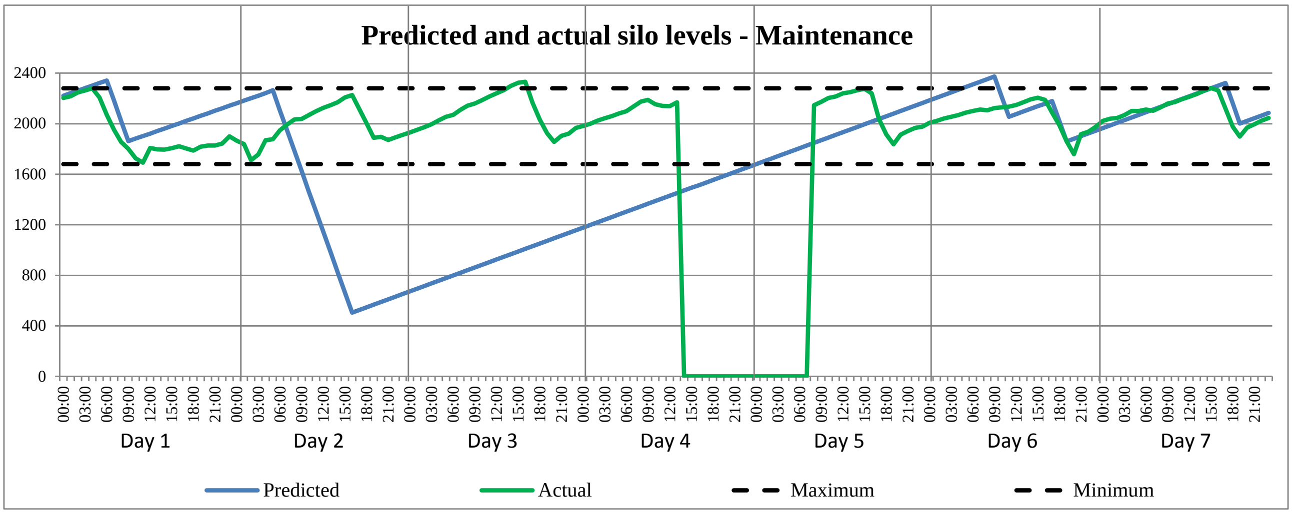

Figure 62: Predicted and actual silo levels for raw mill 4 – Maintenance

Cement milling process line:

The cement milling schedules for the first week are given Figure 63. The schedules indicate 4 evening stoppages for cement mill 1 and 3 for cement mill 2. The maintenance procedure of cement mill 2 is scheduled for the third day and the mill is scheduled to start milling at 20:00.

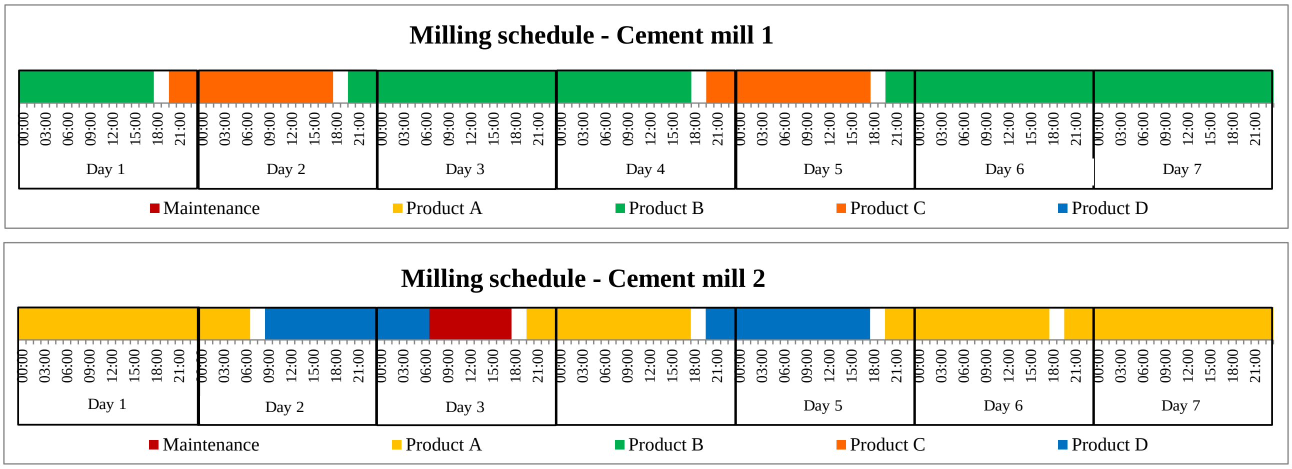

Figure 63: Cement milling schedule – Week 1

The predicted silo levels are given in Figure 64 and Figure 65.

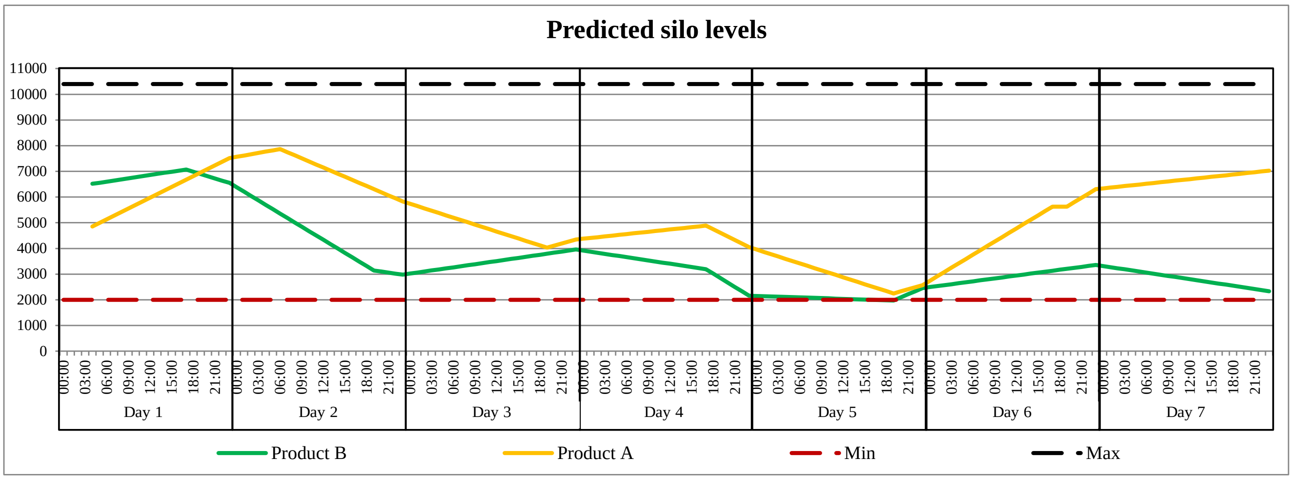

Figure 64: Predicted silo levels – Cement product A and B

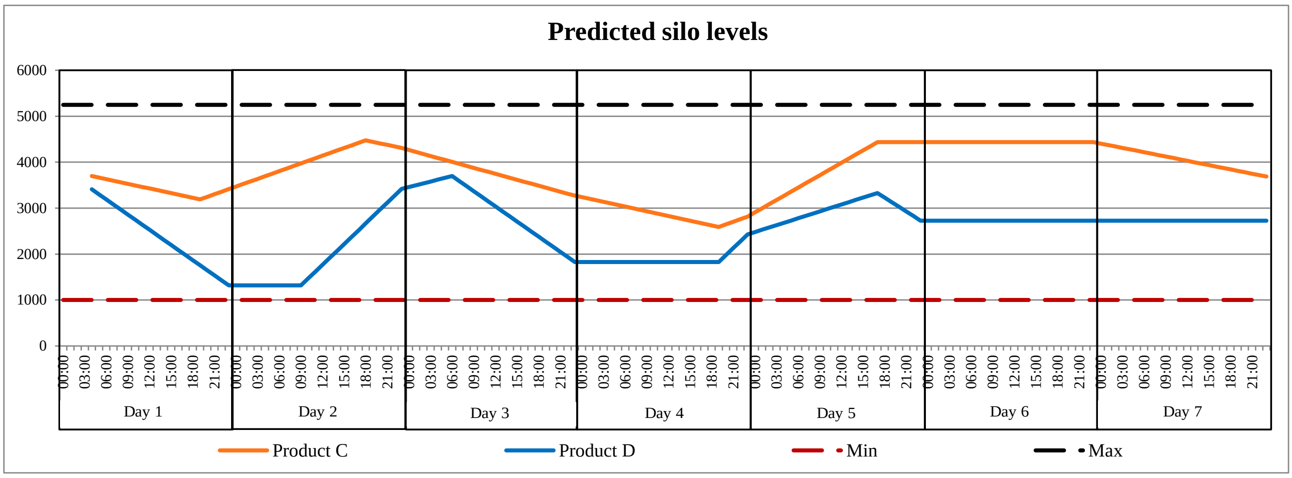

Figure 65: Predicted silo levels – Cement product C and D

The actual mill operations are given in Figure 66. In week 1, cement mill 1 was stopped 4 times and cement mill 2 three times. On day 1, 4 and 6 cement mill 2 experienced technical problems.

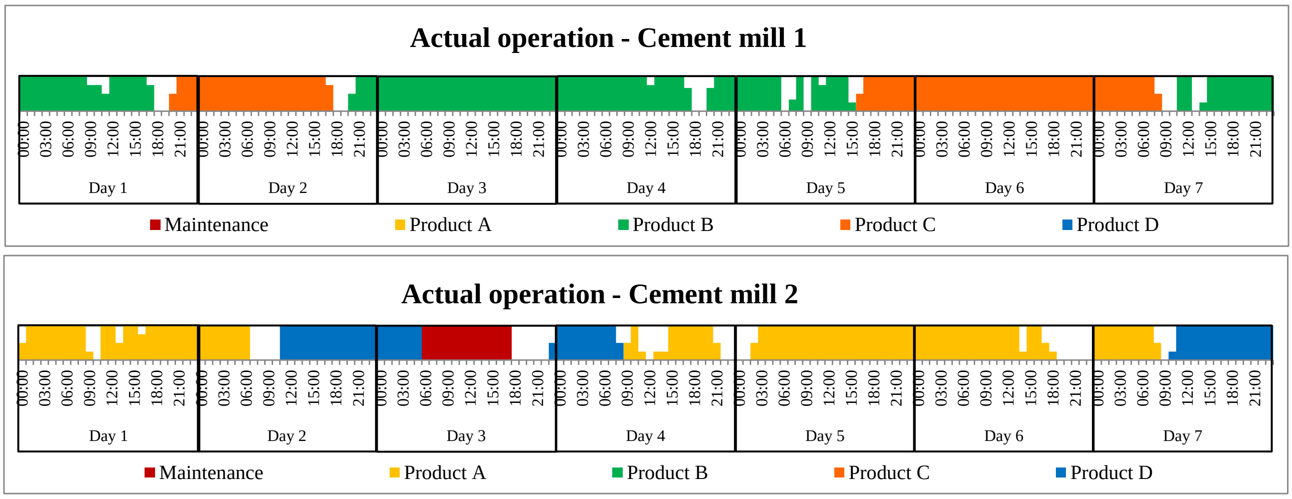

Figure 66: Actual cement mill operation – Week 1

The actual silo levels are given in Figure 67 and Figure 68. Note that the silo levels of products B and C are almost the same as predicted. This is due to the actual mill operations that was almost the same as the milling schedule. On cement mill 2, the mill operation deviated from the milling schedule and therefore the silo levels also deviated from the predicted silo levels.

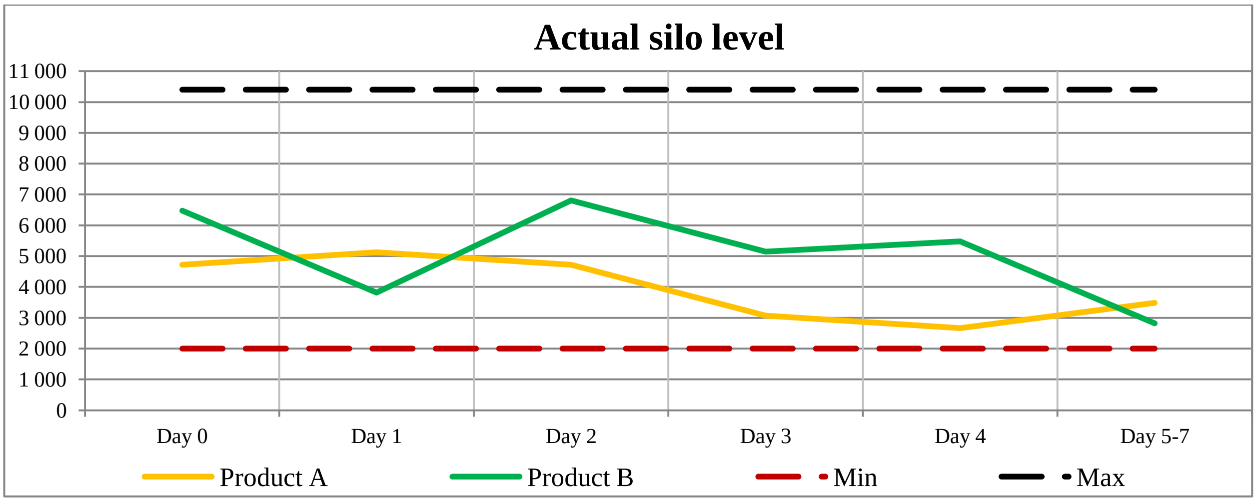

Figure 67: Actual silo levels – Cement product A and B

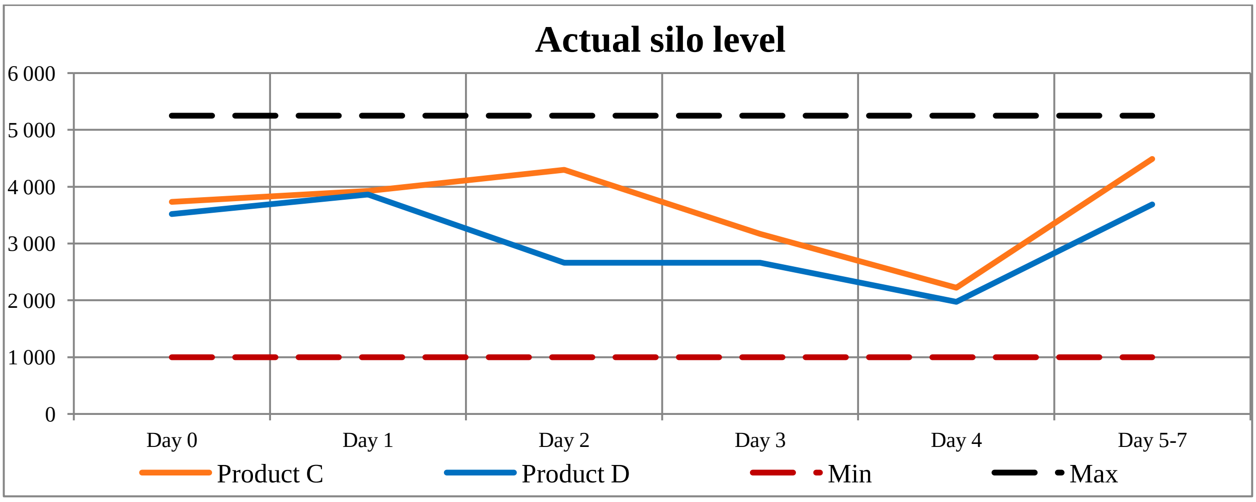

Figure 68: Actual silo levels – Cement product C and D

A.4 Load reduction

Mill stop percentages

Table 43 to Table 44 give the mill stop percentage for the milling schedules and actual operations. The mill stop percentages were calculated from the number of mill stoppages.

Table 43: Scheduled mill stop percentages

Milling schedule	**Load reduction availability [%]**		
Mill	**Weekday**	**Saturday**	**Sunday**
Raw mill 3	90%	100%	0%
Raw mill 4	50%	100%	100%
Cement mill 1	40%	50%	0%
Cement mill 2	50%	100%	50%

Table 44: Actual mill stop percentages

Actual operation	**Mill stop percentage [%]**		
Mill	**Weekday**	**Saturday**	**Sunday**
Raw mill 3	70%	75%	50%
Raw mill 4	90%	100%	100%
Cement mill 1	50%	50%	0%
Cement mill 2	20%	100%	50%

Baselines

The average Weekday, Saturday and Sunday load profiles calculated in section 4.2 are used as the Weekday, Saturday and Sunday baselines.

Table 45: Baselines, in MW

Hour	Weekday	Saturday	Sunday
00:00	14.57	15.85	13.47
01:00	15.02	15.39	14.43
02:00	15.40	15.48	14.09
03:00	15.39	15.63	13.56
04:00	15.25	15.19	14.16
05:00	14.94	15.46	14.97
06:00	14.26	15.31	14.21
07:00	13.50	14.92	13.67
08:00	12.93	14.21	13.93
09:00	12.77	13.82	13.81
10:00	12.66	13.49	12.42
11:00	12.60	13.33	12.58
12:00	12.58	14.23	12.60
13:00	12.28	14.86	12.49
14:00	12.14	14.79	12.19
15:00	12.41	14.64	12.60
16:00	12.87	13.95	13.30
17:00	12.48	13.19	13.40
18:00	9.26	10.44	11.69
19:00	9.15	9.63	11.25
20:00	11.23	9.99	12.63
21:00	12.74	12.31	13.33
22:00	13.71	12.78	13.67
23:00	14.40	12.43	13.86

Mill utilisation

$$Mill\ utilisation\ =\ average\ running\ capacity\ /\ maximum\ running\ capacity \quad (9)$$

The mill utilisation calculated for Weekdays, Saturday and Sundays are given in Table 46.

Table 46: Mill utilisation

	Weekday	Saturday	Sunday	Unit
Average running capacity	12.67	13.57	13.35	[MW]
Maximum running capacity	19.43	19.43	19.43	[MW]
Utilisation factor	**65.2%**	**69.9%**	**68.7%**	**[-]**

Total load reduction capacity

The average load reduction capacities for the milling schedule and actual operation for Weekdays, Saturdays and Sundays are given in Table 47 and Table 48.

Table 47: Average load reduction capacity according the milling schedules, in MW

LR Capacity	Total	Weekday	Saturday	Sunday
Raw mill 3	4.58	4.12	4.58	0.00
Raw mill 4	3.39	1.70	3.39	3.39
Cement mill 1	5.32	2.13	2.66	0.00
Cement mill 2	4.75	2.38	4.75	2.38
All mills	**18.04**	**10.32**	**15.38**	**5.77**
Mill utilisation		**65.2%**	**69.9%**	**68.7%**
Average LR capacity		**6.73**	**10.74**	**3.96**

Table 48: Average load reduction capacity according the actual operations, in MW

LR Capacity	Total	Weekday	Saturday	Sunday
Raw mill 3	4.58	3.21	3.44	2.29
Raw mill 4	3.39	3.05	3.39	3.39
Cement mill 1	5.32	2.66	2.66	0.00
Cement mill 2	4.75	0.95	4.75	2.38
All mills	**18.04**	**9.87**	**14.24**	**8.06**
Mill utilisation		**65.2%**	**69.9%**	**68.7%**
Average LR capacity		**6.44**	**9.94**	**5.53**

Load reduction

The average load reduction for the milling schedules and actual operations are plotted for Weekdays, Saturdays and Sundays in Figure 69 to 71.

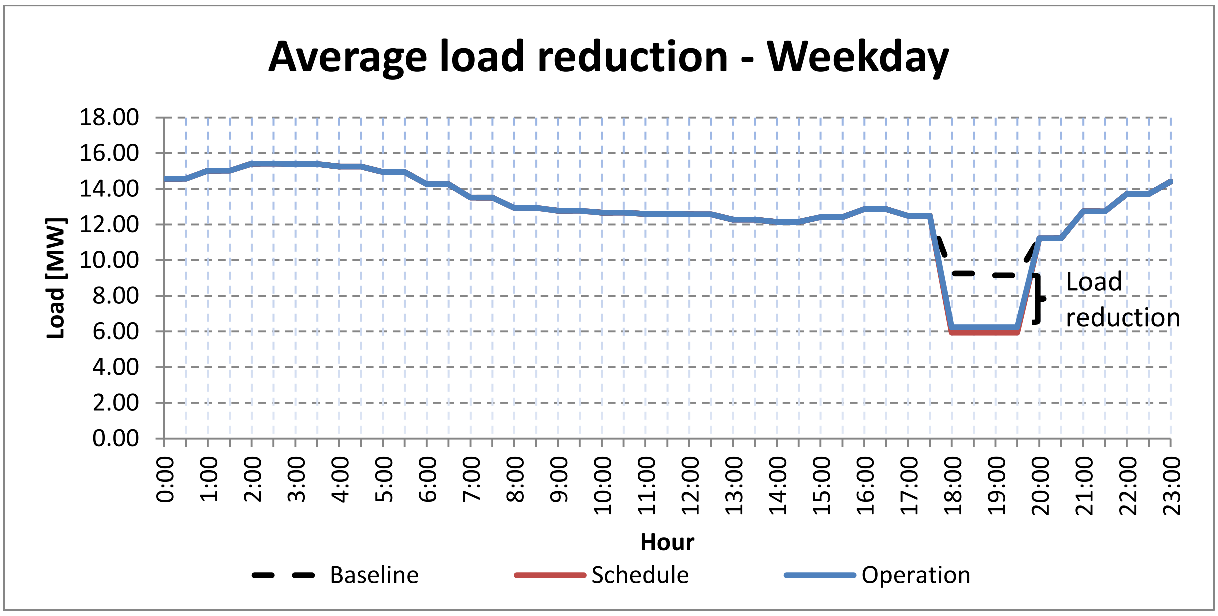

Figure 69: Average load reduction for Weekdays

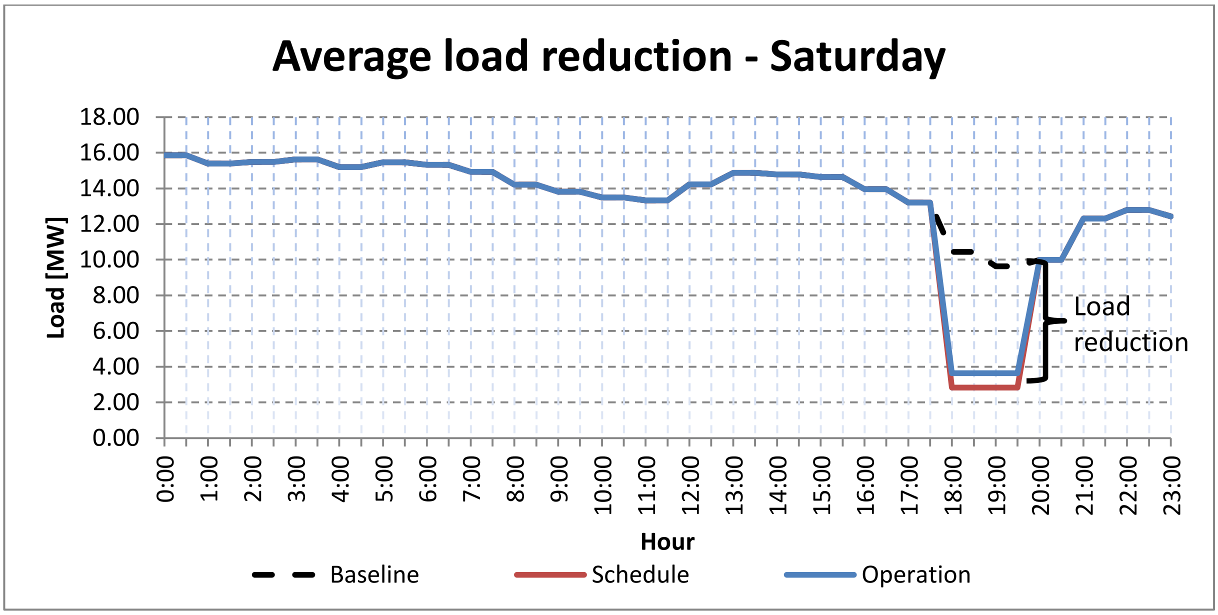

Figure 70: Average load reduction for Saturdays

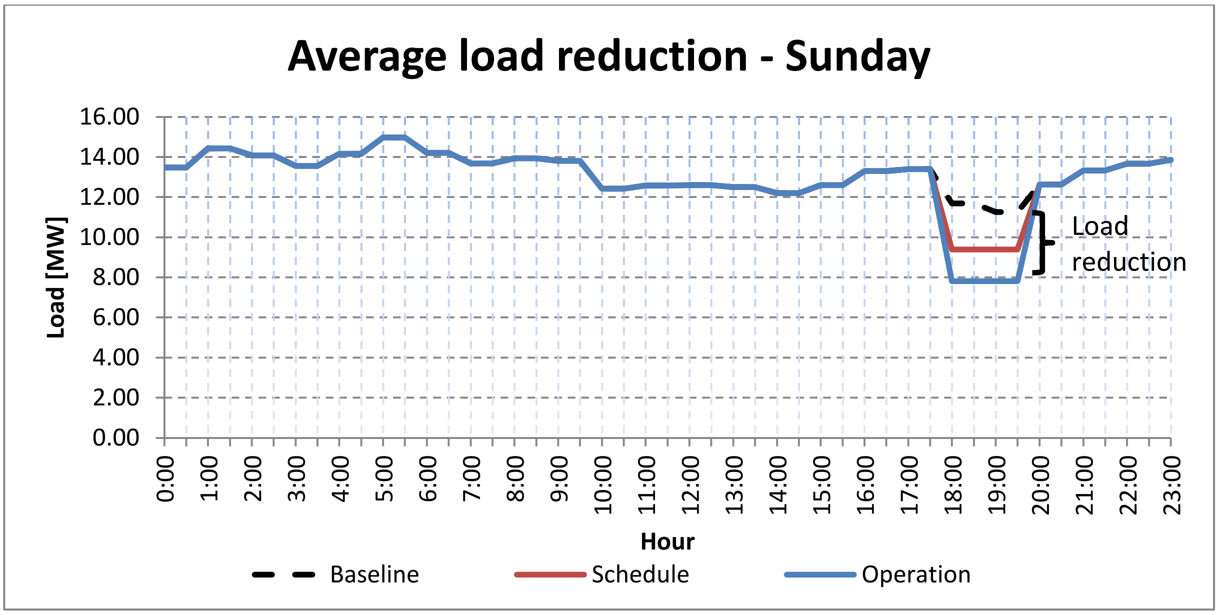

Figure 71: Average load reduction for Sundays