Formulating a multi-criteria decision-analysis model for a gypsum manufacturing facility in South-Africa

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Mini-dissertation accepted in partial fulfilment of the requirements for the degree Master of Business Administration at the North-West University

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ABSTRACT

The acquisition of gypsum, a crucial primary resource, within the complex structure of the cement sector in South Africa is a significant determinant affecting the uninterrupted production and long-term viability of the industry. This comprehensive study report explores the various aspects of gypsum procurement in the cement industry in South Africa. The subject matter comprises a comprehensive examination of geological factors, assessments of environmental impacts, complexities within the supply chain, and the management of stakeholders.

The main aim of this study is to examine the process of gypsum procurement in the cement industry of South Africa and find suitable alternatives to the current supply chain. This is of importance as the current resources are depleting thereby requiring future alternatives.

Methods: The present study employs a rigorous methodology that encompasses a comprehensive assessment of existing literature, both through desktop research and a systematic literature review. Additionally, questionnaires are utilised to evaluate sections of the subject matter. In this study, the researcher aims to assess the capacity requirements of the inland cement industry, analyse the available gypsum sources in South Africa, and suggest the most effective strategies for procuring gypsum. To achieve this, the researcher employs the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) technique.

The results of the study indicate the annual installed capacity of cement in the inland cement sector, the availability of gypsum reserves, and the economic advantages of sourcing gypsum from Richards Bay. In this report, the researcher presents a comprehensive analysis of financial and management strategies that might be used by industry players.

The research setting is shaped by several limitations, including geographical borders, product specificity, reliance on existing knowledge, potential perspective bias, scope constraints, and the necessity of examining alternate transportation methods.

In conclusion, this research study provides a fundamental and essential resource that may be utilised to facilitate well-informed decision-making within the cement sector of South Africa. The focal points of this study encompass the diffusion of knowledge, conducting financial investigations about the sources of gypsum, evaluating the feasibility of shifting production sites and recognising the significance of material drying in reducing costs within the supply chain. The managerial recommendations primarily centre around the optimisation of the logistical supply chain and the allocation of additional costs towards the establishment of future production facilities.

The observations and recommendations presented in this research have the potential to generate positive transformations throughout the gypsum supply chain of South Africa's cement industry. Furthermore, it brings attention to under-investigated areas for future research initiatives, promoting the development of resilience, sustainability, and expansion within this vital domain of the construction materials business.

This research plays a crucial role in facilitating the understanding and management of the intricate processes involved in gypsum procurement. It aims to enhance decision-making by providing comprehensive and well-informed insights. Furthermore, it seeks to contribute to the long-term sustainability and growth of the gypsum market within the cement sector of South Africa.

CHAPTER 1 INTRODUCTION

1.1 Introduction

The gypsum industry plays a crucial role in the cement manufacturing processes of central South Africa, with no suitable alternatives currently known. The South African cement market relies heavily on a single gypsum supplier, with few production years left.

According to (Quennoz & Scrivener, 2012), gypsum is added to cement to regulate the setting curve of cement and to ensure plasticity within the first hours of the hydration process. The use of gypsum at the optimum content also improves the properties of cement (Mohammed & Safiullah, 2018).

Numerous gypsum sources are available within the constraints of South Africa; these sources are not all equally economically viable. This report will utilise and apply the Multi-Criteria Decision Analysis (MCDA) model to propose the optimal geographical location for a manufacturing facility. This study will serve as an outline for future expansion in the South African gypsum industry.

Selecting a location for a manufacturing facility is complex as it requires balancing conflicting criteria such as proximity to resources, transportation costs, local regulations, and environmental- and social impacts. This study will utilise an MCDA model to gain better insight into these criteria and their influence on the best-suited location for the facility.

1.2 Background to the study

The current most prominent producer of gypsum has a finite life and is left with no definite contingency plan to rectify the situation (Goudriaan, 2018). Common industry knowledge dictates that should the current supplier not find economically viable solutions locally, most gypsum within the cement industry must be imported. This will pose the sector with significant challenges, such as failing ports, fluctuating foreign exchange rates, and local loss of labour in an already struggling economy.

1.3 Problem statement

Very little formal research has been conducted in South Africa's cement industry. This industry is formally known as "Cement and Concrete Product Manufacturing: NAICS 3273" and falls under the non-metallic mineral product manufacturing sub-sector.

Gypsum is part of the basic definition of Portland Cement in national standards around the world (Liu *et al.*, 2015), and it is required to meet minimum standards of cement manufacturing. This raw material is grounded into cement to better the cement paste's rheological properties, ensuring workability during the initial hydration period (Lerch, 2008).

The geographical location of a manufacturing facility plays a crucial role in the business model's success. The geographical area where a manufacturing facility is situated influences the total absorbed cost of the final material for the consumer through access to resources, transportation costs to the manufacturing facility, and transportation costs to the end consumer.

The problem is that the inland cement industry's capacity requirements from the gypsum industry are not yet quantified or analysed. This will, therefore, be the focus of the study.

1.4 Research objectives and questions

The primary objectives of this study are as follows:

- To quantify the inland cement industry capacity requirements from the gypsum industry.
- Quantify and analyse the current known sources of gypsum that can be suitable for supplying the required production capacity.
- To propose the optimal option, create an ideal solution model and apply a Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS) methodology.

The research questions associated with the research objectives can be illustrated as:

- What is the current capacity of the inland cement industry in the region under study?
- What are the existing sources of gypsum that could potentially supply the required production capacity in terms of each source?
- Using the TOPSIS methodology, what are the optimal solutions for sourcing gypsum to meet the capacity requirements of the cement industry?

1.5 Contribution of the study

The field of study for this research paper is operational management with a focus on supply chain management. Therefore, this study is limited to the sector formally known as "Cement and Concrete Product Manufacturing: NAICS 3273" and falls under the non-metallic mineral product manufacturing subsector. However, this study will be limited to the inland cement manufacturing sector of South Africa. This is limited to primary cement manufacturers in the conventional sense; this report will not include third-party blenders. For this report, no cement manufacturing facilities currently exist in Free State or Mpumalanga, negating them from the scope of inland cement manufacturing.

The geographical boundaries of this study are limited to the material supply in Northwest, Gauteng, and Limpopo (Figure 1.1). This will not restrict material sources outside these geographical boundaries but will only limit the client base.

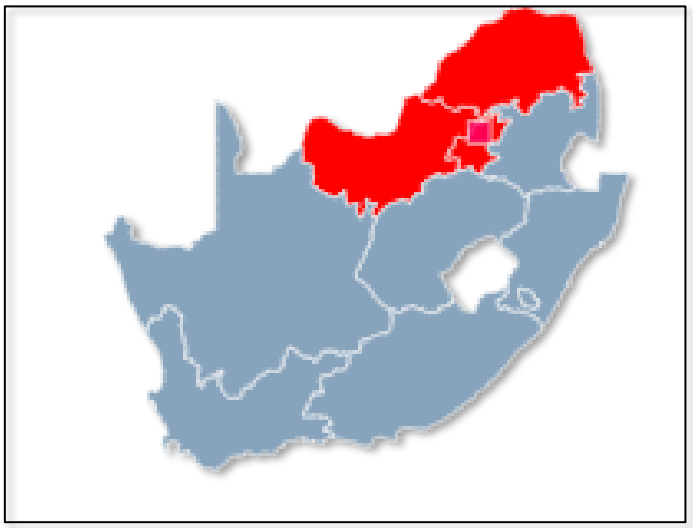

Figure 1.1: Illustration of the geographical boundaries of the study'

[Source: Own Compilation]

1.6 Layout of the study

This research is meticulously structured to comprehensively explore the gypsum industry within the cement value chain in the inland region of South Africa. The layout guides the reader through a logical progression, ensuring each section builds upon the previous, culminating in a comprehensive exploration of the gypsum supply challenges in the inland South African cement industry.

Chapter 1 serves as an introductory section, presenting a detailed overview of the study by analysing the historical and current backdrop of the gypsum sector. The provided passage effectively formulates the problem statement by clearly highlighting the main challenges and issues the research intends to tackle. The study objectives are explicitly delineated, differentiating between primary and secondary targets. The key research question is formulated to serve as the central inquiry directing the investigation. The study's contribution is illustrated, emphasising its significance and possible impact on the industrial and academic sectors. The study's scope encompasses the specific subject of study, the sectors being investigated, and the geographical boundaries. Additionally, the study's contributions are iterated.

Chapter 2 will thoroughly examine relevant published literature about the gypsum sector, encompassing its obstacles and prospective remedies, providing a full review. The primary objective of this chapter is to lay down a theoretical framework for the study by integrating the existing body of knowledge and identifying areas where the research can contribute to filling up gaps.

Chapter 3 is devoted to examining the research paradigm and methodology, furnishing a full explanation of the research paradigm, strategy, and methodological decisions. This will include an overview of the research approach, duration of the study, selection of participants, methods for data

collecting, and the statistical and data analysis methodologies utilised. Furthermore, this chapter will discuss the factors that must be considered to ensure the reliability and validity of the research findings.

The forthcoming chapter will conduct an in-depth systematic overview of the literature and a comprehensive analysis of the collected data. This chapter holds significant importance as it explores the available literature and conducts an analysis based on empirical data, establishing a foundation for fully comprehending the gypsum business and its position within the cement value chain. This study aims to empirically solve all the research questions and add to the knowledge body.

The study will be concluded in Chapter 5, providing a comprehensive conclusion and suggestions. The study will integrate the research outcomes and put forth practical suggestions for stakeholders in the sector. In addition, the study will address its inherent limits, offering a comprehensive understanding of the findings and proposing potential directions for future scholarly investigations.

Although not constituting a designated chapter, the annexures will encompass additional materials such as consent approvals, questionnaires, lab reports, and geographical surveys. The documents above provide evidence for the research outcomes and contribute more background information, serving as valuable supplementary materials to the primary content of the study.

By employing this structured approach, the study aims to allow the reader to understand the current climate within the inland gypsum supply chain holistically.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This section will serve as a preliminary literature review of the use of gypsum in cement manufacturing. This study will utilise a funnel approach to illustrate the challenges faced by the cement industry's supply chain by investigating the following points, as shown in Figure 2.1: Literature review methodology.

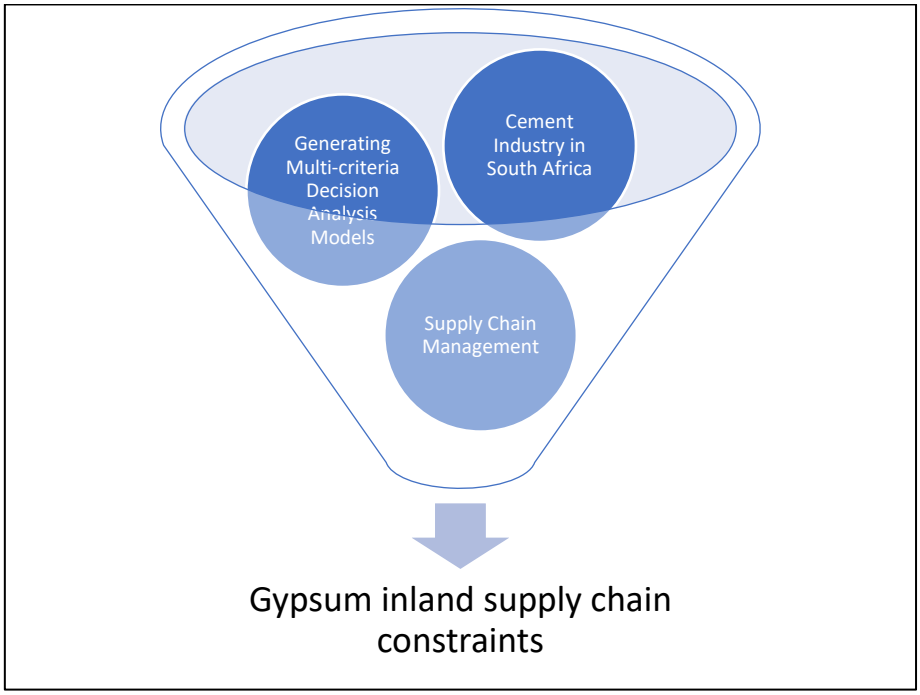

Figure 2.1: Literature review methodology

[Source: Own contribution]

2.2 Generating multi-criteria decision analysis models

Multi-Criteria Decision Analysis (MCDA) is a decision-making tool that has gained significant attention in various fields due to its ability to handle complex decision-making scenarios involving multiple conflicting criteria (Mühlbacher & Kaczynski, 2016). MCDA is a sub-discipline of operations research that explicitly considers multiple criteria in decision-making environments (La Torre, 2020).

MCDA models are beneficial when decision-makers must consider quantitative and qualitative aspects (Torabi *et al.*, 2012). These models allow decision-makers to evaluate multiple conflicting criteria, rank or prioritise different options and make informed decisions (Keisler & Linkov, 2021:1513). The use of MCDA models in decision-making processes helps ensure that all relevant factors are considered and that the final decision is comprehensive and robust (Stewart, 2008).

There are several MCDA models, each with unique characteristics and suitability for different decision-making scenarios (Abdullah *et al.*, 2021). Some of the most commonly used MCDA models include the Analytic Hierarchy Process (AHP), which, according to (Glaize *et al.*, 2019) was used the most in their studies within the healthcare industry, Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), which according to (Abdullah *et al.*, 2021) has been extensively utilised in the disasters management sphere, and the Elimination and Choice Expressing Reality (ELECTRE) method.

It is noted (Bandyopadhyay, 2023) that a significant number of MCDA models exists, with a total of six different models reviewed, namely Multi-Attribute Utility (MAUT) (De La Vega *et al.*, 2018), MACBETH method (Kundakcı, 2019), and MAURA method whereby all three will not be utilised in this study.

The AHP is a widely used MCDA method developed by Thomas L. Saaty in the 1970s (Souidi *et al.*, 2020:03009). AHP structures a complex problem into a hierarchy of sub-problems, making it easier for decision-makers to set priorities and make the best decision (Lakhani *et al.*, 2020). The AHP model uses pairwise comparisons (Feizizadeh & Ghorbanzadeh, 2017:27) to determine the weight of each criterion and sub-criterion, and then calculates a score for each alternative based on these weights. The best option is the alternative with the highest score (Yilan *et al.*, 2020).

On the other hand, the TOPSIS is a method that identifies solutions that are closest to the ideal solution (Papathanasiou *et al.*, 2018) and farthest from the negative-ideal solution (Srirangan & Sathiya, 2017). Developed by Hwang and Yoon in the 1980s (Papathanasiou *et al.*, 2018), TOPSIS uses a geometric approach (Raja & Rajan, 2022) to determine the relative closeness of each alternative to the ideal solution. This method is beneficial when the best alternative is not immediately apparent, and a more systematic approach (Xie & Zhang, 2023) is needed to evaluate the alternatives.

The ELECTRE method is a set of outranking methods where alternatives are compared pairwise to determine which alternatives outrank the others (Regier & Peacock, 2017). Developed by Bernard Roy in the 1960s (Słowiński, 2018:3), the ELECTRE method is often used in situations where there is no single best alternative (Jurczak *et al.*, 2022), and the decision-maker needs to make a choice based on a set of acceptable alternatives.

When comparing the different alternatives, it is important to understand the unique intricacies of each method to ensure the correct method is utilised. These differences and similarities are illustrated in

Table 2.1: Comparative Analysis of Multi-Criteria Decision Analysis Methods: TOPSIS, AHP, and ELECTRE.

Table 2.1: Comparative Analysis of Multi-Criteria Decision Analysis Methods: TOPSIS, AHP, and ELECTRE

Criteria	TOPSIS	AHP	ELECTRE
Methodology	Uses a geometric approach to determine the relative closeness of each alternative to the ideal solution (Parida *et al.*, 2017).	Structures a complex problem into a hierarchy of sub-problems and uses pairwise comparisons to determine the weight of each criterion and sub-criterion (Mourato *et al.*, 2023:4915).	Uses pairwise comparisons to determine which alternatives outrank the others (Jandová *et al.*, 2016:1714).
Strengths	Can handle multiple criteria and alternatives and provides a clear ranking of alternatives based on their closeness to the ideal solution (Radzib *et al.*, 2021).	Allows for decomposing a complex problem into a hierarchy, making it easier to handle. It also provides a clear ranking of alternatives.	Useful in situations with no best alternative; the decision-maker must choose based on a set of acceptable alternatives. This is evident from studies where similar multi-solution problems were faced (Zarghami & Szidarovszky, 2011).
Weaknesses	Does not handle qualitative criteria well and requires that all criteria be quantifiable (Park *et al.*, 2021).	The pairwise comparison process can be time-consuming and complex, especially for large problems (Mourato *et al.*, 2023:4915).	Does not provide a single best solution, but a set of acceptable alternatives (Hidayat *et al.*, 2022:118).
Suitability for Complex Problems	Suitable for problems with multiple criteria and alternatives, where a clear ranking of alternatives is needed (Nguyen *et al.*, 2022:3720).	Suitable for structuring complex problems into a hierarchy, especially when there are multiple levels of criteria and sub-criteria (Wang *et al.*, 2020:134).	Suitable for problems where there are multiple acceptable solutions, and the decision-maker needs to choose among them (Jandová *et al.*, 2016:1714).

Criteria	TOPSIS	AHP	ELECTRE
Data Requirements	Requires quantitative data for all criteria to be used optimally and can be used for qualitative data as well (Aouadni *et al.*, 2017:353).	Can handle both quantitative and qualitative data, but requires a clear understanding of the relative importance of each criterion and sub-criterion (Wang *et al.*, 2020).	Can handle both quantitative and qualitative data, but requires a clear understanding of the relative importance of each criterion (Agrebi *et al.*, 2017; Zarghami & Szidarovszky, 2011).

[Source: Own contribution]

2.3 Industry-specific MCDA models

When considering their application, it is essential to examine MCDA models' use in sectors related to or involved with the gypsum industry. The researcher will concentrate on studies that have used MCDA models in this context because the gypsum business predominantly supports the cement value chain.

Like many other industries, the cement sector must make difficult decisions based on several competing factors (Soltanzadeh *et al.*, 2021). These choices can include picking the best suppliers of raw materials (Amrina *et al.*, 2016), like in the case of gypsum, selecting the most effective production techniques, and figuring out the best distribution and logistics plans. In these situations, MCDA models can offer insightful information and aid decision-makers in reaching sound judgments.

For instance, an MCDA model was employed to assess the prospect of hybrid energy in the cement industry of Pakistan in a study by (Basheer *et al.*, 2022). The study considered price, energy effectiveness, CO_2 emissions, and technological maturity. The MCDA model's outcomes assisted the researchers in determining the most promising technologies and offered useful information for cement industry decision-makers in Pakistan. Another study utilised an MCDA model to explore the environmental and economic benefits of co-burning refuse-derived fuels and sewage sludge in the cement industry. This research, conducted by (Wojtacha-Rychter & Smoliński, 2022), employed a multi-case study approach to delve into the intricacies of this complex issue. The MCDA model was instrumental in assessing various scenarios and their potential impacts, both economically and environmentally.

In a different study by (Abiodun *et al.*, 2022) titled "Cutting Cement Industry CO_2 Emissions through Metakaolin Use in Construction", MCDA was used to examine the possibility of using metakaolin to lower CO_2 emissions in the cement business. The use of environmentally friendly materials in the building, construction, and transportation industries might help reduce carbon dioxide emissions,

and the MCDA model was crucial in estimating the compressive strength of various concrete combinations.

MCDA models are useful in many areas of the cement industry. Still, there is a glaring gap in their application to the choice and optimisation of raw material manufacturing facilities. Most current research focuses on energy efficiency, environmental impact, and CO_2 emissions reduction. Examples of these studies include those by (Basheer *et al.*, 2022), (Wojtacha-Rychter & Smoliński, 2022), and (Abiodun *et al.*, 2022). The precise application of MCDA models to the decision-making procedures involved in manufacturing raw materials, such as the procurement and processing of gypsum, has not yet been fully investigated. This is a serious flaw because these choices are essential to the cement industry's sustainability and efficiency. Therefore, future research should work to close this gap by creating and utilising MCDA models that can assist decision-makers in the cement sector in optimising their raw material manufacturing processes; this gap will be addressed in this dissertation.

2.4 Gypsum as an additive in cement

According to (Quennoz & Scrivener, 2012), gypsum is added to cement to regulate the cement's setting curve and ensure plasticity within the first hours of the hydration process. Both natural and chemical by-products of gypsum are suitable for use in cement (Bensted, 2002). Chemical gypsum, however, has trace elements of impurities that are required to be treated before it is suitable for use in Ordinary Portland Cement (OPC) (Singh, 2000).

Gypsum is consumed within the cement industry as an additive at a rate of 3-5% of their final consumption (Caillahua & Moura, 2018). This indicates that 30-50kg of gypsum is required for every ton of cement produced. The production process of cement can utilise numerous waste by-product gypsum streams to replace natural gypsum (Caillahua & Moura, 2018). Gypsum availability in South Africa consists of both chemical and natural gypsum sources. A study was conducted by (Tzouvalas *et al.*, 2004), which did significant work to find alternatives for using natural gypsum, the most notable of which is the utilisation of Flue-Gas Desulfurization (FGD).

The main availability of natural resources occurs in the Northern Cape and Western Cape (Nevondo, 2009). The report further notes that phosphoric gypsum is available in the North-West at Potchefstroom and Rustenburg (Phokeng), Limpopo at Phalaborwa, Gauteng at Modderfontein (Depleted), and Kwazulu-Natal at Richards Bay (Nevondo, 2009).

The primary source of gypsum within the inland South African region is owned and operated by OMV PTY LTD. This company produces and sells over 350 kilotons of gypsum annually (Corporate, 2022). It is translated from the percentage of gypsum required to blend cement as three to five per cent.

This equates to enough gypsum to produce 7-11.6 megatons (MT) of final product produced by this single company.

Worryingly, the total reserves between the two current sources (Potchefstroom and Rustenburg) are estimated as only 1.30MT and 1.40MT, respectively, as of 28 February 2022, with only 0.90MT available for use in cement at the Potchefstroom manufacturing facility. This equates to the actual resources available for cement production at 2.10MT by the main producer of cement (Corporate, 2022).

2.5 Cement industry in South Africa

The literature study will investigate only the consumption of inland cement factories within South Africa, namely the North-West, Limpopo, Gauteng, and Mpumalanga factories. This region has ten main cement factories, as seen in *Table 2.2: Inland cement factories and approximate* capacity. These ten cement factories are owned and operated by five prominent cement-producing companies: AfriSam South Africa PTY LTD, Lafarge Africa, Dangote Cement (known as "Sephaku Cement"), PPC Cement, and Mamba Cement. This study will exclude cement factories in the coastal provinces (Kwazulu-Natal, Western, and Northern Cape). Table 2.2 shows the total installed capacity within the South African inland region at 12.55MT.

Table 2.2: Inland cement factories and approximate capacity

Company	Cement Factory	Approximate Location	Approximate Capacity (MT/yr.)	Source
AfriSam South Africa PTY LTD	AfriSam Dudfield	Lichtenburg, North-West, South Africa	1.80	(Edwards, 2014)
AfriSam South Africa PTY LTD	AfriSam Roodepoort	Roodepoort, Gauteng, South Africa	1	(Anon, 2021)
Dangote Cement	Sephaku Aganang	Lichtenburg, North-West, South Africa	1.25	(Edwards, 2014)
Dangote cement	Sephaku Delmas	Delmas	1.40	(Edwards, 2014)
Lafarge Africa	Lafarge Lichtenburg	Lichtenburg, North-West, South Africa	2	(Edwards, 2014)
Lafarge Africa	Lafarge Randfontein	Randfontein, Gauteng, South Africa	1	(Edwards, 2014)
PPC	Dwaalboom	Dwaalboom, North-West, South Africa	1	(Edwards, 2014)
PPC	Slurry	Lichtenburg, North-West, South Africa	1.52	(Edwards, 2014)
PPC	Hercules	Pretoria, Gauteng, South Africa	0.58	(Edwards, 2014)

Company	Cement Factory	Approximate Location	Approximate Capacity (MT/yr.)	Source
The Mamba Cement Factory	Mamba	Northam, Limpopo, South Africa	1	(Pelser *et al.*, 2017)

[Source: Own contribution]

2.6 Supply chain management

Supply chain management is defined by (Mangan & Christopher, 2005) as: "The network of organisations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer". This study will focus on the Key Performance Indicators (KPIs) that govern a typical supply chain. The focus will be placed on the portion from sourcing, transporting, and converting gypsum within the cement supply chain. (Stadtler, 2008) defines the KPIs of supply chain management as:

- Delivery performance measures using actual versus planned delivery dates.
- Supply chain performance measures, i.e., the adaptability of the supply chain solution.
- Assets and inventories measures, i.e., the assets over the inventory; this will not be essential in this study.
- Costs that not only refer to the purchasing price of the material.

All aspects of the KPIs mentioned above must be analysed to evaluate an option within the gypsum supply chain for the inland cement industry.

When analysing the supply chain constraints, the focus must be placed on exploring the sourcing of material and not only the procurement (Gottfredson *et al.*, 2005). This is iterated by (Talluri & Narasimhan, 2004) when stating that a long-term relationship with suppliers is vital in enhancing organisational performance. The weighing in of long-term relationships is required when making strategic partnership proposals.

Strategic sourcing will form the foundation of the supply chain study by rooting the focus on managing sourcing relationships, as illustrated by (Shook *et al.*, 2009). Supply chain management can formulate sustainable solutions by focusing on this. It is noted (Wallace & Xia, 2014) that companies of all sizes focus on a more sustainable approach to procurement and sourcing.

When analysing the value of a particular solution, the focus should be placed on the total cost of material and not only the price. A Total Cost of Ownership (TCO) approach must be followed

(Wouters *et al.*, 2005). The total cost of ownership considers aspects such as quality, delivery, administration, communication, failure, and maintenance (Degraeve *et al.*, 2000). These aspects must be considered when analysing the supply chain.

CHAPTER 3 RESEARCH METHODOLOGY

3.1 Introduction

The research methodology section of this dissertation outlines the approach and methods used to conduct the study on the selection of a location for a manufacturing facility in the gypsum industry in South Africa. A quantitative approach was chosen for this study, using a Multi-Criteria Decision Analysis (MCDA) model to evaluate the proximity of raw resources and customers to potential locations. The data analysis section of the methodology will also include a statistical analysis of the results obtained from the MCDA model to support the findings and conclusions of the study.

According to (Patil & Mankar, 2016), there are nine prime objectives of the research:

- ***To Discover New Facts:*** Uncovering previously unknown information or understanding in various fields.
- ***To Verify and Test Important Facts:*** Validating and confirming the accuracy and reliability of existing knowledge.
- ***To Identify Cause-and-Effect Relationships:*** Analyzing events, processes, or phenomena to understand how and why they occur.
- ***To Develop New Scientific Tools, Concepts, and Theories:*** Creating innovative methodologies and theoretical frameworks for better understanding and solving both scientific and non-scientific issues.
- ***To Find Solutions to Scientific, Non-Scientific, and Social Problems:*** Addressing and resolving challenges in various domains, ranging from science to social issues.
- ***To Overcome or Solve Problems Occurring in Everyday Lives:*** Applying research to practical problems faced in daily life, aiming for tangible improvements.
- ***To Systematize Knowledge:*** Organizing and structuring knowledge systematically for enhanced accessibility and comprehension.
- ***To Formulate Policies:*** Aiding in the creation of policies based on evidence and research findings.
- ***To Predict and Control Future Trends and Phenomena:*** Using research to foresee future developments and potentially influence or control them for desired outcomes.

Figure .1 illustrates the main departure point to formulate this study's research methodology.

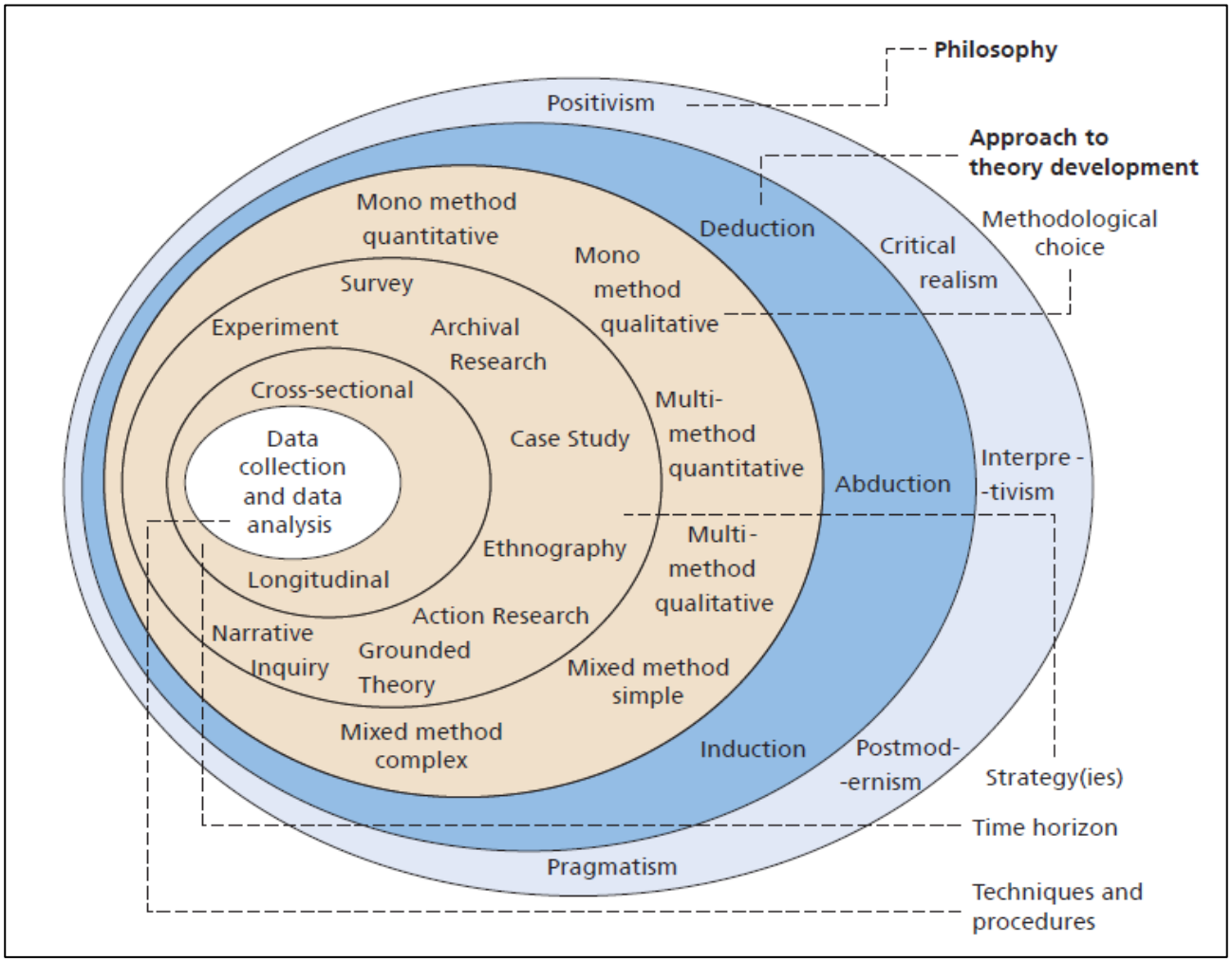

Figure 3.1: Saunders's research onion

[Source, Melnikovas, 2018]

The research will utilise this approach to decide the philosophy, theory development, methodological choice, strategies to employ, time horizons, and the final implementation techniques and procedures. By utilising the outer layers of the "research onion", one can discern the correct option between deductive and inductive research approaches (Sahay, 2016).

As part of the "research onion", the relevant research paradigm needs to be chosen. This is heavily influenced by the relevant research philosophy chosen by the researcher (Melnikovas, 2018). According to (Khaldi, 2017), empiricism and rationalism are two principal prevailing research methodologies that can be translated into the inductive and deductive reasoning approaches.

3.2 Research paradigm

As per the literature review of Saunders (Saunders & Lewis, 2017), the researcher decided on the research paradigm by utilising the "research onion". The first step is to determine the philosophy to use. Five main philosophies exist.

- ***Positivism:*** Research conducted by considering pure data and facts without being influenced by the interpretation of human bias (Alharahsheh & Pius, 2020).
- ***Critical realism:*** Critical realism is noted (Fletcher, 2020) as the middle way between positivism and interpretivism. This philosophy criticises both traditional philosophies by questioning whether the notion that what is real is only quantifiable by what the researcher can observe.
- ***Interpretivism:*** Truth and knowledge are subjective, and impartiality does not exist, as argued (Ryan, 2018).
- ***Post-modernism:*** Rests on qualitative studies and looks at the anomalies in research (Muhaise *et al.*, 2020).
- ***Pragmatism:*** Used mainly to understand the underpinning philosophical research approach (Shah *et al.*, 2019).

This study will adopt a positivist approach since it is decided that the researcher will study the research objectively and that the results can be generalised to the population. The researcher accepted this as suitable for the study as the objective is to create an MCDA model to propose the optimal geographical location for a manufacturing facility based on specific criteria and numerical data. This study will provide a systematic and objective way to evaluate the available data.

Positivism also assumes that an objective reality can be studied and the world can be quantified and measured (Park *et al.*, 2020). This paradigm is consistent with the research objective of quantifying and developing a model to propose an optimal solution based on quantifiable numerical data.

3.3 Research approach

This study will include both primary and secondary data. The approach to theory development lends itself to a deductive approach. A deductive approach can be utilised when using previous knowledge, available data, or beliefs to acknowledge the likelihood of findings (Young *et al.*, 2020).

3.4 Methodological choice

When defining the methodological choice the study will be based on, it is essential to factor in the research question. This can be used as a guiding principle to decide the most suitable method. It is noted by (Zait & Zait, 2009) that: "The manner of realisation of the scientific approach (data collection, treatment, analysis, interpretation, generalisation) can be quantitative, qualitative or a

mixed method approach, defining what the researcher label as "scientific research method" in the largest sense possible."

A quantitative study is most suitable for this study as it allows for collecting and analysing numerical data. This will be required to create an appropriate model to explore the various options posed to the cement industry.

Using primary (formal quotes) and secondary (government reports, internal company reports, and integrated financial reports) data sources, the researcher can extract numerical data to create and populate the MCDA model. Furthermore, MCDA techniques such as the Analytical Hierarchy Process (AHP) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) are formulated as quantitative approaches. For the purposes of this study a TOPSIS method was utilized.

3.5 Research strategy

According to (Kiyala, 2019), at the heart of the research lies the methodology and the methods to generate knowledge. Secondary information consists of data sources already gathered, including government reports, industry studies, and archived data sets. Limited primary data will be required to fulfil the study and will be primarily limited to formal quotes for the transportation portion of the TOPSIS model.

A secondary research (archival research) approach was adopted, with previously generated data to be interpreted to understand the current and future supply chain constraints. The researcher will require the limited use of primary data; this will be limited to a single questionnaire that verifies known knowledge as still accurate.

3.6 Time horizon

For this study, the researcher will adopt a cross-sectional time horizon. This means that the researcher will collect the data at a single time. This design was appropriate for this study as the study aims to identify the most suitable location for a manufacturing facility in South Africa based on specific criteria and numerical data. By collecting data at a single point, the researcher can provide an up-to-date, accurate representation of the situation at the time of the research.

3.7 Study sampling

The target population of this study was the inland cement industry. The list of possible producers was populated through publicly available data, with the target population in a limited geographical area. Through the capital and size intensiveness of the target population, the researcher can easily argue that oversight of possible missed participants is highly unlikely with reports cross-referencing

with a snowball sampling technique. By contacting one producer and gaining insight into potential other producers, which aligns with government reports, it is negated that the researcher missed any participants.

3.8 Empirical data collection

The researcher will leverage the relationship with the study population in the target population to confirm publicly available data sets. Data sets that are to be interpreted include:

- Scholarly articles, publicly available documents such as EIA's (Environmental Impact Assessments), news articles, technical publications, and specification sheets.
- The largest producer of gypsum's internal memos, management accounts, production forecasts, and reports. The researcher will utilise this to quantify current resource availability.
- Audited financial statements and integrated reports of the target population are available in the public domain.
- Verification of publicly available data through data gathering by senior management of target populations through a questionnaire. Requests will be made periodically by mail to constituents of each company in the target audience to verify information pertained in the public domain through cross-referencing with internal controls.

3.9 Statistical/data analysis

The main goal of the research is to create an MCDA model to propose the optimal geographical location for a gypsum manufacturing facility. The researcher will employ the following statistical/data analysis techniques:

- ***Descriptive statistics:*** Descriptive statistics will summarise and describe the data collected from questionnaires (request for quotes). This will include measures such as means and frequencies. This will be the only portion of primary data within the research.
- ***MCDA techniques:*** Techniques such as AHP and TOPSIS will be utilised to rank the options.
- ***Sensitivity analysis:*** A sensitivity analysis will be conducted on all the criteria to ensure the validity of the data.

Additionally, the researcher will use a geographical information system technology to overlay the geographical information on top of each other to allow better interpretation of the data.

3.10 Reliability and validity

Reliability and validity are important considerations in all aspects of research, both quantitative and qualitative approaches (Golafshani, 2003). The researcher will ensure reliability and validity in the study through the following methods.

3.10.1 Reliability

According to (Cohen *et al.*, 2017), different definitions exist for reliability in literature. (Jacob, 2017) defines it as a method of testing consistency, stability, and equivalence quality. Reliability is defined by (Zhu, 2013) as the consistency of measurements when the testing procedure is repeated. It is, hence, common practice that the consistency of the approach measures reliability through different researchers.

Reliability is ensured in this research findings by utilising an established, trusted research methodology, including an MCDA model, which has been proven reliable (Shekhovtsov *et al.*, 2021). The MCDA model is seen as a systematic and structured approach that enables decision-makers to compare multiple options based on various criteria based on relative importance and performance.

The reliability will be further increased by utilising multiple data sources, ensuring oversight is brought into the study design through a study leader who reviews the relevant research methods to eliminate bias further. The primary data's reliability will be ensured by cross-referening to secondary data obtained during the literature review.

3.10.2 Validity

Any research study's validity is a crucial component. It relates to the extent to which the research measures what it set out to measure (Heale & Twycross, 2015). Within the study, the researcher used numerous data sources, rigorous data analysis techniques, and a systematic and open research approach to ensure the validity of the research findings.

The researcher consulted several data sources, including a thorough assessment of the pertinent literature, interviews with business leaders, and surveys of the target population, to ensure the study's internal validity. These data sources were triangulated to ensure that the research conclusions were based on diverse viewpoints and sources.

3.11 Ethical considerations

This study is based on a quantitative research paradigm and will not touch on sensitive social issues. There are, however, still ethical considerations that need to be considered.

Ethics heavily rely on the frame of reference and is influenced by numerous aspects such as morality, culture, and affiliation. Early experiences in a researcher's life play a severe role in the ethical perspectives of students (Nittala *et al.*, 2018). This study must adhere to the North-West University (NWU) code of ethics, as illustrated on the NWU website (Corporate, 2018).

The first ethical consideration that needs to be considered is informed consent. This study will apply the essential elements as outlined to ensure informed consent. This consists of eight parts, as illustrated by (Roberts, 2010), of which only five are relevant to this study:

- A summary overview of the research conducted.
- A description of reasonable risks.
- An explanation of practical benefits any party may gather from the research.
- A detailed contact list of the researcher will allow the subject to contact the researcher should any queries arise in the future.
- A statement that participation is voluntary and that the participant will incur no penalty should the participant not be willing to contribute to the study.

Informed consent will only be required when using non-publicly available knowledge and will be held to the minimum in the scope of this study. For this study, a single questionnaire will be utilised that requires only single data points to be verified from an analytical viewpoint; this holds no ethical implications.

The second ethical consideration that needs to be considered is confidentiality. Since this study will hold confidential information from numerous sources with some commercial value, the confidentiality of data will need to be communicated to possible parties who can choose to keep the information personal should any harm be apparent in sharing this information.

Some ethical considerations are apparent while interpreting the data and must be eliminated, which can be summed up as bias. It is essential to note that across all research designs, bias exists and can occur at each stage of the research process (Smith & Noble, 2014). Since the researcher is employed by the leading supplier of the commodity in question, significant effort must be made to eliminate bias when interpreting data and setting up research methods.

This research paper will consider only corporate information, and hence, the extent of the Protection of Personal Information Act (4 of 2013) will have little to no impact on this study. However, the researcher will take great care to ensure compliance should any personal information be utilised in the study.

3.12 Executability

This study is seen to be executable based on the following criteria:

- The study sample will be the inland cement industry. The specific information required is mainly in the public domain in terms of released financial statements and integrated reports.
- The study is executable as all information is available and noted not easily, but the researcher can make concrete conclusions through interpolating data.
- Permission is granted for all sensitive data from the biggest producer of gypsum in South Africa.
- All costs incurred by the study are to be funded by the researcher.
- No sensitivity is forecasted in terms of vulnerable groups.
- Permission from initial target audience, who is defined as the pertinent producers of cement in the chosen area is given.

Through the above, it is illustrated that the study is executable.

CHAPTER 4 SYSTEMATIC LITERATURE REVIEW AND DATA ANALYSIS

4.1 Introduction to systematic literature review and data analysis

The fourth chapter of this dissertation focuses on conducting a methodical examination of the literature and data analysis that will act as the cornerstone for comprehending the subtleties and complexity of the gypsum industry within the cement value chain in the inland region of South Africa. This chapter attempts to provide a thorough, data-driven analysis that will guide subsequent decision-making processes by employing a multi-pronged strategy that uses publicly available data. The following are the chapter's goals:

- ***Overview of installed capacity:*** The first section will use data that is readily accessible to the public to provide a current summary of the installed capacity for cement mills in the inland region. Wherever possible, consumption data from the previous two years will be averaged to achieve this.
- ***Underexploited gypsum sources:*** Next, a summary of the three principal underused gypsum sources will be given: Richards Bay (KZN), Phalaborwa (Mpumalanga), and Loeriesfontein (Northern Cape). This will include information about the area, the quality, and the expected reserve amounts.
- ***Multi-Criteria Decision Analysis (MCDA) Model generation:*** The last and most complex component will focus on creating MCDA models to evaluate different gypsum sourcing options.

By utilising the analysis methods mentioned above, the researcher aims to, within this chapter, generate the following useable information:

- ***Gravitational model overview:*** A gravitational model method will be utilised to first find the ideal solution for a manufacturing facility bearing no consequence to the availability of raw materials. From here, further gravitational models will be generated to find the optimum placement of manufacturing facilities for each raw material resource. This will be used in the TOPSIS method.
- ***Transport Model:*** A thorough transport model that combines the value chain overview.
- Production Costing Environment: An estimated production costing environment will be developed to provide a financial perspective on various sourcing options.
- ***Application of the TOPSIS method:*** The model will be applied to various sourcing methods, and the TOPSIS method will be utilised to determine the best manufacturing site for the available sources.
- ***Criteria weighting:*** Relative weights will be assigned to each of the criteria to select the best choice out of the several possibilities of the possible gypsum sources.

By accomplishing these goals, this chapter seeks to establish a solid analytical framework that will be valuable to chapter 5 and further explore the optimisation of gypsum sourcing in the cement sector.

4.2 Value chains of cement and gypsum

Understanding the cement value chain is crucial to understanding the complexities of the gypsum manufacturing facility in South Africa's interior. The procedures that turn raw materials into cement, the finished product, make up the cement value chain. This section thoroughly describes the steps involved in making cement and emphasises how important gypsum is to those steps.

4.2.1 Cement manufacturing process

When manufacturing cement, various steps ensure a good quality cement is generated. Understanding and comprehending the steps required to understand where gypsum is incorporated is imperative.

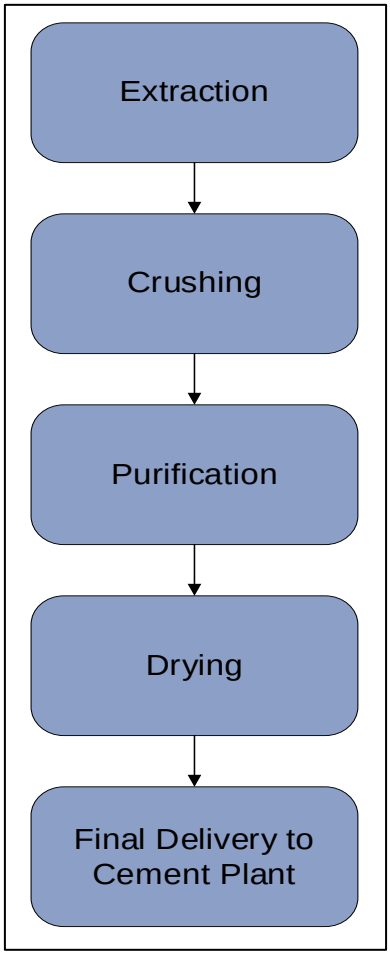

Figure 4.1: Flowchart indicating the cement value chain with different configurations

[Source: Own cotribution]

Figure 4.1 illustrates that the cement value chain has the following main steps:

- ***Mining of limestone:*** The process begins with limestone extraction from quarries. Limestone serves as the primary raw material for cement production.
- ***Crushing and blending:*** The limestone is crushed into a fine powder once mined. Other additives may be blended with the limestone at this stage, but gypsum has not been added yet.
- ***Calcination in a rotary kiln:*** The finely crushed limestone and blended additives undergo a burning process known as calcination in a rotary kiln. This process results in the formation of a product called clinker.
- ***Blending:*** The clinker is then transported to the blending step mixed with 3-5% gypsum to produce cement. Adding gypsum at this stage is crucial as it controls the setting time of the cement.
- ***Packaging:*** The cement is packaged for distribution once the blending process is complete.

It is noteworthy to mention that there are two types of cement factories:

- ***Integrated factories:*** These facilities undertake both the calcination and blending processes. They produce clinker and then mix it with gypsum to make cement.
- ***Blending plants:*** These facilities do not produce clinker. Instead, they source clinker from other locations and focus solely on blending. Both types of factories utilise gypsum in their operations. In South Africa, most producers with multiple facilities adopt a strategy where one facility produces enough clinker to supply both their primary integrated plant and their sub-blending facilities.

After understanding the cement value chain, the researcher can now start to analyse the value chains of gypsum.

4.2.2 Gypsum value chain for cement manufacturing

Gypsum has a distinct value chain that differs depending on its origin and is a necessary component in cement manufacture. The two types of gypsum most used in the cement industry in South Africa are natural and synthetic. To comprehend their significance and the procedures they go through before being used in cement production, the researcher now goes deeper into the value chains of both types.

4.2.2.1 Natural gypsum value chain

Before the extraction process starts, appropriate gypsum reserves are identified by geological surveys. This entails evaluating the quality, depth, and volume of the gypsum deposits. A value chain can be set up once a suitable reserve has been identified (Figure 4.2: Flowchart indicating the natural gypsum value chain.

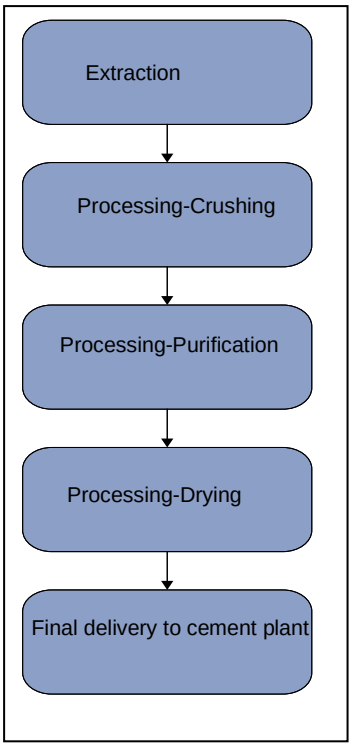

Figure 4.2: Flowchart indicating the natural gypsum value chain

[Source: Own contribution]

Illustrated is a flowchart showing the natural gypsum value chain, which is the overview of the value chain represented by natural gypsum manufacturing for cement use:

1. ***Extraction:*** After a location is chosen, the mining procedure begins. Overburden must be removed, followed by drilling, blasting, and transporting the gypsum to the processing area.
2. ***Processing:***
   - ***Crushing:*** To enable subsequent processing, the size of the mined gypsum is first reduced. Big boulders must be broken into more manageable pieces to do this. Gypsum is first crushed and then screened to separate the finer particles used to make cement from the coarser ones that may require additional processing.
   - ***Purification:*** Gypsum that has been mined may undergo a purification procedure to remove any undesired components or impurities, depending on its purity.

- ***Drying:*** Should wet processing be utilised during the purification stages, gypsum will then be required to be subsequently dried to remove moisture and make it more appropriate for storage and transportation.

3. ***Final delivery to cement plant:*** Gypsum is frequently loaded directly into trucks or packaged in bulk bags before being transported. This is traditionally done in South Africa by employing bulk road transport or, less often, using rail.

4.2.2.2 Value chain for synthetic gypsum

While sharing similarities with its natural counterpart, synthetic gypsum has its unique processes, especially when considering phospho-gypsum in the South African context. Phospho-gypsum, a byproduct of the phosphate fertiliser industry, is the predominant synthetic gypsum used in South Africa. Its preparation for cement uses primarily involves a wet process, introducing additional moisture to the product. This moisture must be reduced to optimise transport costs.

Figure 4.3: Flowchart indicating the phosphoric-gypsum value chain provides a comprehensive overview of the value chain associated with the production and delivery of phospho-gypsum for cement use:

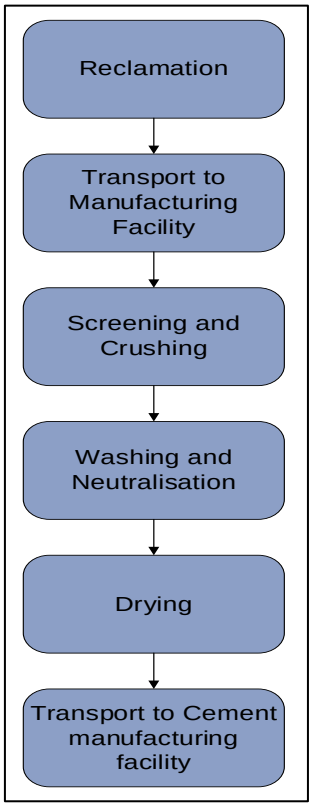

Figure 4.3: Flowchart indicating the phosphoric-gypsum value chain

[Source: Own contribution]

1. **Reclamation:**
    - ***Source:*** Phospho-gypsum is reclaimed from old fertiliser stacks, which typically contain around 6% free moisture.
2. **Transport to manufacturing facility:**
    - ***Moisture content:*** The reclaimed phospho-gypsum, with its intrinsic moisture content from the heaps (approximately 6% free moisture), is transported to the processing facility.

3. **Processing:**
    - ***Screening and crushing:*** The first step is removing large particles from the phospho-gypsum. This is achieved by screening the material and then crushing it to produce finer particles suitable for cement production.
    - ***Washing and neutralisation:*** To ensure the phospho-gypsum meets the quality standards for cement production, it undergoes washing and neutralisation processes. These steps help in removing impurities and unwanted components.
    - ***Drying:*** Given the wet nature of the processing methods, the phospho-gypsum contains excess moisture. It is then dried to reduce its free moisture content to around 20%, making it more suitable for transportation and storage.
4. **Transportation to final cement client.**
5. **Packaging and delivery:**
    - Depending on the requirements of the cement facility, the processed phospho-gypsum might be packaged in bulk or loaded directly into transport vehicles. In South Africa, transportation is primarily done via bulk road transport, with rail being a less frequent option.

Even though both synthetic and natural gypsum follow similar value chains, it is imperative to note that moisture at various stages plays a crucial role in the final landed costs of material for the end consumer. The intricate nature of synthetic gypsum means that material pre-processing intrinsically has a lower moisture content than the final material, allowing for a differentiated approach when choosing the optimal manufacturing facility.

4.3 Overview of installed capacity

When considering the overview of the installed capacity within the inland region, it is imperative to note that this is a very academically under-published sector within South Africa. It is important to understand that the industry operated under a lawful cartel within the South African environment and was exempted from competition legislation from the 1940s to 1996 (Theron & Van Niekerk, 2017). The impact of having a cartel exempted this industry from numerous regulatory bodies and neglected the growth of academic literature on consumption within this sector. The cartel was finally disbanded in 1996, which embodied researchers' interest in the empirical analysis of competition within the

industry (Mojapelo, 2017). Even through the newfound vigour in this region, no regulatory body exists that aggregates the production and sales data within this industry. This adds substantial complexity to analysing the supply chains within this industry, as little to no published work is conducted on the market share of competitors.

Before delving into the updated data, it is crucial to address the limitations of the existing literature. Table 2.2, primarily sourced from Edwards (2014) and Pelser *et al.* (2017), provides a snapshot of the installed capacities of various cement factories in the inland region of South Africa. While this information is a useful starting point, it is notably dated. Most of the data is from 2014 and 2017, which may not accurately reflect the current landscape of the cement industry.

To address this shortcoming, the researcher will utilise publicly available data and a singular survey to generate a new overview of cement manufacturing capacity within South Africa's inland region.

4.3.1 AfriSam South Africa

AfriSam Cement South Africa operates two main operating facilities within the inland region of South Africa. These two factories are known as Dudfield and Roodepoort, respectively.

From a gypsum perspective, AfriSam's Dudfield site in South Africa is involved in the production of cement, which requires various raw materials, including limestone, iron ore, shales, and, notably, gypsum. The gypsum is purchased and transported to the Dudfield site by rail and road, where it is stored in bunkers or stockpiles along with other raw materials.

In the cement production, gypsum plays a crucial role during the final stages. After the calcining process in the kilns, clinker is produced. This clinker may be sold as is or milled and mixed with gypsum and other additives to produce cement. Adding gypsum helps control the setting time of the cement, making it a vital component in the production process.

Gypsum is mixed with the clinker and possibly other additives and then milled to produce the final cement. This cement is either sold in bulk or packaged and palletised for distribution, which is carried out via truck and rail.

4.3.1.1 AfriSam Dudfield and Roodepoort

AfriSam Dudfield is the clinker production facility for both Dudfield and Roodepoort operations. AfriSam Dudfield has an installed blending capacity of 1.3 million tons per annum (Miller, 2021).

AfriSam Roodepoort is a blending facility for the AfriSam group and can blend 1 million tons per annum (Creamer, 2021).

4.3.2 Dangote Cement

Dangote Cement, also known as Sephaku Cement, a significant player in the cement industry, operates two facilities in the inland region of South Africa, like AfriSam. These facilities are strategically located to optimise production and distribution, and they serve different but complementary roles in the cement manufacturing process.

4.3.2.1 Aganang facility

Located in Lichtenburg, the Aganang facility is an integrated cement manufacturing plant. According to Dangote Cement's official operations website, this plant handles clinker production and blending. The blending capacity of the Aganang facility is noteworthy, with an installed capacity of 1.8 million tonnes per annum in clinker production, and blending capability is noted as 1.2 million tonnes per annum. This high capacity allows Aganang to serve as a significant supplier for local consumption and its sister facility, Delmas.

4.3.2.2 Delmas facility

The Delmas facility, in contrast, specialises solely in blending. It does not engage in clinker production but rather receives its clinker supply from the Aganang facility. The Delmas plant has a blending capacity of 1.5 million tonnes per annum, making it another substantial contributor to Dangote Cement's overall production capacity in the inland region.

The interconnected nature of these two facilities allows for a streamlined and efficient production process. The dual role that Aganang plays in clinker production and blending enables it to supply high-quality clinker to Delmas, which, in turn, focuses on blending to meet specific market demands. This symbiotic relationship enhances the operational efficiency of both plants and contributes to Dangote Cement's competitive edge in the market.

Figure 4.4: Dangote cement installed blending capacity split illustrates the installed capacity at the two facilities, totalling a combined 2.7 million tonnes per annum of blended capacity.

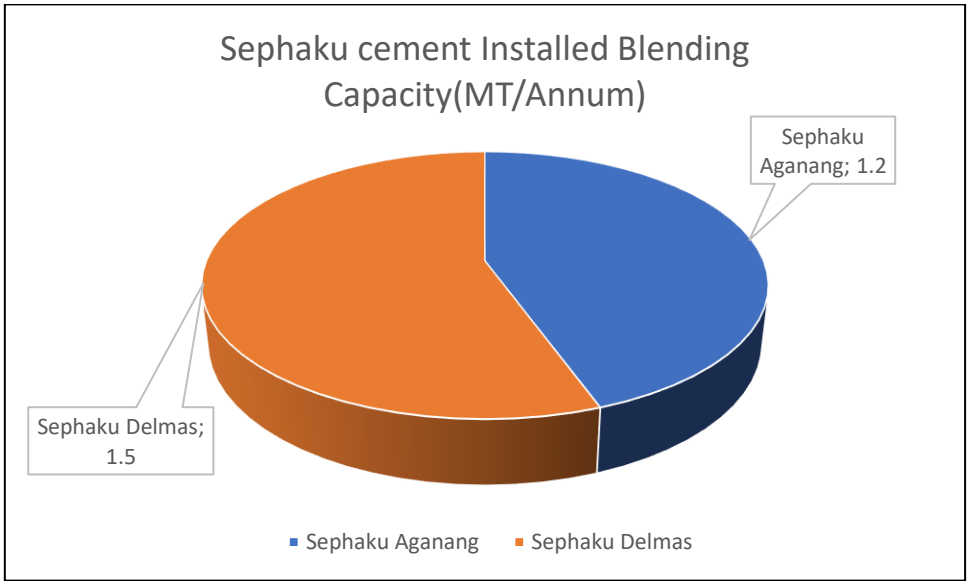

Figure 4.4: Dangote cement installed blending capacity split

[Source: Own contribution]

4.3.3 Lafarge Cement

Lafarge Cement operates on a model similar to that of AfriSam and Sephaku, with an integrated clinker production and blending facility at Lafarge Lichtenburg and a blending facility in Randfontein.

Lafarge is owned by a consortium called Holcim, which is known as one of the largest cement producers in the world. According to Holcim LTD's annual integrated financial statements, these two facilities' total installed blending capacity is 3.2 million tonnes per annum (LTD, 2021). The split is not easily recognisable within the public domain but will be identified using the market survey.

4.3.4 PPC Cement

PPC Cement is widely regarded as the producer with the largest installed capacity in Southern Africa. PPC operates three main blending facilities within the target population: PPC Dwaalboom, PPC Hercules, and PPC Slurry.

4.3.4.1 PPC Dwaalboom

PPC Dwaalboom is an integrated cement manufacturing plant with a clinker capacity of approximately 1.8 million tons per year. PPC Dwaalboom is in the North-West Province of South Africa, close to Dwaalboom. This factory has an installed blending capacity of approximately 850,000 tons annually (Bowyer, 2022).

4.3.4.2 PPC Hercules

PPC Hercules is a blending plant in Pretoria, Gauteng, South Africa. PPC Hercules gets its clinker supply from PPC Dwaalboom and serves as the PPC Group's milling and blending facility. PPC Hercules has an installed capacity of 1.15 million tons per annum and the combined capacity of Hercules and Dwaalboom is cited as 2 million tons per annum (Corporate, 2019). PPC Hercules is supplied by PPC Dwaalboom's internal clinker manufacturing capacity.

4.3.4.3 PPC Slurry

PPC Slurry is an integrated cement plant close to Mahikeng in the North-West Province of South Africa. This plant is considered an integrated plant and was upgraded in 2017 from a 1.2 million tons per year manufacturing facility to a 1.9 million tons per year manufacturing facility (Olieveira, 2017).

4.3.5 Mamba Cement Company

The Mamba cement company owns and operates a cement manufacturing facility in the Northam region of Limpopo, South Africa (Pelser *et al.*, 2017). Mamba has only one integrated facility with a blending capacity of more than 1 million tons per annum (Barradas, 2014). Although no official blending capacity number is available in the public domain, the value quoted by (Barradas, 2014) aligns with the information provided by the senior leadership of Mamba Cement in the official questionnaire.

4.3.6 Summary of installed capacity

The summary of installed capacity for the local inland cement industry is illustrated in the table below with reference made to the original literature study, in-depth literature study, and questions (Table 4.1). This will highlight the discrepancy between the sources of information. For this study, the researcher will utilise the data provided by the surveys where available.

Table 4.1: Summary of client consumption from multiple sources

Cement Factory	Approximate capacity from original literature review (MT/yr.)	Approximate capacity from in-depth literature review (MT/yr.)	Approximate capacity from survey (MT/yr.)
AfriSam Dudfield	1.80	1.3	1.5
AfriSam Roodepoort	1	1	1
Sephaku Aganang	1.25	1.2	1.2
Sephaku Delmas	1.40	1.5	1.4

Cement Factory	Approximate capacity from original literature review (MT/yr.)	Approximate capacity from in-depth literature review (MT/yr.)	Approximate capacity from survey (MT/yr.)
Lafarge Lichtenburg	2	Portion of 3.2	2.1
Lafarge Randfontein	1	Portion of 3.2	1
Dwaalboom	1	1.8	1.8
Slurry	1.52	1.9	1.9
Hercules	0.58	1.15	1.15
Mamba	1	1	1.32
Total	12.55	14.05	14.37

[Source: Own contribution]

The survey did not provide information from PPC factories (Dwaalboom, Slurry, and Hercules) but was only verified via email.

4.4 Overview of underexploited gypsum sources

South Africa has abundant mineral resources due to its diversified geological landscape. Among these, various sources of gypsum, a necessary ingredient in cement manufacture, are still mostly untapped. These undeveloped deposits can significantly alter the cement industry's gypsum supply chain, reducing reliance on imports and possibly lowering costs.

The three significant underutilised gypsum sources in the nation are highlighted in this section:

- ***Natural gypsum resource close to Loeriesfontein:*** Due to the distinctive geological and climatic features of the area, Loeriesfontein, which is in the Northern Cape Province, is thought to contain sizable amounts of natural gypsum. For the remainder of this report, the researcher will refer to this resource as "Loeriesfontein resource".

- ***Phosphoric gypsum resource near Richards Bay:*** A significant port city in KwaZulu-Natal, is close to several industrial enterprises, including those involved in phosphate production. As a byproduct of these businesses, phosphoric gypsum is a possible cement manufacturing source. For the remainder of this report, the researcher will refer to this resource as "Richards Bay resource".

- ***Phosphoric gypsum resource near Phalaborwa:*** Located in the Limpopo Province, it is another centre for phosphate-related enterprises. Like Richards Bay, phosphoric gypsum, a byproduct of these industries, offers potential for mining and use in cement production. For the remainder of this report, the researcher will refer to this resource as "Phalaborwa resource".

The researcher will examine these sources in the following sections: their traits, projected reserves, difficulties, and potential advantages. The main objective is to give a thorough understanding of these resources and their possible effects on the cement industry in South Africa.

4.4.1 Loeriesfontein resource

4.4.1.1 Geological overview/origin

Loeriesfontein, situated within the Northern Cape Province, is part of the vast Karoo Basin (Smithard *et al.*, 2015). The Karoo Basin is known for its sedimentary rock formations, which have evolved over millions of years (Jones & Scheiber-Enslin, 2022). The presence of gypsum in this region can be attributed to ancient evaporative water bodies, similar to what can be seen in (Rivers *et al.*, 2021) from their findings in the Qatar water basins. As these water bodies evaporated under the arid conditions, they left behind deposits of minerals, including gypsum. Over time, these deposits were buried under sediment layers, leading to the formation of gypsum-rich strata. The unique combination of the region's geological history and its arid climate has made it a potential reservoir for natural gypsum.

4.4.1.2 Background and current operations

Loeriesfontein, located in the expansive Northern Cape Province, is home to the Boesmanland gypsum mine (Northern Cape, 2017). This mine, while not extensively documented in public records, holds significance in the gypsum supply chain of South Africa.

The Boesmanland mine, officially recognised by the Northern Cape Department of Mineral Resources (DMR) (Northern Cape, 2017), is owned by Saint-Gobain Construction Products South Africa. Saint-Gobain, a global leader in construction products, has a longstanding history of mining operations, and its presence in Loeriesfontein underscores the potential value of the Boesmanland gypsum resource.

The mine operates as an opencast mine, extracting minerals from an open pit. This method is particularly suitable for resources like gypsum that are located closer to the earth's surface. The current mining right for Boesmanland spans an impressive 400 hectares, as highlighted by Francis van Jaarsveld in his study titled "Characterising and mapping of wind transported sediment associated with opencast gypsum mining" (Van Jaarsveld, 2008).

The mining operations are technologically advanced, employing Wirtgen continuous surface milling miners. These machines are designed to extract gypsum efficiently with minimal wastage. The gypsum is extracted in strips, each measuring 1.9 m in width and having a cutting depth of 120 mm. These strips can range from 200 to 600 m in length. The operational efficiency of the Wirtgen miners

is evident in their ability to cut, crush, and prepare the gypsum for shipment, reducing it to a size of 20 mm or less (Van Jaarsveld, 2008).

While public records suggest that the Boesmanland mine remains operational, industry insights paint a slightly different picture. According to (Corporate, 2023), significant quantities of gypsum from this mine are not currently being utilized within the study population. This discrepancy between operational status and actual market utilization raises questions about the mine's current production capacity, market challenges, or potential strategic decisions by Saint-Gobain.

4.4.1.3 Geographical location and footprint

The Loeriesfontein gypsum deposit is located approximately 80 km north of the town of Loeriesfontein, with the specific coordinates being 30°12'38.8"S 19°30'19.5"E, as illustrated in Figure 4.5. The deposit is somewhat isolated, with no direct access to public roads. The primary means of reaching the deposit is via a locally maintained dirt road, which stretches for about 86 km before connecting to the R357 Provincial Road. This lack of direct access to major roads can pose challenges in terms of transportation and logistics.

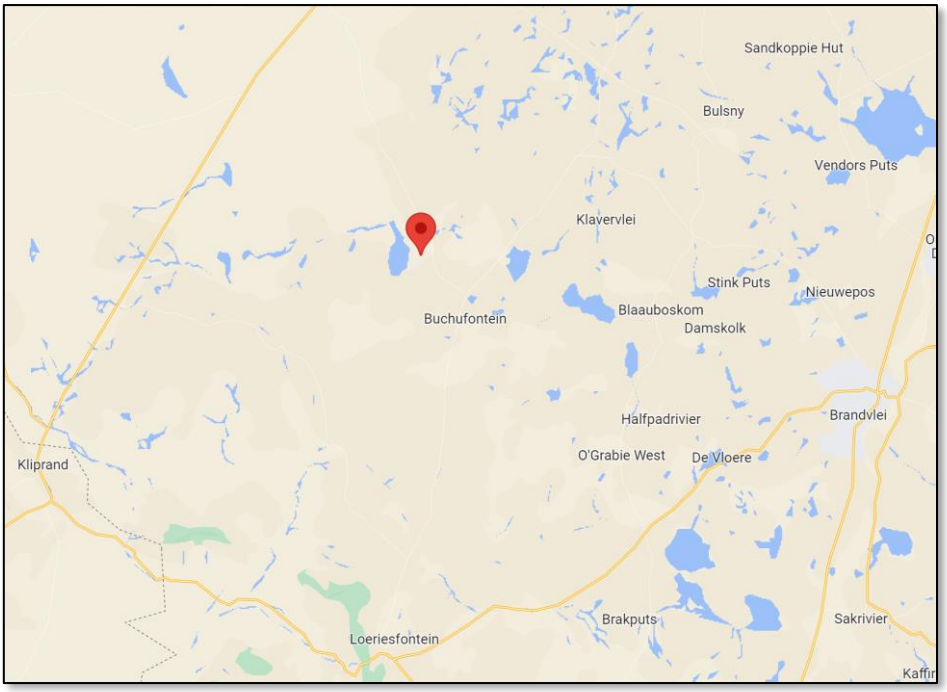

Figure 4.5: Map illustrating Loeriesfontein deposit location

[Source: Google Earth]

The infrastructure surrounding the Loeriesfontein deposit is predominantly rural. Loeriesfontein, the closest town, had a population of approximately 2,744 residents per the 2011 census (SA, 2011). While it provides basic amenities, its small size and limited infrastructure might not support large-scale industrial operations.

The nearest industrialized town is Upington, located about 360 km away. Upington, a more developed urban centre, offers better infrastructure, transportation facilities, and other essential services. However, its distance from the deposit can raise concerns, especially when considering mined gypsum transportation, manufacturing spares' availability, human resource considerations, and other operational requirements such as diesel.

Given the deposit's remote location and the limited infrastructure in the immediate vicinity, any potential exploitation must factor in the logistical challenges. Transportation costs for bringing in equipment and shipping out mined gypsum could be significant. Additionally, the availability of skilled labour might be a concern, given the rural nature of the surrounding area. Lastly, consistent supplies, such as diesel for machinery, would need careful planning and logistics, considering the distance from major supply centres.

4.4.1.4 Resource size and quality

The gypsum extracted from Loeriesfontein is of high quality, with a purity level ranging between 95-98% on a dry basis. This level of purity is advantageous for several reasons:

- ***Processing efficiency:*** High purity means minimal processing is required to prepare the gypsum for end-use applications, reducing operational costs.
- ***Transportation efficiency:*** The gypsum from Loeriesfontein has a free moisture content of below 5%. This low moisture content, combined with its high purity, ensures efficient transportation. Essentially, when transporting this gypsum, one primarily transports the product itself and not unnecessary moisture, leading to cost savings in transportation.

A Wirtgen continuous miner ensures the gypsum is extracted efficiently and consistently, maintaining its high purity levels(Van Jaarsveld, 2008)

While there is limited published data on the exact size of the Loeriesfontein gypsum deposit, its extent is noteworthy. According to van Jaarsveld (Van Jaarsveld, 2008), the mining right for the deposit spans an area of 400 hectares. Furthermore, based on insights from Mr Goudriaan, derived from previous engagements, the proven reserves of the deposit are estimated to be around 18 million tons (Goudriaan, 2023). Beyond this, there are substantial unproven reserves, indicating that the actual size of the deposit could be even larger.

4.4.2 Richards Bay resource

4.4.2.1 Geological overview/origin

Richards Bay, located along the northeastern coast of South Africa, is a significant port and a hub for various industries. Foskor, a local phosphate manufacturing company in South Africa, owns and operates a phosphoric-acid manufacturing facility in Richards Bay (Masok *et al.*, 2018). Phosphoric gypsum, or phosphogypsum, is a byproduct of the process used to convert phosphate rock into phosphoric acid (El Zrelli *et al.*, 2018).

Illustrated in Figure 4.6, when phosphate rock is reacted with sulfuric acid in these plants, phosphoric acid is produced, and phosphogypsum is generated as a byproduct. Given the volume of phosphate processing in the region, significant amounts of phosphogypsum are produced, making it a potential resource for various applications, including cement production.

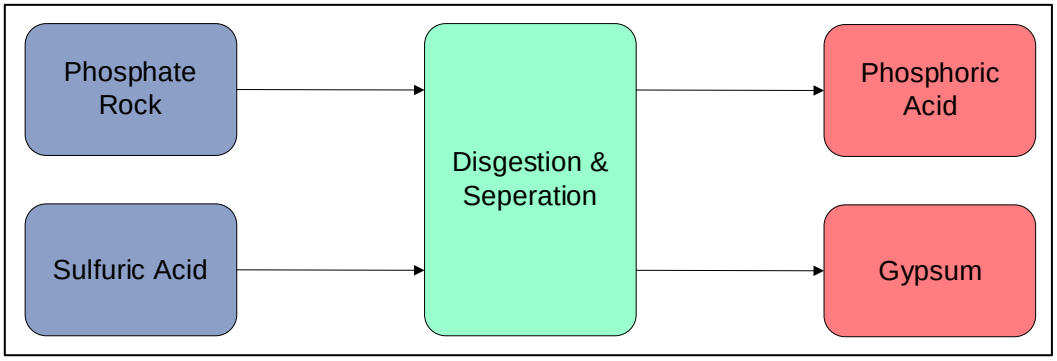

Figure 4.6: Manufacturing process of phospho-gypsum from phosphoric acid

[Source: Own contribution]

It is important to note that both the current sources of phosphoric gypsum (Rustenburg and Potchefstroom) originated from the same apatite rock (phosphoric rock) as the Richards Bay resource (Corporate, 2022). This is important as the impurities within the final phosphogypsum, which affect the suitability for cement use, mainly rely on the apatite rock source used when manufacturing the gypsum (Grabas *et al.*, 2019).

4.4.2.2 Background and current operations

The Richards Bay gypsum resource is owned by Foskor, a leading South African producer of phosphoric acid, sulphuric acid, and granule fertilizer (World, 2012). Despite owning the resource, Foskor does not actively market the gypsum derived from it. According to (World, 2012), some environmental concerns are raised due to the leaching of the current gypsum stacks.

Even though Foskor does not actively market the resource, the resource is exploited under a royalty agreement by EnviroMzingazi Gypsum (EMG) (Savids, 2018), a company specializing in the extraction and marketing of gypsum.

The Richards Bay gypsum resource is unique in its composition. It comprises both a historic stack of stored phosphogypsum and what is termed "new horizon gypsum". The latter is produced daily as a byproduct of Foskor's operations. However, instead of being stored or processed further, the new horizon gypsum is disposed of via a dense water marine outfall system. This method of disposal, while efficient, also indicates the potential for future expansion and utilization of this gypsum, although such prospects are beyond the scope of this report. According to a parliamentary written reply to questions posed by Dr MJ Cardo, the minister of economic development noted that Foskor produces approximately 2.0 million tonnes of gypsum annually in this fresh stream (Assembly, 2016).

Interestingly, despite the vast reserves, there is no dedicated processing plant for refining the gypsum for use in cement at this resource. Instead, the primary utilization of the gypsum from this resource is by local sugarcane farmers, who use it to improve soil conditions and enhance crop yields (Savids, 2018).

4.4.2.3 Geographical location and footprint

As illustrated in Figure 4.7, the Richards Bay gypsum deposit is strategically located within the Richards Bay local municipality, with the specific coordinates being 28°78'62"S and 32°00 '10"E. One of the key advantages of this deposit's location is its direct accessibility to the R34 highway, a major transportation route. This direct access ensures efficient transportation and logistics, making bringing in equipment and shipping out mined gypsum easier.

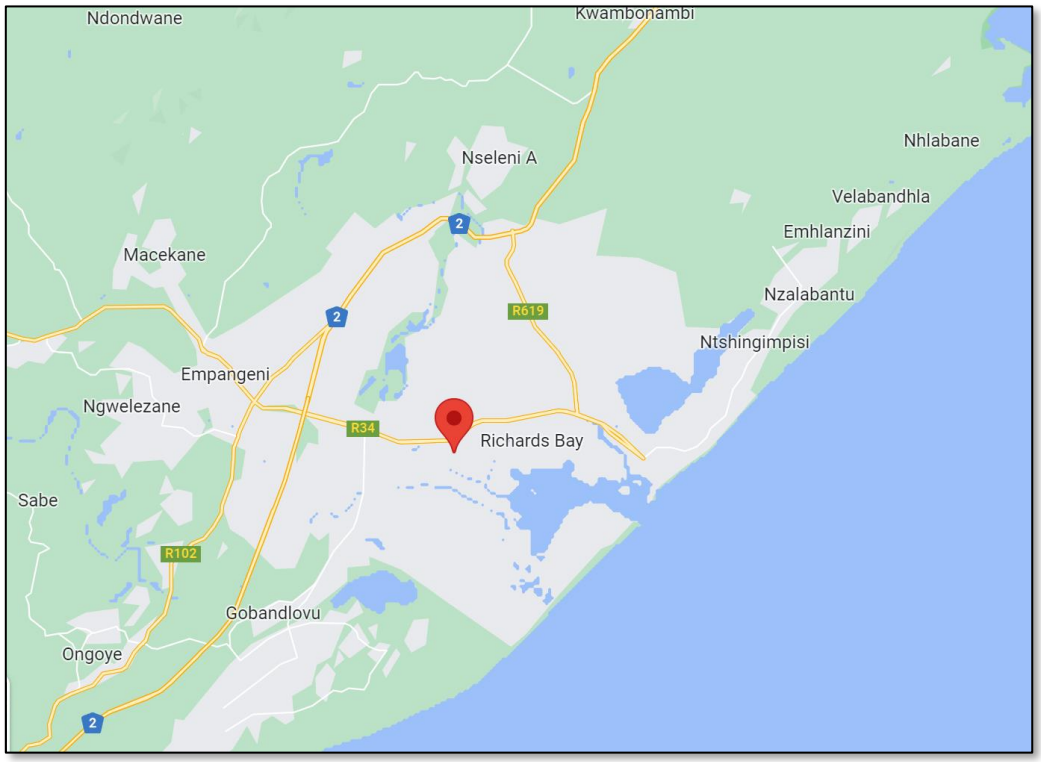

Figure 4.7: Map illustrating Richards Bay deposit geographical location

[Source: Google Earth]

Another significant advantage of the Richards Bay deposit is its proximity to the Richards Bay harbour, which is a mere 15 km away. The harbour is one of the largest ports in Southern Africa, facilitating both national and international trade. This proximity to the harbour simplifies the logistics of transporting gypsum and opens potential export opportunities, strategically positioning the deposit for both local consumption and international trade.

Richards Bay is an industrialized town, ensuring the necessary resources for large-scale operations are readily available. Whether it's skilled labour, machinery, manufacturing spares, or other operational requirements, the town's developed infrastructure ensures that these needs can be met locally. This reduces the operational challenges that might be faced in more remote or less developed locations.

4.4.2.4 Resource size and quality

The Richards Bay gypsum deposit, as surveyed by Henlu du Preez in February 2020, holds an estimated 7.445 million tons of gypsum, as illustrated in Annexure E.

Annexure D: Geographical surveys. Laboratory tests conducted in April 2022 further shed light on the quality of this resource, revealing an average purity of 96.1% on a dry basis, as illustrated in *Annexure C: Lab Reports*. This level of purity is indicative of the resource's high quality and offers several advantages:

- Processing efficiency: The high purity of the Richards Bay gypsum means that minimal processing is required to prepare it for end-use applications. This translates to reduced operational costs and faster processing times.
- Transportation efficiency: However, the gypsum from Richards Bay has a higher free moisture content, averaging 16%, compared to the 10% observed in Phalaborwa. While its high purity is a boon for transportation, the elevated moisture content poses a challenge. When transporting this gypsum, a significant portion of the weight is due to the moisture, which can impact transportation costs and efficiency.

Despite the moisture challenge, the quality of the gypsum remains consistent, ensuring that it meets industry standards and requirements.

Regarding the deposit's size, the aerial geographical survey by Henlu du Preez provides a clear picture. The estimated 7.445 million tons is a substantial volume, indicating that the deposit can support long-term mining operations. The high purity and significant volume position the Richards Bay gypsum deposit as a valuable resource in South Africa's gypsum industry.

4.4.3 Phalaborwa resource

4.4.3.1 Geological overview/origin

Phalaborwa, located in the heart of the Limpopo Province, is renowned for its vast mineral wealth, particularly its rich deposits of phosphate minerals (Gómez-Arias *et al.*, 2022). Foskor, a leading phosphate manufacturer in South Africa, has significant operations in Phalaborwa, serving as the source for most phosphate rock in Southern Africa (Porteus, 2018). Like the Richards Bay facility, the Phalaborwa plant, operated by Sasol, converted phosphate rock into phosphoric acid, which yields phosphogypsum as a byproduct. The manufacturing facility in Phalaborwa involved a similar process to Figure 4.6.

Drawing parallels with the Richards Bay resource, it's pivotal to highlight that the phosphogypsum produced in Phalaborwa originates from the same apatite rock source as that of Richards Bay. This commonality in the source rock is significant. The impurities in the resultant phosphogypsum, which can influence its appropriateness for cement production, are largely determined by the characteristics of the apatite rock used in the phosphoric acid production process (Grabas *et al.*, 2019).

4.4.3.2 Background and current operations

Currently, the Phalaborwa gypsum resource is not being exploited on a large scale. According to insights from Mr Goudriaan, the resource remains largely untapped, especially in an economic context (Goudriaan, 2023). There are localized efforts by individuals to reclaim some of the gypsum for use by local farmers. However, these efforts are minimal and do not significantly impact the vast reserves available at the resource. In the broader scope of this report, such localized reclamation is not of primary significance.

While the current exploitation of the Phalaborwa gypsum resource is limited, its future holds promise. The resource has been earmarked for large-scale exploitation by Rainbow Rare Earths (Singh, 2021), a company specializing in extracting rare earth minerals. The focus of this exploitation will be on extracting rare earth minerals, which constitute a mere 0.6% of the total stack (Jamasmie, 2023). However, the extraction process will involve processing the entire stack.

This presents a unique symbiotic opportunity. The extraction of rare earth minerals does not render the gypsum unusable for cement production. As such, while Rainbow Rare Earths focuses on rare earth minerals, the processed gypsum can be reclaimed for use in the cement industry. This dual-purpose processing can lead to significant cost savings, especially regarding material handling, making gypsum extraction more economically viable.

4.4.3.3 Geographical location and footprint

The Phalaborwa gypsum deposit is located within the Phalaborwa local municipality, with its specific coordinates being 23°58'53.2"S, 31°05'32.3"E; this is illustrated in Figure 4.8. A significant advantage of this deposit's location is its direct accessibility to the R40 road, which further connects to the primary N4 Corridor. This connectivity ensures efficient transportation routes for incoming equipment and outgoing mined gypsum.

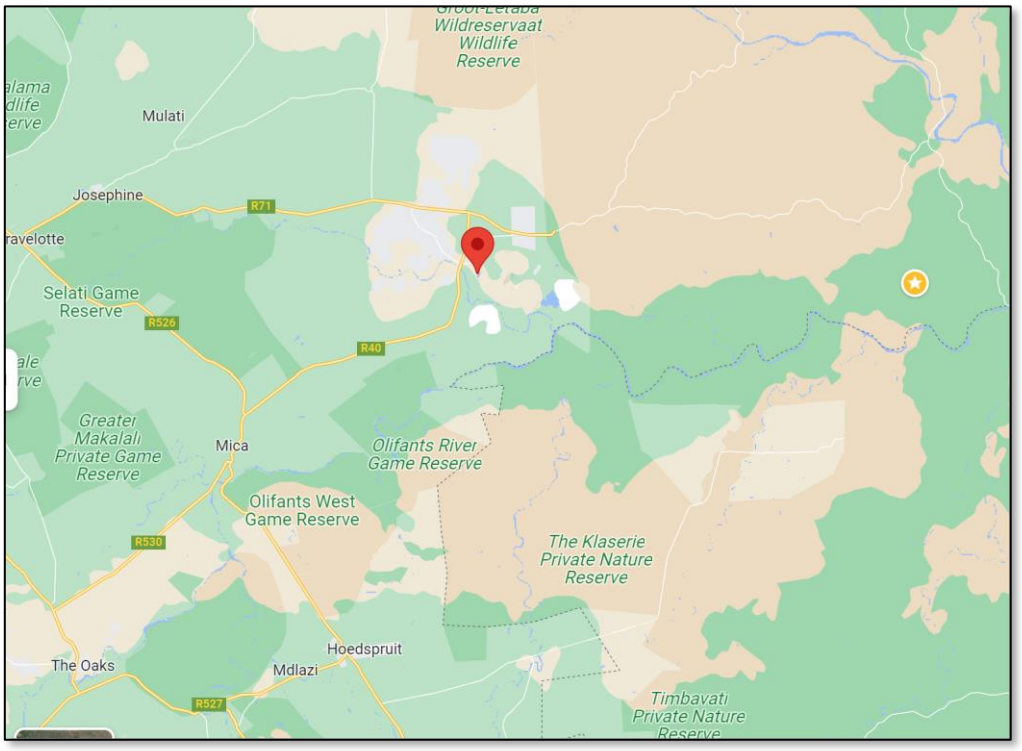

Figure 4.8: Map illustrating Phalaborwa resource geographical location

[Source: Google Earth]

Phalaborwa, while a rural town, has an industrialized character, reflected in its infrastructure and amenities. As per the 2011 census, the town had a population of 13,108 residents. This population size, combined with the town's industrial nature, ensures that basic resources required for mining operations, such as skilled labour, machinery, and other operational necessities, are available locally.

However, the closest metropolitan area is Polokwane, located approximately 212 km away for more specialised needs or larger-scale operations. While this distance is not insurmountable, it does add a layer of logistical consideration, especially for frequent or large-scale transportation needs.

While Phalaborwa offers better infrastructure and accessibility compared to more remote locations like Loeriesfontein, it still presents certain challenges. The town's rural nature means that while basic operational requirements can be met locally, more specialized needs might necessitate sourcing from farther away, like Polokwane. This can impact operational efficiency and costs.

4.4.3.4 Resource size and quality

The gypsum extracted from Phalaborwa is of exceptional quality, boasting a purity level of 98.6% on a dry basis, as per *Annexure C: Lab Reports*. Such a high purity level offers several advantages:

- ***Processing efficiency:*** The near-perfect purity of the Phalaborwa gypsum means that very minimal processing is required to prepare it for its end-use applications. This reduces operational costs and ensures a faster turnaround in processing times.

- ***Transportation efficiency:*** The gypsum from Phalaborwa has a free moisture content of 10%. When combined with its high purity, this relatively low moisture content ensures that transportation is highly efficient. When transporting this gypsum, most of the weight is the product itself, not unnecessary moisture. This characteristic leads to cost savings in terms of transportation and ensures that a higher volume of the actual product is transported.

Based on an article from Miningmx (Ryan, 2021), the Phalaborwa gypsum deposit is substantial, estimated at 35 million tons. Such a volume indicates that the deposit can support long-term mining operations, ensuring a consistent supply of high-quality gypsum for years.

4.4.4 Summary of underutilized gypsum resources

With its diverse geological landscape, South Africa is rich in mineral resources. Among these, gypsum, a crucial component in cement production, is a significant underutilized source. These dormant deposits can reshape the gypsum supply chain for the cement industry, potentially reducing dependence on imports and possibly decreasing costs. This section provides a comparative analysis of the country's three significant underutilized gypsum sources: the Loeriesfontein resource, the Richards Bay resource, and the Phalaborwa resource.

Table 3.2: Gypsum resources summative comparison

Resource	Location (Nearest Town & Province)	Estimated Resource Size (Million Tons)	Purity (%)	Resource Moisture Content (%)	Accessibility (Rating)	GPS Coordinates
Loeriesfontein	Loeriesfontein, Northern Cape	18 (Proven)	95-98	<5	Difficult	30°12'38.8"S, 19°30'19.5"E
Richards Bay	Richards Bay, KwaZulu-Natal	7.445	96.1	16	Easy	-28.7862°S, 32.0010°E
Phalaborwa	Phalaborwa, Limpopo Province	35	98.6	10	Medium	23°58'53.2"S, 31°05'32.3"E

[Source: Own contribution]

* Note: The accessibility ratings are based on the provided information and might need further validation based on more detailed logistical and infrastructural assessments.

Key Observations from Table 4.2:

- ***Purity:*** All three resources offer high-purity gypsum, with Phalaborwa leading at 98.6%. Such purity levels reduce the need for extensive processing, ensuring cost savings.
- ***Moisture content:*** Loeriesfontein gypsum stands out with the lowest moisture content, making it the most efficient for transportation. In contrast, despite its high purity, the Richards Bay resource has a higher moisture content, which can impact transportation costs.
- ***Accessibility:*** With its proximity to the R34 highway and the Richards Bay harbour, Richards Bay offers the best logistical advantage. In contrast, Loeriesfontein, with its dirt road access, might pose transportation challenges.

As the researcher delves deeper into analysing these resources, it becomes evident that each deposit offers challenges and opportunities with its unique characteristics.

4.5 Multi-Criteria Decision Analysis Model Generation

4.5.1 Gravitational model generation

In the initial phase, the researcher's primary attention will be directed towards clients within the cement industry, to disregard any limitations related to the availability of raw materials. This will establish the standard for the optimal solution, which will then be employed in the TOPSIS approach inside the MCDA model framework. The subsequent models will incorporate the accessibility and geographical distribution of raw materials, facilitating a fully nuanced comprehension of the most advantageous operational approach.

4.5.1.1 TOPSIS-method optimal gravitational model clients only

To develop a complete gravity model encompassing the entire cement industry's terrain within the chosen geographical bounds, the researcher synthesised data from two main sources. Initially, the researcher utilised the consumption statistics presented in Table 4.1, providing a comprehensive overview. The table provides a comprehensive overview of the prevailing consumption patterns in the industry, drawing upon a synthesis of historical records and newly constructed surveys from this study. The surveys played a crucial role in ensuring that the model accurately represents the latest and most precise consumption trends.

To enhance the accuracy and effectiveness of the model, the researcher incorporated the consumption data into the analysis, taking into consideration the insights obtained from the overview of the installed capacity section, which provided a summary of the installed capacity. This section

offers highly significant info about the geographical positioning of each institution, specifically providing their precise GPS coordinates. The amalgamation of these two datasets was of paramount importance. The utilisation of this method not only facilitated comprehension of consumption patterns but also facilitated the identification of precise consumption sites, establishing the foundation for the gravitational model.

Table 4.3: Gravitational method client information

Cement Factory	Approximate Location	Latitude (Decimals)	Longitude (Decimals)	Tons (MT)	Gypsum Dosage (%) Dry Weight	Usage per annum (Tons)	Coordinates (Degrees, Minutes, Seconds)
AfriSam Dudfield	Lichtenburg, North-West, South Africa	-26.1843333	25.99281	1.5	5%	90000	26°11'03.6"S 25°59'34.1"E
AfriSam Roodepoort	Roodepoort, Gauteng, South Africa	-26.1795556	27.88419	1	5%	60000	26°10'46.4"S 27°53'03.1"E
Sephaku Aganang	Lichtenburg, North-West, South Africa	-26.1683333	25.86825	1.2	5%	72000	26°10'06.0"S 25°52'05.7"E
Sephaku Delmas	Delmas	-26.1548611	28.69231	1.4	5%	84000	26°09'17.5"S 28°41'32.3"E
Lafarge Lichtenburg	Lichtenburg, North-West, South Africa	-26.237	26.181	2.1	5%	126000	26°08'11.9"S 26°10'52.1"E
Lafarge Randfontein	Randfontein, Gauteng, South Africa	-26.2069167	27.6615	1	5%	60000	26°12'24.9"S 27°39'41.4"E
Dwaalboom	Dwaalboom, North-West, South Africa	-24.81	26.831	1.8	5%	108000	24°48'38.9"S 26°49'50.1"E
Slurry	Lichtenburg, North-West, South Africa	-25.8148056	25.84583	1.9	5%	114000	25°48'53.3"S 25°50'45.0"E
Hercules	Pretoria, Gauteng, South Africa	-25.722	28.17	1.15	5%	69000	25°43'20.7"S 28°10'13.9"E
Mamba	Northam, Limpopo, South Africa	-24.986	27.546	1	5%	60000	24°59'12.6"S 27°32'48.6"E

[Source: Own contribution]

Table 4.3, contains information on the clients involved in the gravitational method by means of the Haversine formula. The geographical placement of each cement factory had a crucial role in establishing the distance to a certain site. The distance was calculated with the Haversine formula. This mathematical equation determines the most direct distance between two points on a spherical surface based on their latitude and longitude coordinates expressed in decimal degrees (Basyir *et al.*, 2017:270).

The Haversine formulae are formulated by (Azdy & Darnis, 2020:012104) as follows:

$$distance = 2.R.arcsin\left(\sqrt{sin^2\left(\frac{\Delta lat}{2}\right) + cos(latitude2).cos(latitude1).sin^2\left(\frac{\Delta long}{2}\right)}\right)$$

Within the Haversine formula, the value of R is 6371, equivalent to the Earth's average radius in kilometres.

The latitude and longitude of each factory were separately utilized in collaboration with the arbitrarily chosen point at a random location, this was utilized to serve as the first iteration and bears no value to the final location chosen.

The distance for each factory as indicated in table 4.4 was thereafter multiplied by the entire quantity of gypsum that requires transportation, as seen in Table 4.3.

The product is then referred to as the 'arm weight' and is denoted by the unit KM*T (Kilometre multiplied by ton). By utilising this method, Table 4.4 was generated:

Table 4.4: Gravitational workbook cement industry clients

Company	Cement Factory	Distance To optimal location (KMS)	Arm Weight (KM*T)
AfriSam South Africa PTY LTD	AfriSam Dudfield	51.33709259	77.00563889
AfriSam South Africa PTY LTD	AfriSam Roodepoort	144.8691945	144.8691945
Dangote Cement	Sephaku Aganang	62.05795631	74.46954757
Dangote cement	Sephaku Delmas	224.7034206	314.5847889
Lafarge Africa	Lafarge Lichtenburg	39.64862914	83.2621212
Lafarge Africa	Lafarge Randfontein	123.5327775	123.5327775
PPC	Jupiter	135.1375065	243.2475117

Company	Cement Factory	Distance To optimal location (KMS)	Arm Weight (KM*T)
PPC	Slurry	63.17972468	120.0414769
PPC	Hercules	174.2710262	200.4116802
The Mamba Cement Factory	Mamba	155.5218399	155.5218399
Total			1536.946577

[Source: Own contribution]

The Excel Solver tool was utilised to ascertain the most advantageous site for a gypsum manufacturing facility. The goal was to minimise the total product of KM*T for the model by manipulating the coordinates of the arbitrary point. The coordinates obtained from the optimisation procedure indicate the optimal site for establishing a gypsum manufacturing facility, considering solely the transportation expenses associated with the value chain.

It is vital to underscore that this model signifies the preliminary iteration, wherein distances are computed as the shortest Euclidean distance between locations. In the subsequent sections, the researcher shall enhance this model by integrating Geographical Information System (GIS) software. This approach enables the computation of distances by utilising real road networks, offering a more accurate depiction of transportation costs and obstacles.

By utilising this strategy, the optimal location for the manufacturing facility, negating the access to raw resources, was generated by the model as a point with a latitude of -25.975 and a longitude of 26.452. The researcher could plot this point on a map by utilising the Google Maps platform.

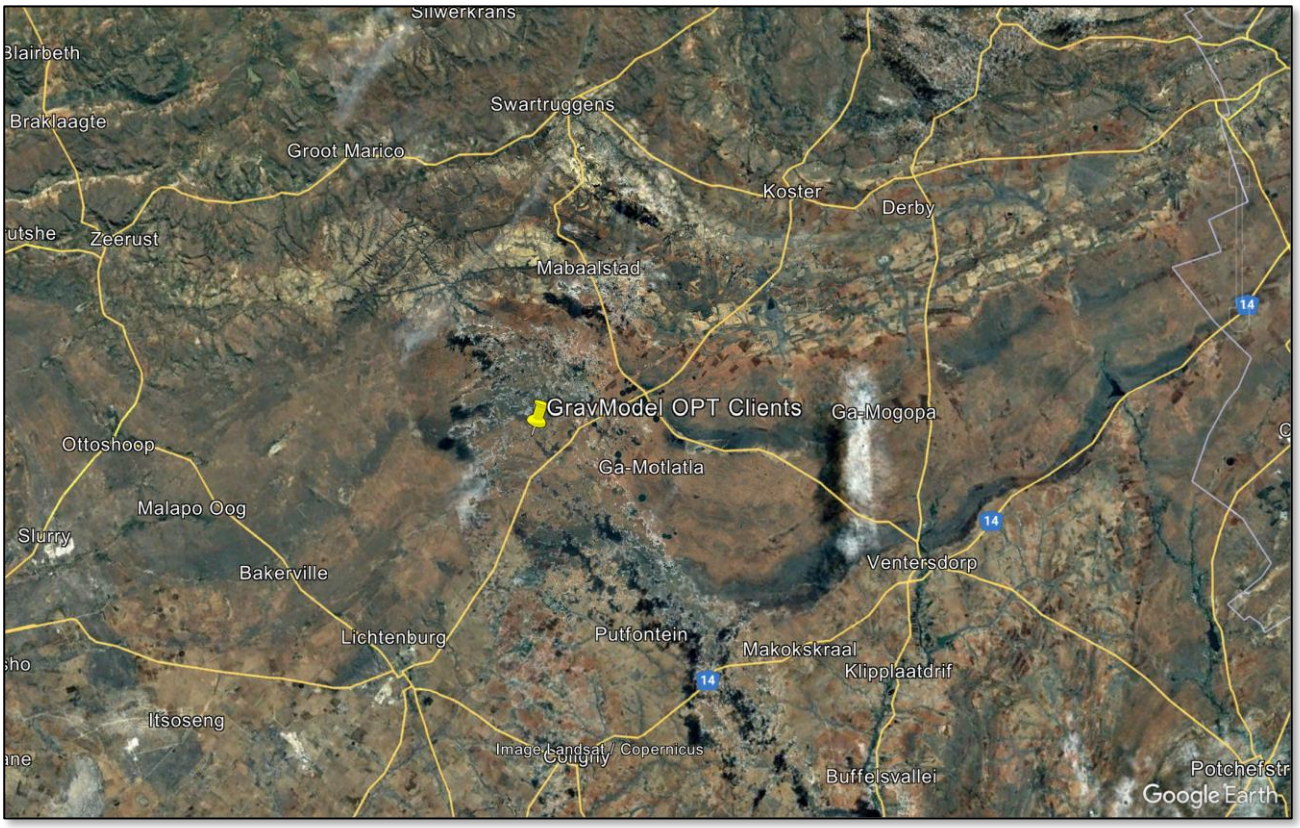

Figure 4.9: Optimal location using gravitation model cement factory only

[Source: Google Earth]

Figure 4.9 indicates that the researcher found that the optimal location to place a gypsum factory for the client base would be roughly 32 km northwest of Lichtenburg. This will be utilized in the subsequent sections to compare the solutions found when incorporating the different raw material resources.

4.5.1.2 Gravitational model incorporating Richards Bay gypsum material source

In this part, the researcher enhanced the gravitational model by integrating the gypsum material source from Richards Bay into the equation. This additional information offers a more thorough insight into the dynamics of the supply chain, encompassing the transportation of raw materials to the manufacturing plant and the subsequent distribution of the finished product to individual clients within the cement sector.

The geographical position of the gypsum material supply, as described in Section 4.4 Overview of underexploited gypsum sources, remains constant.

Emphasising the disparity in moisture levels between the initial raw material and the ultimate final product is of utmost importance. The moisture content of the raw gypsum sourced from Richards Bay exhibits a notably lower value than the final product often supplied to the cement sector. This

attribute facilitates the conveyance of lower moisture products to the proximity of the ideal production location before introducing the requisite water for neutralisation, potentially resulting in cost efficiencies within the supply chain.

The aggregate quantity of raw material conveyed from Richards Bay to the production site is calculated by adding up the dry tonnage needed by each client, considering the moisture content of the source.

The provided excerpt in the form of Table 4.5 presents comprehensive data about each cement factory, encompassing their respective geographical coordinates, quantities of cement produced in tonnes, and the gypsum requirements.

Table 4.5: Extract from Richards Bay gravitational model

Cement Factory	Latitude (Decimals)	Longitude (Decimals)	Tons	% Gypsum Dry Weight	% Total Gypsum @FM
AfriSam Dudfield	-26.1843	25.99281	1.5	5%	90000
AfriSam Roodepoort	-26.1796	27.88419	1	5%	60000
Sephaku Aganang	-26.1683	25.86825	1.2	5%	72000
Sephaku Delmas	-26.1549	28.69231	1.4	5%	84000
Lafarge Lichtenburg	-26.237	26.181	2.1	5%	126000
Lafarge Randfontein	-26.2069	27.6615	1	5%	60000
Dwaalboom	-24.81	26.831	1.8	5%	108000
Slurry	-25.8148	25.84583	1.9	5%	114000
Hercules	-25.722	28.17	1.15	5%	69000
Mamba	-24.986	27.546	1	5%	60000
Raw Material	-28.7862	32.001			737625

[Source: Own contribution]

The Excel Solver function was utilised to ascertain the ideal site for the manufacturing plant, considering the raw material source and client locations, following a process similar to Section 4.5.1.1. The primary goal remained focused on minimising the overall product of KM and MT while also considering the increased intricacy associated with the transportation of raw materials.

Based on an analysis of the raw material supply originating from Richards Bay, it was ascertained that the most favourable position is at a latitude of -26.64653238 and a longitude of 28.56143583.

By utilising the Google Maps platform, the coordinates may be graphically depicted to illustrate the most advantageous site for the gypsum manufacturing plant, considering both the origin of the raw materials and the target market.

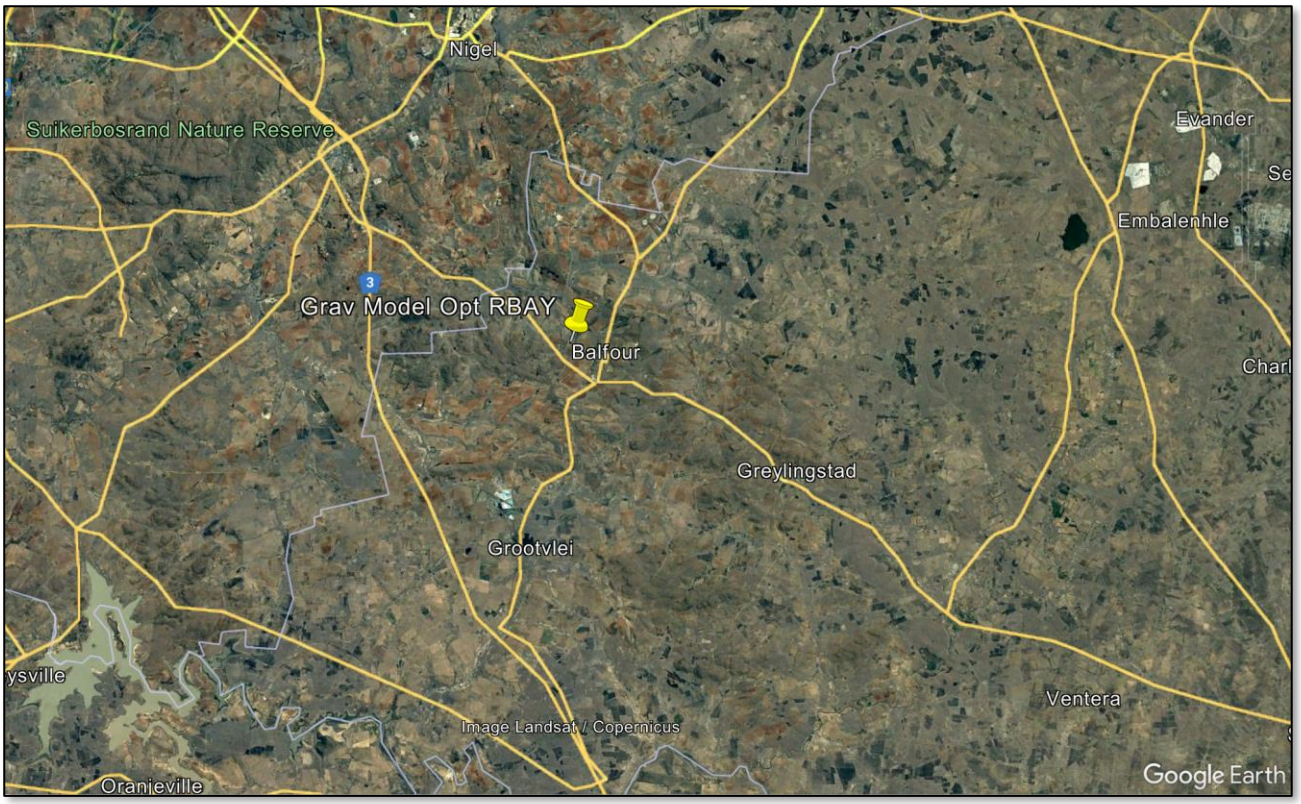

Figure 4.10: Gravitational model optimal location Richards Bay

[Source: Google Earth]

Figure 4.10 illustrates the optimal location to place a manufacturing facility, considering the raw material source in Richards Bay. This geographical area functions as a crucial point of reference, providing valuable information regarding the optimal placement for a gypsum manufacturing plant, considering the transportation of raw materials and the distribution of products to clients from the Richards Bay source. The researcher will review this model for the other areas in the following sections.

4.5.1.3 Gravitational model incorporating Phalaborwa raw material source

In this section, the researcher enhanced the gravitational model using the raw material source derived from Phalaborwa. This adjustment provides a comprehensive analysis of the supply chain, considering the intricate transportation dynamics involved in the movement of goods from Phalaborwa to the manufacturing site and the subsequent distribution process to the client. The geographical coordinates of the raw material source in Phalaborwa, as previously discussed in Section 4.4, remain unchanged. This source presents a novel aspect to the examination, highlighting

the transit logistics originating from Phalaborwa, which diverge from the dynamics linked to Richards Bay.

The aggregate weight of unprocessed material sent from Phalaborwa to the production site is ascertained based on the dry weight demanded by individual customers, considering the moisture level inherent in the Phalaborwa source. A similar model was generated to *Table 4.5: Extract from Richards Bay gravitational* model with only the geographical location changed from Richards Bay to the Phalaborwa raw resource.

By employing the Excel Solver function, following the approach outlined in Section 4.5.1.2, the objective was to determine the most favourable site for the gypsum manufacturing plant, considering the origin of the raw materials from Phalaborwa and the clients' locations. The study aimed to reduce the overall Kilometer tons travelled.

Based on the study, it has been found that the most favourable position, considering the availability of raw materials from Phalaborwa, is situated at a latitude of -25.21109379 and a longitude of 28.62839015

By utilising the Google Maps platform, the researcher could visually depict the most favourable site for the gypsum manufacturing facility, considering the origin of the raw materials from Phalaborwa and the distribution of the client base.

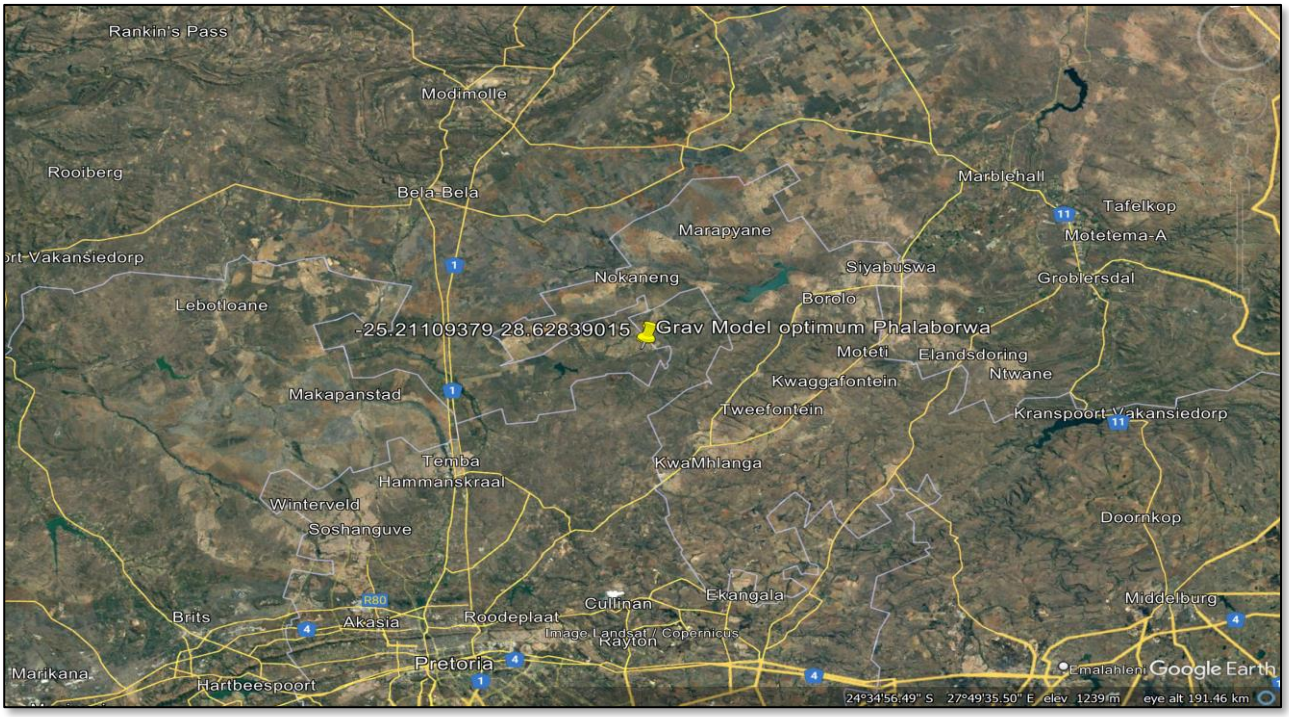

Figure 4.11: Gravitational model optimal location Phalaborwa

[Source: Google Earth]

Figure 4.11, illustrates the optimal location that considers the Phalaborwa raw material source. This location functions as a crucial point of reference, providing valuable insights on the optimal placement for a gypsum manufacturing facility, considering the transportation of raw materials from Phalaborwa and the distribution of products to clients. In the following sections, the researcher will enhance this model by examining the outcomes obtained when integrating alternative raw material sources in terms of the Loeriesfontein resource.

4.5.1.4 Gravitational model incorporating Loeriesfontein raw material source

Within this portion, the researcher proceeded to incorporate the primary supply of raw material obtained from Loeriesfontein into the gravitational model. The town of Loeriesfontein possesses distinctive geographical and logistical characteristics that contribute to the supply chain dynamics and impact the most suitable site for the gypsum manufacturing facility.

The geographical coordinates of the raw material source at Loeriesfontein exhibit a consistent and unchanging nature, as previously delineated. The model considers the transportation logistics of Loeriesfontein, considering its unique problems and advantages.

To ascertain the aggregate tonnage of raw material conveyed from Loeriesfontein to the production facility, the researcher considers the dry tonnage requested by each client, which is then modified to account for the moisture content of the Loeriesfontein source.

By employing the Excel Solver feature, the researcher aimed to determine the most advantageous site for the gypsum manufacturing plant, considering both the origin of the raw materials from Loeriesfontein and the locations of the clients. The objective was to reduce the overall KM*T value by incorporating the intricacies linked to the shipping process from Loeriesfontein.

Based on the investigation, considering the raw material source from Loeriesfontein, the most favourable position was identified at a latitude of -26.35610074 and a longitude of 25.71567105.

By utilising the Google Maps platform, the researcher could effectively depict the ideal geographical position for the gypsum manufacturing plant, considering the origin of the raw materials from Loeriesfontein and the distribution of the client base.

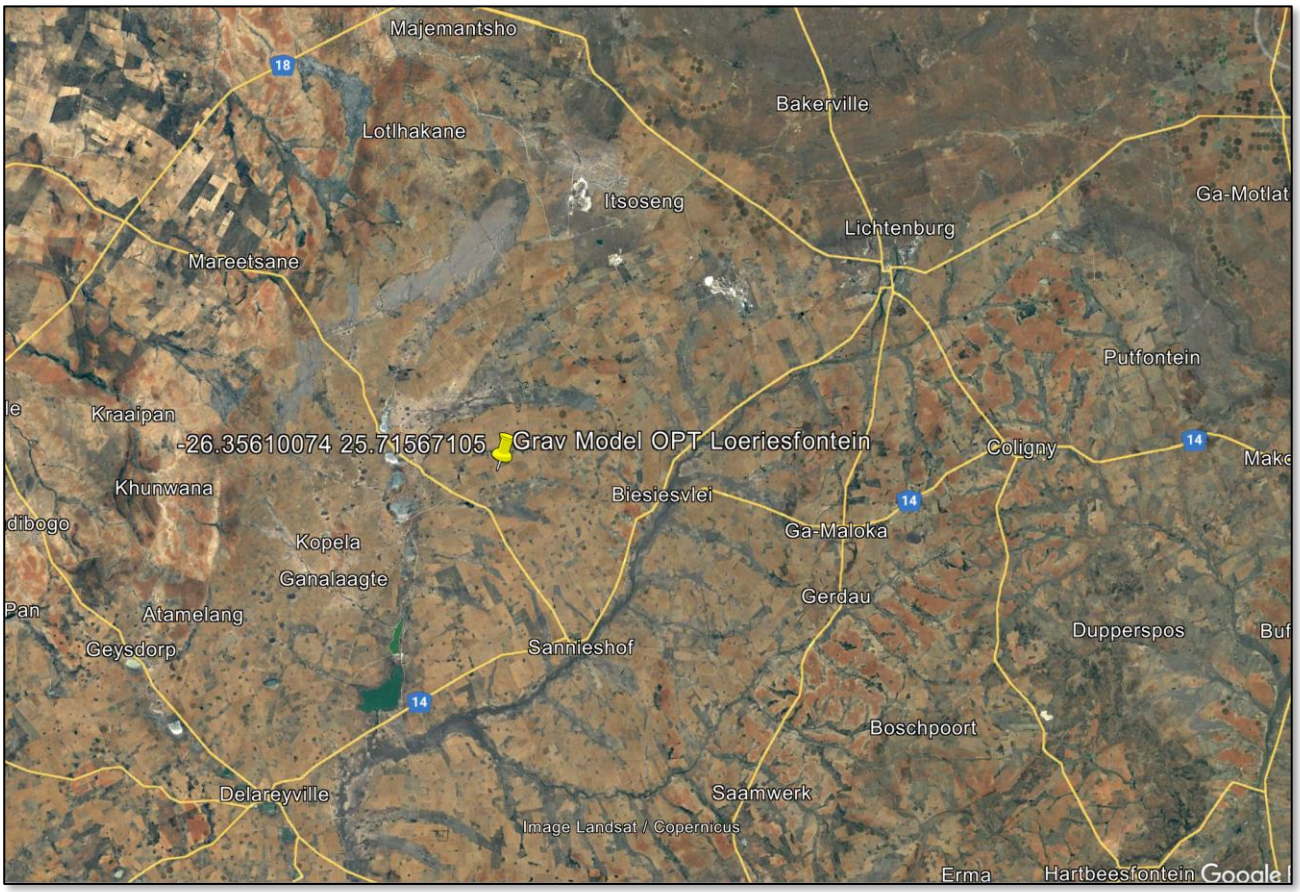

Figure 4.12: Gravitational model optimal location Loeriesfontein

[Source: Google Earth]

The strategic value of this position is derived from its proximity to the Loeriesfontein illustrated in Figure 4.12, which facilitates efficient transportation of raw materials and distribution to clients. The following sections will provide a more in-depth analysis and comparison of this region with other raw materials suppliers.

4.5.1.5 Summary of gravitational models and fundamental implications

The preceding sections have presented gravitational models that provide comprehension of the dynamics within the supply chain, specifically regarding determining the most advantageous site for a gypsum manufacturing facility. The models were developed to maximise the efficiency of the transportation component, which plays a crucial role in determining the overall operational expenses.

Table 4.6: TOPSIS proximity to the ideal solution of each resource

Description	Latitude (Decimals)	Longitude (Decimals)	Distance From Optimal Location
Clients only (Optimal location)	-25.97	26.451	-

Richards Bay Resource	-26.64653238	28.56143583	223.4052813
Phalaborwa Resource	-25.21109379	28.62839015	234.0977627
Loeriesfontein Resource	-26.35610074	25.71567105	85.02272958

[Source: Own contribution]

While Loeriesfontein appeared to be the optimal solution using the TOPSIS methodology, a deeper analysis revealed that this metric might not be the most appropriate. The primary reason is that it doesn't account for the complexity of the total distance travelled.

A more refined metric, represented as T*KM, considers the product of total tons transported and the total kilometres each ton travels, factoring in moisture content. Table 4.7 contains the results:

Table 4.7: Transport from gypsum source to cement factory

Scenario	Total T*KM
Richards Bay Resource	476 530 458.11
Phalaborwa Resource	380 850 616.92
Loeriesfontein Resource	670 402 748.55

[Source: Own contribution]

From this perspective, the Phalaborwa resource emerges as the optimal solution, even though its gravitational midpoint isn't the closest to the ideal solution. This underscores the importance of considering multiple factors and not relying solely on one metric.

However, it's crucial to understand that this analysis still has limitations. The current model only considers direct distances and not actual road lengths. Furthermore, logistical intricacies like return legs for trucks, existing routes, and infrastructure proximity haven't been factored in.

The nearest notable town to each optimal point was identified to ensure that the facility isn't isolated from essential infrastructure to address these limitations:

- Richards Bay option: Balfour, Mpumalanga, South Africa
- Phalaborwa Option: Hammanskraal, Gauteng, South Africa
- Loeriesfontein Option: Mahikeng, Northwest, South Africa

The researcher will delve deeper into these locations, considering road distances for raw material and final product transportation. Additionally, transport quotes will be sourced to incorporate the impact of existing supply routes, providing a more holistic and practical understanding of the supply chain dynamics.

4.5.2 Supply chain material transport overview

The gravitational study yielded fundamental insights into the most suitable sites for establishing the gypsum manufacturing plant, considering direct distances. Nevertheless, in practical situations, the precise road distances significantly impact the efficiency and cost-effectiveness of the supply chain. In this section, the researcher will further the research by examining the road connectivity distances for each transportation leg in the three scenarios, utilising Google Maps as the GIS data source.

By utilising this data, a budget quote from a major transport broker in South Africa was requested to serve as a barometer for the planned logistics costs.

4.5.2.1 Richards Bay transport overview

Utilising Google Maps as the GIS data source, the road distances from the raw material source in Richards Bay to the proposed manufacturing facility in Balfour and subsequently to each client's location were determined. Table 4.8 presents each client's road distances and the derived arm weight (KM*T).

Table 4.8: Richards Bay TOPSIS road distances

Cement Factory	Road distance to Balfour(km)	Arm Weight (KM*T)
AfriSam Dudfield	328	29 520 000.00
AfriSam Roodepoort	111	6 660 000.00
Sephaku Aganang	340	24 480 000.00
Sephaku Delmas	67	5 628 000.00
Lafarge Lichtenburg	319	40 194 000.00
Lafarge Randfontein	130	7 800 000.00
Dwaalboom	338	36 504 000.00
Slurry	368	41 952 000.00
Hercules	140	9 660 000.00
Mamba	265	15 900 000.00
Richards Bay Raw Resource	514	379 139 250.00
Total		597 437 250.00

[Source: Own contribution]

Upon obtaining the road distance data, transportation quotes were solicited from a major transport broker in South Africa. The quotes provide a tangible metric for the anticipated logistical costs of the Richards Bay scenario. Table 4.9 outlines the cost per ton and the total costs for transporting materials from each client's location:

Table 4.9: Richards Bay TOPSIS Road transport costs

Cement Factory	Cost per ton	Total Costs
AfriSam Dudfield	R 470.00	R 42 300 000.00
AfriSam Roodepoort	R 260.00	R 15 600 000.00
Sephaku Aganang	R 490.00	R 35 280 000.00
Sephaku Delmas	R 78.00	R 6 552 000.00
Lafarge Lichtenburg	R 470.00	R 59 220 000.00
Lafarge Randfontein	R 280.00	R 16 800 000.00
Dwaalboom	R 470.00	R 50 760 000.00
Slurry	R 510.00	R 58 140 000.00
Hercules	R 340.00	R 23 460 000.00
Mamba	R 430.00	R 25 800 000.00
Richards Bay Raw Resource	R 560.00	R 413 070 000.00
Total		R 746 982 000.00

[Source: Own contribution]

The Richards Bay scenario, when evaluated based on road distances and logistical costs, presents a significant investment in terms of transportation. The total arm weight and associated costs provide a clear picture of this option's logistical challenges and expenses.

It's essential to consider that while Richards Bay might present higher costs in some areas, there could be other benefits, such as the quality of the raw material or the reliability of the supply, which might offset these costs. However, from a purely logistical perspective, the costs associated with the Richards Bay scenario are substantial and will play a significant role in the final decision-making process.

In subsequent sections, a similar analysis will be conducted for the other scenarios to provide a comparative perspective and aid in selecting the most cost-effective and efficient option.

4.5.2.2 Phalaborwa transport overview

The Phalaborwa situation, which represents a possible source of raw materials, necessitates a thorough examination of the distances involved in road transport and the corresponding costs to ascertain its viability within the broader supply chain.

Using Google Maps, the road distances from the raw material source in Phalaborwa to the proposed manufacturing facility in Hammanskraal and then to each client’s location were mapped out. Table 4.10 presents these road distances and the derived arm weight (KM*T) for each client:

Table 4.10: Phalaborwa TOPSIS Road distances

Cement Factory	Road distance to Hammanskraal (km)	Arm Weight (KM*T)
AfriSam Dudfield	293	26 370 000
AfriSam Roodepoort	117	7 020 000
Sephaku Aganang	257	18 504 000
Sephaku Delmas	115	9 660 000
Lafarge Lichtenburg	266	33 516 000
Lafarge Randfontein	132	7 920 000
Dwaalboom	268	28 944 000
Slurry	305	34 770 000
Hercules	43	2 967 000
Mamba	164	9 840 000
Phalaborwa raw resource	427	314 965 875
Total		494 476 875

[Source: Own contribution]

Upon determining the road distances, transportation quotes were sourced from a prominent transport broker in South Africa. Table 4.11 provides a breakdown of the cost per ton and the total costs for transporting materials from each client's location:

Table 4.11: Phalaborwa TOPSIS Road transport costs

Cement Factory	Cost per ton	Total Costs
AfriSam Dudfield	R 450.00	R 40 500 000.00
AfriSam Roodepoort	R 290.00	R 17 400 000.00

Cement Factory	Cost per ton	Total Costs
Sephaku Aganang	R 470.00	R 33 840 000.00
Sephaku Delmas	R 280.00	R 23 520 000.00
Lafarge Lichtenburg	R 450.00	R 56 700 000.00
Lafarge Randfontein	R 330.00	R 19 800 000.00
Dwaalboom	R 430.00	R 46 440 000.00
Slurry	R 470.00	R 53 580 000.00
Hercules	R 72.00	R 4 968 000.00
Mamba	R 360.00	R 21 600 000.00
Phalaborwa Raw Resource	R 690.00	R 508 961 250.00
Total		R 827 309 250.00

[Source: Own contribution]

Upon further examination of the Phalaborwa scenario, it becomes evident that a substantial logistical expenditure is involved, as evidenced by the analysis of road distances and associated costs. The calculated weight of the arm and the corresponding expenses offer a clear comprehension of this alternative's operational complexities and monetary consequences.

Although Phalaborwa may offer certain benefits, such as its proximity to specific clients, it is important to note that the logistical expenses connected with this situation are substantial. It is imperative to carefully consider and evaluate these expenses for other potential advantages, such as the quality of raw materials or supply reliability.

In the subsequent sections, the researcher will explore other scenarios, providing a comparative analysis to aid in the decision-making process for selecting the most optimal and economically viable solution.

4.5.2.3 Loeriesfontein transport overview

The Loeriesfontein scenario represents yet another potential raw material source. As with the previous scenarios, it's crucial to evaluate the road distances and associated transportation costs to determine their feasibility within the supply chain. Utilising Google Maps, the road distances from the raw material source in Loeriesfontein to the proposed manufacturing facility in Mahikeng and subsequently to each client’s location were determined. Table 4.12 presents these road distances and the derived arm weight (KM*T) for each client:

Table 4.12: Loeriesfontein TOPSIS Road distances

Cement Factory	Road distance to Mahikeng(km)	Arm Weight (KM*T)
AfriSam Dudfield	61	5 490 000.00
AfriSam Roodepoort	262	15 720 000.00
Sephaku Aganang	51	3 672 000.00
Sephaku Delmas	372	31 248 000.00
Lafarge Lichtenburg	70	8 820 000.00
Lafarge Randfontein	253	15 180 000.00
Dwaalboom	223	24 084 000.00
Slurry	24	2 736 000.00
Hercules	297	20 493 000.00
Mamba	286	17 160 000.00
Loeriesfontein raw resource	915	674 926 875.00
Total		819 529 875.00

[Source: Own contribution]

Upon obtaining the road distance data, transportation quotes were solicited from a major transport broker in South Africa. Table 4.13 provides a breakdown of the cost per ton and the total costs for transporting materials from each client location:

Table 4.13: Loeriesfontein TOPSIS Road Transport

Cement Factory	Cost per ton	Total Costs
AfriSam Dudfield	R 78.00	R 7 020 000.00
AfriSam Roodepoort	R 430.00	R 25 800 000.00
Sephaku Aganang	R 240.00	R 17 280 000.00
Sephaku Delmas	R 540.00	R 45 360 000.00
Lafarge Lichtenburg	R 220.00	R 27 720 000.00
Lafarge Randfontein	R 400.00	R 24 000 000.00
Dwaalboom	R 380.00	R 41 040 000.00
Slurry	R 220.00	R 25 080 000.00
Hercules	R 520.00	R 35 880 000.00
Mamba	R 460.00	R 27 600 000.00
Loeriesfontein Raw Resource	R 1 290.00	R 951 536 250.00
Total		R 1 228 316 250.00

[Source: Own contribution]

Loeriesfontein presents many advantages. However, it is important to highlight the substantial logistical expenses connected with this choice, particularly when compared to alternative scenarios. The careful evaluation of cost-effectiveness, alongside variables such as the quality of raw materials and the constancy of supply, assumes a central role in the decision-making process.

Furthermore, the considerable distance between the Loeriesfontein raw material source and the suggested manufacturing facility raises concerns. Significant distances can potentially exacerbate weaknesses in the supply chain, particularly in situations that are susceptible to disruptions or unanticipated delays.

When examining this research, comparing the concrete logistical costs with the wider benefits that Loeriesfontein may offer is crucial. It is imperative to consider a broad perspective encompassing the current expenses and the long-term strategic benefits to make a comprehensive decision.

As the study progresses, attention will be shifted towards other aspects of the value chain. This shift is important as it allows for a comprehensive investigation to identify the most practical and cost-effective option.

4.5.2.4 Summary of transport overview and insights

The transportation of raw materials and completed goods is a crucial element within the supply chain, directly influencing overall cost-efficiency and operational performance. Within this section, the researcher comprehensively examines the three scenarios, namely Richards Bay, Phalaborwa, and Loeriesfontein, to identify the most advantageous logistical approach.

Table 4.14 offers a detailed overview of the logistics costs per tonne for each cement factor, providing valuable insights into the associated expenses for each scenario. Upon initial examination of the data, it becomes apparent that Richards Bay continually presents the most economically advantageous option for nearly all cement manufacturers, save for PPC Hercules.

Table 4.14: Comparative total logistical costs per cement factory

Cement Factory	Richards Bay	Phalaborwa	Loeriesfontein
AfriSam Dudfield	R 1 030.00	R 1 140.00	R 1 368.00
AfriSam Roodepoort	R 820.00	R 980.00	R 1 720.00

Cement Factory	Richards Bay	Phalaborwa	Loeriesfontein
Sephaku Aganang	R 1 050.00	R 1 160.00	R 1 530.00
Sephaku Delmas	R 638.00	R 970.00	R 1 830.00
Lafarge Lichtenburg	R 1 030.00	R 1 140.00	R 1 510.00
Lafarge Randfontein	R 840.00	R 1 020.00	R 1 690.00
Dwaalboom	R 1 030.00	R 1 120.00	R 1 670.00
Slurry	R 1 070.00	R 1 160.00	R 1 510.00
Hercules	R 900.00	R 762.00	R 1 810.00
Mamba	R 990.00	R 1 050.00	R 1 750.00

[Source: Own contribution]

This table, which amalgamates incoming and outgoing logistics per ton, underscores the economic advantage of the Richards Bay scenario. When aggregated over large volumes of materials transported, the cost savings can translate to substantial financial benefits.

The variation from the optimal solution, indicated in Table 4.15, further accentuates the cost-effectiveness of the Richards Bay scenario. It provides a differential view, highlighting the cost variance of each scenario from the optimal solution.

Table 4.15: Variation from optimal solution per raw resource

Cement Factory	Richards Bay	Phalaborwa	Loeriesfontein
AfriSam Dudfield	R -	R 110.00	R 338.00
AfriSam Roodepoort	R -	R 160.00	R 900.00
Sephaku Aganang	R -	R 110.00	R 480.00
Sephaku Delmas	R -	R 332.00	R 1 192.00
Lafarge Lichtenburg	R -	R 110.00	R 480.00
Lafarge Randfontein	R -	R 180.00	R 850.00
Dwaalboom	R -	R 90.00	R 640.00
Slurry	R -	R 90.00	R 440.00
Hercules	R 138.00	R -	R 1 048.00
Mamba	R -	R 60.00	R 760.00

[Source: Own contribution]

The data presented in the table demonstrates a clear pattern wherein Richards Bay continually emerges as the most economically efficient option, exhibiting the lowest transportation costs for nearly all cement manufacturers. The one exception to this pattern is evident in the case of PPC Hercules, whereas Phalaborwa presents a slightly more cost-effective alternative.

Insights into transport from different sources include:

- ***Dominance of Richards Bay:*** The Richards Bay scenario consistently offers the lowest logistical costs for almost all cement factories. This suggests that the geographical positioning of Richards Bay relative to the cement factories and the raw material source offers a logistical advantage.
- ***The PPC Hercules anomaly:*** The Phalaborwa scenario is more cost-effective for PPC Hercules, indicating that a specific logistical chain unique to PPC Hercules makes Phalaborwa a more viable option for this factory.
- ***High costs of Loeriesfontein:*** The Loeriesfontein scenario consistently ranks as the most expensive in terms of transport costs. The significant distance from the Loeriesfontein raw resource to the proposed manufacturing facility primarily contributes to these elevated costs.
- ***Cost variance insights:*** The variable costing from the optimum table reveals that while Richards Bay is often the most cost-effective, the cost difference between it and the other scenarios can vary significantly depending on the specific cement factory. This suggests that a one-size-fits-all approach may not be optimal, and individual factory requirements should be considered.
- ***Holistic evaluation:*** While the cost is a significant factor, it's essential to consider other elements like raw material quality, supply reliability, and potential future expansions or changes in the market dynamics. For instance, if a particular scenario offers a slightly higher logistical cost but guarantees a more consistent and higher quality raw material supply, it might still be the preferred choice.

Navigating the intricacies of logistics, the transport contractor highlighted a significant variable: the dependency of transportation costs on diesel prices. Specifically, 50% of the quoted costs for all routes, except the Richards Bay-Balfour leg (which stands at 65%), are subject to rise-and-fall adjustments based on diesel price fluctuations. Given the volatile nature of diesel prices, this factor can substantially impact the overall logistical costs. The quotes were based on a foundational diesel price of R25.22 per litre. As the researcher delves deeper into the analysis, it becomes imperative to incorporate this variable diesel pricing factor, especially when evaluating the attractiveness of each scenario for the individual cement factories.

In conclusion, the Richards Bay scenario, overall, offers the most cost-effective logistical solution. However, individual nuances, such as the specific requirements of PPC Hercules, highlight the importance of a detailed, factory-specific analysis. Decisions should be based on cost-effectiveness, supply reliability, and strategic long-term considerations. This will be evaluated in the MCDA model later in the report.

4.5.3 Production costing estimation from empirical data

The researcher has sourced data from the country's leading gypsum producers to understand comprehensively the production costs associated with gypsum manufacturing in South Africa (Goudriaan, 2023). This data offers a transparent breakdown of the estimated production costs, as detailed below:

- Raw Material: 39%
- Electricity: 7%
- Fuel: 8%
- Staff Costs: 14%
- Parts and Maintenance: 7%
- Lime: 5%
- P&G's and Markup: 20%

For the context of this analysis, it's essential to highlight that the researcher is operating under the assumption that the primary cost drivers remain consistent across different production scenarios. The only exception is the royalty associated with raw material acquisition, subject to negotiations with each raw material resource holder.

Given the current Average Selling Price (ASP) of R320.21 for the 2022 financial year (Goudriaan, 2023), the researcher can deduce the estimated cost contributions for each of the primary drivers in terms of Rand per ton:

Table 4.16: Estimated production costing for gypsum

Cost Component	Percentage of Total Cost	Estimated Cost (R/ton)
Raw Material	39%	R 124.88
Electricity	7%	R 22.41
Fuel	8%	R 25.62
Staff Costs	14%	R 44.83
Parts and Maintenance	7%	R 22.41
Lime	5%	R 16.01
P&G's and Markup	20%	R 67.24
Total	100%	R 320.21

[Source: Own contribution]

* Note: The estimated costs in the table above are derived by multiplying the ASP with the respective percentage for each cost component.

Table 4.16, provides a clear picture of the cost structure in South Africa. Raw material acquisition is the most significant cost driver, underscoring the importance of effective negotiations and strategic partnerships with raw material suppliers. The subsequent sections will delve deeper into the implications of these costs and utilize this in formulating an MCDA model.

4.5.4 MCDA model generation and weighting

The MCDA model is a systematic methodology that aids decision-making by assessing numerous possibilities by a predetermined set of criteria. Due to the intricate nature of the topic under investigation, the utilisation of MCDA offers a methodical and lucid approach to evaluate and prioritise different alternatives, guaranteeing the inclusion of all pertinent elements.

This section provides an in-depth analysis of the MCDA model generation and the weighting technique utilised in this study. The process commences with carefully identifying and establishing criteria, which are crucial in delineating the specific factors used to assess and evaluate various alternatives. Subsequently, an examination of the weighting of these factors is undertaken, elucidating their respective significance within the context of the decision-making procedure. Evaluating alternatives offers valuable insights into the relative performance of each option to the predetermined criteria. Following this, the section on results and analysis gives the MCDA outputs, providing a distinct ranking of the many choices. Finally, a sensitivity analysis is performed to assess the outcomes' robustness, ensuring the findings' dependability and ability to survive fluctuations in specific factors.

The next sections include an in-depth analysis of each stage in the MCDA process, providing a complete comprehension of the approach and its implementation in the present study.

4.5.4.1 Criteria selection

Selecting appropriate criteria is a foundational step in the MCDA process. These criteria are the parameters against which various alternatives are evaluated, ensuring a comprehensive and objective assessment.

The criteria for this study were derived from a combination of literature reviews, expert opinions, and industry-specific considerations. Notably, the document mentions using MCDA techniques such as AHP and TOPSIS, often requiring a clear set of criteria for effective application. Additionally, the emphasis on the cement and gypsum value chains suggests that industry-specific factors played a significant role in criteria selection.

To ensure a comprehensive evaluation of the alternatives in the MCDA process, the criteria have been classified into three main categories: environmental, quality, and economic. Each category encompasses factors crucial for decision-making regarding gypsum sourcing in the cement sector.

- **Environmental criteria:**
  - ***Total kilometres travelled:*** One of the primary environmental concerns in gypsum sourcing is the distance travelled to procure the material. Minimizing the total kilometres travelled reduces transportation costs and significantly diminishes the carbon footprint, aligning with global sustainability goals and reducing environmental impact.

- **Quality criteria:**
  - ***Purity of gypsum:*** The purity of gypsum plays a pivotal role in its effectiveness and the quantity required in the cement production process. High-purity gypsum ensures that lesser amounts need to be added or transported, optimizing the production process and ensuring the quality of the final product.

- **Economic criteria:**
  - ***Inbound logistics:*** Efficient inbound logistics can lead to cost savings and timely procurement of gypsum. Factors such as transportation modes, lead times, and storage requirements play a role in determining the economic viability of a sourcing option.
  - ***Outbound logistics:*** Once the gypsum has been sourced and processed, its distribution to the required destinations must be efficient and cost-effective. This involves considerations like transportation methods, distribution channels, and delivery times.
  - ***Raw material costs:*** The direct cost of procuring gypsum is significant. Variations in raw material costs can significantly impact the overall economics of the sourcing decision.
  - ***Diesel costs:*** Given the reliance on transportation in gypsum sourcing, diesel costs become a crucial economic criterion. Fluctuations in diesel prices can substantially impact the total cost of sourcing.

This detailed classification provides a structured framework for the MCDA process, ensuring that all relevant factors are considered in evaluating alternatives. The subsequent sections will delve into the weighting of these criteria and the evaluation process based on them.

4.5.4.2 Weighting of criteria

The weighting of criteria in MCDA is a pivotal step, ensuring that evaluating alternatives reflects each criterion's relative importance. Given the industry trends and the specific context of this study, weights have been allocated to each main category: environmental, quality, and economic.

Weights have been allocated based on current industry trends and the study's objectives. The breakdown is as follows:

- ***Environmental criteria:*** 0.5/10(5%)
  The environmental impact, while crucial, is given a weight of 0.5 out of 10. This reflects the industry's growing sustainability awareness but acknowledges other pressing concerns.

- ***Quality criteria:*** 1.5/10(15%)
  Ensuring the quality of gypsum is important, especially in terms of its purity and effectiveness in cement production. Thus, it's weighted at 1.5 out of 10.

- ***Economic criteria:*** 8/10(80%)
  Economic considerations are paramount in the industry. Logistics, raw material costs, and diesel expenses are decisive in sourcing decisions. Given its utmost importance, this criterion is a heavy weight of 8 out of 10.

Scoring methodology:
For the evaluation of alternatives under each criterion:

- The top-performing alternative in each category will receive a full score.
- Subsequent alternatives will be scored based on the percentage difference from the top scorer.
- These scores will then be aggregated to a 10, ensuring transparency and ease of comparison.

This scoring methodology ensures that the evaluation process is both objective and reflective of the relative performance of each alternative. The subsequent 'Alternative evaluation' section will delve into the scoring of each alternative based on this methodology and the allocated weights.

4.5.4.3 Alternative evaluation

In the preceding section, the researcher introduced the methodology for evaluating alternatives using a scoring system. This section delves into a detailed evaluation of the alternatives based on three distinct criteria: environmental, quality, and economic. Each criterion has its unique set of parameters that influence the decision-making process. The total kilometres travelled by each alternative location is assessed for the environmental criterion. This is crucial as it directly impacts the operation's carbon footprint and overall environmental sustainability. The quality criterion focuses on the purity of the product. A higher purity often translates to a superior product, influencing customer satisfaction and brand reputation.

Lastly, the economic criterion evaluates the financial feasibility of each alternative. This includes a comprehensive breakdown of costs, from raw material prices to various logistical expenses. The economic evaluation ensures that the chosen alternative is not only environmentally sustainable and of high quality but also economically viable. In the subsequent sections, the researcher will delve deeper into each criterion, comprehensively analysing how each location fares and justifying the scores assigned.

- **Environmental criterion**

The assessment of the environmental consequences associated with a supply chain has become a matter of growing importance in contemporary society, given the prevailing emphasis on sustainability and the imperative to mitigate carbon emissions. The distance travelled within a supply chain is a significant environmental problem due to its direct association with fuel use and the resulting carbon emissions.

To assess the ecological consequences of each potential site, the researcher utilised the Kilometre*Ton metric, which was previously computed in Section 4.5.2. The value denotes the cumulative logistical distance encompassing the entirety of the supply chain. This figure was divided by the average weight of an interlink, recorded at 34 km, to enhance comprehensibility and reliability. The division has furnished us with the aggregate distance in km covered by each possibility.

Upon obtaining the total kilometres travelled, the researcher sought to understand how each location compared to the optimal solution. This was achieved by calculating the percentage difference from the optimal for each alternative. In this context, the optimal solution is the one with the least environmental impact, i.e., the shortest total kilometres travelled.

Finally, the researcher applied an aggregated scoring system out of 10 to provide a clear and concise evaluation. This score was determined based on each option's deviation from the optimal solution. A location closer to the optimal solution received a higher score, indicating a more environmentally friendly alternative. This is shown in Table 4.17.

Table 4.17: Environmental MCDA scoring table

Environmental	Richards Bay	Phalaborwa	Loeriesfontein
Total KM's Travelled	14 015 601.71	11 201 488.73	19 717 727.90
%Difference from Optimal	-25%	0%	-76%
Score/10	7.49	10.00	2.40

[Source: Own contribution]

In summary, after considering the merits of all three places, it can be concluded that Phalaborwa emerges as the most optimal choice from an environmental standpoint, with Richards Bay closely following suit. Loeriesfontein performs less in this category due to its comparatively higher number of kilometres travelled.

- **Quality criterion**

The consideration of quality is an essential element in all decision-making processes, particularly in products or services that directly influence consumers or end-users. In this assessment, the principal

criterion for assessing quality was the level of purity exhibited by the product, as expounded upon in Section 4.4.

A product's purity level is a reliable measure of its quality, as higher levels of purity typically result in enhanced product performance and increased consumer satisfaction. Due to the importance of the matter, it was crucial to evaluate the performance of each location in this regard and to quantify this evaluation to provide a more direct comparison.

To derive the scores, the researcher first identified the location with the highest purity, which in this case was Phalaborwa, and considered it as the benchmark or optimal solution. The percentage difference for each location was then calculated relative to this benchmark. This approach ensures that the location with the highest purity always receives a perfect score of 10.

Subsequently, an aggregated scoring system out of 10 was applied, like the environmental criterion. The scores were determined based on each location's deviation from the optimal purity level. A smaller deviation meant a higher score, indicating a closer match to the desired quality level. This is shown in Table 4.18.

Table 4.18: Quality MCDA scoring table

Quality	Richards Bay	Phalaborwa	Loeriesfontein
Purity	96.10	98.60	96.50
%Difference	3%	0%	2%
Score/10	9.75	10.00	9.79

[Source: Own contribution]

In summary, Phalaborwa emerges as the leader in the quality criterion with the highest purity level. Loeriesfontein closely follows, with Richards Bay slightly behind. All three locations offer high-quality products, with only minor differences in purity levels.

- **Economic criterion**

The economic criterion is undeniably the cornerstone of this evaluation, holding a staggering 80% weight in the decision-making process. This overwhelming emphasis is a testament to economic feasibility's pivotal role in ensuring any venture's sustainability and profitability.

Given the paramount importance of this criterion, a meticulous and comprehensive analysis is warranted. At the heart of this analysis are two fundamental variables: the cost of raw materials and the diesel price. For the scope of this study, these values were held constant across all locations. The raw material price was pegged at R124.88, as detailed in the production costing section, and the diesel price was set at a base rate of R25.22. It's crucial to note that while these figures serve

the current evaluation, they are dynamic and subject to change. Therefore, for future decision-making endeavours using this model, a periodic review and update of these figures are imperative.

Diving deeper into the economic evaluation, the researcher segmented the costs into six primary components that constitute the total supply chain costs. A notable aspect of this breakdown is the calculation of the diesel-dependent portion. This was derived using the formula: quoted price per ton * diesel portion ÷ base diesel price of R25.22 × current diesel price(2023) (which remains R25.22 for this study). This formula was applied to both inbound and outbound logistics. Table 4.19 was generated utilising the methodology explained above:

Table 4.19: Supply chain costs overview of different sources

Variables (R/ton Average)	Richards bay	Phalaborwa	Loeriesfontein
Inbound Logistics Costs Fixed	R 196.00	R 345.00	R 457.50
Inbound Logistics Costs Diesel Dependant	R 364.00	R 345.00	R 457.50
Outbound Logistical Costs Fixed	R 198.05	R 188.82	R 164.16
Outbound Logistical Costs Diesel Dependant	R 198.05	R 188.82	R 164.16
Estimated Manufacturing Costs Ex. Raw Materials	R 198.52	R 198.52	R 198.52
Raw Materials Costs	R 124.88	R 124.88	R 124.88
Total Supply Chain Costs, Excluding VAT	R1 279.50	R 1 391.04	R 1 566.73

[Source: Own contribution]

Upon obtaining each location's total supply chain costs, the researcher scored each based on their economic feasibility. The scoring methodology remained consistent with previous criteria, where the location with the most favourable economic outcome was the benchmark. Utilising the same methodology as above, Table 4.20 was generated:

Table 4.20: Economic MCDA scoring table

Economic Criteria	Richards Bay	Phalaborwa	Loeriesfontein
Estimated Supply Chain Costs	1 279.50	1 391.04	1 566.73
%Difference	0%	-9%	-22%
Score/10	10.00	9.13	7.76

[Source: Own contribution]

In summary, Richards Bay is the most economically feasible alternative, with Phalaborwa closely trailing behind. Loeriesfontein, although viable, experiences elevated supply chain expenses, rendering it the least advantageous option among the three. The comprehensive assessment of

economic factors and considerations of environmental impact and quality standards offers a broad perspective on the many options, facilitating well-informed and equitable decision-making.

The researcher will now utilize both the weighting of the criteria and the alternative evaluation to choose the most appropriate option in the subsequent section.

4.5.4.4 Summary of results

The results and analysis section is the pinnacle of the MCDA model. The synthesis of facts and insights collected from the preceding parts provides a thorough perspective on the various choices, evaluating their performance across multiple parameters. This portion holds significant importance, as it establishes the fundamental basis upon which well-informed decisions can be formulated.

Score summary

Table 4.21 offers a concise overview of the performance of each location based on three criteria, namely environmental, quality, and economic.

Table 4.21: Score summary MCDA

Score Summary	Richards Bay	Phalaborwa	Loeriesfontein
Environmental	7.49	10.00	2.40
Quality	9.75	10.00	9.79
Economic	10.00	9.13	7.76

[Source: Own contribution]

From the table, it's evident that:

- Phalaborwa excels in the environmental and quality criteria, securing a perfect score in both.
- While slightly lagging in environmental and quality, Richards Bay achieves a perfect score in the economic criterion.
- Loeriesfontein faces challenges in the environmental criterion but performs commendably in quality.

MCDA weighted scores

Considering each criterion's relative importance (or weight) is essential to ensure a balanced evaluation. Table 4.22 provides a holistic view by multiplying the scores of each location by the respective weights of the criteria.

Table 4.22: MCDA weighted scores per raw resource

MCDA Weighted Scores	Richards Bay	Phalaborwa	Loeriesfontein
Environmental	3.74	5.00	1.20
Quality	14.62	15.00	14.68
Economic	80.00	73.03	62.04
Total Score	98.36	93.03	77.92

[Source: Own contribution]

After analysing the weighted scores:

- The Richards Bay resource emerges as the leading candidate, attaining a comprehensive score of 98.36, mostly driven by its robust economic performance.
- The Phalaborwa resource demonstrates a well-rounded performance across all parameters, as evidenced by its total score of 93.03.
- The Loeriesfontein resource, with a score of 77.92, is influenced by its environmental rating; however, it continues to exhibit competitiveness in quality.

In-depth analysis of MCDA results

The MCDA model's results provide a multi-faceted perspective on the alternatives, revealing each location's strengths, weaknesses, and potential opportunities. The researcher now delves deeper into these results' intricacies to extract more nuanced insights.

Environmental analysis:

- Phalaborwa stands out as the environmental leader, achieving the optimal score. Its reduced kilometres travelled implies lower carbon emissions and suggests potential cost savings in long-term fuel consumption. This positioning can be leveraged in marketing strategies, emphasizing sustainability and eco-friendliness.

- While not the leader, Richards Bay still presents a respectable environmental score. The 25% deviation from the optimal might be an area of improvement, possibly by optimizing routes or considering alternative transportation methods.

- Loeriesfontein faces a significant challenge in this criterion, severely impacting its score by the many kilometres travelled. This could lead to higher operational costs and a larger carbon footprint, which might concern environmentally conscious stakeholders.

Quality analysis:

- All three locations showcase commendable quality scores, indicating the product's purity is consistently high. This is a positive sign, suggesting that customers will receive a high-quality product regardless of the sourcing location.
- Phalaborwa and Loeriesfontein are almost neck-to-neck, with the former having a slight edge. This close competition implies that quality alone might not be a decisive factor in the final decision, but it's reassuring to know that both locations uphold high standards.
- Richards Bay, though slightly trailing, still offers a competitive quality. The minor difference in purity percentages might not be discernible to the end consumer, but it's an area where continuous improvement can be targeted.

Economic analysis:

- Richards Bay emerges as the frontrunner, with its perfect score underlining its economic viability. The location's cost structure, especially logistics, gives it a competitive edge that can translate to better profit margins.
- Phalaborwa, while strong in other criteria, faces challenges here. The 9% deviation from the optimal suggests areas within the supply chain where costs can be optimised. A deeper dive into its logistical and operational expenses might reveal opportunities for savings.
- Loeriesfontein, with the highest supply chain costs, needs strategic interventions to enhance its economic feasibility. The 22% deviation from the optimal is significant and might impact profitability if not addressed.

Overall assessment:

- Richards Bay presents a compelling case as a balanced choice, excelling economically and holding its ground in environmental and quality criteria.
- With its environmental and quality leadership, Phalaborwa can be considered if these criteria gain more weight in future evaluations or if there are strategic reasons to prioritize them.
- Loeriesfontein, while facing challenges, shouldn't be dismissed. Its quality scores are competitive, and its economic and environmental scores can be improved with targeted interventions.

In conclusion, while the scores provide a clear snapshot, the real value lies in understanding the underlying dynamics of each location. The MCDA model offers a roadmap, but the journey involves continuous assessment, optimization, and strategic decision-making.

The researcher will now continue with the sensitivity analysis of the model.

4.5.4.5 Sensitivity analysis

The sensitivity analysis aims to understand how changes in key input parameters affect the outcomes of this model. Given the close competition between Richards Bay and Phalaborwa, it's crucial to determine the robustness of the model against fluctuations in diesel price and raw material price for these two contenders.

Diesel price sensitivity:

Economic perspective: When examining the economic perspective, diesel prices play a pivotal role, especially in logistics costs. The analysis indicates that for Phalaborwa to surpass Richards Bay in economic attractiveness, the diesel price would need to skyrocket to R124.86. Given the current market conditions and historical trends, such a surge in diesel prices is highly improbable. This establishes that, from an economic standpoint, the model remains largely insensitive to fluctuations in diesel prices.

MCDA perspective: From a holistic MCDA viewpoint, encompassing all criteria, the diesel price would need to reach an equally unrealistic value of R79.41 for Phalaborwa to match Richards Bay. This further underscores the model's robustness against diesel price variations.

4.7.2 Raw material price sensitivity

Economic perspective: Raw material costs are a significant component of the total costs. For Phalaborwa to economically outshine Richards Bay, its raw material pricing should be a staggering R111.54 lower than Richards Bay. This translates to a massive 90% reduction from the current rate, which is practically unfeasible. Thus, the economic model remains steadfast and insensitive to raw material price changes.

MCDA perspective: When considering the broader MCDA framework, for the scores between Richards Bay and Phalaborwa to level out, the raw material in Phalaborwa needs to be priced 68% cheaper than in Richards Bay. While this isn't as extreme from the economic perspective, achieving such a significant price reduction would necessitate aggressive negotiations and might still be challenging. This suggests that while the MCDA model is generally robust, there's a slight sensitivity regarding raw material pricing in Phalaborwa.

4.7.3 Sensitivity Analysis Conclusion

The sensitivity analysis reveals the resilience of the MCDA model against potential changes in key parameters. While there's a minor sensitivity concerning raw material pricing from an MCDA perspective, the model remains steadfast against diesel and raw material price fluctuations. This robustness is reassuring, as it means the decisions derived from this model will remain consistent even if market conditions shift moderately. However, it's always prudent to revisit and recalibrate the model periodically, especially if there are significant market upheavals or strategic shifts in the business environment.

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter serves as the end of a basis research undertaking that has thoroughly investigated the complexities of gypsum procurement within the framework of the cement sector in South Africa. Throughout the preceding chapters, the investigation has encompassed various topics. It is the view of the researcher that the report extensively explored several aspects, such as geography, environment, supply chain, and stakeholder management, which are crucial components of this subject matter. As the researcher progresses through the concluding phase of this study, the insights and understandings that have surfaced serve as the fundamental basis upon which the researcher formulates the final assessments and proposals to overcome the obstacles and capitalize on the prospects within the gypsum supply chain ecosystem in the South African cement industry.

In this section, the researcher begins by recapping the study's main objectives, providing a concise overview of the fundamental goals that have directed this research's efforts. Following this, the researcher comprehensively examines the research outcomes, duly considering the inherent constraints that have influenced the scope of this study. Recognizing these limitations is crucial since it provides a contextual framework for interpreting the findings and formulating recommendations. The researcher strongly believes that by acknowledging and accepting these limits, the researcher grows a deeper understanding of the forthcoming results and recommendations.

The objective of this chapter is to provide practical and effective insights that can stimulate favourable transformations in the gypsum supply chain framework within the cement industry of South Africa. In addition, the objective is to provide a comprehensive framework for future study, identifying unexplored avenues that have the potential for enhancing the researcher's knowledge and making significant contributions to the long-term viability and growth of the gypsum market within the cement industry in South Africa. Therefore, the present chapter aims to provide a brief summary of the research findings and offer guidance for future investigations to strengthen and revitalize this crucial aspect of the construction materials industry.

5.2 Summary of the study

Any given industry's efficacy and long-term viability are contingent upon effectively managing its supply chains. Within the South African cement industry, the consistent availability and procurement of gypsum, a crucial raw material, holds significant importance in maintaining uninterrupted production. This section presents a thorough investigation that rigorously analyses the capacity needs of the inland cement industry, evaluates the current supplies of gypsum, and suggests ideal strategies for effective gypsum procurement. To investigate this supply chain, the researcher

established explicit goals and implemented a systematic methodology incorporating rigorous research approaches and analytical procedures. In the following sections, the researcher will clarify the aims, elaborate on the approach, and offer the results to enhance comprehension of this crucial aspect of the cement industry.

5.2.1 Objectives and approach

The study's key objectives were carefully defined to cover critical components of the gypsum supply chain in the South African cement industry.

The first objective of this study was to quantify the capacity requirements of the inland cement industry for the gypsum supply.

The second objective of this study was to analyse and quantify the known sources of gypsum in South Africa to determine their suitability for meeting the production capacity requirements of the cement industry.

The third objective of the study aimed to offer an optimal strategy for sourcing gypsum by developing an ideal solution model and employing the TOPSIS technique.

The study systematically addressed each of these aims.

The quantification of the capacity of the inland cement industry was conducted in this study through the utilisation of a comprehensive technique. The research methodology employed in this study consisted of a thorough desktop literature review, a meticulous, systematic literature review, and a survey to the cement factories. The approaches used in this study collectively yielded findings indicating an annual installed capacity of cement from 14.05 million tonnes, according to the systematic literature review, and 14.37 million tonnes, according to the surveys conducted. The slight disparity between the comprehensive analysis and the survey outcomes validates the conclusions' precision.

The study conducted a comprehensive analysis and quantitative assessment of the established gypsum reserves in South Africa. Three primary options arose, each possessing unique attributes such as geographical placement, the projected quantity of resources, level of purity, and moisture content. The alternatives yielded significant information regarding prospective sources of gypsum supply.

The study employed MCDA methodology through the TOPSIS method to determine the most favourable approach for sourcing gypsum. The analysis encompassed logistical considerations, empirical assessments of manufacturing expenses, and the incorporation of weighted MCDA elements. From the MCDA perspective, Richards Bay has been identified as the most favourable

choice. Furthermore, a sensitivity analysis was conducted to verify the model's resilience concerning discretionary factors, including diesel and raw materials costs. These factors did not have a substantial impact on the outcome of the MCDA and hence further proved the resilience of the model.

5.2.2 Outcome of the MCDA

Utilizing the MCDA model, designed with three primary criteria, namely environmental, quality, and economic factors, was essential in evaluating the suitability of various gypsum supply alternatives. The economic criteria were assigned the highest weight of 80%, followed by quality at 15%, while environmental issues made a smaller contribution of 5%. The findings indicated that Richards Bay achieved the greatest scores in the economic category, while Phalaborwa scored the highest in both environmental and quality. Notably, in terms of quality, all sources exhibited a similar scoring; this indicates that, at least on a practical scale, all three sources seem feasible. The environmental criteria was not a determining factor.

While constructing the MCDA, the aggregate expenses associated with the supply chain, excluding value-added tax (VAT), were determined for each respective region. This aggregated score relied heavily on the road transport costing quotes. Richards Bay has been identified as the most economically feasible choice, with a comprehensive cost of R1279.50 per ton. Phalaborwa ranks second with a total cost of R1391.04 per ton, while Loeriesfontein comes in third with a total cost of R1566.73 per ton. These are the average cost for a particular cement factory for the final material to their door.

Following a thorough assessment of the MCDA findings, the ensuing part will explore the constraints of the study, offering a comprehensive understanding of the research's extent and limitations.

5.3 Limitations of the study

While comprehensive, the scope and depth of this research are not without certain limitations. These constraints, some of which are self-imposed, are essential to acknowledge as they provide context to the findings and offer avenues for future research. The primary limitations of this study include:

1. Geographical constraints: The research is geographically confined to inland South Africa. While this focus allows for a detailed exploration of this specific region, it may not capture the nuances and dynamics of gypsum sourcing in coastal areas or other international regions.

2. Product specificity: The study exclusively examines cement-grade gypsum. While ensuring depth in the research, this specificity means that other grades or types of gypsum used in various industries are not considered.

3. Knowledge-based limitations: The research relies on current known sources based on prevalent industry knowledge. There might be emerging or lesser-known sources of gypsum that are not covered in this study.

4. Perspective limitation: The study is primarily informed by the viewpoint of one leading supplier. While efforts have been made to ensure objectivity, there's an inherent risk of bias. It's crucial to interpret the findings with this potential bias in mind.

5. Broader industry implications: Gypsum finds applications in many industries, including wallboard production, plasters, agriculture, and road stabilization. This study, however, is narrowly focused on its application in the cement industry. A broader exploration could provide a more holistic understanding of the gypsum market dynamics.

6. Scope of the gypsum market: This research aims to identify solutions to the gypsum supply challenges faced by the inland South African cement industry. It does not claim to represent the entirety of the gypsum market or its multifaceted challenges and opportunities.

7. Transportation improvements: Within the current South African context, the only viable solution to transportation for gypsum at these volumes is road transport; however, the use of rail can significantly impact the models. Future work should focus on finding alternative transportation methods as the researcher can see that transportation has a significant cost implication on the total supply chain.

While narrowing the scope of the current study, these limitations also highlight potential areas for future research. Exploring these avenues could provide a more comprehensive understanding of the gypsum market, its challenges, and possible solutions.

5.4 Recommendations

Throughout the investigation, it became apparent that the current body of literature on the cement sector lacks data, presenting obstacles to making informed decisions. It is highly advisable to engage in lobbying endeavours to promote the dissemination of knowledge within the sector, particularly regarding crucial matters such as acquiring raw materials such as gypsum.

5.4.1 Financial recommendations

Considering the comparable financial aspects observed in Phalaborwa and Richards Bay, additional studies into both options are advisable. The closeness of the economic costs between these two facilities illustrates a possible dual solution in the future. Should a single choice be apparent and the other source not sterilized, competition from another industry player might reduce the overall sales of the current market leader.

The gravitational model generated within this study proposes that the optimal location for a gypsum manufacturing facility is near the existing Rustenburg resource. Nevertheless, the potential relocation to a different site, such as Balfour in the Mpumalanga Province, may have noteworthy financial ramifications for the cement sector. Before making any installation, measuring and effectively conveying its financial implications accurately is imperative.

According to the research, it is advisable to establish the ultimate manufacturing facility in Balfour, Mpumalanga, as a replacement for Rustenburg and Potchefstroom. This strategy involves utilizing road transport for manufacturing operations in Balfour and distributing the products from this location.

Examining the drying process of materials and its impact on transporting substances with high moisture content, as observed in Rustenburg and Potchefstroom, presents significant considerations concerning overall transportation expenses. It is recommended that research be conducted about the drying of materials at the Balfour site to mitigate supply chain costs. This study assumed a similar % free moisture of material of 20%, such as the current status quo from Rustenburg and Potchefstroom; this can be reduced by mechanical drying.

Considering the extended operational expenses associated with using a mechanical drying technique, such as a kiln, is crucial to ascertain an economically viable resolution. When comparing the costs of drying versus the savings in logistical costs, an informed decision can be made to reduce the overall supply chain costs.

5.4.2 Managerial recommendations

The study revealed that for the best alternative identified through MCDA, Richards Bay, manufacturing and raw material costs accounted for a relatively small percentage of total costs (15,5% and 9.6%, respectively). On the other hand, transportation costs (74.7%) represented a significant portion of the total delivered costs. Hence, management should prioritize optimizing the logistical supply chain. The following recommendations are made:

1. Optimization of the logistical supply chain: Management should shift their focus from discretionary costs, within the current model of selling ex-gates at Rustenburg and Potchefstroom, to optimising the logistical supply chain. This includes exploring ways to reduce transportation costs, such as rail freight. Negotiate rail transportation: Management should actively explore negotiating rail transportation, as it can be a game-changer in the MCDA by significantly reducing logistical costs. This effort could make any option viable, for the purposes of this study this is investigated.

2. Consideration of multiple facilities: While a single manufacturing facility may offer economies of scale, the analysis indicates that the sensitivity of the supply chain lies in optimizing logistical

costs. Therefore, management should consider setting up two smaller facilities to optimize the supply chain further, even if it reduces the economics of scale. Offset additional supply chain costs: The current gypsum manufacturer should consider offsetting the additional supply chain costs to the cement industry from the current optimal point. This revenue can be used to fund the future acquisition and installation of a manufacturing facility. Capitalizing on the existing competitive advantage of the current facility is of utmost importance.

Considering all the above aspects, the researcher will now write the conclusion.

5.5 Conclusion

Throughout this study, the researcher has explored the complex terrain of gypsum acquisition within the framework of the cement sector in South Africa. The preceding chapters of the study have facilitated an examination of multiple facets, encompassing geological elements, environmental variables, complexities within the supply chain, and the management of stakeholders. The analysis of each factor has significantly helped the development of a comprehension of the gypsum supply chain ecosystem within the cement industry of South Africa.

As the researcher concludes this study, reflecting upon the fundamental aims that have served as the driving principles for the research endeavours is important. By doing so, the researcher presents a perspective on the research findings while also noting the limitations that have determined the extent of the study. By acknowledging and accepting these limits, the researcher can provide an understanding of the findings and present a framework for future research. By recognising these constraints, the researcher can gain a deeper understanding of the research findings' intricacies and the feasibility of the suggestions.

This chapter fulfils a dual function. The primary objective of this study is to offer concrete and impactful perspectives that can stimulate favourable changes within the gypsum supply chain structure of the cement industry in South Africa. Furthermore, it provides a strategic plan for future research endeavours, highlighting unexplored avenues that can enhance the researcher’s comprehension and significantly contribute to the continuous expansion of the gypsum market in South Africa's cement sector.

Properly managing supply chains is a critical factor in the success of any flourishing industry. The acquisition of gypsum, a crucial raw material, plays a pivotal role in maintaining uninterrupted production within the cement sector in South Africa. This study thoroughly examined the capacity needs of the domestic cement sector, evaluated the available gypsum resources in South Africa, and outlined the most effective approaches for acquiring gypsum. The explorations were conducted with clear objectives and followed a methodical technique, including a comprehensive literature review, questionnaires, and analysis.

The inland cement industry's capacity evaluation yielded an annual installed cement capacity of 14.37 million tonnes. The assessment of gypsum reserves in South Africa has shown three main alternatives, each possessing distinct characteristics that present opportunities for sustainable sources of gypsum supply. By utilizing MCDA through the TOPSIS methodology, the researcher has determined that Richards Bay is the most economically advantageous option for sourcing gypsum. At the same time, Phalaborwa demonstrated superior performance in terms of environmental and quality criteria.

However, it is crucial to recognize the intrinsic constraints of this research. The context in which the findings must be understood is shaped by various constraints. These constraints encompass geographical boundaries, product specificity, reliance on existing knowledge, potential perspective bias, a limited scope within the broader industry landscape, and a need to explore alternative transport modes beyond road transport.

In summary, the researcher emphasises the significance of knowledge transmission within the cement industry, specifically concerning procuring essential raw materials such as gypsum. Based on the alignment of their economic characteristics, the financial proposals include additional inquiries into the Phalaborwa and Richards Bay regions. Furthermore, the research conducted in this study provides insights into the possible advantages of investigating the drying process of materials at the Balfour site to reduce costs across the supply chain.

Regarding management, key considerations for industry leaders include optimizing the logistical supply chain to minimize transportation expenses, evaluating the feasibility of multiple facilities to improve supply chain efficiency, actively engaging in negotiations for rail transportation, and allocating additional supply chain costs toward establishing future manufacturing facilities. According to the research, it is advisable to establish the ultimate manufacturing facility in Balfour, Mpumalanga, as a replacement for Rustenburg and Potchefstroom

This study offers a thorough examination that establishes a strong basis for making well-informed decisions and acts as a guiding principle for future research endeavours focused on strengthening the gypsum supply chain framework in the cement sector of South Africa. The acquisition of knowledge and insights during this study shed light on the path ahead, presenting opportunities for a cement sector in South Africa that is characterized by resilience, sustainability, and prosperity.

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ANNEXURE A: CONSENT APPROVAL

OMV (Pty) Ltd
N12 Highway Stilfontein
PO Box 823 Stilfontein, 2550
t: +27 (0) 18 484 1312
f: +27 (0) 18 484 5011
www.omv.co.za

2023/01/26

Dear Marinus,

LETTER GRANTING ACCESS TO SECONDARY INFORMATION

We are hereby granting you permission to utilize secondary data for your mini-dissertation titled "Formulating a multi-criteria decision analysis model of a gypsum manufacturing facility within South Africa." We understand that you will not be conducting interviews or making any observations at the OMV gypsum manufacturing facility.

We appreciate your interest in our operations and are happy to grant you permission to utilize the secondary data available for your research. We trust that you will handle the data with the utmost confidentiality and use it only for academic purposes.

If you have any concerns or questions regarding this permission, please do not hesitate to contact us.

Sincerely,

Oscar Goudriaan

Managing Director

Reg. No.: 2014/011295/07
Directors: OC Goudriaan, MM Adonis, MJ van den Berg

ANNEXURE B: QUESTIONNAIRE TO CEMENT INDUSTRY CLIENTS

NWU Business School
North-West University
Private Bag x6001
Potchefstroom, 2520
http://commerce.nwu.ac.za/business-school

Dear Participant,

Questionnaire on Cement Gypsum usage:

I hope this message finds you well. We are reaching out from the North-West University's MBA program to seek your valuable input for our ongoing study titled, "Formulating a multi-criteria decision analysis model of a gypsum manufacturing facility within South Africa."

Your insights, as a leader in the industry, are invaluable to the depth and accuracy of our research. The attached questionnaire aims to gather specific data on Gypsum usage within your company. We understand the importance of confidentiality and would like to assure you that all information provided will be used solely for academic purposes and will be treated with the utmost discretion.

Informed Consent:
By completing and returning this questionnaire, you are providing your informed consent for us to utilize the information you provide in our study. Participation is entirely voluntary, and you may choose to withdraw at any time without any repercussions. If you have any questions or concerns about the study or the use of your data, please do not hesitate to contact us.
We genuinely appreciate your time and consideration in assisting with this research. Your expertise and insights will significantly contribute to the success and relevance of our study.
Thank you for your participation.
Warm regards,

Marinus van den Berg
MBA Candidate
North-West University Potchefstroom
073 997 0602

NWU Business School
North-West University
Private Bag x6001
Potchefstroom, 2520
http://commerce.nwu.ac.za/business-school

NWU MBA Questionare

Company Name:_____
Person Completing the questionnaire name:_____
Job Title:_____

Factory 1:
Factory Name:_____
Estimated location:_____
Installed Capacity blending (Tons):_____
Optional:
Gypsum Dosing % Dry Weight(Estimate):_____

Factory 2:

Factory Name:_____
Estimated location:_____
Installed Capacity blending (Tons):_____
Optional:
Gypsum Dosing % Dry Weight(Estimate):_____

Factory 3:

Factory Name:_____
Estimated location:_____
Installed Capacity blending (Tons):_____
Optional:
Gypsum Dosing % Dry Weight(Estimate):_____

ANNEXURE C: LAB REPORTS

Modderfontein Laboratory Services (Pty) Ltd
Registration Number : 1966/001741/07
P. O. Box 27
Modderfontein
1645
Tel: +27 011 457 1800
Fax: +27 011 608 0923

Client Name: NJATI HOLDINGS
Client Address: P.O.Box 1436
Fontainbleau
2032
Date Received: 09/03/2022
Date Reported: 01/04/2022
Product Name: Richards Bay Gypsum

Gr. No.: 301851
Lims ID: 313776

P.O. No.:

Batch No.: 17022022

CERTIFICATE OF ANALYSIS

Test	Test Method	Result	Specification	Unit
Calcium as Ca	MDF 820	20.5	>18	% m/m
Sulphur as S	ALFA 10/1	15.0	>12	% m/m
Total Magnesium as Mg	MDF 820	0.07		% m/m
Water Soluble Magnesium as Mg	MDF 820	0.07		% m/m
$CaSO_4.2H_2O$	Calculation	80.7		% m/m
$CaSO_4.2H_2O$ (Dry Basis)	Calculation	96.1		% m/m
pH (10% slurry)	ALFA 19/1	7.4		units
Loss on drying @ 220 ^oC	Gravimetric	32.9		% m/m
Free Moisture	Gravimetric	16.0		% m/m
Sieve Analysis: <2.0 mm	Wet Screening	100.0		% m/m
Sieve Analysis: <1.0 mm	Wet Screening	100.0		% m/m
Sieve Analysis: <0.25 mm	Wet Screening	100.0		% m/m
Sieve Analysis: <0.106 mm	Wet Screening	96.5		% m/m
Arsenic as As	MDF 821	<1	50	mg/kg
Cadmium as Cd	MDF 821	<0.1	20	mg/kg
Chromium as Cr	MDF 821	1.0	1750	mg/kg
Copper as Cu	MDF 821	75	750	mg/kg
Lead as Pb	MDF 821	7.9	400	mg/kg
Mercury as Hg	MDF 821	<0.5	10	mg/kg
Nickel as Ni	MDF 821	0.9	200	mg/kg
Selenium as Se	MDF 821	<2	15	mg/kg
Zinc as Zn	MDF 821	11	2750	mg/kg

Results reported are on sample as received.
NOTE: 1) $CaSO_4.2H_2O$ calculated on dry basis by removing the free moisture content.
2) Calculated results reflect the likely composition.

D. Reddy
Fertilizer Manager

Disclaimer: MLS is an AgriLasa certified Laboratory for fertilizer. MLS is certified under ISO 9001 (Certificate #LS1804). MLS is responsible for management of all information obtained and /or created during performance of service and shall treat it as confidential. MLS strives to undertake all activities or services impartially

4/04/22

Modderfontein Laboratory Services (Pty) Ltd
Registration Number : 1966/001741/07
P. O. Box 27
Modderfontein
1645
Tel: +27 011 457 1800
Fax: +27 011 608 0923

Client Name: NJATI HOLDINGS
Client Address: P.O.Box 1436
Fontainbleau
2032
Date Received: 09/03/2022
Date Reported: 01/04/2022
Product Name: Phalaborwa Gypsum

Gr. No.: 301851
Lims ID: 313774

P.O. No.:

Batch No.: 21022022

CERTIFICATE OF ANALYSIS

Test	Test Method	Result	Specification	Unit
Calcium as Ca	MDF 820	20.6	>18	% m/m
Sulphur as S	ALFA 10/1	16.4	>12	% m/m
Total Magnesium as Mg	MDF 820	0.07		% m/m
Water Soluble Magnesium as Mg	MDF 820	0.07		% m/m
$CaSO_4.2H_2O$	Calculation	88.4		% m/m
$CaSO_4.2H_2O$ (Dry Basis)	Calculation	98.6		% m/m
pH (10% slurry)	ALFA 19/1	3.2		units
Loss on drying @ 220 ^oC	Gravimetric	28.8		% m/m
Free Moisture	Gravimetric	10.3		% m/m
Sieve Analysis: <2.0 mm	Wet Screening	99.8		% m/m
Sieve Analysis: <1.0 mm	Wet Screening	99.6		% m/m
Sieve Analysis: <0.25 mm	Wet Screening	99.5		% m/m
Sieve Analysis: <0.106 mm	Wet Screening	91.2		% m/m
Arsenic as As	MDF 821	<1	50	mg/kg
Cadmium as Cd	MDF 821	<0.1	20	mg/kg
Chromium as Cr	MDF 821	4.3	1750	mg/kg
Copper as Cu	MDF 821	9.3	750	mg/kg
Lead as Pb	MDF 821	13	400	mg/kg
Mercury as Hg	MDF 821	<0.5	10	mg/kg
Nickel as Ni	MDF 821	0.5	200	mg/kg
Selenium as Se	MDF 821	<2	15	mg/kg
Zinc as Zn	MDF 821	1.5	2750	mg/kg

Results reported are on sample as received.
NOTE: 1) $CaSO_4.2H_2O$ calculated on dry basis by removing the free moisture content.
2) Calculated results reflect the likely composition.

D. Reddy
Fertilizer Manager

Disclaimer: MLS is an AgriLasa certified Laboratory for fertilizer. MLS is certified under ISO 9001 (Certificate #LS1804). MLS is responsible for management of all information obtained and /or created during performance of service and shall treat it as confidential. MLS strives to undertake all activities or services impartially

4/04/22

ANNEXURE D: GEOGRAPHICAL SURVEYS

D. VOLUME RESULTS

Two independent answers were obtained for the volumes:

Answer 1: 7 336 962 m³

Answer 2: 7 574 909 m³

Average: 7 455 935 m³

Please note that the bottom surface of the dump could not be surveyed and was interpolated from the perimeter points.

H.T. DU PREEZ
Professional Land Surveyor
PLS-1111

Figure 1 Richardsbay volumes survey

ANNEXURE E: ETHICS APPROVAL

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

Private Bag X1290, Potchefstroom
South Africa 2520

Tel: 018 299-1111/2222
Fax: 018 299-4910
Web: http://www.nwu.ac.za

Senate Committee for Research Ethics
Tel: 018 299-484
Feziwe.Mseleni@nwu.ac.za

31 March 2023

ETHICS APPROVAL LETTER OF STUDY

Based on approval by the **Economic and Management Sciences Research Ethics Committee (EMS-REC)** on 31/03/2023, the Economic and Management Sciences Research Ethics Committee hereby **approves** your study as indicated below. This implies that the North-West University Senate Committee for Research Ethics (NWU-REC) grants its permission that, provided the special conditions specified below are met and pending any other authorisation that may be necessary, the study may be initiated, using the ethics number below.

Study title: Formulating a multi-criteria decision analysis model of a gypsum manufacturing facility within South Africa

Study Leader/Supervisor (Principal Investigator)/Researcher): Prof Nelda Mouton-MBA

Student: Van den Burg MJ(25066013)

N	W	U	-	0	0	6	3	1	-	2	3	-	A	4
Institution				Study Number						Year			Status	

Status: S = Submission; R = Re-Submission; P = Provisional Authorisation; A = Authorisation

Application Type:
Commencement date: 1/4/2023 **Risk:** Low
Expiry date: 1/5/2024
Approval of the study is initially provided for a year, after which continuation of the study is dependent on receipt and review of the annual (or as otherwise stipulated) monitoring report and the concomitant issuing of a letter of continuation.

Special in process conditions of the research for approval (if applicable):

-

General conditions:

While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, the following general terms and conditions will apply:

- *The study leader/supervisor (principle investigator)/researcher must report in the prescribed format to the EMS-REC:*
  - *annually (or as otherwise requested) on the monitoring of the study, whereby a letter of continuation will be provided, and upon completion of the study; and*
  - *without any delay in case of any adverse event or incident (or any matter that interrupts sound ethical principles) during the course of the study.*
- *The approval applies strictly to the proposal as stipulated in the application form. Should any amendments to the proposal be deemed necessary during the course of the study, the study leader/researcher must apply for approval of these amendments at the EMS-REC, prior to implementation. Should there be any deviations from the study proposal without the necessary approval of such amendments, the ethics approval is immediately and automatically forfeited.*

- *Annually a number of studies may be randomly selected for an external audit.*
- *The date of approval indicates the first date that the study may be started.*

n the interest of ethical responsibility, the NWU-SCRE and EMS-REC reserves the right to:

- *request access to any information or data at any time during the course or after completion of the study;*
- *to ask further questions, seek additional information, require further modification or monitor the conduct of your research or the informed consent process;*
- *withdraw or postpone approval if:*
  - *any unethical principles or practices of the study are revealed or suspected;*
  - *it becomes apparent that any relevant information was withheld from the EMS-REC or that information has been false or misrepresented;*
  - *submission of the annual (or otherwise stipulated) monitoring report, the required amendments, or reporting of adverse events or incidents was not done in a timely manner and accurately; and / or*
  - *new institutional rules, national legislation or international conventions deem it necessary.*

The EMS-REC would like to remain at your service as scientist and researcher, and wishes you well with your study. Please do not hesitate to contact the EMS-REC or the NWU-SCRE for any further enquiries or requests for assistance.

Yours sincerely,

Mark Rathbone

Digitally signed by Mark Rathbone
DN: cn=Mark Rathbone, o=North-West University, ou=Business management, email=mark.rathbone@nwu.ac.za, c=ZA
Date: 2023.04.12 14:39:22 +02'00'

Prof Mark Rathbone
Chairperson: NWU Economic and Management Sciences Research Ethics Committee

ANNEXURE F: LANGUAGE EDITOR DECLARATION

The Magic Word
What's the word?
The Magic Word: Proofreading and copy-editing services
Cell phone: +27 72 666 5201
Email: simone.kriek@gmail.com
Website: www.themagicword.co.za

2023/11/16

MJ van den Berg
North-West University
Master in Business Administration degree student
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Declaration TMW2023/005: Copy-editing service delivery

Our communication regarding my commitment to provide a declaration concerning the abovementioned refers.

I appreciate your use of The Magic Word's services. I am pleased to make the following declaration **(Table 1)**.

Table 1: Declaration

Declaration TMW2023/005: Copy-editing service delivery	
I, Mrs Simone (Kriek) van Rooyen, Owner and Editor of The Magic Word: Proofreading and copy-editing services, declare that I have copy-edited the following student's assignment.	
Dissertation title:	Formulating a multi-criteria decision analysis model of a gypsum manufacturing facility in South Africa
Student's initials and surname:	MJ van den Berg
Student's persistent digital identifier (ORCID ID):	orcid.org 0000-0002-0028-5750
Student's dissertation submitted in partial fulfilment of the requirements for the following degree at the North-West University:	Master in Business Administration
Student's supervisor:	Prof N Mouton
Dissertation examination date:	November 2023
Student number:	25066013

Thank you for the opportunity to present you with this copy-editing service delivery declaration. Please direct any queries regarding the content of this declaration to the undersigned.

Yours sincerely

Mrs Simone (Kriek) van Rooyen
Owner and Editor
The Magic Word
Cell phone: +27 72 666 5201
Email: simone.kriek@gmail.co.za