Optimising the application of modern and conventional trackless mobile machines in chrome smelting operations

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DEDICATION

I dedicate this research to my family, colleagues, and peers. All those who motivated, supported, and encouraged the development of this idea and research, you contributed and helped me to achieve completion.

PREFACE AND ACKNOWLEDGEMENTS

This research topic and the reason for starting with an MBA comes from the investment in and appreciation for the organisation I'm part of and working in. The goal is to improve systems, assets, and people to such an extent that the business thrives for years to come, and what better way than to start with yourself. A family-run business not only requires commitment that comes from self-motivation but also requires staying up to date with the latest improvements and developments within its business operations industry. In developing oneself as a future leader, conducting research that contributes to the organisation is a key component of sustainable success.

Therefore, the goal of considering and developing a research topic relevant to the current situation, challenges, and opportunities came in the form of the organisation's largest asset and largest part of the business. Trackless mobile machines (TMMs) are the assets used to deliver a service and ensure income. The balance between applying conventional and modern TMMs and optimising the useful life of these TMMs could be what sets you apart from other organisations. Therefore, optimisation of the application of conventional and modern TMMs, as well as understanding the industry, its potential, its technological developments, and being at the forefront of development and the introduction of new methods would build a culture driven by safety, efficiency, and effectiveness, all of which would ensure organisational sustainability.

I would like to acknowledge and thank the following people, groups, and institutions, as without them and their support, this goal would have stayed a dream:

- Without faith, I would be lost. Thank you to our Lord Jesus Christ for a healthy mind, eager soul, and blessings in abundance.

- My wife, Chantell Erasmus, tough times don't last; as with so many challenges, you are my daily inspiration, driving force, and biggest supporter. The true epitome of a strong relationship is not wondering if it would last during difficulty but knowing I couldn't achieve anything without you. Thank you for believing in me even when I do not.

- Lia-Elle Erasmus, our daughter in heaven, losing you has been my greatest battle in life, but your life is my greatest inspiration. Without wanting to make you proud, I would have given up, and not only on this paper.

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DECLARATION

I, Danie Erasmus, declare that this research dissertation titled: **Optimising the application of modern and conventional trackless mobile machines in chrome smelting operations,** and the work presented in this research dissertation is both my own and generated by me from my original research. It is submitted in partial fulfilment of the requirements of the degree Master of Business Administration at the North-West University Business School. To the best of my knowledge and belief, no material previously published or written by another person, except where due references are made, is contained in this mini-dissertation.

Danie Erasmus.

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ABSTRACT

South Africa has one of the largest chrome ore deposits worldwide, providing ferrochrome through furnace production. Internal movement and bulk material handling is a specialised service rendered within the greater value chain. This market is ever-changing, demanding, and competitive; constant growth and development are required to ensure efficiency throughout the value chain.

To be competitive on a global scale, the chrome smelting industry in South Africa needs to adopt new technology in its bulk material handling operations. However, most of Almar’s clients have not optimised the application of conventional and modern TMMs in their haulage operations, which can be detrimental to mine productivity, client satisfaction and the quality of service delivery. The unproductive application of conventional and modern TMMs in chrome mining's bulk material handling operations poses a competitive challenge to the industry.

This study investigates how a blend of conventional and modern TMMs can be optimally applied to increase the productivity of on-site bulk material handling in South African chrome mines. To this end, a TMM fleet optimisation approach is proposed using client-specific internal data from the Almar Investments (Pty) Ltd (Almar) database. It also focuses on future technological TMM developments: how emulators, remote control TMMs, and electric-powered vehicles could change the industry's future and improve efficiency.

Organisations increasingly depend on partners within their supply chain to improve business processes and minimise costs to achieve and maintain a competitive advantage. The aim is to evaluate optimisation to stay relevant within the supply chain. The primary objective of this study is to find the balance between conventional and modern TMMs for on-site bulk material handling, optimise current business operations, and investigate new advances in solutions to stay relevant. Several secondary objectives were applied and reached; the study applied cost-benefit and data analysis techniques to determine the feasibility of the optimisation.

Data from Almar’s database were used to determine when using an increased number of modern TMMs in the client’s haulage operations is advantageous. Factors such as breakdown frequency, standing time per TMM life cycle and TMM category, as well as availability and utilisation of TMMs occurring over periods ranging from 5 000 - 10 000 hours to 20 000 - 25 000 hours, were considered to determine when it becomes advantageous to use more modern TMMs than conventional ones. It was established that after two years of operation, more modern TMMs than conventional ones should be employed in the haulage operations of the company investigated.

Calculations using the PI index at an increment of one year up to seven years show that at 6.5 years and a total profitability index of 1.408, the contributions of conventional and modern TMMs to the PI are the same. Over long periods (years six and seven), using more than 50% up to 90% modern TMMs in hauling operations is an advantageous investment strategy for Almar's client.

The contribution of this study would be to determine the optimisation of conventional and modern TMMs for increased efficiency to ensure future sustainability for an established organisation.

Key terms: TMM, Conventional, Modern, Sustainability, Efficiency, Effectiveness, Chrome smelting, Service delivery, Value chain, Machines, Safety, Production, Economies of scale, Market share, South Africa, Outsourcing, financial metric, cost-benefit analysis.

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Capital budget: The purpose of capital budgeting is to acquire a long-term venture or to build a new plant for the business.

Disparate impact: The outcome of data analysis can cause inadvertent harm to a company.

Exploratory data analysis: Examining data to uncover patterns, spot anomalies, test hypotheses, and verify assumptions based on summary statistics and graphs.

Earth-moving equipment: Heavy machinery that can move and grade soil and rock. Additionally, they are used in materials handling, demolition, mining, and any other industry that requires more power than humans can provide.

Front-end loader: A machine with a scoop or bucket on an articulated arm at the front for digging and loading earth.

Ferrochrome (FeCr): An iron and chromium alloy usually containing 50% to 70% chromium.

Fleet management: The actions needed to keep a fleet running efficiently, on time, and within budget.

Fleet tracking: A fleet tracking system that uses GPS technology to monitor the activity of fleet vehicles and assets (e.g. workers and equipment).

Ferrochrome smelter industry: Treating and converting raw chrome ore to ferrochrome as a final product through a furnace smelting operation.

Fleet management software: Allows fleet managers to monitor their vehicles, equipment, and drivers continuously.

Geographical boundaries: A geographical area on a map of South Africa identified by boundaries.

General Packet Radio Service: GPRS is mobile communications through cellular networks, transferring data using packet-based technology.

Global System for Mobile communication: A digital mobile phone network that is widely used globally.

Information systems: Information, knowledge, and digital products that can be collected, stored, and processed electronically.

Investment profitability metrics: Includes Nett Present Value (NPV), Internal Rate of Return (IRR) and Profitability Index (PI).

Key performance indicator: Measuring an organisation's or employee's success in meeting its performance objectives in a quantifiable manner.

Metal extraction process: Also referred to as chrome recovery plants, which treat waste 'slag' material through water-based jigging and DMS plants or dry magnet plants to recover chrome left in waste material.

Mixed-method research approach: Employing both quantitative and qualitative research methods.

On-site bulk material handling: The entire process of handling all material, processed and unprocessed, within the parameters of the site, on-site movement, stockpiling, feeding, loading, and hauling of bulk material handled.

Positivistic research philosophy: Only factual knowledge gained through observation including measurement, is trustworthy.

Primary data: Primary data that the researcher has generated, collected through primary sources.

Public data: All information made freely available by government bodies or local collectivities.

Quantitative data: The numerical value of data in the form of counts or numbers.

Quantitative analysis: The process of collecting and analysing numerical data.

Qualitative data: Answers the 'what', 'how', and 'why' of phenomena.

Qualitative analysis: Analyses non-quantifiable information to determine a company's value or prospects.

Research ethics: Governing standards of conducted research on how the research is planned, conducted, and executed to ensure that the entire process conforms to research community norms, standards, and guidelines.

Road freight industry: The transport of goods on public roads employing a goods vehicle, for compensation, by employers and employees associated with this industry.

Supply chain management: Transforming raw materials into final products and managing the flow of goods and services.

Supply chain: The production and fulfilment of goods and services demands. As a trading partner community, it strives to satisfy end customers.

Service-level agreement: A contract between a service provider and its customers specifies which services the provider will provide and the service standards the provider must meet.

Safety, Health, Environment, and Quality: Commitment to employee health and safety, environmental protection, and customer satisfaction.

Total Quality Management: The philosophy that every staff member should maintain high standards of work in every aspect of the company's operations.

Trackless mobile machines: Self-propelled manned or remote machines used in transport or mining activities or mining-related activities either above ground or underground.

Tramming: To haul in a tram or over a tramway.

Secondary data: Data already collected through primary sources. Data collected by someone other than the primary user.

LIST OF ABBREVIATIONS

ADT: Articulated dump truck

AHT: Autonomous Haul Trucks

Almar: Almar Investments (Pty) Ltd

DMR: Department of Minerals and Resources

GDP: Gross Domestic Product

LHD: Load-haul-dump

TMM: Trackless Mobile Machine.

TQM: Total Quality Management

OEM: Original Equipment Manufacturer

OSH: Occupational Health and Safety

SHE: Safety, Health, and Environment

PGM: Precious Group Metals

AT: Autonomous Trucks

EMV: Equipped Manual Vehicles

TPM: Total Plant Maintenance

NPV: Net Present Value

H2s: Hydrogen Sulphide

CO: Carbon Monoxide

NOx: Nitrogen Oxides

ADAS: Advanced Driver Assistance Systems

KPI: Key Performance Indicator

MHSA: Mine Health and Safety Act

MRAC: Mining Regulation Advisory Committee

AMT: Asset Management Tool

CAPEX: Capital Expenditure

CHAPTER 1: NATURE AND SCOPE OF STUDY

1.1 INTRODUCTION

Trackless mobile machines (TMMs) are self-propelled mobile machines employed underground or above ground to mine, transport, or perform associated operations (Department of Mineral Resources, 2015:5). The machines are mobile because they can move on wheels, skids, tracks, mechanical shoes, or any other device fitted to them (Department of Mineral Resources, 2015:5). These TMMs perform various tasks, from raw material arrangement to final product dispatch of various types, sizes, and forms.

This study aims to investigate how a blend of conventional and modern TMMs can be optimally applied to increase the productivity of on-site bulk material handling in South African chrome mines. The purpose of this chapter is to describe how this aim will be achieved in the current study. This chapter describes various steps that will be followed to reach this goal.

The first step is formulating the problem statement, which is the specific gap(s) (section 2.6.14) in the existing literature that this research aims to address. Second, the paradigmatic perspectives are discussed. Third, the study's primary and secondary objectives, which refer to the specific outcomes expected to be achieved, are discussed. The research's specific outcomes are reflected in the title of this research endeavour. Closely related to the problem statement and objectives, the research question aims to resolve a problem that has not been addressed before. Fourth is a discussion on this study’s research methodology, which is how the researcher systematically plans the study to achieve its goals. Fifth, this chapter concludes with an overview of the significance and benefits of the research, rigour, validity, reliability, and ethical considerations.

1.2 BACKGROUND

1.2.1 Context of the study

Almar Investments (Pty) Ltd's (Almar) core mission is to create a strategic partnership with their customers, built on providing comprehensive operational solutions and creating value through promoting optimised efficiency. In addition, continual improvement of operational strategies in conjunction with operations optimisation is implemented, which develops a sustainable strategic partnership (SPH, 2023).

This study focuses on the engagement of supply chain performance and its influence on on-site bulk materials handling service delivery within the chrome smelting industry. This organisation delivers services across several provinces in South Africa, with the potential and intention to pursue international markets. Two of the organisation’s main competitive advantages are vested in its people and unique technological advances within its business field.

Delivering exceptional and high-quality services depends on technology and optimising the organisation's equipment and resources. Therefore, service delivery largely depends on its management, employees, and overall effective management of the entire supply chain. An essential contribution to organisational success is the working environment established for management and employees alike, with a family mindset and the entitlement of each employee to contribute to a greater goal. Engaged, motivated, and invested employees improve a company's efficiency and contribute to its financial success (Osborne & Hammoud, 2017:52).

1.2.1.1 Broader research area

Extensive research and development have led to three major equipment manufacturers’ commercialisations of autonomous loading and haulage technology (Gustafson *et al.,* 2017:185).

The available systems are:

- AutoMine®, and AutoMine® Lite from Sandvik Mining (Sandvik, 2018),
- Cat® and Cat® MineStar™from Caterpillar (Caterpillar, 2023),
- Scooptram Automation from Atlas Copco (Atlas Copco Scoop Automation, 2016).

These systems enable the autonomous operation of LHDs (load-haul-dump machines) in a single- or multi-loader configuration. Currently, the market has a few offerings regarding the latest available technology. Cat Minestar’s Command is an autonomous solution with increased safety and efficiency advantages for opencast operations (Caterpillar, 2023; IM, 2023). Automine from Sandvik allows integration between automation and manual operations, enabling the completion of production cycles without stopping and with minimal human integration (Automine, 2020; IM, 2020). Epiroc offers underground automation by seamlessly adding trucks to traffic management without stopping production (Epiroc, 2020). They also deliver battery-powered machines for a greener environmental footprint.

Mining operations face daily challenges in reducing costs, increasing productivity, and working more efficiently and safely. The industry continues to look for innovative ways to address these challenges. Caterpillar could address these challenges with the Cat MineStar Command by making their products safer, stronger, and more productive through developing technology that improves the efficiency of the equipment and the entire business operations (Caterpillar, 2023). The Cat Command system is an autonomous solution, including remote control to fully autonomous solutions. Working seamlessly with all equipment, personnel, and the environment assists the organisation in boosting efficiency, safety, and productivity and reducing overall costs. It also helps to reduce the mining footprint and improve machine availability with increased consistency and accuracy of operations. These factors enable working safely in challenging environments with the added benefit of increased profitability. The Cat Command systems offer underground, dozing, drilling, and hauling capabilities. Being a comprehensive system, the Cat Command delivers the full benefits of automation. Cat is continuing to find new ways to make these solutions available for all mining types and sectors within the industry, regardless of size or application. With the current systems implemented, even the simplest systems can yield considerable benefits—with significant safety and efficiency gains. With Cat's years of international experience and significant global footprint, it can address any requirement, addressing the company's challenges, whether it is just beginning the automation journey or ready to take the next step by employing Cat Minestar.

Mines have worked with Sanvik innovations and solutions like Automine for autonomous haulage for many years. Sanvik continuously improves its products to make them suitable and easy to use for any mining application. These products have been developed by listening to customer needs and improving safety, flexibility, and output (Automine, 2020). Sandvik's AutoMine systems connect to OptiMine, enabling efficient production planning. Planning tasks are dispatched to the Automine system, enabling the trucks to go to a desired location automatically (Automine, 2020). This traffic flow of automated trucks is controlled by advanced fleet traffic management systems, with upgraded safety systems allowing the splitting and merging of safety zones and enabling flexible interaction between manual and automated equipment. With the new surface navigation enabling autonomous underground trucks to work on the surface, these trucks can complete full production cycles without stopping, with minimal human interaction, and start new production tasks immediately. Sanvik Automine enables trucks to run accurately at high speed with increased safety and efficiency. This entire process is controlled by reporting back to a control room on the progress of the production tasks. Thus, the operations can be adjusted based on real-time status information. These continuous innovations would ultimately enable the mine to achieve lower costs per ton, with increased productivity and a safer working environment.

Epiroc automation for underground trucks makes it possible to add and bring new trucks into an area, adding them to the traffic management system without stopping production with the check-in/check-out procedure (Epiroc, 2020). Epiroc has been committed to developing battery-electric powered, zero-emission equipment, reducing the mine's environmental footprint (Epiroc, 2020). As a result, the health and safety of operators are protected, along with increased productivity and performance. The Scooptram ST14 Battery is designed with a hi-tech infrastructure to improve performance further (Creamer Media's Engineering News, 2023). A ring control system, a digital infrastructure, controls all tramming functions, which can be integrated to achieve a fully autonomous operation.

1.2.1.2 Shortcomings of existing technology

The technology required for safer, more efficient, more productive, and greener operations can fulfil the future need for automated and electric-operated cars and machines. However, the influence of the furnace and smelting operations on automated and battery-powered machines is unknown. Hot application work involves operating machines in areas with temperatures over 1000 °C. The impact of this heat factor on battery-powered and automated machines could be detrimental to the equipment.

Smelting plants are operated in very confined spaces. The current automated machines are tested and used in opencast and underground mining operations. These operations are usually dictated by one-way traffic, with little machine interaction. In a smelting plant, numerous machines operate close to unplanned traffic routes.

1.2.1.3 Identifying the gap or need for the intended research

With less environmental impact, a greener footprint has become a growing focus for the chrome mining industry, including smelting plants. Therefore, battery-powered machines have been identified as a key technology to investigate. Additionally, the heat component of the smelting industry, to which both machines and people are exposed, has prompted the development of autonomous machines to keep people away from the most dangerous points and areas on the plant. There should be no risk of injury or death from rockfalls or collisions with stationary and moving objects.

Battery-powered machines offer the following advantages (Bartelmus, 2014:8; Boudreault, 2019:34-38):

- better working conditions due to the absence of noxious exhaust gases (CO, NO_X, H_2S, SO_2, and NH_4), diesel particulate matter and dust, excessive noise, and vibrations,
- improved productivity by increasing equipment availability and reliability and utilising equipment better,
- reduced operational cost (longer service life, decreased maintenance requirements, and more actual working hours),
- the potential to overcome personnel shortages (if one operator can control more than one machine, fewer operators need to be employed).

1.2.2 Trends and status quo regarding the utilisation of conventional and modern TMMs in South Africa and around the world

In modern TMM business operations, availability and utilisation are the two most vital areas for measuring TMMs' performance. Therefore, availability and utilisation are defined as measuring the hours available in the shift, the amount of these hours the TMM was available and ready to use, and how the TMM was employed for the hours that it was available.

The industry norm within South Africa across all mining and bulk material handling sectors is 80% availability. The 80% availability trend is based on the hours given, with the knowledge that a TMM must be serviced, washed, refuelled, and stopped for operator shift change. The 20% downtime should ideally include any unforeseen breakdowns; therefore, standing time will be divided into planned and unplanned time. The utilisation should ideally be as close to 100% as possible, but the industry norm is around 95% utilisation. Therefore, 80% availability × 95% utilisation equals 75% of the available shift time that the TMM will be utilised.

In balancing conventional and modern TMMs, a minimal level of utilisation must be achieved. Depending on production requirements, each site's minimum required utilisation could differ. When there are too many conventional TMMs, the same level of availability and utilisation should be maintained, resulting in increased labour and overall costs. However, employing only modern TMMs is time-consuming as these machines are usually under a warranty. Servicing a modern TMM might take longer because Original Equipment Manufacturer (OEM) requirements must be met. In terms of financing costs, a modern TMM is also more expensive than a conventional one. Therefore, ideally, the perfect balance between modern and conventional TMMs is the preferred method.

1.3 PROBLEM STATEMENT

The application of modern and conventional TMMs in chrome smelting operations must be optimised to ensure cost-effective, sustainable, and profitable service delivery.

Sustainability is ensured by balancing relevant or redundant conventional and modern TMMs’ maintenance and financing costs.

Change within an organisation or industry is envisioned by obtaining a clear picture of the operation processes. By understanding the needs and constraints with an end goal, leaders, managers, and employees should gather information to create a better working environment for everyone. Leończuk (2016:105) states that performance measurement is part of SCM (Figure 1) and directly impacts the effective planning, control, monitoring, and analysis of the logistics process. It provides information on costs, profits, and results in a format that facilitates decision-making.

According to Kirovska *et al*. (2016:8), SCM is the process of planning, implementing, and controlling the supply chain operations to satisfy customers as efficiently as possible. They state that customer satisfaction will drive efficiency in a supply chain.

A well-defined strategy facilitates the process of proper goal setting. Optimising business operations allows for optimum turnover and ensures the organisation's sustainability. If this strategy is predicated on being a strategic partner for clients, it would ultimately ensure market relevance, leading to greater profits for the organisation and the end user.

Maintaining efficient material flow during periods of uncertain labour ensures supply and CAPEX/OPEX availability (Carter, 2020).

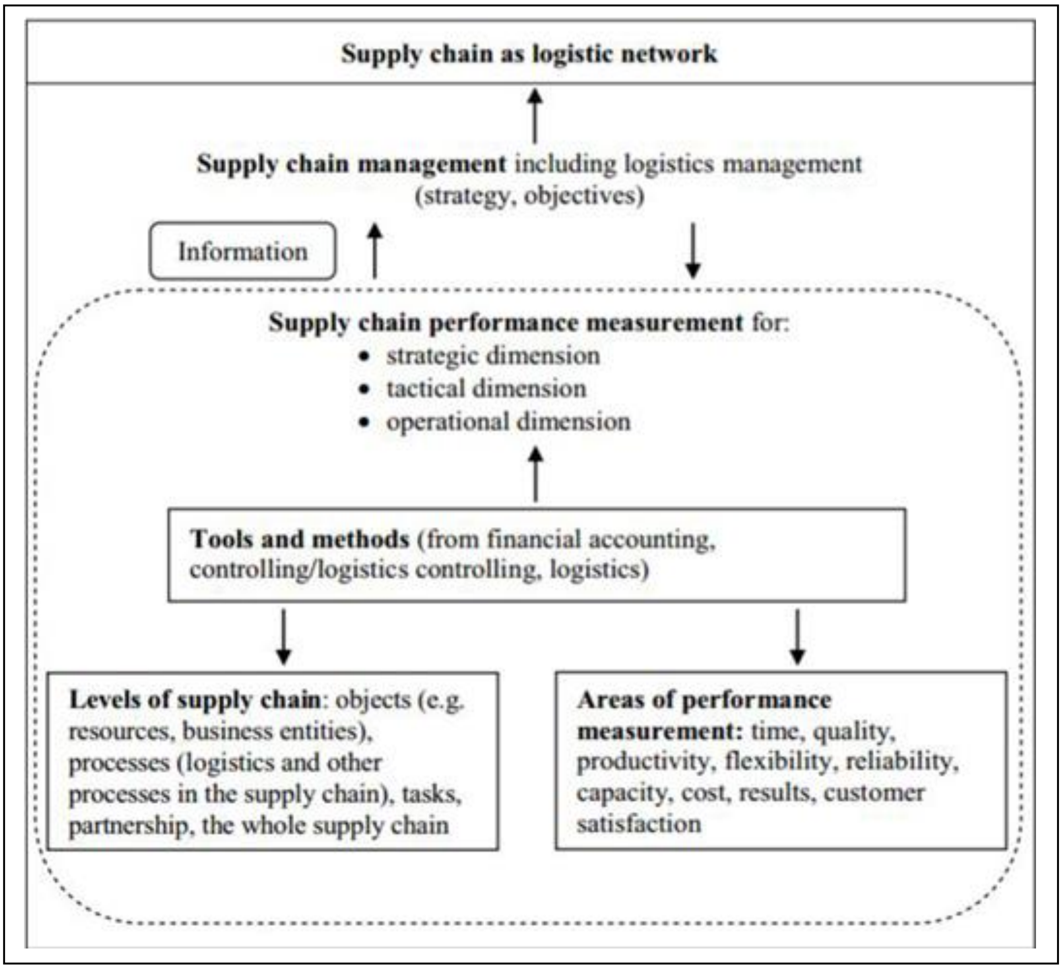

Figure 1 Categories of supply chain performance indicators (adopted from Dobroszek cited by Leończuk, 2016:105).

With an optimised current business operation, keeping a clear goal of the future in mind, the organisation needs to stay innovative and develop new and modern ways of improving current business operations that are safer, more effective, and even more efficient in understanding client and industry needs. Monitoring global changes in the market regarding the environment and technological advancements is essential.

However, most of Almar’s clients have not identified the optimal level of operation between conventional and modern TMMs to maximise profits. Consequently, client satisfaction and the quality of service delivery are negatively impacted, which could lead to client attrition. Essentially, if a company's fleet of conventional and modern TMMs is not optimally applied, working intervals and mine productivity are adversely affected (Wang *et al*., 2020; Salama, 2014:45). Optimisation is achieved by thoroughly grasping the organisation's essence, correctly managing resources, ensuring sustainability, and attaining to global standards.

The problem being investigated in this study is the unproductive application of conventional and modern TMMs in the chrome mining industry's hauling operations.

1.4 PARADIGMATIC PERSPECTIVE

1.4.1 Meta-theoretic assumptions

Operational efficiency is improved by combining conventional TMMs with modern ones in chrome smelting operations, ensuring organisational sustainability. It is assumed that both modern and conventional TMMs available on the market should be used. Optimising the hours worked per TMM will result in lower maintenance than financing costs. As a result, the net profit will be lower than the investment costs, resulting in favourable investment profitability metrics. Also, it is assumed that client satisfaction and service delivery will be high if the employment of manned and remote-controlled TMMs is optimised for low transport costs and high productivity and profitability.

Chrome smelting in South Africa competes on a global scale. Considering that the future application of modern and conventional TMMs is necessary to remain competitive, it is assumed that state-of-the-art technology will improve efficiency and ensure sustainability. Concerning the organisation's transportation operations, conventional TMMs should still be considered since they ensure stability and play a vital role in maintaining the existing market threshold and expertise in transporting chrome ore during the chrome smelting process. By adopting new technological developments in the TMM industry, the redundancy of conventional TMMs is assumed to be avoided. However, a conversion to modern TMMs will result in higher transport operation and service delivery costs. Both scenarios should be embraced by doing what works, including growth and prospect areas.

1.4.2 Theoretic assumptions

The current research concerns the application of conventional and modern TMMs, which form part of the mining company's SCM strategy. In order to maximise total profitability, this research involves managing flows between and among stages in a supply chain (section 1.3). Customers manufacture alloys used in manufacturing stainless steel, metal ceramics, and chrome plating (Murthy *et al*., 2011:375). The profitability of chrome mines is, therefore, highly dependent on customer satisfaction and service quality.

This study will investigate the advantages of a multimodal transportation system that utilises conventional and modern TMMs. In this way, the advances of modern equipment can be obtained without sacrificing the reliability of conventional equipment, and an optimised fleet setting can be evaluated within its life cycle to evaluate the fleet's implementation, growth, and maturity.

Almar is a business services provider leading clients in the chrome smelting industry to apply TMMs. Customer satisfaction is crucial because it shows whether Almar's clients are content with its services. Poor service delivery will harm Almar's profitability.

The disconfirmation paradigm and expectancy-value concept can describe customer satisfaction (Isac & Rusu, 2014:85-87; Sattari, 2007:28-31). According to the disconfirmation theory, customers compare the service they have received with their own standards. Using an expectation–value concept, customers judge the likely outcomes of using a product or service based on its benefits. Thus, every complaint should be accepted, analysed, and addressed since it is only the tip of the iceberg (Besterfield *et al*., 2012:61; Blumenthal & Weiche, 2017:7). When dissatisfied customers believe their complaint has been heard and solved, they are more likely to buy again (Besterfield *et al*., 2012:61; Blumenthal & Weiche, 2017:7).

Almar provides a high-quality service to clients by using robust and reliable modern equipment and conserving fuel or eliminating its use by investing in battery-driven TMMs. By incorporating assistance systems and controls, modern equipment is seen as having greater fuel efficiency and assisting operators in conducting work more safely and efficiently. By implementing remote-controlled simulator and emulator units, electric machines would have a smaller environmental impact and reduce overhead costs.

Fuel is one of the most significant expenses in the chrome mining industry, and TMMs running 24/7 contribute to this expense. Minimising these costs can result in enormous savings for client companies, but managing fuel effectively can be a significant challenge. Fuel costs vary based on location. Unpredictable economic factors and fluctuating regulations also create complications.

Among other things, Total Quality Management (TQM) involves advising Almar's clients on using fuel-saving systems. It assists in lowering fuel costs and maximising fuel efficiency. Tracking inventory and idling time across the fleet can identify inefficiencies in fuel usage. Modernising the fleet of TMMs and optimising TMM scheduling would be two ways to improve fuel efficiency. Modern TMMs have improved fuel efficiency due to the advancement of technology and the legal requirement to meet specific fuel consumption standards.

Implementing Occupational Safety and Health (OHS) systems in an organisation improves TQM. Several studies have shown the effectiveness of TQM activities if employees are involved in an organisation's Safety, Health, and Environment (SHE) systems, continuous improvement initiatives, risk management, and hazards analysis studies. (Abdalla, 2014:58; Aksoy & Kahraman, 2015:153; Álvarez-Santos *et al*., 2018:136).

1.4.3 Methodological assumptions

It is assumed that the mixed-method approach would best address the research problem. This research method is likened to pragmatism, and it is stressed that 'mixed methods researchers' apply an array of approaches to collecting and analysing data rather than subscribing to only one method (Creswell, 2014:4; Doyle *et al*., 2016:627-631).

Researchers who use mixed methods in their research collect and analyse data, integrate findings, and draw conclusions using qualitative and quantitative approaches (Saunders *et al*., 2012:161).

Section 3.3.4 discusses the fundamentals of mixed-method research.

1.5 OBJECTIVES

1.5.1. Primary objective

The primary objective of this study is to find the balance between conventional and modern TMMs for on-site bulk material handling, optimise current business operations, and investigate advanced solutions to stay relevant.

1.5.2. Secondary objectives

The study seeks to optimise the usage of TMMs in haulage operations for Almar Investments' clients in the chrome mine industry. For this purpose, the following secondary objectives have been identified:

- to study the relationship between conventional and modern TMMs, which could ultimately improve the equipment's optimisation and sustainability,
- to analyse future technological advancements in the operational field,
- to analyse the impact of technological advancement on sustainability,
- to establish the relationship between conventional and modern TMMs and their influence on profitability,
- to examine the relationship between conventional and modern TMMs to optimise operation profits.

1.6 RESEARCH QUESTIONS

The problem statement leads to the following primary research question:

How will the relationship between conventional and modern TMMs affect on-site bulk material handling optimisation and sustainability?

The secondary research question is:

What is the contribution that conventional and modern TMMs will make to the growth of an organisation?

1.7 HYPOTHESIS STATEMENT

Bulk material handling optimisation and sustainability could be significantly improved by optimum use of modern and conventional TMMs.

1.8 RESEARCH METHODOLOGY

This section summarised the methodology used to conduct this research. It includes the literature review (section 1.8.1), and the Saunders and Tosey Research Onion model (section 1.8.2), which will be applied to the empirical study (section 1.8.3). The empirical study will explore the research paradigm, approach, methodological choice, research strategy, time horizon, study population and sampling, reliability and validity, measuring instrument design, data collection, and statistical analysis.

1.8.1 Literature review

This study will include a literature review of the available and relevant literature. A literature study offers a synopsis of the current knowledge of a topic in terms of content and research methods used and demonstrates the gap between content and research methods (Hofstee, 2018:91).

The following sources were used within the literature review: academic books, web-based articles, national legislation, and publications in newspapers, magazines, and academic journals. The following databases were considered:

- ResearchGate: An excellent database which provides full access to many articles related to keywords entered by the researcher.
- ScienceDirect: It is Elsevier's website, which provides access to a comprehensive bibliography of scientific and medical publications.
- Scopus: A large commercial, bibliographic database covering scholarly literature across a wide range of fields.
- The Web of Science: Bibliographic database of 22 000 peer-reviewed journals world-wide.
- SACat: A national catalogue of books and journals in South Africa.
- Nexus: A database compiled by the NRF that comprises current and completed research in South Africa.
- SAePublications: South African journals.
- ProQuest: International dissertations in full text.
- Google Scholar: An academic and scholarly literature search engine.

The following topics will be discussed within the literature review:

- South Africa holds about 70% of the world’s chrome ore resources and produces 54% of the world’s chrome annually (Africa Mining, 2017). However, the industry needs to find new ways of staying competitive due to the cost and unreliability of power suppliers and labour.
- The service delivery of TMMs within the supply chain of the chrome smelting industry plays a vital role and is one of the most significant contributors to the process.
- As mining and processing plants significantly impact the environment, there is a large need for greener solutions with a smaller and better environmental footprint.
- There is a significant amount of high-risk work and risk of accidents in a smelting plant. Ideally, there should be no dangerous environments or human interactions with machinery.

- Safer and more effective working conditions should ensure sustainability. Therefore, the idea is not to reinvent the wheel within the industry but rather to optimise the supply chain's safest and most efficient part by optimising modern and conventional trackless mobile equipment.
- The above-mentioned point would demonstrate the importance of this supply chain element and highlight its impact on the industry and how it can ensure a safer and more productive process.
- It will be possible to discover new and modern applications and technologies that allow for the optimisation of current operations to improve safety and efficiency by studying modern and conventional TMMs.
- A literature study of the application of TMMs in the industry in general.

1.8.2 Empirical study

1.8.2.1 Research paradigm

The research will follow the positivistic, interpretivist, and pragmatist philosophies.

Positivism has long dominated research in business and management disciplines (Charumbira, 2013:51). The positivistic philosophy holds that science is the only means of discovering the truth (Park *et al*., 2020:690). In positivism, true knowledge is acquired only through sense experience and can be obtained by observation and experiment, which is interpreted through logic and reasoning (Antwi & Hamza, 2015:218). As a result, it implies that measurement can be trusted.

To verify a priori hypotheses that are often stated quantitatively, positivists use the hypothetico-deductive method, which establishes a functional relationship between causal and explanatory factors (independent variables) and outcomes (Park *et al*., 2020:690). However, it is important to note that positivist research is not always quantitative but can also be qualitative. A qualitative study aims to gain a deeper understanding of human beings' experiences and reflections on those experiences (Antwi & Hamza, 2015:2019). The positivist paradigm includes, for instance, experimental studies to examine the effects of interventions through qualitative analysis (section 1.8.2.8).

In interpretivism, reality and knowledge are social products whose construction and meaning cannot be understood in isolation (Howcroft & Trauth, 2005:244-245). According to Saunders *et al.* (2012:137), shared social realities are not discovered but rather emerge from social interactions. Modern and conventional TMMs used in Almar's clients' hauling operations require a detailed qualitative interpretation.

According to its philosophical foundation, pragmatism embraces a plurality of methods as a research paradigm (Kaushik & Walsh, 2019:2). The philosophical and/or methodological approach that works best for the particular research problem should be used (Saunders *et al*., 2012:128). Mixed methods or multiple methods are often associated with pragmatism (Feilzer, 2010:8), where the emphasis is placed on the implications of research rather than the methods themselves.

The appearance of new competitors and technologies leads to increased competition and a growing preoccupation among service-providing companies with creating stronger customer bonds (Yun *et al*., 2016:8). As businesses move online, data has become a crucial resource to understand consumer behaviour, benchmark with competitors and enhance the productivity of the company as a whole. A more prominent online presence allows service-providing companies to reach a larger population and sample group.

In a company, information can be gathered from all levels, as it plays a crucial role in every department, from tracking to logistics to HR. Accurate information gathering is crucial as the organisation is integrated, and information gathering relies on various levels of the business to gather correct and useful information.

The relevant data are available, but some of the information used is sensitive, and how it is analysed and presented will be of great importance for approval.

The proper execution of this study will be relevant to current business, as it will add significant value to current operations and business models. However, future endeavours implementing the proposed new machine and technological advances in equipment might encounter challenges in the change process. It may come at a very high cost and require highly skilled labour. Therefore, the challenges in adopting this change will be complex. However, in this industry, large capital expenditures are a part of daily business; if a proposal can be justified and differentiated over a long enough period to boost long-term benefits and sustainability, execution will be possible.

After numerous discussions with the author's superiors, management, and directors, a collective decision was made to conduct research to optimise conventional and modern TMMs for on-site bulk material handling, as the information could be gathered ethically and timeously.

1.8.2.2 Methodological choice

Data can be analysed through numerical comparisons and determination of investment profitability metrics by selecting the methodological approach based on qualitative or quantitative data. The following aspects will be addressed in the study:

- Content analysis: determining the presence of concepts or themes within given qualitative data.
- Systematic review: reviewing evidence.
- Secondary data: data collected other than by the primary user. Racial and demographic backgrounds will not be disclosed.

The aim is to use data currently available within the organisation to add value by exploiting data that can provide detailed trends, examples, and values and to pursue these findings, generating greater yields, improving TMM life expectancy, and adding to the overall organisational sustainability. The nature of the data reviewed and analysed for current operations will be identified through content analysis and evidence review.

Data and information used within the study are predominantly internal to the organisation.

The further review of information and data debates the overall market trend and the nature of technological advances within the industry.

1.8.2.3 Research strategy

The research strategy is the overall plan for conducting a research study. It guides the planning, execution, and monitoring of the research process and affords research guidance. The following strategy will be followed:

- Experimental: introducing intervention or involvement and studying the effects, typically randomised and grouped by chance.
- Cross-sectional: data gathered from a population at a specific point in time to make interpretations and conclusions about possible connections.
- Longitudinal: examining repeated actions to track and detect changes, correlational research through collecting and observing data.

This study will use a combination of cross-sectional and longitudinal research, as the information will be based on actual data within operations. The idea is not to gather new data but to analyse and interpret the current structures, data, and systems to evaluate information and contribute to findings in optimising the organisation's operations and ensuring sustainability.

Longitudinal research will be performed on a shift-to-shift (3 x 8-hour shifts), day-to-day, month-to-month, and year-to-year basis. With 24/7, 365 days a year operation, it is imperative to research the combined operational spectrum to gather a complete picture of the operational data.

Inductive reasoning aims to develop a theory and challenges existing theories. As part of analysing and optimising the current fleet, deductive reasoning will be used to challenge current organisational theories. Inductive reasoning will be used to develop new theories for the implementation of technological advances for new TMMs.

1.8.2.4 Time horizon

A time horizon can also be seen as a time planning horizon. It is used to evaluate phenomena that occur over a period or study a phenomenon at a specific time (Saunders *et al*., 2012:190). The latter is called a cross-sectional study and involves collecting data at a specific point in time, also referred to as a short-term data study. The latter is known as a longitudinal study and involves data collection repeatedly over a long period, which is then compared.

Because Almar was established in 1996, the time horizon consists of data recorded over the past 27 years. More comprehensive data sources, such as fuel consumption and hour usage per site and area, are needed to evaluate innovation and technology's progress over time holistically. However, the data for the past 12 months/1 year’s will be evaluated in detail for the data analysis.

1.8.2.5 Study population and sampling

By developing strategies to increase efficiency, this study aims to maximise the efficiency and sustainability of TMMs. This will be achieved within the chrome smelting industry by improving supply chain performance and its impact on bulk materials handling. To this end, modern and conventional TMMs available on the market will be evaluated according to the following main themes:

- how and when to replace conventional TMMs with modern ones,
- at the time of replacement, determining the optimal number of hours worked per TMM,
- analysing maintenance and financing costs,
- analyze investment profitability metrics to determine when modern and/or conventional TMMs are a good investment.

In research, determining a sample group or evaluating a particular group does not always refer to people (Baran & Jones, 2017:109).

Internal data was used for the majority of the study. Permission was given in three phases. In order to gather the needed information, senior management, the Financial Director, and the General Manager needed to review a process plan. After approval was granted, each department HOD approved information taken from the department.

Thereafter, the information to be analysed was submitted to the general manager for approval before it could be analysed. Findings and results needed to be presented to a board of senior management and the Heads of Department before the research study could be compiled.

1.8.2.6 Designing the measuring instrument

Measuring instruments are methods through which data is obtained for research and analysis. Data as a broad model refers to existing information and knowledge presented in a more suitable form for further usage. Research aims to increase knowledge by systematically discovering things (Saunders *et al*., 2012:5).

To prove the relation between conventional and modern TMMs for current and future business operations, organisational information and data within the organisation's structures were sourced for conventional and modern TMMs within the current modes of operation. The same applies to conventional TMMs within future operations. Data on modern TMMs and new technology was collected and compiled from OEM suppliers within the industry, technology partners, and developers within the same sector of operations or development.

1.8.2.7 Collection of data

The collection of data refers to the process of gathering quantitative and qualitative data for evaluation and analysis.

The primary source for this study was the organisation's internal database, with data spanning the past 27 years. Only the past 12 months/1 year's data was analysed in detail. Section 3.6.1 describes how Almar's database can be searched for client-specific data. The approval of Almar's management was obtained beforehand to access its databases (Annexure A).

1.8.2.8 Reliability and validity

Numerical data was validated and checked against the source to establish validity and reliability within quantitative research. In order to verify the processed and analysed data with the original data and values, this information was referenced, and figures were balanced to subtotals and totals.

Validity, reliability, objectivity, precision, and generalisability are used to evaluate the rigour of quantitative studies, which are intended to describe, predict, and verify empirical relationships under relatively controlled circumstances (Antwi & Hamza, 2015:219). Hypotheses and variables are measured to test a general causal explanation (Antwi & Hamza, 2015:219). Experimental designs are used to measure effects (Antwi & Hamza, 2015:219). In quantitative research, variables are examined to test objective theories (Creswell, 2014:2). These variables can be measured to analyse numbered data statistically, usually using instruments such as surveys, experiments, and databases (Creswell, 2014:2).

In much the same way that physical scientists treat physical phenomena, quantitative purists make assumptions that are consistent with what is commonly known as the positivist paradigm (Tuli, 2010:98). According to positivism, there is only one tangible reality, which can be seen, understood, measured, and predicted. (Park *et al*., 2020:691). Under different exposure or treatment conditions, causal inferences often use the counterfactual (as a result of a different cause, the outcome would likely have occurred) to conceptualise and inform the relationship between cause and effect (Tilden & Snowden, 2018:703). In research design, as well as analysis, causality plays a significant role.

Causal inferences will be applied in this research by adopting an experimental design. In the open literature, experimental design is defined in various ways. According to Cash *et al*. (2016:7), an experimental design can be broadly defined as testing a treatment against other variables that may affect the outcome. Kandal (2011:41) defined it similarly as a research method in the social sciences where a controlled experimental factor is given special treatment to be compared with a constant factor. It implies creating a set of procedures to test a hypothesis systematically by investigating a relationship between variables. An experiment must have at least one independent and dependent variable that can be controlled precisely. An independent variable must be observed and recorded over time to draw plausible conclusions about its relationship with the dependent variable. A sound experimental design requires a thorough understanding of the system being studied.

In this study, experimentation is defined as a mixed-method research methodology combining multiple methods to address research questions appropriately and principled, including collecting, analysing, interpreting, and reporting qualitative and quantitative data (Dawadi *et al*., 2021:26).

It follows that there are five key steps in designing an experiment:

- consider the variables and how they are related,
- write a specific, testable hypothesis,
- design experimental treatments to manipulate the independent variable,
- assign subjects to groups, either between subjects or within subjects,
- plan how the dependent variable will be measured.

In order to draw valid conclusions, a representative sample and any extraneous variables that might influence the results should be selected (Baran & Jones, 2017:109).

The reliability of qualitative research was established through valid sources, proper referencing, author validation, and reassurance from industry-proven studies; thus, verifying qualitative information with real-world examples.

The strategies that were employed to obtain high-quality data are discussed below:

Ahmad *et al*. (2019:2829) highlight the following general characteristics of qualitative research:

- It analyses the problem setting and provides insights.
- It studies highly complex phenomena not elucidated by quantitative research because it is unstructured, exploratory, and undirected.
- It generates ideas or hypotheses for later quantitative research.
- Based on observation and interpretation, it is used to gain a deeper understanding of human behaviour, experience, attitudes, intentions, and motivations.
- A participatory research approach emphasises the participants' views over the researcher's.

Antwi and Hamza (2015:219) provide a theoretical framework for qualitative research. They maintain that qualitative research is interpretive and aims to understand a particular phenomenon rather than to generalise. This was accomplished by applying real-world situations as they unfolded. Thus, qualitative research tends to be non-invasive, non-manipulative, and non-controlling. Qualitative research focuses more on understanding the problem in its unique context than on generalisability.

1.8.2.9 Analysis of data

Data was analysed by inspecting the data retrieved from the database of client organisations. The data was also used to calculate investment profitability metrics over different periods to compare conventional and modern TMMs, or combinations thereof, as potential investment opportunities.

1.9 RESEARCH METHOD

The research method comprises all techniques, strategies, and tools employed to complete the experiment and solve the research problem (Adams *et al*., 2014:1,6). As mentioned in Section 1.4.3, a mixed-method research method is adopted. Section 3.3.4 describes this research method in more detail.

1.10 CONTRIBUTION OF THE STUDY

Contracting companies specialising in on-site bulk material handling within a specialised field and market invested in due to the equipment specifically designed and applicable to this type of service delivery would face significant challenges in transitioning to other operating fields or adopting new business ventures.

Therefore, the contractor and client must be involved in the production process to achieve a sustainable working environment. The company is a strategic partner that employs the best people for the job.

Clients within this sector require timely and accurate service delivery, with significant capital expenditure. Therefore, time and money are essential for a contracting company to ensure efficiency and effectiveness and, eventually, to ensure service delivery of a high standard. It is of utmost importance that equipment is used optimally, which will significantly increase productivity.

As digital design develops in modern times, the set of functional purposes of the enterprise's strategic development programme is supported by a set of well-defined, well-thought-out techniques, tools, and tactical decisions that are uniquely created within every organisation and are crucial to the success of the country's mining sector (Afonasova *et al*., 2019:23).

The contribution of this study would establish an optimal balance between modern and conventional TMMs, evaluate the relationship between them, and ensure a profitable contracting company with sustainable service delivery. Conducting the study for modern versus conventional TMMs would deliver an optimal point in maintenance and finance costs. In this way, the TMM's lifespan is optimised, which affords the best possible return on investment.

With sustainability in mind, battery-powered vehicles are seen as the future. Therefore, the need for mining lithium and graphite, for example, will increase. Thus, on-site bulk material handling will still be applicable. However, converting to battery-powered equipment will ultimately guarantee a significant competitive advantage, boosting sustainability. Safety being one of the key driving factors in the mining industry, the possibility of remotely operated TMMs has also become a pivotal point in considering the approach to future bulk material handling.

1.11 LAYOUT OF THE STUDY

This mini-dissertation will take the form of a written scientific report. The research will be unique, and creative ideas and thoughts will be presented to optimise operational processes. The study will have the following layout:

Chapter 1: Nature and scope of the study

This chapter gives the reader a brief background on this study's purpose and the document's layout. It includes the formal problem statement, research objectives, study limitations, and the research method.

Chapter 2: Literature review

The topic is divided into its contributory concepts. Each is introduced and explored within the context of this study.

Chapter 3: Research Methodology

The chapter conducts the empirical study by gathering qualitative and quantitative data from Almar's internal database. There is also a description of the techniques employed in analysing the data to obtain trends and exact numerical values that describe the application of modern and conventional TMMs in the chrome industry.

Chapter 4: Results and discussion

Numerical data are validated by verifying the processed and analysed data with the original data and values. Contributing inferences were drawn and discussed based on the data obtained from the client database. Results of calculating Profitability Index metrics in an optimum ratio in the application of modern versus conventional TMMs are presented and discussed.

Chapter 5: Conclusions and recommendations

Conclusions are drawn, and recommendations are made from the knowledge gained in the literature study and the results from the empirical study. The shortcomings of the current research and how the secondary objectives were achieved are also highlighted.

CHAPTER 2. LITERATURE REVIEW

2.1 INTRODUCTION

The previous chapter discusses the research topic, the background of TMMs in chrome mining, the primary and secondary objectives of the research, the research questions, the research method, and the research methodology. Topics such as research paradigms, methodology choices, data collection and analysis strategies, and strategies are discussed in the research methodology.

In this chapter, a detailed open literature analysis is performed to extract and synthesise the main points, issues, findings, and research methods prevalent in the application of modern and conventional TMMs in the local and international chrome mining industry. It is followed by a justification of the current research topic and the purpose statement.

Thereafter, considerations are discussed for a competitive advantage in on-site bulk material handling in the chrome industry. Furthermore, an overview of the chrome smelting operations and the value chain in the chrome mining industry are provided. Subsequently, the influence of mining and processing on the South African economy, the competitive forces in the on-site bulk and material handling industry, and concepts such as outsourcing, vertical integration, and value chain are discussed in the context of the South African chrome mining industry.

2.2 THE MINING, PROCESSING, AND CHROME SMELTING INDUSTRY OF SOUTH AFRICA

2.2.1 The South African Mining Industry

South Africa is a commodity-rich country with large ore deposits ranging from fair to extremely superior-grade material (Department: Mineral Resources Republic Of South Africa, 2016:1). Looking at the South African GDP and the mining industry's role in this country, South Africa is internationally ranked 5th in GDP contribution by mining (University of the Witwatersrand, 2022). South Africa possesses ore reserves of more than US$2.5 trillion, with 16 commodities ranked in the top 10 internationally (University of the Witwatersrand, 2022). South Africa has the largest reserves of platinum group metals (PGMs) (88%), manganese (80%), chromite (72%), and gold (13%) in the world (Ahiakwo *et al.,* 2018:105). It is ranked second in titanium minerals (10%), zirconium (25%), vanadium (32%), vermiculite (40%), and fluorspar (17%) (Ahiakwo *et al.,* 2018:105). In addition, the country contains 17% of the world’s antimony reserves (Ahiakwo *et al.,* 2018:105).

Based on production, South African mining ranks third globally in terms of precious group metals (PGMs) (59%), vanadium (25%), ferrochrome (39%), aluminium silicates (60%), vermiculite (35%), zirconium (32%), and titanium metals (19%) (University of the Witwatersrand, 2022). The mining industry in South Africa contributed 4% to the national GDP, from R475 billion in 2021 to R494 billion in 2022 (Minerals Council South Africa, 2023).

During 2022, South Africa reported a total sale of minerals of R880 billion, an increase of 3% from R856 billion in 2021, surpassing the previous record by R24 billion (Economist Intelligence, 2023). The mining sector contributes 4% of South Africa's GDP and employs half a million people (Creamer Media's Mining Weekly, 2023). However, an industry of this magnitude is detrimental to other areas within a country, its communities, and its population.

Environmental impact is the most significant counter to a large economic and employment contributor. There are thousands of abandoned gold mines scattered across South Africa, polluting the air with noxious dust, and polluting the water with toxic chemicals that damage the environment, health, economy, and way of life (Olade, 2015). For the people living around these rundown and neglected sites, the impact on their health and well-being can be severe. To maintain the mining industry as a valuable contributor to GDP while improving the lives and well-being of the mine employees, the people, and the communities living in and around these affected areas, it is vital to continuously improve green initiatives in the mining sector, with an ultimate goal to achieve a nett zero impact.

Due to the presence of gold, diamonds, platinum, iron ore, copper, chromium, manganese, titanium, silver, uranium, and beryllium in South Africa, the impact on commodities, mining, and the environment is significant (Britannica, 2023). Globally, all the commodities are traded and in demand on global markets (Kilian *et al.,* 2018:4). As a result, when one commodity is in lower demand, another is in higher demand. Despite complex global markets, it allows a country like South Africa and its mining sector to continue to produce, employ, and grow. The disadvantage, however, is that each of these commodities comes with its own environmental, health, and safety impact.

The mining industry in South Africa does not come without challenges, facing issues such as a lack of technical skills, increased environmental impact, illegal mining, energy reliability, issues in the supply chain, worker safety, security within operations, and massive demand increase (Singh, 2017:223-224). These issues must be addressed and improved for growth in the mining sector.

2.2.2 Processing and Chrome Smelting industry of South Africa

The processing of materials produced by the mining sector is established by adding progression or development to the value chain for a country with high, rich, and various ore deposits (Korinek, 2020:9). This progression period of processing materials increases the wealth generation from the commodity and adds to the overall value chain. Doing this makes more significant profits by selling minerals, and processing processes are established within the economy's value chain, leading to job creation and wealth (Korinek, 2020:6).

Mineral processing entails using technology to separate waste rock and valuable minerals from ore, thereby increasing its usable value (Peuker *et al*., 2012:4). This process is followed by extractive metallurgy, resulting in a sludge that contains more concentrated minerals (Peuker *et al*., 2012:4). Normally four types of mineral processing can be distinguished (Sepro Mineral Systems, 2019):

- Comminution: size reduction in particles.
- Sizing: size separation through either classification or screening.
- Concentration: surface and chemical properties within the material are used in processes such as flotation to separate concentrates.
- Dewatering: separation of liquids and solids thickeners using processes such as filter pressing, filtration, or thermal drying.

Chrome smelting plants are prominent role players in the mineral processing and ore export value chain globally and within South Africa. In the chrome smelting process, raw chrome ore materials are processed into concentrated pellets and directed to large arc furnaces to separate ferrochrome (as product) and slag (as waste material) (du Preez *et al*., 2023:3-4). Ferrochrome metal is then broken down and crushed into sizes that are specified by specific requirements; afterwards, it is ready to be exported (du Preez *et al*., 2023:7).

Chromium ore exported in 2021 from South Africa amounted to $1.83 billion, where the main distribution destinations were Mozambique, China, India, and Indonesia (OEC, 2023). As the largest producer of both chromite ore and ferrochrome, South Africa is the leader in processing, smelting, and exporting these materials (Dlamini & von Blottnitz, 2023:2; du Preez *et al*., 2023:2).

2.3 PLANT HIRE, CONTRACT MINING, BULK AND MATERIAL HANDLING INDUSTRY OF SOUTH AFRICA

2.3.1 Plant hire industry South Africa

Rather than self-purchasing, the plant hire industry gives construction, mining, and bulk or normal processing plants and industries the opportunity to rent TMMs temporarily as an alternative to purchasing them. Thus, the plant hire industry is a service delivery industry that utilises machinery and equipment primarily to contribute to another party (referred to as the clients) in adding to their value chain.

Equipment rental, or plant hire, is a service delivery industry that supplies equipment, machines, and tools of all shapes and sizes (Research Nester, 2023). A mine's production processes employ a variety of equipment, such as handheld tools, power generation, powered access, or earthmoving equipment (Rotabroach, 2022). In the South African mining sector, it is focused on earthmoving equipment within processing plants.

Machines and plants differ because machinery has moving parts, whereas plants do not, but they use similar electronics, devices, and computers to control them. The moving parts of machines are also classified as machinery. Static or fixed plants can be used for industrial, mining, or bulk services. A fixed or static plant is sometimes identified as machinery because it is used within production processes for mines or processing plants and has moving components, much like moving machines. Equipment or facilities used in connection with or seen as part of the production process or system of producing output or production can, therefore, be considered machines (Kenton, 2022).

Plant hire is seen as an innovative and entrepreneurial field where jobs are created, and efficiency and innovation are implemented to create opportunities previously not even considered (Pappas, 2020:93). It allows businesspeople and innovators to be creative and to establish opportunities for future role players and new business ventures. In South Africa, economic growth, job creation, and innovation are needed for a healthier business environment and development (Habiyaremye *et al*., 2022:1,12,18; National Planning Commission, 2012:92).

2.3.2 Contract mining industry in South Africa

Mine owners appoint mining specialists with the necessary knowledge, expertise, and skills to conduct mining services for transporting, loading, and on-site bulk material handling and for drilling, blasting, and other mining activities (Pappas, 2020:45). Both parties would enter this process through an agreement, usually a legal agreement enforceable by law. It ensures that both adhere to what is expected regarding service delivery and payments.

These specialists, or contract miners, conduct numerous mining operations for the mine owners, such as blasting, drilling, processing operations, equipment maintenance, budgeting, and even the scheduling of work and operations (Suglo, 2009:61; Rupprecht, 2015:1021).

Seasonal mining employment is typically achieved through contract mining and is based on a fixed term, usually three to five years, based on the size and scale of the project (Cartier & Bürge, 2011:1087; Dreschler, 2001:22). The only fluctuation in these terms will depend on company requirements (supply and demand), market conditions, and service delivery. These contract miners are employed, contracted, and managed through a procurement and bidding process. They are screened, recruited, and placed according to experience, price, and skills by a third party or in-house procurement department.

In the case of surface mining, contractors are used for load and haul operations, blasting operations, and conducting drilling (Rupprecht, 2015:1021). Contract work could be awarded for mining, support, shaft sinking, cover drilling, construction work, vamping, and sweeping for underground mining (Rupprecht, 2015:1021).

2.3.3 The bulk material handling industry in South Africa

The term bulk material handling consists of the following main categories:

- industrial stocks,
- storage and handling equipment,
- engineered systems,
- bulk material handling equipment.

All these categories can apply to needs typically arising in bulk material handling industries and areas.

In addition to stockyards, stockpiles, storage facilities, bulk material, and bulk material handling systems, the following can be used to handle granular products (Figure 2):

- stackers,
- track and railcar dumpers,
- conveyor belts and/or rail trains,
- recliners,
- ship loaders.

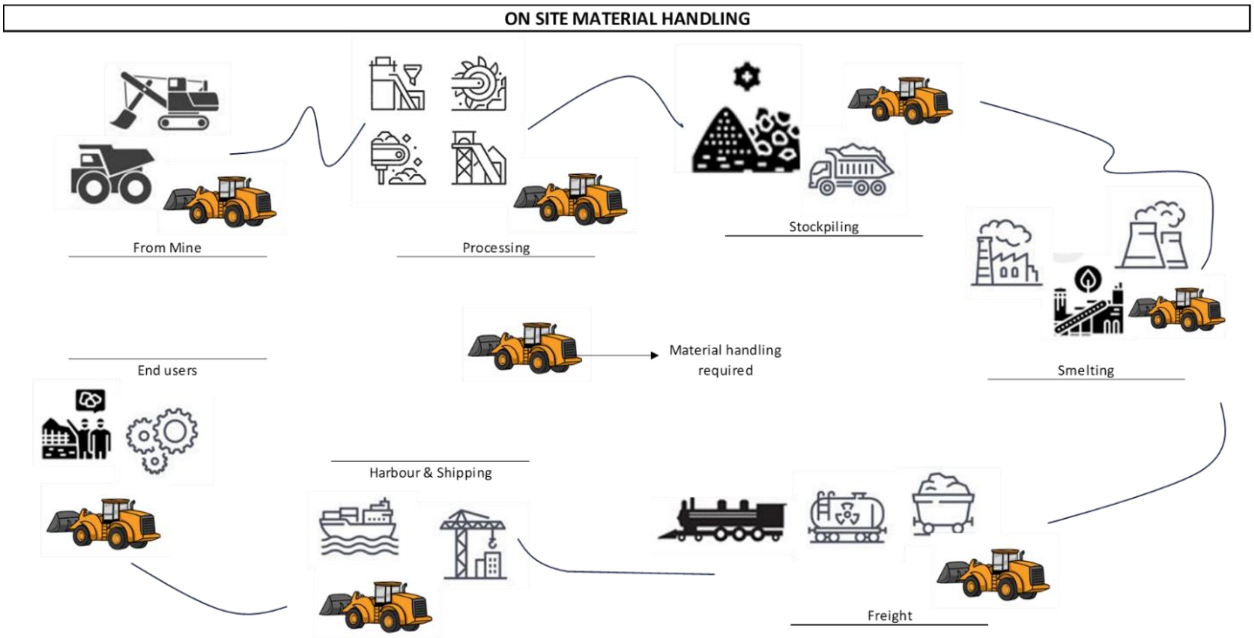

Figure 2 Typical stages in material handling in mining operations (911 Metallurgist, 2016).

Equipment is generally designed to transport and handle all bulk dry materials and commodities. Usually, dry materials in bulk material handling are those elements and materials that can be stored in heaps and are lumpy, powdery, or granular.

In logistics and manufacturing, bulk material handling plays a pivotal and vital role in warehouses, retail stores, and manufacturing plants. Almost every item of physical commerce has been transported at some stage, either by lift trucks, conveyors, plants, machinery, or any other type of bulk material handling equipment.

2.4 INFLUENCE OF MINING AND PROCESSING ON THE SOUTH AFRICAN ECONOMY

For a country’s residents and communities, and for the public, a growing and healthy economy is vital for general welfare. GDP, or gross domestic product, is directly linked to the country’s economic growth. Therefore, a country’s GDP can be seen as the country's income. If the GDP increases, the economy grows, and if the economy grows, the GDP increases. It is often accompanied by increased income, automatically leading to increased tax revenue, consumption, and employment. The inverse effect is also valid, where a decline in the economy or GDP will see a decline in the GDP or adverse economic growth (Callen, 2023).

According to EconomicsEssays (2009), a rise in a country's GDP would then ultimately mean:

- Reduced poverty,
- Improved public service,
- Lower unemployment.

Like any other country, the South African economy's importance is not different from other economies. The South African market is classified as an emerging market (Bick & Sidubi, 2018). The medium-term growth outlook for the South African economy has deteriorated (Bick & Sidubi, 2018). Real GDP growth is currently projected to average 1.4 % from 2023 to 2025, compared to 1.6 % in the 2022 Medium Term Budget Policy Statement (MTBPS) (Department National Treasury, Republic of South Africa, 2023:13).

The quarterly growth figures for South Africa from 2020 until 2023 are given in Figure 3. It shows that real GDP (measured by production) increased by 0.4% in the first quarter of 2023, following a decrease of 1.1% in the fourth quarter of 2022. However, it decreased from 13.7% in the second quarter of 2020 to 0.4% in the first quarter of 2023. The very low GDP measured in the second quarter of 2020 is attributed to the effect of the Covid-19 pandemic.

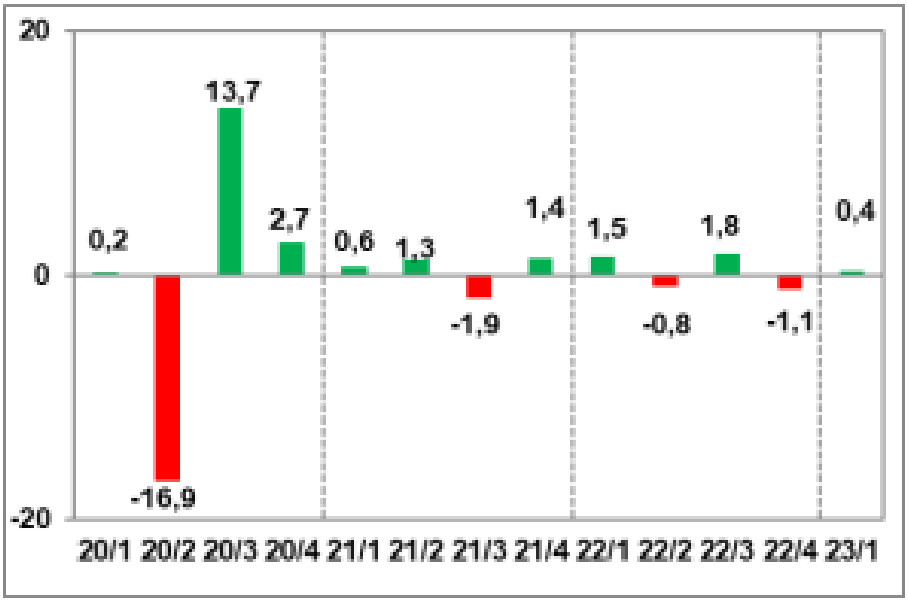

Figure 3 Quarterly growth figures in South Africa from June 2020 until January 2023 (Stats SA, 2023a).

This inconsistent growth does not help to decrease the unemployment rate of 27.2% (Stats SA, 2023b, 3). In addressing the issue of unemployment, consistent growth larger than the growth of the population is required (Meyer, 2017:179).

Despite a significant decline in absolute and relative contributions of the South African mining sector to the economy, the mining sector is an important contributor to the country’s economic growth and development (OECD, 2017:1). Areas of significant contribution include GDP, foreign exchange earnings, taxes and royalties, employment or human resource development, and research and development (Minerals Council of South Africa, 2023:1). In 2023, the mining industry’s contribution to GDP was 4% and provided employment to approximately 500 000 people (Möncks *et al*., 2023:1).

2.5 UNDERSTANDING THE RESEARCH INTENT

The ultimate intent of this study is to research how optimisation within chrome smelting operations can be achieved through increased efficiency while ensuring organisational sustainability by applying modern and conventional TMMs in chrome smelting operations. Therefore, optimising the application of TMMs can be achieved by evaluating modern and conventional TMMs in the form of current machines available on the market, determining when and how to replace conventional machines with modern TMMs, and determining the optimal hours worked per machine when it is replaced. Furthermore, it is critical to evaluate maintenance and financing costs. To this end, the study aims to determine when maintenance costs exceed financing costs, which will be detrimental to financial metrics such as IRR, NPV, PI, ROI, ROA, debt-to-equity ratio, and cost of capital. The study also aims to examine the impact of TMM availability on service delivery and client satisfaction. As a result, an optimal number of manned and remote-controlled TMMs should be determined where transport costs and output are low.

The second aspect of modern and traditional TMMs concerns how they will be used in the future. The aim is to embrace state-of-the-art technology to improve efficiency and ensure sustainability. However, since the TMMs in use ensure stability in the organisation's transportation operations, they will still be considered. Therefore, the strategy is to embrace new technology without sacrificing the existing market threshold and expertise the company has gained from conventional TMMs and their operation. It implies that two extremes pose risks to the organisation: if it does not adopt new technological developments in the TMM industry, its transport operations may become obsolete. Conventional TMMs will inevitably wear out over time and require expensive repairs. The other extreme is when the organisation fully converts to modern TMMs. This approach will give rise to increased costs of transport operations and service delivery. Both these scenarios pose risks to the industry; however, both modern and conventional TMMs have tremendous advantages and potential, which should be embraced by continuing to do what works and by including areas of growth and prospects.

To ensure proper service delivery, a vast fleet for selection must be continually upgraded to ensure client service delivery and proper customer value (SPH, 2023). Typical TMMs are listed in Annexure B.

2.6 LITERATURE REVIEW: UNDERSTANDING MODERN AND CONVENTIONAL TMMs FOR OPTIMISATION

2.6.1 Introduction

Mechanisation with an emphasis on applying TMMs and automation of production processes in the chrome mining industry is a core aspect of this study. In this context, it refers to the transition from working exclusively by hand to using hand tools or powered equipment (Shan *et al*., 2020:1). By enabling people to handle a workload that would otherwise have been overwhelming, it significantly increases the efficiency and productivity of the production activities.

Typical areas of mechanisation in mining operations are the transport of inventory and products and performing process steps (Horst & Zdziebko, 2021:9). In the case of automation, advanced sensors and a rich data environment of autonomous trucking are employed to automate and optimise the mining processes, manage central haulage, and remotely control switchgear (Gaber *et al*., 2021:4; Horst & Zdziebko, 2021:8-11; Marklund, 2017:1;).

Adopting mechanisation in maintaining the on-site bulk material handling in chrome mines has the following benefits:

- Machines are generally cheaper and more efficient than humans (Lynas & Horberry, 2011:75; Shan *et al*., 2020:1).
- There is increased responsibility on the mining leadership and stakeholders to operate safe mines, which has led to the increased drive towards mechanisation. Using mechanised tools and equipment can prevent frontline workers from being exposed to potential hazards (Lynas & Horberry, 2011:75; Shan *et al*., 2020:1).
- Machines are generally more productive and free humans to perform other important tasks, such as planning and other decision-related tasks (Lynas & Horberry, 2011:75; Shan *et al*., 2020:1).
- Mechanisation can improve access to orebodies that would be hazardous and unprofitable if mined through conventional means (Lynas & Horberry, 2011:74).
- Machines provide process consistency and reliable data and information (Horst & Zdziebko, 2021:10).

- Generally, autonomous trucks (ATs) have been designed to reduce the risk of equipment contact with auxiliary equipment or equipped manual vehicles (EMVs) (Gaber *et al.,* 2021:2).
- During the mining operation stage, it ensures that activities are implemented to achieve the intended effects on the organisation and economy.

Some recorded socio-economic effects of mechanising mines are (Gumede, 2018:3):

- the elimination of some jobs,
- the creation of new jobs and roles.

The socio-economic effects of mechanisation can easily result in socio-economic conflicts (Gumede, 2018:4). Additionally, research from other industries shows that mechanisation and automation improve productivity and that job losses are at times not as dire as would have been anticipated (Gumede, 2018:4). As a result of the high level of unskilled labour in South Africa and the low economic class, the socio-economic impact of job losses could lead to increased community unrest (Khuluvhe *et al*., 2022:64). The socio-economic impact could adversely affect innovation and technology adoption if not handled correctly (Khuluvhe *et al*., 2022:45).

South African research on mechanisation has primarily focused on efficiency or productivity (Gumede, 2018:4). The South African mining industry must also adopt principles of human and organisational behaviour (Gumede, 2018:4).

The introduction of trackless mobile equipment failed initially and almost resulted in its abandonment for mining development. This failure was due to the incorrect application of the equipment and the absence of preventive maintenance (Muller *et al.,* 1959:452). The lack of knowledge of the cost of mechanical maintenance was the main factor that led to mining engineers doubting the success of the new methods (Muller *et al.,* 1959:452). Only after a scheduled preventive maintenance programme had been introduced and preventive measures had been taken was this mechanised mining method placed on a competitive footing, and its success improved (Muller *et al.,* 1959:452).

2.6.2 Advantages/disadvantages of conventional and modern TMMs

This section discusses the advantages and disadvantages of manned and remotely controlled TMMs. TMMs controlled by humans are primarily conventional, while TMMs controlled remotely are mostly modern.

Based on the researcher's own experience, manned TMMs have the following advantages:

- The quantity of manned TMMs needed in each area and for each section within the operations is known.
- The use of manned TMMs has been tried and tested.
- The operators are familiar with the equipment.
- Its parts are readily available.

Based on the researcher's own experience, the following disadvantages are associated with manned TMMs:

- safety concerns,
- old technology,
- inevitable driver fatigue and mistakes or incidents,
- human error and human abilities that impacts the machine's efficiency.

Advantages associated with remote TMMs (Brundrett, 2014:32-34) are:

- Increased efficiency: for example, in manual mode, large machines operating in narrow drifts find it more difficult to avoid the walls. Remote TMMs, however, follow a straight path through the drift due to their navigation systems. Operators can also operate multiple machines, resulting in lower overhead costs due to increased efficiency.
- Higher utilisation: AHTs have higher utilisation rates because they do not have to stop for lunch breaks or switch drivers, representing a significant downtime for each machine. As a result, fewer autonomous haul trucks are required to move the same amount of material compared to manual haul trucks.
- Improved performance: autonomous haul trucks outperform manually driven haul trucks because they operate more consistently. They travel between locations along the most direct path every time without swaying. Human operators can take longer to drive between locations, especially during the later shifts. Autonomous vehicles brake, accelerate, and shift gears more efficiently. They are not inoperative due to driver changeover or other similar interruptions.
- Reduced labour and related cost: eliminating drivers from haul trucks represents autonomous haul trucks' most significant cost savings. Labour savings from automating trucks is much higher than the additional labour costs required to run the autonomous trucks. While haul truck drivers are eliminated, autonomous haul truck systems must still be monitored and managed. It requires different skills because these managers are looking after several vehicles rather than driving one. However, many of these employees can work from centres located in urban areas and interact with autonomous vehicles via Ethernet.

- Improved safety: autonomous haul trucks primarily improve safety by removing humans from the dangerous mining environment. The additional sensors and improved communication systems required to navigate autonomous haul trucks improve safety by detecting obstructions, such as workers. Trucks operate more safely because there is no risk of fatigue or complacency, no matter how long the vehicle operates.
- There is an increase in safety in hot applications.
- It is a modern and emerging technology.

Based on the researcher's experience, disadvantages of remote TMMs include the following:

- retraining the operators,
- operator redundancy,
- operators and the industry's acceptance of new technology, which may have cost implications.

2.6.3 Safety considerations in the application of TMMs

Although manned TMMs are still the preferred type of equipment used within the industry, safety is an important reason for considering other operational means. Chrome mining involves handling material at extremely high temperatures in smelting plants (Mining Watch Canada, 2012:2). If an operational malfunction in the TMM or operator error should occur, the chances that a TMM will burn out completely are very high. However, operator cabs are manufactured with high-temperature resistance (Gustafson *et al*., 2017:187). The quest to eliminate any possibility of fatalities led to the innovation of remotely operated TMMs (Gustafson *et al*., 2017:185). These TMMs are fitted with a third-party remote control system that the operator can override to operate the TMM manually. The operator is within a fifty-metre range of the TMM (Gustafson *et al*., 2017:185). Outside this range, a TMM stop and shutdown will occur.

The quest for efficiency, safety, and fewer emissions led to further investigations into emulators and electric TMMs (Gustafson *et al*., 2014:342). As with remote control TMMs, emulators require fewer operators per TMM, reducing safety risks. Emulators are more forgiving towards the equipment because they respond directly to machine movements, unlike remote-operated equipment (Van der Hoeven *et al*., 2007:124-125). As for electric equipment, the technology is available but has not yet been tried and tested within the chrome smelting industry.

Although technological advances have made various remote-controlled TMMs available, the correct application for the specific industry or task should be identified and applied. Various methods of remote control are possible with telecontrol, from simple stand-off control via umbilical connections to remote and automatic control (Kononov, 2017:6). Suitable communication channels can be physical line systems via electrical cables, TMM trailing power cables and fibre optic cables, or wireless systems based on radio or infrared signals (Kononov, 2017:6). Many systems are in operation worldwide in applications such as long walling, continuous miners and road headers, load-haul-dump TMMs, and drill rigs (Kononov, 2017:6). These suitable channels will be identified and applied based on site and operational constraints and requirements. Remote areas might be unable to use wireless applications, and areas with high traffic flow might be unable to apply cable communication. These solutions are application-specific, and technology has advanced to a point where different solutions can be provided.

These factors and limitations are also influenced by whether the mining operations are located in first-world or third-world countries. More advanced technology and remote-controlled TMMs are prevalent within first-world countries. Although South Africa has a healthy mining environment, it is currently not at the forefront of these advances. Commercial products that use this technology are available from several companies across the globe (Mine Health and Safety Council, 2022). However, in the South African context, only limited trials have occurred. Therefore, this study proposes a strategy to approach this problem, taking into consideration the local needs and conditions and the human factor when introducing new technologies to the SA mining context (Kononov, 2017:6). The environmental factors, as well as limitations on skilled labour, are some of the constraints South Africa must overcome to make use of these safety and productivity aids available in global markets.

Challenges to overcome on order to safely and manageably deployment self-driving TMMs are the following (Brundrett, 2014:18):

- policies regarding liability for damage,
- resistance of individuals to forfeit control of their TMMs at higher costs,
- software reliability and cyber security,
- implementation of a legal framework and government regulations,
- a loss of driver-related jobs.
- reliance on surface markings for staying in lanes and determining traffic obstacles and traffic intensity.

2.6.4 Maintenance of TMMs

Proper maintenance and repair are crucial for any kind of equipment that is subjected to operations (Patel, 2021:7). It is possible to implement a successful maintenance planning system as long as systems and procedures are formally developed and implemented to provide a logical, disciplined approach to maintenance (Perenti, 2020). Achieving a high standard of maintenance procedures and practices for underground mobile mining equipment is essential in the current world of high business competition, significant technology advancements, and strict environmental laws and policies (Robatto Simard *et al*., 2023:26-27, 30).

Standards and maintenance practice approaches can be grouped into the following major groups (Robatto Simard *et al*., 2023:27):

- Corrective maintenance is defined as maintenance that must be redone, or that is correcting something that was already broken. It is the most expensive form of maintenance, especially if it must be done urgently because no planning or coordination can be done (Mkemai, 2011:10).
- Preventive maintenance is done before a component fails (Mkemai, 2011:15). A service can also be seen as preventative maintenance. The item to be maintained can be replaced or reconditioned, depending on the item's condition. The failure rate of the item is its probability of failure over a given period (Mkemai, 2011:10).
- Predictive maintenance involves monitoring equipment status so that corrective maintenance can be carried out before a failure occurs (Robatto Simard *et al.*, 2023:27). The use of predictive maintenance practices has been associated with cost reduction, increased equipment reliability, and a reduction in equipment environmental impacts (Robatto Simard *et al*., 2023:30).
- Predetermined maintenance (PDM) concerns maintenance based on a scheduled amount of hours. For PDM implementation to be successful, the failure rate of an item needs to increase as the usage time of an item increases (Robatto Simard *et al.*, 2023:27).
- Total plant maintenance (TPM) involves all personnel from top to bottom so that a culture of maintenance is instilled. TPM aims to maximise equipment effectiveness. It consists of a range of methods that are known from maintenance management experience to be effective in improving reliability, quality, and production (Mkemai, 2011:12). TPM attempts to improve a company by improving both the personnel and the plant and changing the corporate culture (Mkemai, 2011:12).
- Reliability-centred maintenance ensures equipment is used for what it is intended to do over its lifespan. This is achieved through a detailed analysis of failure modes and causes (Mkemai, 2011:13).

- Condition-based monitoring is applied where equipment or parts are inspected regularly to evaluate their condition and to predetermine replacements or repairs (Ali & Abdelhadi, 2022:1). A condition monitoring system measures parameters to ensure that maintenance is performed before a failure occurs based on predetermined criteria. Inspection is done regularly by a person involved in maintenance to ensure that maintenance is performed as soon as required (Ali & Abdelhadi, 2022:1).

Computerised maintenance management systems are effectively employed in the complex maintenance management process (such as day-to-day workflow), generating information that identifies key maintenance issues that impact hidden costs and improving overall business performance (Wienker *et al*. 2016:418-420).

The maintenance of underground mobile mining equipment is complex due to factors such as a harsh environment, potential risks, and the distant location of workshops (Gustafson, 2013:3). The harsh operating environment complicates maintenance (Gustafson, 2013:3). To reduce costs, the general industrial trend is towards planned and condition-based maintenance and towards minimising all acute repair work (Tomlingson, 2010:130). In a mining operation, too many unplanned repairs and too much maintenance work on the mobile mining TMMs significantly reduce the overall availability of the TMMs (Tomlingson, 2010:29) and increases production costs (Sayadi *et al.,* 2012:133), which can negate the investment made in automation.

In the open literature, it is generally assumed that the benefits of automatic operation include lower maintenance costs, optimum gear shifting, less wear and tear, and no overheated engines (Gustafson *et al*., 2014:354; Gustafson *et al*., 2017:185; Sandvik, 2016; Voronov *et al*., 2020:5; Xiao *et al*., 2022, 6). These are possible for two reasons: the driving always perfectly matches the situation, and TMM downtime is reduced over time due to the automatic tramming (Xiao *et al*., 2022:20). Even though the maintenance issue was an early argument in favour of automated LHD TMMs, it is now acknowledged that maintenance personnel require more extensive skills and experience (Gustafson *et al*., 2017:188).

Variables in the maintenance of TMMs are fuel, maintenance, tyres, repairs, depreciation, and data on battery and tyre replacement (Gustafson *et al*., 2017:186). The equipment procurement phase includes optimal use (operation), logistics support, and replacement policy that coincides with the latest technology (Shukri *et al.,* 2013:2). Vehicle operating cost models may be formulated empirically, mechanistically, deterministically or probabilistically (Wennström, 2014:17). Purely mechanistic models are based on responses like stresses, strains and deflection. Mechanistic-empirical models are based on empirical regression equations that are related to the responses. Deterministic-based models predict deterioration for a single value, while for probabilistic-based models the deterioration is expressed as probability functions resulting in ranges of probable conditions. Vehicle operating cost models can be applied to varied conditions, such as the relationships of vehicle characteristics, road geometrics, the road surface type, the condition of the road surface, environmental factors, and vehicle speed, and only require a limited amount of data for model calibration (Shukri *et al.,* 2013:2).

When spare parts replacement and other maintenance costs are included, the total spent is expected to increase (Shukri *et al.,* 2013:3).

Acquisition-, maintenance-, operating-, and disposal costs form part of the lifespan cost (Wennström, 2014:17). By estimating the total lifespan cost for each truck, the user can forecast total estimated expenses more accurately (Shukri *et al*., 2013:4).

The maintenance function corresponds to production and has a significant effect on the capacity and quality of the products produced (Shukri *et al.,* 2013:5). Maintenance procedures aim to keep machinery or vehicles in good working condition as well as to keep maintenance costs low (Shukri *et al*., 2013:5). Fuel, repairs, maintenance, consumables, depreciation, and financing costs are among the highest costs to evaluate (Shukri *et al*., 2013:1). In addition to evaluating operating costs, operational maintenance costs can also be considered to determine optimal operating conditions (El Nemr, 2022:333).

Fuel and electricity are considered as part of operation costs. Maintenance and running costs are determined by factors such as engine overhaul, transmission oil renewal, engine oil renewal, generator and motor maintenance, clutch disk replacement, and brake drum and disk replacement (Shukri *et al.*, 2013:6).

As part of the operating costs, it is assumed that energy cost depends on fuel and electricity prices (Shukri *et al.,* 2013:6). Even though electric vehicles are environmentally friendly, their employment may lead to a lack of recharging stations surrounding the system (Shukri *et al.,* 2013:6). A diesel TMM emits harmful CO_2 emissions, but it never faces recharging problems (Shukri *et al.*, 2013:6). Total lifespan costs depend, to a large extent, on preventive maintenance cost (Shukri *et al.,* 2013:7). The cost of maintaining and operating trucks or other fleets are strongly dependent upon the characteristics of the specific model (Shukri *et al.,* 2013:7). Research has focused on measuring how fuel, maintenance, tyres, repairs, and depreciation affect fleet costs (Shukri *et al.*, 2013:8).

Before being able to calculate and estimate the cost of maintenance and operations, the major factors detrimental to the costs must be carefully assessed (Shukri *et al.,* 2013:8). Among the main factors that affect the costs of repairing the vehicle are the cost of spare parts, engines, tyres, batteries, and labour (O'Connor, 2014:5). In addition, environmental and external factors are highlighted because they have a significant impact on the cost of maintenance and operation of TMMs (Shukri *et al.,* 2013:8). These factors should be considered and evaluated within the South African context to measure advantages and disadvantages of electric and diesel-powered vehicles.

2.6.5 Reliability of conventional and modern TMMs

The current challenge in modern teleoperated TMMs is to provide suitable conditions for human operators to operate the system efficiently and safely from a distance (Sulaiman *et al.,* 2015:59). The applications can be divided into manned, unmanned, and teleoperated TMMs (Sulaiman *et al.,* 2015:59).

Investing in automating LHD machines requires high machine reliability (Gustafson, 2013:4). The collective terms used to describe availability and its influencing factors are reliability, maintainability, and maintenance supportability (Gustafson, 2013:4). Dependability is not a numerical indicator but an umbrella term used to describe availability and reliability (measured with Mean Time Between Failure, MTBF) (Gustafson, 2013:4). Maintainability is measured with Mean Time To Repair (MTTR) and maintenance supportability with Mean Waiting Time (MWT) (Gustafson, 2013:4). MTBF and MTTR can be modelled using the quantitative data of the system components (Gustafson *et al*., 2013:76). MTBF and MTTR are used as indicators to manage the performance of the TMM (Gustafson, 2013:23)

The operation of autonomous systems can be controlled either remotely with a tether or wirelessly (Sulaiman *et al*., 2015:57). Tether tracking systems typically have a spool located on the mobile machine that dispenses and reels in a tether as the mobile TMM travels around a job site. The operators receive real-time video images, while the commands from the operators are transmitted through wireless links conducted using the unmanned construction system (Sulaiman *et al*., 2015:58).

2.6.6 Efficiency and safety awareness

Manufacturers have placed the most significant emphasis on safety, which is seen as the essence of mining operations (Gaber *et al.,* 2021:6). This can be done either by improving efficiency or by allowing robots to operate in areas that humans find inoperable (Gaber *et al.,* 2021:7).

In manned TMMs, operators' fatigue and repetitive motions can be reduced through increased efficiency and safety features. In remote-controlled TMMs, assistance to the operator is afforded by improved capability and accuracy.

A simple but repetitive task can create a condition where the operator feels tired, which will reduce efficiency and safety awareness (Sulaiman *et al.,* 2015:60). It consists of the automation of some repetitive tasks such as digging holes and trenches (Gustafson, 2013:2). The automation is accomplished through the learning process on how the operator does the task (Gustafson *et al*., 2023:76). Although this system is not equipped with remote-controlled ability, it can reduce operator training time and enhance digging accuracy (Sulaiman *et al.,* 2015:60).

Teleoperated and controller-operated TMMs allow human intervention, with the added benefit of controller-aided TMMs for safety. TMMs can replace human intervention for added safety.

Teleoperated TMMs involve a method to control excavators from some distance away (Sulaiman *et al.,* 2015:61). The proposed system enables the operator to control the TMM effectively, utilising the conventional haptic devices (Sulaiman *et al.,* 2015:64). In a virtual world or remote environment, a haptic device offers the operator an extra sense of touch through force and torque feedback (Khan & Andersson, 2011:1; Sri Gurudatta Yadav & Krishnaiah, 2013:139). In the case of modern TMMs, efficient manipulation is possible by using visual feedback from the operator (Sulaiman *et al.,* 2015:64). These authors determined the effectiveness of remote-controlled operations by calculating the degree of working efficiency. The results showed that remote-controlled operations of a TMM conducted at local construction sites are 50% more efficient than direct operation (Sulaiman *et al.,* 2015:64).

2.6.7 Training

Simulators can be used to provide the necessary learning technique to control a TMM (Sulaiman *et al.,* 2015:64). Although effective training is required for operators of manned TMMs, devices or systems that could aid in the training of these operators are required, such as simulator machines.

2.6.8 Automation

There is no exception to automating vehicles and equipment, where manufacturers strive to develop smart machinery that can be remotely operated and controlled and autonomously perform tasks. A global drive towards autonomously driven equipment and vehicles is currently the driving force behind technological innovations (Nastjuk *et al*., 2020:1). The adoption of autonomous haul trucks (AHTs) in the mining industry is eminent because automation and autonomous vehicles are on the rise across a broad spectrum of industries globally (DAC.digital, 2023).

Automating mining equipment is an important requirement in the mining industry because mining operations need to increase the workers' safety and increase the processes' productivity, efficiency, and predictability (Tampier *et al.,* 2021:1).

The current market trend within the industry, especially in South Africa, is an increased demand for safety requirements and labour constraints (Khuluvhe *et al*., 2022:19,92). These factors create a greater need to increase TMM efficiency to benefit operational efficiency. However, performance has progressively deteriorated with more labour and safety constraints (Nardini *et al.,* 2012:65).

Mining houses are now striving for higher productivity, which requires a step change to achieve increased competitiveness in the marketplace (Nardini *et al*., 2012:66). To this end, customers have an appetite for innovative products and safer and more efficient working processes. Therefore, adopting modern TMMs in the form of newer technology has advantages in service delivery requirements.

Emulators and remote-controlled TMMs boost efficiency by requiring less labour for the same TMM and provide a safer working environment since human intervention is removed from danger zones (Nardini *et al*., 2012:66).

Unmanned TMMs refers to TMMs that operate without direct human control (Sulaiman *et al.,* 2015:65). Sulaiman *et al.* (2015:65) studied an operating system that is the first fully autonomous loading system for TMMs capable of loading trucks with soft material at the speed of an expert human operator. This study suggests that modelling the operation function facilitates the application of the unmanned TMM and provides experience for the advanced control of other unmanned construction TMMs (Sulaiman *et al.*, 2015:65).

Lynas and Horberry (2011:74) classify different levels of automation into three broad categories, namely:

- Lower-level automation: this is where the human being (operator) is in full control of the system and technology only assists with warnings, for instance, proximity detection systems.
- Mid-level automation: this level involves having an operator control the equipment from a nearby location. The operator is in control at most times, but some functions are controlled by the system.
- Full automation: in this category, the operator is in a remote location and controls the equipment using computers, joysticks, and other controls.

AHTs have demonstrated notable fuel consumption performance as a result of their driving consistency (Gaber *et al.,* 2021:2). They can operate on a 24/7 schedule with no idling time as there is no shift change and no breaks are required (Gaber *et al.,* 2021:2). A manual truck operator can affect 35% of fuel economy. In contrast, an automated truck operator can improve fuel consumption by 4%, with 25–50% less downtime (Gaber *et al*., 2021:2). As a result, AHTs strengthen mining operations by improving operational efficiency (Gaber *et al*., 2021). However, these wireless technologies pose challenges, such as frequency interference, channel utilisation, and signal jamming (Gaber *et al.,* 2021:2).

According to Marshall *et al*. (2014:5-8), robotics contributes to mining and other domains in the following areas:

- assisting workers in hazardous environments that pose health risks, such as excessive heat, dust, poisonous smoke, or hydrogen sulphide (H2S),
- eliminating labour shortages,
- enhancing health and safety,
- achieving better performance than humans.

The application of autonomous technology to haul trucks in mining has received much attention recently due to an increase in mineral demand, lower availability of skilled workers, and mineral deposits that are lower grade and in more remote locations (Brundrett, 2014:3). The global demand for minerals and metals has seen record increases (Brundrett, 2014:3).

Autonomous vehicles can drive from one location to another without guidance or assistance from a person (Brundrett, 2014:11). They do this by collecting data about their environment, understanding the data by employing statistical analysis, and taking appropriate actions (Gaber *et al*., 2021:2). Autonomous vehicles also exchange data with other vehicles and with infrastructure, such as stop signals (Gaber *et al*., 2021:2). The following four varying levels of vehicle automation have been documented (Brundrett, 2014:15; Voronov *et al*., 2020:2):

- Remote control: an excavator or bulldozer is usually controlled in dangerous places where there is a risk of landslides, explosions, or rock falls. Operators using remote controls can see the TMM.
- Telemetric control: an operator can control mining equipment from a distance using cameras and sensors. The operator can control equipment safely and receive information about the TMM's location and condition.
- Algorithm laid down by a program: one operator controls multiple equipment units.
- Full automation: a fully automated vehicle can control everything from ignition to gear shifting, steering, and braking. Automation increases the productivity of mining TMMs.

Programs control them; thus, the operator need only monitor their efficiency and intervene in case of a problem.

AHTs are more efficient than manned trucks because expensive equipment is employed 24/7 (Brundrett, 2014:4; NIOSH, 2020). Aside from being more efficient, automated trucks also reduce costs because of shorter cycle times, lower fuel consumption, and improved tyre wear (Nastjuk *et al*., 2020:1). Moreover, a mine with fewer personnel improves human safety (Gaber *et al*., 2021:4; Voronov *et al*., 2020:1). This technology eliminates some jobs, contributing to potential cost savings (Voronov *et al*., 2020), but it also creates new jobs with better worker skills in safer environments (Brundrett, 2014:4).

2.6.9 Battery-powered electric vehicles (BEVs)

The environmental impact of battery-powered TMMs and their advantages over their diesel-powered counterparts are closely related. BEVs can create a safer, cleaner, and healthier working environment by reducing combustion products and liquid pollutants (e.g. oil, transmission fluid, and radiator fluid) from the workplace and reducing noise exposure levels. Diesel engines can negatively impact underground work environments due to their noise, heat, and odour. Additionally, diesel emissions include carbon monoxide (CO) and dioxide (CO_2), nitrogen (NO_x) and sulphur oxides (SO_x), hydrocarbons, and diesel particulate matter (DPM) (Halim *et al.*, 2022:203).

Battery-powered TMMs in the mining sector have the following disadvantages compared to diesel engines (Halim, 2022:10,13):

- Mines face new challenges regarding infrastructure, maintenance, and operating constraints with BEVs.
- The energy density of fossil fuels remains higher than that of electric power despite recent advances in battery technology. Specific energy density (energy per unit mass) describes how much energy can be stored in a given amount of mass. The range and capacity of a vehicle are thus determined thereby.
- Since refineries convert raw petroleum products into portable fuel, diesel equipment has the advantage of standardised fuel. Due to the battery pack's complexity and the battery charging process, BEVs do not share this convenience with conventional vehicles.
- BEVs and diesel equivalents have different capital expenditures, depending on how the battery is paid for. Renting or leasing batteries can result in significant battery costs. Capital expenditures can be avoided by focusing on operational expenditures.

BEVs offer several advantages to the mining industry (Halim, 2022:13):

- Performance improvements lead to an increase in the amount of tonnes mined, which leads to increased revenue. With more powerful electric drives, equipment performance (breakout/lifting capacity, acceleration, and speed) can be improved for units with similar payload capacities.
- The adoption of BEVs will lead to further advancements in battery and electric components; additionally, costs will decline, enabling OEMs to continue improving vehicle design for both performance and cost.
- Due to the high reliability of electric motors and the static nature of electric drives and controllers for electric motors, maintenance costs can be lower for electric engines than diesel engines.

Over a year, the analysis of each TMM showed that modern equipment did not necessarily improve productivity (Gumede, 2018:3). In most cases, the productivity was reduced (Gumede, 2018:3). Operators rejected innovations due to skills shortages, different TMM functions, and different standards (Gumede, 2018:3).

2.6.10 Conventional vs. modern TMMs

Development increases enable an organisation to increase capacity, introduce innovation, or boost efficiency by replacing conventional TMMs with modern ones. Technological advances are introduced, and better availability is ensured, affording both operational and financial benefits. The need to increase development rates is not a new challenge, and the benefits from higher development rates are both financial (with a better NPV result) and operational (allowing more flexibility) (Nardini *et al.,* 2012:65).

Krunić *et al*. (2018:404-408) presented two model approaches to the lifespan assessment of mining TMMs. One is based on reliability theory, and the other on the principle of cost-effectiveness. During the exploitation of TMMs, their level of reliability decreases. At the same time, operating costs increase (Teplická *et al.,* 2020:4). These indicators of opposing trends are used to detect the operating capacity of TMMs, and they provide the basis for deciding on the validity of further operation and maintenance or replacement of TMMs (Teplická *et al.,* 2020:4).

TMMs can be controlled remotely or manually. Remote-controlled TMMs and advanced driver assistance systems (ADAS), such as adaptive cruise control and automated lane-keeping systems, are now standard (Shahandashti *et al.*, 2019:9,15, 21). Remotely controlled TMMs place the operator outside potentially dangerous excavation and hauling operations (Klingberg, 2023:1). Furthermore, remote operators may work in teams, monitoring several vehicles and taking control as passengers or automated driving systems require (Klingberg, 2023:18). Remotely controlled

TMMs can potentially decrease the number of accidents because many occur due to the 'human factor' of driving (Merchant & Lindor, 2012:1322).

With the increasing complexity and degree of automation of equipment, capital costs have steeply increased (Gustafson, 2013:1). Therefore, there is an increasing demand for higher production using existing LHD TMMs while limiting the number of the available active loading areas (Gustafson, 2013:1). The increasing emphasis on safety and ergonomics gives automatically operated loaders an edge over manually operated ones (Gustafson, 2013:1). With an automatic system, the operator can be taken out of the mine and can simultaneously control up to three LHD TMMs (fleet automation), with the potential of increasing both productivity and safety (Gustafson, 2013:1).

When it is used in day-to-day operations, the automated process offers flexibility and convenience for the operators (Gustafson, 2013:1). In addition, the resulting health and safety benefits will lead to the long-term well-being of the operators (Gustafson,. 2013:1).

However, there are drawbacks compared to direct manual operation of a construction TMM (Goodall, 2020:8; Nishiyama *et al.,* 2013:2). When an operator operates the TMM by watching the monitor, compared to direct operation, it is not as easy to understand the work site conditions, feel the depth of the bucket, or move the TMM quickly. Mohape and Zarske (2018:17) and Nishiyama *et al.* (2013:2, 4, 7) calculated that the operational efficiency of remotely controlled TMMs is about 60% to 70% lower than that of manned operations due to inexperienced operators and complexities, such as locating the three-dimensional position of the bucket and the bar to hold the objects, which is time-consuming. They established that it is possible to enhance the operational efficiency if any other operation can be conducted simultaneously with the rotating operation during remote control.

Teplická *et al.* (2020:1) investigated the impact of a combination of mobile and stationary mining TMMs and their optimal distribution in the mining process to increase the efficiency of mining and processing of raw materials. They found that success in the mining industry requires having the best mining TMMs and achieving optimal placement for them in the mining process (Teplická *et al.,* 2020:1). To this end, a suitable alternative to machinery optimisation is a combination of stationary production lines and mobile equipment and their optimal distribution in the mining process. It results in time savings, reduced downtime, increased productivity, and reduced operating costs (Sánchez & Hartlieb, 2020:1388; Tholana *et al*., 2013:474). Reduced costs result in more funding available in the business and will result in increased profits (Ahsan, 2018:71).

The most straightforward comparison between manual and automatic loading is production, i.e. the tonnage of loaded material per unit of time (Gustafson, 2013:21; Marklund, 2017:6). In terms of production, the results show that manual loading is more efficient in the short term, as three out of four LHDs have a higher tonnage loaded per hour (Gustafson, 2013:23; Marklund, 2017:7). However, when looking at the tonnage loaded per activity, automatic loading catches up to manual loading and produces more tonnage in the long term, with three out of four LHDs achieving this higher production (Gustafson, 2013:23; Marklund, 2017:7). The higher availability of automatic loading is attributed to the fact that manual loading takes much more time than automatic loading. Therefore, there is more time for breakdowns and production stops to occur than for manual loading (Marklund, 2017:7).

For manual loading, the most common stops concern external circumstances in the mine, such as blocked access, fallen boulders, and minor breakdowns of the LHD (Marklund, 2017:7). For automatic loading, the most common stops concern the automatic system and the equipment used to operate the automated LHD, followed by those caused by external circumstances, similarly to manual loading (Marklund, 2017:7). Automatic loading has proportionally fewer stops than manual loading (Marklund, 2017:7).

It is concluded that modern TMMs and innovation measures such as automation result in higher productivity in mine hauling operations.

2.6.11 Impact of technical and operational factors on effectiveness of automatic LHD TMMs

The type and number of trucks are selected based on the loading equipment used (Salama, 2014:8). The truck size selection depends on the number of cycles the loader needs in order to fill a truck (Salama, 2014:8). A high-capacity truck and a lower-capacity loader will increase the required number of loader cycles, which leads to an extended cycle time for the hauler and a lower production rate (Salama, 2014:8). The number of trucks also depends on other factors such as productivity estimate, the available time in a shift, the queuing of trucks at loading and dumping points, traffic congestion, among others (Salama, 2014:9).

Energy consumption plays a significant role in selecting and managing loading and hauling equipment (Salama, 2014:19).

Electric LHDs may use overhead electric lines, batteries, or trailing cables (Salama, 2014:20). Batteries offer the highest flexibility. However, battery vehicles are heavy and must be recharged regularly (Salama, 2014:20). Overhead power lines may be feasible where routes remain constant for an extended period but are impractical for LHDs that require a high level of manoeuvrability (Salama, 2014:20). The most viable way to power electric LHDs is with a trailing cable plugged into the mine’s electrical infrastructure (Salama, 2014:20). Electric units have low noise levels, no exhaust gases, and low demand for ventilation because they generate less heat (Salama, 2014:20). For many years, diesel trucks have been utilised for material transportation in open-pit and underground mining operations. However, electric trucks are gaining attention in various deep underground mines (Salama, 2014:20).

TMM hours and the amount of loads carried by the TMM play an important role in determining the time the TMM was used. The amount of time that a TMM has been in use can be a good KPI in maintenance activities (Mkemai, 2011:34). The two parameters above can enable the project leader to plan an effective maintenance interval for the equipment (Mkemai, 2011:34). The longer equipment is in use, the higher the possibility of developing failures. Hence, shorter time intervals required for planned maintenance will result in the effective performance of the equipment and will enhance the production process (Mkemai, 2011:34).

2.6.12 Best practices

It is widely recognised that technology plays a vital role in developing and applying new mining methods, improving safety, health, and operational effectiveness in South African mines (Macfarlane, 2001:115). Many mining companies see introducing new technology into mining operations as a strategic necessity to improve safety and operational effectiveness (Macfarlane, 2001:115). Failure to do so may come with a significant opportunity cost and have a detrimental effect on future development because the system has not been adequately engineered, and the risks have not been adequately assessed and managed (Macfarlane, 2001:115). Successfully managing this will require systematic programmes and processes that will allow these technologies and methods to be implemented sustainably (Macfarlane, 2001:115).

According to Macfarlane (2001:17), before technology implementation, the following should be considered:

- The technology to be introduced must be appropriate to the work system's development level.
- The technology to be introduced must have a clear objective that is identifiable in terms of bottom-line benefit.
- Introducing a new technology must be part of a common vision shared by all.
- The work system into which the technology is to be introduced must be adequately engineered to ensure its success.
- The workforce who will operate the new technology or work process must be involved every step of the way in its design and implementation.

Any new technology plan must have a quantifiable purpose and benefit to the business, whether in terms of economics or health and safety (Macfarlane, 2001:119). The culture phase allows for checking if everything has fallen into place (Macfarlane, 2001:123). It is a review process to address the results measured against planned outputs, as highlighted in the vision and feasibility study, and to assess whether each phase has succeeded (Macfarlane, 2001:123). The successful implementation of new technology is vital for the future of the South African mining industry, for it to maintain its competitive position, and for its sustainable development (Macfarlane, 2001:124).

2.6.13 Manned or remote

In the quest for optimisation, the topic of manned and remote TMMs is at play. In some operations, both manned and remote-operated TMMs are currently used (Sulaiman *et al*., 2015:59). Underground and opencast mines often use TMMs to move ore (Gustafson, 2013:1; Kotze, 2013). Remotely operated TMMs are currently being sought due to concerns over operator safety, low operational efficiency, and low cost (Gustafson, 2013:11). Chrome mining involves handling material at extremely high temperatures in smelting plants (Mining Watch Canada, 2012:2). If an operational malfunction in the TMM or operator error should occur, the chances that a TMM will burn out completely are very high. However, operator cabs are manufactured with high-temperature resistance (Gustafson *et al*., 2017:187). The quest to eliminate any possibility of fatalities led to the development of remotely operated TMMs (Gustafson *et al*., 2017:185). These TMMs are fitted with a third-party remote control system that the operator can override to operate the TMM manually. The operator is within a fifty-metre range of the TMM (Gustafson *et al*., 2017:185). Outside this range, a TMM stops and shutdown will occur.

Although manned TMMs are still the preferred type of equipment used within the industry, safety will soon not be the only reason for considering other operational means. The quest for overall efficiency, safety, and fewer emissions led to further investigations into emulators and electric TMMs (Gustafson *et al*., 2014:342). As with remote control TMMs, emulators require fewer operators per TMM, reducing safety risks. Emulators are more forgiving towards the equipment as the emulators have a direct response to any movements the TMM makes, unlike remote-operated equipment (Van der Hoeven *et al*., 2007:124-125). As for electric equipment, the technology is available but has not yet been tried and tested within the chrome smelting industry.

2.6.14 Contribution and purpose of this study

Because Almar's business is built on TMMs and services delivered with them, TMMs and the replacement strategy behind them are crucial to organisational success. The organisation prides itself on being a strategic partner to its clients. This trust can only be built between the client and the organisation delivering the service if it is based on exceptional service delivery (Anning-Dorson *et al*., 2020:2). Therefore, it is crucial to have the best possible TMMs availability to ensure that service delivery is of a high standard. Furthermore, a TMM's increased lifespan benefits the organisation financially. Financing equipment and knowing its maintenance and financing costs over its lifespan is essential. Stretching this replacement cycle to a larger number of hours achieved per TMM increases financial efficiency for the organisation. Thus, the replacement strategy between conventional and modern TMMs is vital to organisational sustainability.

Increasing efficiency and service delivery when implementing new technology in the industry is vital to ensure that the organisation stays relevant to the operations and the industry. Exploring new technology and modern ways of using TMMs will enable sustainability in client growth. Embracing new technology, such as remote-operated TMMs and emulators, will boost significant safety enhancements to a service that is dangerous to perform.

This research aims to determine the influence of conventional and modern TMMs within current and future business operations on profitability, client satisfaction, and service delivery. The study focuses on a market-leading organisation within the chrome smelting process's slag and bulk materials handling industry. The aim is to provide the right equipment at the right time and as effectively and efficiently as possible. Transport is the key element of a logistics chain and the backbone of the entire supply chain (Daniela & Ovidiu, 2014:34; Li, 2014:2). Transport management makes it possible to achieve the seven Rs of logistics (getting the right product, in the right quantity, in the right condition, at the right place, at the right time, to the right customer, at the right price) (Teoman, 2020:232-233).

The organisation currently handles service delivery to 90% of the chrome smelting industry and prides itself on long-term partnered relationships with its clients. The clients are viewed as strategic partners in the industry.

This study seeks to optimise business operations by finding a balance between applying conventional and new bulk material handling TMMs in chrome mining. Optimisation by adopting technological advances and improving the current fleet composition ensures organisational sustainability.

2.7 SUPPLY CHAIN MANAGEMENT

A supply chain is a collection of value-adding activities that connect the enterprise's suppliers with its customers (Gautam & Prabhakar, 2019:88). Lu and Swaminathan (2015:710) and Chopra and Meindl (2013:1) define these activities as the entire process of creating and delivering new products and services: procuring raw materials, transforming them into semi-finished and finished products, marketing them, delivering them to consumers, and maintaining service delivery.

By developing supply chain relationships, supply chain management integrates supply chain activities (Akhter *et al*., 2018:31). Effective supply chain management affords a sustainable economic advantage by managing supply chain assets, products, information, and fund flows to maximise total supply chain surplus (Chopra & Meindl 2013:4). In this process, products are designed, procured, forecasted, produced, distributed, fulfilled, and supported after sales (Lu & Swaminathan, 2015:710).

Chopra and Meindl (2013:4) define a company's competitive strategy as the customer needs it seeks to satisfy through its products and services. Therefore, to achieve a competitive advantage, companies increasingly depend on their supply chain partners to drive down costs, increase forecast accuracy, increase profits, improve inventory control, and improve processes (Lai *et al*., 2013:3038; Mofokeng & Chinomona, 2019:1). Collaboration facilitates joint planning and forecasting, and the sharing of information, resources, and incentives among members (Mofokeng & Chinomona, 2019:1).

The organisation valuated in this chapter forms part of a larger supply chain and stands firmly as a trusted service provider within the supply chain. Being a strategic partner improves their competitive advantage by becoming a preferred supplier and service provider, adding value and competitive advantage to their clients.

As a result of this relationship between clients and suppliers, a larger market share has been achieved, to the point that a niché market is being controlled. Staying up to date with the latest market trends, requirements, technology, and developments is essential in ensuring sustainability (Jung & Kim, 2023:13).

The competitive advantage for a contracting third-party rental company is ensuring that service delivery is extremely high. Therefore, the equipment needed for service delivery must be of the newest standard. Accordingly, the equipment must adhere to environmental and client requirements, incorporate new technologies, and keep up with dynamic market changes (Garcia *et al.,* 2021:1110; Tidd *et al.,* 2020:109). The optimal application of modern and conventional TMMs must be evaluated to ensure organisational sustainability and, ultimately, competitive advantage.

2.8 COMPETITIVE ASSESSMENT OF ON-SITE BULK AND MATERIAL HANDLING INDUSTRY

Longenecker *et al*. (2007:98) define a competitive advantage as offering a product or service that customers perceive to be superior to competitors' products, thereby increasing profitability. Some of the most common paths to competitive advantage include differentiation based on price/value, unique service features, notable product attributes, customer experience, and accessibility (Longenecker *et al*., 2007:98).

Companies must constantly evolve their strategies to ensure sustainable competitive advantage (Farida & Setiawan, 2022:4). Therefore, competitive advantage and competitive advantage strategies are usually short-term. Competitors usually seek ways to duplicate competitive advantages that market leaders have successfully implemented. Continuously evolving competitive strategies make it more challenging for competitors to increase their market share.

In the following section, Porter's Five and Seven Forces analysis is used to assist businesses in understanding their industry's competitive dynamics and developing competitive advantage strategies.

2.8.1 Porter’s Five Forces

The character and strength of competitive forces functioning in an industry are never the same from one industry to another (Thompson *et al*., 2012:102). The Five Forces Model, developed by Porter, illustrates that the competitive forces affecting the industry’s profitability go beyond the rivalry among competing sellers in the market. Porter identified four further coexisting sources that create pressures within an industry (Thompson *et al*., 2012:102).

Porter's Five Forces are presented in Figure 4. The following five competitive forces are at play:

- rival sellers’ competition,
- suppliers,
- potential of new entrants’ competition,
- substitute product producers’ competition,
- bargaining power from customers or buyers.

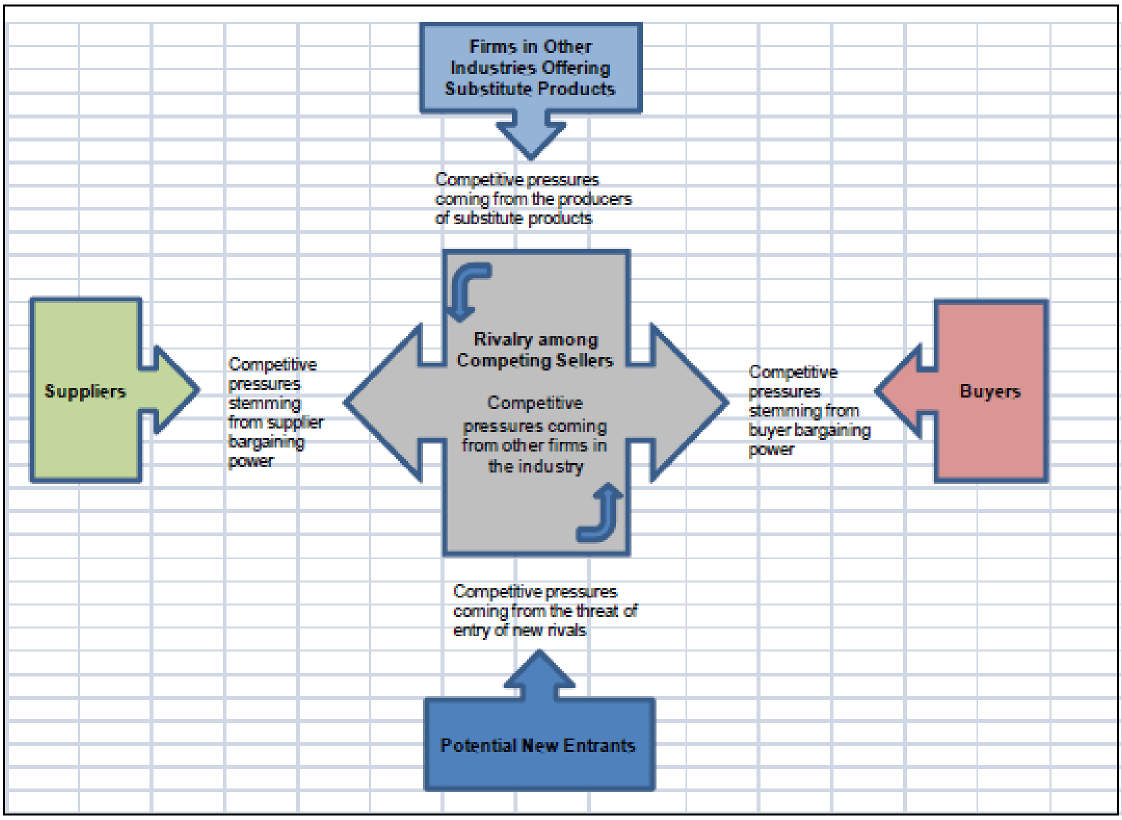

Figure 4 Porter's Five Forces Model (Thompson *et al*., 2012:103).

2.8.1.1 Rival sellers' competition

Rival service providers affect the competitive spirit within the industry. Markets are continuously tested because contracts are based on a tender process. A successful bidder has a specified contract period (three to five years), with the possibility of being granted an extension. As a result, reputation must be maintained for three to five years to prevent rivals from competing, even though rivals can compete only once a year. Almar Investments, a contracting plant hire company, is only one among various other companies that deliver the same service. However, it has established itself in a niché market, making rival competition rare.

2.8.1.2 Suppliers

Almar is a supplier within the chrome smelting industry value chain. Therefore, it forms part of the value chain as a service supplier to their clients. However, companies that are suppliers to Almar play a vital role in its success and in ensuring accurate and effective service delivery. Suppliers to the industry need to adapt to the fast-paced requirements, or they will not add value. For example, if a breakdown occurs after hours, parts are needed urgently; suppliers need to be equipped to handle this and need to grow with the industry as a supplier. Competitive rates are not only reflected in ultimate service delivery cost; suppliers must also adhere to the required mining charter and mining legislation to ensure overall service delivery and compliance.

2.8.1.3 The potential of new entrants' competition

An opportunistic competitor is considered a possible new entrant in the market because it would try to gain access to the industry through a tender process. In recent years, however, aside from B-BBEE requirements, it has been observed that companies, suppliers, and clients alike have increasingly taken on responsibility for the surrounding communities. It is evident that development and empowerment are becoming increasingly important in the mining and processing industries. Communities are not only seeking jobs but are also demanding and requiring business opportunities. As a result, existing companies are expected to grow, develop, and create their own competition and new entrants to the market.

2.8.1.4 Substitute product producers' competition

Substitute products are seen as the way to keep the evaluated company relevant to the industry. The experience gained over the past few years is an asset that cannot be taught or replaced. Therefore, this knowledge needs to be transferred to new developments within the industry. The organisation aspires to transition from conventional TMMs to a more modern fleet, where technological advances are at the helm. By employing remote control and automated TMMs, risk is eliminated, safety is enhanced, and efficiency is increased. It aspires to a situation where the ideal thought process and the practical application meet. Therefore, substitute products from competitors are not the impact but rather substitute products from within.

2.8.1.5 Bargaining power from customers or buyers

The entire industry is based on supply and demand. Therefore, the advantage to major role players within the industry has been to restrict supply and stockpile material for more profitable and higher pricing times, eliminating end-product buyers' bargaining power. For the contracting company supplying machinery, having the buying power to accumulate large quantities of TMMs enables better buying prices and shorter financing terms, ultimately boosting profitability. Therefore, at the tender and contract inception, client and supplier bargaining power is met through the timely delivery of quality service with high-quality products.

2.8.2 Thompson and Strickland’s Seven Forces

Porter's model has several major disadvantages as a tool for analysing industries. Although it is extensively used to assess competition in an industry, it cannot explore factors, such as economic factors, that affect the management strategy. Furthermore, it does not identify the major factors responsible for changing industry conditions. With this model, it is also difficult to assess the competitive position of rivals, their possible strategic moves, and the attractiveness of an industry.

Thompson and Strickland (2001) have developed a seemingly comprehensive industry analysis model that overcomes the drawbacks of Porter's model. It considers all the relevant issues within an industry that should be evaluated to assess the overall industry situation, including the level of competition.

According to Thompson and Strickland (2001), the following seven forces should be considered to perform an industry analysis:

- dominant economic features of the industry,
- sources of competitive forces,
- driving forces,
- rival companies’ market position,
- competitors’ strategic moves,
- key success factors within the industry,
- overall attractiveness, profitability, and prospects of the industry.

Each of these factors is discussed below. It shows that analysing these factors reveals the industry's competitive structure.

2.8.2.1 Dominant economic features from the industry

Within the chrome smelting industry as the main value chain, the main cost drivers or economic features are electricity, raw materials, maintenance, labour, and contractor/service delivery costs. Evaluating the service delivery of utilising TMMs as a contracting company within the chrome smelting value chain, the main cost drivers or economic features when comparing modern and conventional TMMs are fuel, labour, overheads/operational cost and consumables (like oil and grease), financing cost, and repairs and maintenance cost.

2.8.2.2 Sources of competitive forces

Sources of competitive forces are supplier power, buyer power, competitive rivalry, threat of substitution, and threat of new entry. For the evaluated company, buying power enables supplier power through economies of scale established by the organisation when buying and acquiring TMMs, parts, and consumables, such as fuel and oils, at discounted bulk buying prices. These initiatives and cost savings are used to deliver better services at more competitive prices to clients and to boost overall efficiency with greater profitability. Satisfactory service delivery at competitive pricing removes the threat of new entrants. It also boosts the company's competitive rivalry by innovating with the new technology of remote TMM emulator substitutions and constant development. In this way, it minimises threats of new entrants in the market.

2.8.2.3 Driving forces

The driving forces include being driven by the product, market, return on investment (profit), growth, technology, human resources, and safety. The main goal for any business is to become and stay profitable and to generate shareholder wealth. However, the organisation needs to focus on stakeholder wealth to do so. It enables safety as the key driving force in mining and processing plants. Conducting business operations safely and effectively will ensure a sustainable environment. Therefore, the goal is to manage all driving forces as safely as possible. The initiatives of the evaluated company are to be evolved with safety in mind. It can be accomplished by removing the person from an unsafe area and replacing the work with a mechanically operated alternative. Thus, solutions are not always price-driven but driven by sound business decisions, as they evaluate what is best for the environment, the business, and its employees.

2.8.2.4 Rival company's market position

Rival companies occupy the same field of business operations and offer the same relative services. For Almar, the services delivered to the industry are of a specialised nature, and over the past few years, the company has seen immense growth to the extent that it now controls the majority of the market share, which is to the advantage of both the client and the organisation, with an overall reduction in overheads and operational cost, greater efficiency, better service delivery, and more timely response. As a result of satisfied clients and sustained relationships, rival companies' market positions have decreased significantly. Customer perception within on-site bulk material handling is appropriately the most significant driving force in self-evaluation. In order to meet corporate social investment initiatives, which are client requirements and also community responsibilities, local SMMEs are developed within the organisation's field of expertise. In developing local communities, future competition for the same work is created, which involves transferring skills and developing the local communities and SMMEs, therefore creating more rival companies and developing rival companies within the community to a position where the developed community SMME is in a position to tender for the work they were developed on.

2.8.2.5 Competitors' strategic moves

Competitors use strategic moves to change market supply and demand through newly launched products or services, threatening the market status quo. The chrome smelting industry, especially material handling by TMMs, has been tried and tested in this price-sensitive industry. Indecisive market exploitation could be devastating to a new entrant, new company, or rival not within the industry. Therefore, the only company able to apply strategic initiatives is one already conducting similar business operations, which is currently only Almar.

2.8.2.6 Key success factors within the industry

Success factors are principally those essential to business processes. For Almar, it would be leadership, safety and safety performance, employees, operational operations, efficiency, service delivery, and profitability to maintain sustainability.

2.8.2.7 Overall attractiveness, profitability, and prospects of the industry

Market attractiveness within an industry is based on perceptions rather than conclusive proof and reference. Based on large turnover, the perception is generally formed that net income or profitability is based on large income. However, the high adverse exposure these TMMs face and their sensitivity increases repair and maintenance costs and replacement frequency, reducing net asset value with a higher than normal depreciation value. High heat exposure forces a higher turnaround time on TMMs, causing a lower TMM availability rate at crucial times. Economies of scale within the industry enable Almar Investments to maintain its sustainable competitiveness in the marketplace. Therefore, the industry's overall prospects are favourable based on economies of scale.

2.9 OUTSOURCING

Outsourcing refers to the procurement of materials and services inputs by a firm from an outside source (Troacă & Bodislav, 2012:53). Services, or even goods, initially manufactured in-house by an organisation's staff and employees are done by contracting these processes out to a company outside of the organisation. Olaore and Adebisi (2013:82) define outsourcing as purchasing goods and services from outside suppliers rather than producing them internally. As an outsourced service, one of the key activities within the value chain is adding value to it so that the quality of service contributes significantly to overall business operations. Consequently, customer loyalty is established, ensuring long-term service outsourcing by most chrome-smelting businesses in South Africa.

After outsourcing was recognised in 1989 as a business strategy, it became a fundamental part of businesses in the 1990s (The Economic Times, 2023). With the advent of outsourcing, a wide range of services has been offered, not limited to a particular type or sector but including facilities management, accounting, human resources management, customer service, research, supply chain management, marketing, legal documentation, computer-aided design, diagnostic services, content writing, engineering, and design (Troacă & Bodislav, 2012:52-55; Baatartogtokh, 2014:2; Twin, 2022). Outsourcing further developed into industries like mining and processing, where specialised skills and expertise, combined with equipment to perform these tasks, grew into the field of TMM rental and service delivery (Steenkamp & van der Lingen, 2014:852; Obeng *et al*., 2015:92).

Within the supply chain, outsourcing can be used to leverage skills and knowledge (Kalinzi, 2016:17). It could then be used as a competitive advantage within the specific supply chain (Biggemann *et al*. 2014; Kalinzi, 2016:2). Further service level improvements and cost savings can be provided, enabling adaptability to changing market conditions and other challenges (Kalinzi, 2016:1; Moduslink Global Solutions, 2014:3; Tsay, 2013:9). Thus, outsourcing could assist a business to be more agile and flexible. Through gaining more flexibility and agility, companies can do better budget planning by participating in better cash flow projection, quickly disposing of costs and resources during financial difficulties or weak market conditions, and enabling quicker expansion with no need for current or direct capital and no cash flow interruptions (Koçyiğit & Akkaya, 2020:111, 117).

From an executive management perspective, outsourcing can aid in gaining innovations and technological ideas, reducing errors, improving performance, lowering costs, and streamlining current processes. The most significant motivation for using outsourcing is cost-cutting.

2.10 VERTICAL INTEGRATION

Rather than relying on external suppliers or contractors, vertical integration enables a company to streamline its business operations, hence taking more direct ownership within the various stages of its business operations. It is accomplished by conducting more of its services or processes, thus vertically integrating into its business (Kim, 2019:1-2).

Integration can be vertical or horizontal (Kim, 2019:8). Vertical integration entails growth and expansion or diversification within the organisation. A company can expand horizontally into the same or similar business field through acquisitions. Vertical integration is an expansion strategy where the company takes control of one or more stages within its distribution or production of goods and/or services (Pérez-Lara *et al*., 2019:2-3).

The aim is to ensure that all areas of business operation, or as many as are feasible, are controlled or owned by one company. Thus, all stages of production, from the acquisition of raw materials to the physical product retailing, are controlled by the same organisation. Vertical integration is the process to get to this business stage (Pérez-Lara *et al*., 2019:2-3).

The three main types of vertical integration (Figure 5), whether building or buying, consist of (Egger *et al*., 2021:2; Del Prete & Rungi, 2019; Indeed Editorial Team, 2022):

- Backwards integration occurs when the business takes control of its supply chain,
- In forward integration, a business gains control over the distribution of its finished products.
- The concept of balanced integration refers to the ability to benefit from both forward and backward integration.

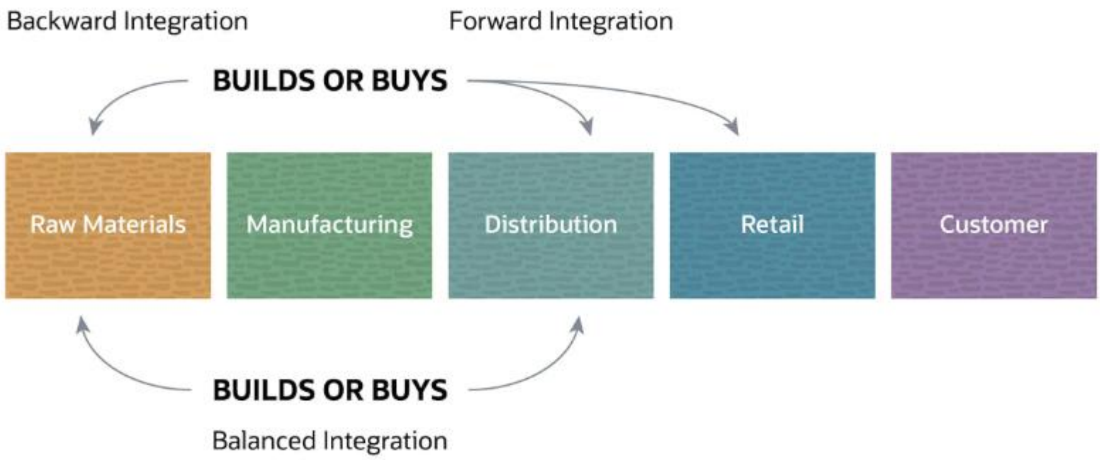

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Figure 5 The three main types of vertical integration (Jenkins, 2023)

Integrating raw materials can supply retail, directly supply customers, or move distribution into manufacturing. The form of integration to be applied can be determined depending on the organization's position within the supply chain.

2.11 VALUE CHAIN

In performing and delivering a service or in creating a product, the various business activities needed or the process involved to supply and manufacture or deliver the specific service is referred to as the value chain of the service or product (Kumar & Rajeev, 2004:74). Multiple stages are involved within the value chain of a service or product's life cycle. These can include but are not limited to, research and development, sales, and everything else needed to ensure that the product is manufactured and delivered or that the service is rendered (Strakova *et al*., 2021:139).

An organisation needs to identify its competitive advantage within the value chain. In analysing this competitive advantage, a strategic management framework in the form of Porter's Value Chain can be used (Strakova *et al*., 2021:139). Porter's Value Chain consists of directly linked activities primarily in production, support, and delivery, allowing the execution of primary activities.

In delivering the optimal value at the lowest possible cost, business efficiency is ultimately achieved through the help of value chains and value chain analysis. Thus, the ultimate goal of value chain analysis is to create an organisational competitive advantage by keeping a company's costs reasonable and as low as possible while increasing productivity within the company, ultimately boosting and improving efficiency and organisational effectiveness, ensuring organisational relevance and ensuring company sustainability (Dubey *et al*., 2020:177).

Value chains refer to a product's or process' full life cycle (Figure 6); this includes the disposal or recycling process, consumption and production, and material and product sourcing. Therefore, within the current business climate, an integral part of business operations regarding strategic planning is done through value chains.

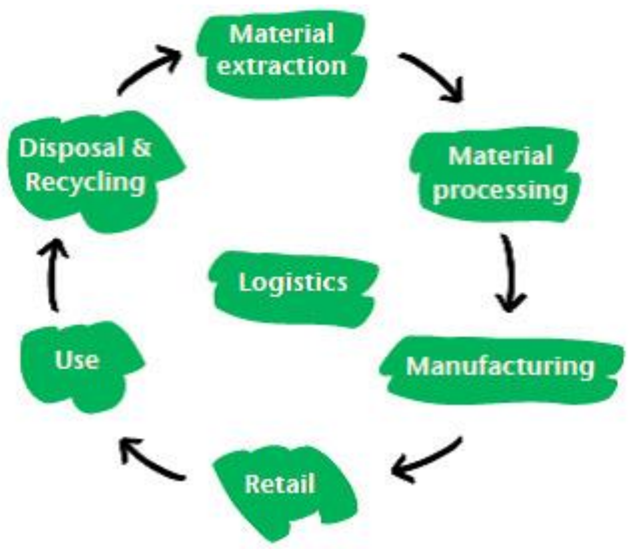

Figure 6 Product life cycle as a value chain (WBCSD, 2011)

Today's industries and markets are intensely interested in and drive for healthier and greener products. Thus, there is a need for healthier and greener production processes and service delivery (Strietska-Ilina *et al*., 2011:4, 9, 11). The term 'green value chain development refers to the concept of developing a greener, more environmentally friendly value chain of sourcing, delivering, producing, and services (DCED, 2012; Hilmi, 2021:454). By developing a green value chain, using environmental rules and regulations and integrating environmental support functions into the value chain and other market players, a systematic approach is used to make the value chain greener, healthier, and more environmentally friendly (Figure 7; Amemba *et al*., 2013:51, 56-57; CCICED, 2021, Yang & Sheu, 2011:10601, 10612;).

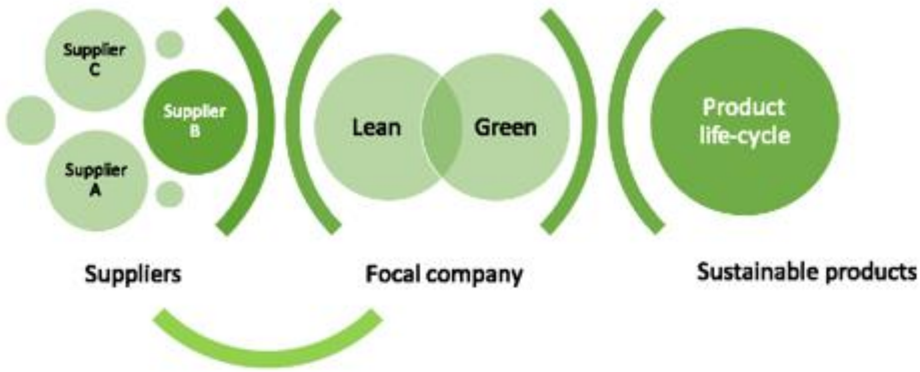

Figure 7 Integrated green supply chain (Couto, 2016:304)

2.12 SUMMARY OF THE CHAPTER

The ultimate research intent of this study is to devise a strategy for the optimisation of the application of TMMs in chrome smelting operations by evaluating modern and conventional TMMs in the form of current TMMs on the market, determining when and how to replace conventional TMMs with modern TMMs, and determining the optimal hours worked per TMM when it is replaced.

A literature review on the application of TMMs in the industry, particularly the chrome mining industry, covers various topics related to optimum implementation (section 2.6). Modern and conventional TMMs offer advantages and disadvantages in on-site bulk material handling operations, and management may use both types of TMMs to maximise productivity. Although conventional TMMs offer stability and security, safety issues related to driver fatigue and error remain a concern. While modern TMMs offer efficiency, utilisation, safety, and performance benefits, the need for human operators largely disappears, adversely affecting employment.

Chromium mining could gain a competitive advantage in the market by adapting modern TMMs. By gradually removing conventional TMMs from the fleet as their operation life expires and replacing them with modern TMMs, an optimum TMM application can be found. The alternative is to use calculations to find the optimal fraction of conventional and modern TMMs to be applied for optimal productivity. Changing environments, a variety of business operations, and a large number of variables can complicate this approach. According to the vehicle replacement theory, it is also possible to find an optimum application of conventional and modern TMMs, which uses a trade-off between decreasing capital costs and increasing running costs with age. Lastly, optimisation can be achieved by considering alternative solutions such as lower TMM costs, better sale prices, or prolonged life rather than replacing conventional TMMs with modern ones.

A number of other factors, such as safety, automation, maintenance, and training, should be considered when determining the optimum application for conventional and modern TMMs in chrome smelting operations (Sections 2.6.4–2.6.14). Since the operator is not near the hazardous chrome smelting operations, autonomous modern TMMs offer a significant safety advantage. Additionally, automation increases productivity and, therefore, market competitiveness. Various standards, practices, and approaches can be distinguished in aiming to achieve a high standard of maintenance procedures for underground mobile mining equipment, which are essential for high business competition and complying with strict environmental laws and regulations.

A company's on-site bulk material handling operations fall within the realm of value and supply chain management. Supply chain management is important because it plays a role in achieving a competitive advantage. A supply chain management strategy relies on supply chain partners to reduce costs, increase forecast accuracy, increase profits, and improve inventory control (Mofokeng & Chinomona, 2019:4).

Furthermore, supply chain management is essential because it manages service delivery or processes that create and deliver a product. Multiple steps are involved in the value chain, such as research and development, sales, and everything else required to ensure that the product is manufactured and delivered or the service is rendered. Porter's Five Forces strategic management framework assists organisations in identifying their competitive advantage within the value chain.

CHAPTER 3. RESEARCH METHODOLOGY

3.1 INTRODUCTION

In the previous chapter, a literature review was conducted to devise a strategy for implementing an optimal combination of conventional and modern TMMs to operate sustainably while optimising productivity.

In this chapter, the methodology used in this study is described. The main themes of the chapter are the application of Saunders' Research Onion, the research approach, the research design, and ethical considerations. Under the research approach, the quantitative and qualitative methodologies followed in this study are discussed in detail. The research design outlines the method of obtaining data from the different client companies and analysing the data.

In addition, this chapter discusses the following theoretical factors that will be used to determine the benefits associated with the optimal application of modern and conventional TMMs in the haulage operations of chrome mines:

- supply chain and business model,
- competitors and current market segmentation,
- industry,
- business cost drivers,
- primary activity and supply chain,
- third-party outsourced logistics,
- investment feasibility calculations,
- four cost-benefit analysis techniques.

A cost-benefit analysis will be performed to compare the project's costs and benefits (Intrac, 2017). Procedures used to perform a costs-benefit analysis for conventional and modern TMMs in the form of capital expenditure, outsourced cost analysis, fuel analysis, nett present value (NPV), internal rate of return (IRR), and profitability index (PI) for both conventional and modern TMMs will also be explained. This analysis will be performed over three, five, and seven years. The cost-benefit analysis is used to determine the value added in terms of the investment profitability metrics for decision-making and optimisation of fleet and machines.

3.2 RESEARCH METHODOLOGY: APPLICATION OF SAUNDERS' RESEARCH ONION

Research methodology is defined as 1) applying science to research, 2) adopting logical steps to solve a problem systematically, 3) assisting the understanding of the process and results of scientific inquiry, 4) describing and analysing research, 5) aiming to clarify the description and analysis of methods, highlighting their limitations and resources, clarifying their presuppositions and consequences, and 6) describing the potential of the research to contribute to the existing body of knowledge (Kothari, 2004:8; Patel & Patel, 2019:48; Podder & Harita, 2019:2). In this definition, research methodology focuses on the problems to be investigated in a research study and differs according to those problems.

Saunders and Tosey (2012/2013:59) presented the overall research methodology in the form of an 'onion', in which the thoughts concerning the research problem lie in the centre, and thus several layers have to be 'peeled away' before coming to this central position, which is data collection and data analysis (Table 1). These layers are the important aspects to be considered in determining the research methodology for a particular research study. Accordingly, research philosophy, methodological approach, strategy, time horizon, and techniques and procedures were the layers identified. While different classifications and definitions of these terms exist, classifications put forward by Saunders *et al*. (2012:128) are preferred here, as they provide an unambiguous overall framework for the complete research process. As mentioned above, the discussion here is limited to the 'research strategy' and its application to this particular mini-dissertation. Figure 8 summarises the application of the Research Onion Model and the justification for choosing each element as applicable to the current study.

Table 1 Saunders and Tosey's Onion model for research methodology.

Layer	**First: Research Philosophy**	**Second: Methodological Choice**	**Third: Strategy(ies)**	**Fourth: Time Horizon**	**Centre: Techniques and Procedures**
Element	Positivism Realism Interpretivism Pragmatism	Mono Method. Quantitative Mono method. Qualitative Multi Method. Quantitative Multi method. Qualitative Mixed method simple Mixed method complex	Experiment Survey Archival Research Case study Ethnography Action Research Grounded Theory Narrative inquiry	Longitudinal Cross-sectional	Data Collection and Data Analysis

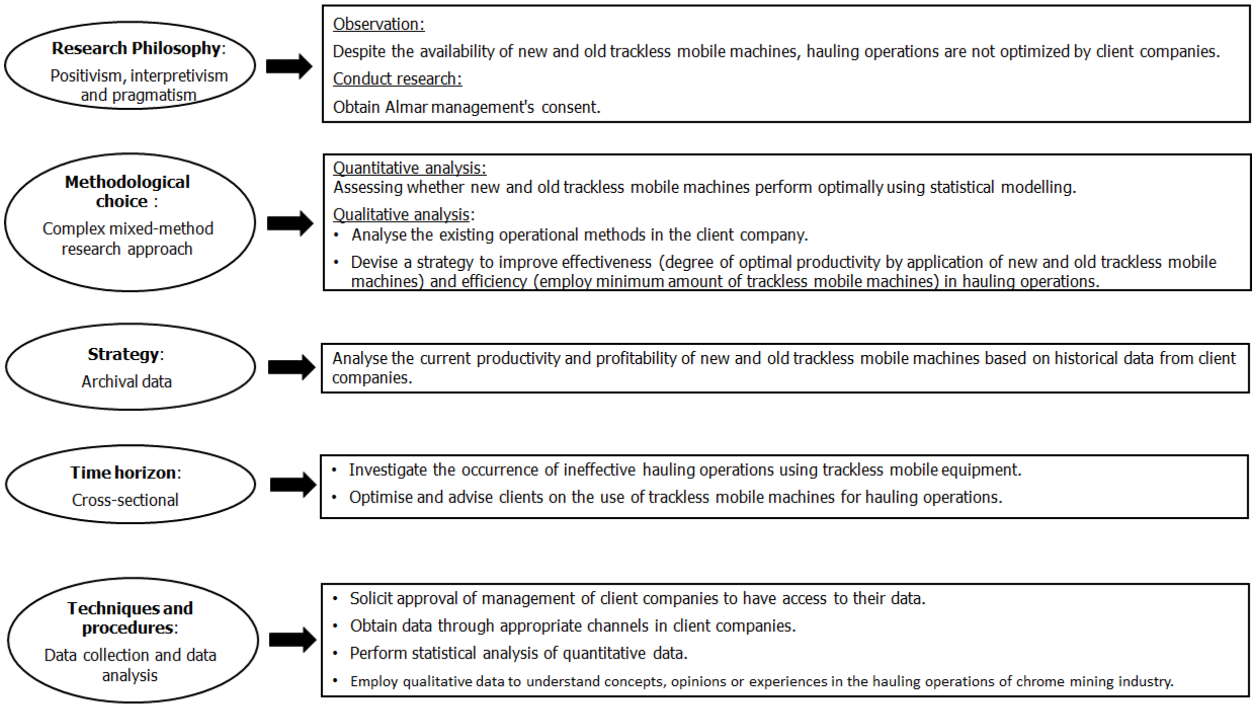

Figure 8 Application of Saunders' Research Onion model to the research approach

3.3 RESEARCH DESIGN

The research design is the comprehensive plan and procedure that will be adopted to answer the research question (Abosede & Onanuga, 2016:113). According to Saunders *et al*. (2012:158), it specifies the sources of data, how they will be analysed, ethical considerations, and the constraints that may be encountered during data collection. Abosede and Onanuga (2016:113) describe research design as arranging conditions for collecting and analysing data in a manner that aims to combine relevance with careful management of resources. According to these authors, the research design can be divided into the following four parts:

1. The sampling design describes how a sample is selected from the population for a study.
2. The technique and procedure of sampling are part of the operational design.
3. An observational design is based on the conditions under which observations will be made.
4. A statistical design determines how information and data will be analysed.

Creswell (2014:55) defines a research design as an overall strategy for connecting theoretical research problems with appropriate and feasible empirical research. It is an investigation that provides a specific direction for the procedures in the research.

In this study, Abosede and Onanuga's (2016:113) guidelines will be followed, which include topics such as data sources and constraints introduced by Saunders *et al*. (2012:159). Then, the mixed-method used in this study will be explained. The section ends with the very important concern of ethical considerations raised by Saunders *et al*. (2012:159).

3.3.1 Sampling design

In this study, the main focus areas and data analysed are:

- overall fuel consumption of current conventional manually operated TMMs during day-to-day operations,
- usage of hours per area and task,
- GET (ground engaging tools) data, lifespan, and hours achievable from TMM attachments,
- financial percentages of capital investments and operational efficiencies,
- information packs relating to site-based operations.

3.3.2 Operational design

Focus areas will be retrieved from the following primary data sources:

- AMT (asset management tool), a system detailing each asset within the fleet's life cycle and available data,
- a populated central database output for hours and diesel figures,
- Vigil Cloud Netstar vehicle tracking system,
- operation control systems and data services in place to track operational activities, such as daily hours, workflow, and employee hours.

Analysing future potential and technological advances for modern TMMs will be conducted by sourcing information from OEM suppliers of TMMs. The following available information and its applicability to the operational process and the industry will be analysed.

PUBLIC DATA

The organisation analysed is not a listed company, so the information is not publicly available.

However, all major suppliers, including a major supplier of TMMs, are listed companies with global footprints. These organisations' financials, sales, and shares are accessible online.

This research, however, requires only information about TMMs relating to the organisation's service delivery.

SECONDARY DATA

Secondary data required for this research would be easily retrievable from the equipment already in operation. For the suppliers, these are products they sell. Suppliers and users would benefit from releasing secondary information regarding modern TMMs.

The deciding factor is to implement the secondary data within the operational application and evaluate its benefit and the extent of its applicability.

As a guiding principle, this study uses the Department of Minerals and Resources (DMR) guidelines for implementing TMMs for on-site bulk material handling (Department of Minerals and Resources, 2015), which includes the MHSA (Mine Health and Safety Act 29 of 1996 and MRAC (Mining Regulation Advisory Committee) guided by ISO 14001 and ISO 19001 as set out within the MHSA.

3.3.3 Observational design

Rahman *et al*. (2020:10) define observational research as observing and describing the behaviour of a subject using human or mechanical observation. Observational studies are often applied in bio-medicine and health research (Thiese, 2015:200). However, they are also well-suited for marketing (Hyman & Sierra, 2016:1) and social science research (Dźwigoł & Barosz, 2020:143). Investigators in observational studies do not act on study participants but observe natural relationships between variables (Thiese, 2015:200). They are subdivided into cohort, cross-sectional, and case-control studies because the researcher exclusively observes (Mann, 2012:39). preceding

Researchers use cohort studies to determine incidence, causes, and prognoses (Mann, 2012:54). Associate studies measure events chronologically and can be employed to distinguish between cause and effect. Cross-sectional studies do not distinguish between cause and effect but are quick and easy methods to determine prevalence (Mann, 2012:56). In case-controlled studies, groups are compared retrospectively (Mann, 2012:57). Studies using prospective cohorts or other techniques are often used to generate hypotheses.

Secondary data obtained from client databases on the use of TMMs in chrome smelting will be used in this study (Section 1.8.2.3). These pre-existing databases provide an excellent and convenient source of data. They enable large numbers of clients to be used in the study prospectively or retrospectively. They can be used to construct a cohort, to produce a sample for a cross-sectional study, or to identify clients with certain conditions or outcomes and produce a sample for a case-controlled study.

3.3.4 Mixed-method design

The central premise of mixed methods is that combining quantitative and qualitative methods provides a better understanding of the problem (section 1.3) than either method alone. According to Creswell (2013:5), mixed-method research is a design comprising philosophical assumptions and inquiry methods. Many phases of the research process involve qualitative and quantitative approaches guided by philosophical assumptions. Quantitative and qualitative data are collected, analysed, and mixed in a single study or series of studies.

The core characteristics of mixed-method research are (Creswell, 2013:5):

- Qualitative and quantitative data (based on research questions) are collected and analysed persuasively and rigorously by the researcher.
- It concurrently combines (or merges) both data forms, sequentially builds on one or embeds one within the other.
- It prioritises one or both types of data (based on what the research emphasises).
- It implements these procedures in a single study or multiple research programme phases.
- It places these procedures in the context of philosophical worldviews and theoretical perspectives.
- It organises the procedures into specific research designs that describe how the study will be conducted.

Considering that neither quantitative nor qualitative data alone will sufficiently answer the research question, this research problem is suited for a mixed-method approach. Quantitative data will be collected to determine the effects of combining different conventional and modern TMMs ratios on productivity. Qualitative data will be sourced from Almar's internal database and is explained in section 1.8.3.2. Mixed methods are the third paradigm, bridging the gap between quantitative (data on TMM employment in client companies) and qualitative (client impressions) data.

Using a mixed-method approach offers various advantages (Doyle e*t al*., 2009:178-179):

- The study becomes more valid when quantitative and qualitative data corroborate each other.
- Mixed methods allow researchers to address questions that cannot be answered using only quantitative or qualitative methods and provide a broader repertoire of tools for meeting study goals.
- Qualitative and quantitative limitations are neutralised, while strengths are enhanced, resulting in more substantial and accurate conclusions.

- It is possible to explain data from one research approach using data from another.
- It is possible to gain a deeper understanding of the phenomenon under investigation by illustrating quantitative findings with qualitative research methods (putting flesh on the bones of dry quantitative findings).
- The qualitative phase of a study may be used to develop hypotheses that will be tested quantitatively in the follow-up study.

It is concluded that combining qualitative and quantitative data will provide the best understanding of a lack of productivity in chrome mine on-site bulk material handling operations due to the lack of balance between the application of conventional and modern TMMs, since it provides the most comprehensive understanding of the problem. Although the mixed-method approach requires more time and effort than qualitative or quantitative methods, it is postulated that a profound understanding of the problem is of great importance to Almar's clients.

Four methodological assumptions characterise qualitative research. They are ontology (the nature of reality), epistemology (knowledge and how it is justified), axiology (values in research), and methodology (the way research is done) (Creswell, 2013:20). Ontological assumptions relate to the nature of reality and its characteristics. With the epistemological assumption, conducting a qualitative study means that researchers try to get as close as possible to the study participants. Researchers make their values known in research according to the axiological assumption. The procedures of qualitative research, or its methodology, are characterised as inductive, emerging, and shaped by the researcher's experience in collecting and analysing the data.

Positivism and subjectivism are two important aspects of ontology. Positivism is explained in section 1.8.2.1. Researchers who adhere to positivism also consider social factors as part of their research. Positivism posits that social entities exist independently of the social actors concerned with them.

Quantitative research is defined from various perspectives in the open literature. Saunders *et al*. (2012:162,482) state that *quantitative* research is:

- based on meanings derived from numbers,
- data collection in numerical and standardised forms,
- the analysis is conducted through diagrams and statistics to explain an issue or phenomenon.

According to Apuke (2017:41), quantitative research involves measuring quantity or amount and applies to phenomena that can be quantified. In order to obtain results, quantitative research involves quantifying and analysing variables. According to Williams (2011), quantitative research begins with stating the problem, generating hypotheses or research questions, reviewing related literature, and analysing the data quantitatively. According to Antwi and Hamza (2015:221), quantitative research uses inquiry strategies such as experiments and surveys to collect data.

The form of data collection, analysis, and presentation clearly distinguishes qualitative from quantitative research. Qualitative research attempts to understand phenomena in ‘natural settings’ by presenting data in words as descriptive narration.

3.3.5 Ethical considerations

Before planning and deciding on the topic of the study, the following questions must be answered:

1. Does the research add value to the organisation and the industry?
2. Have all precautions been taken to prevent compromising sensitive information that, if disclosed, would harm the industry or organisation's reputation or market value?

On the 1st of July 2021, the Protection of Personal Information Act, Act 4 of 2013 [A1] (POPI Act) became effective.

South Africa's POPI Act governs the lawful processing of personal information. All research activities that collect, process, and store personal information are subject to the POPI Act (Adams *et al*., 2021:1). These authors outlined the following roles for various parties involved in the processing (including collection, use, transfer, matching, and storage) of personal information:

- The 'Responsible Party' is the researcher or research institution responsible for determining why and how personal information is processed.
- The 'Operator' is a third party contracted by the responsible party to process personal information on their behalf.
- POPIA compliance is ensured by an 'Information Officer' within an institution.
- 'Data Subject' is the individual whose information is being processed and, in the case of research, the 'study/research participant'.

Lawful processing of personal information requires fulfilling eight conditions outlined in the Act. These conditions are:

1. Accountability: the responsible party must ensure that all the conditions for the lawful processing of personal information laid out in POPIA are complied with when determining the purpose of processing and during processing (Section 8).
2. It is the responsible party's responsibility to ensure that personal information is processed lawfully, to determine that it is necessary to accomplish a defined purpose that could not

be achieved without processing such information and that the information is collected directly from the data subject with informed consent.

3. It is essential to collect and process personal information for a defined purpose, to keep records for no longer than necessary, and to delete or destroy them once the purpose has been fulfilled. Research records containing personal information may be retained where there is a clearly defined need to retain such information and where additional safeguards are in place.
4. Personal information may be further processed if it is used only for research.
5. Accurate, current, complete, and non-misleading personal information must be collected and stored.
6. The responsible parties must maintain a record of processing of all personal information in the following way: During the processing of the data, the data subject must be informed as to why it was collected, who collected it, and where it is being stored, what rights the data subject has to access and delete/correct the information, and whether the data will be transferred to a third party or internationally. The data subject does not need to be informed of the above if their information is processed only for research.
7. Data breaches must be prevented by maintaining the confidentiality and integrity of personal information. Security breaches must be reported to the Information Regulator.
8. The researcher must ensure that the data subject is informed of their right to access, correct, and delete their personal information. POPIA prohibits processing unique personal information such as health, political persuasion, race or ethnic origin, and criminal behaviour.

Information from Almar's databases of their chrome mining clients is used in this study. As part of the NWU ethics principles, humans and animals involved in research must be protected, and adverse effects of research on the environment must be avoided. Ethics in research depend on the field of study and the research methodologies acceptable within that field. To this end, the following aspects of the research must be discussed with Almar’s clients:

- data collection, use, interpretation, and safeguarding,
- reporting, communication of findings, and affordability of conducting and completing research,
- the capacity and competence of the researcher to carry out tasks and take responsibility for them,
- first-author agreements, affiliation, conflict resolution, and who will publish or co-publish,
- Perform and communicate research in a way that is responsive to community needs and aspirations, keeping the community involved, informed, and engaged.

From a normative perspective, the NWU stipulates the following reasons to adhere to solid research ethics standards:

- all aspects of research must be conducted with integrity,
- holding researchers accountable for their research,
- maintaining high standards of professional courtesy and fairness,
- stewardship of research for the benefit of others.

The following are guidelines (Cote, 2021b) for using Almar's clients' data for research:

- The researcher must ask permission to use their data.
- Collecting clients' personal data without their consent is illegal and unethical.
- In addition to owning their personal information, data subjects have a right to know how the researcher plans to collect, store, and use it. When gathering data, the researcher must exercise transparency.
- Data collected must be stored in a secure database. This information should be accessible to clients.
- Research methods and objectives should be explained to Almar's clients. Mobile TMMs are investigated for the sole purpose of optimising their applications.
- The researcher must maintain privacy and prevent the release of data to the public.
- Data must be de-identified to prevent violating the privacy of a client.
- Data must be collected solely to study the optimisation of the application of TMMs.
- The researcher must only collect data relevant to the objective of the study. Disparate impact is avoided by explaining to clients that the research results will not harm the company's reputation.

Under the conditions outlined above, it is legal for someone to process others' personal information. It is required that the subjects be protected by safeguarding their personal information. By regulating how the information received will be stored, organised, processed, and discarded at the end of the study, the integrity and confidentiality of the study will be upheld by preventing loss, damage, or leaking of information.

An ethics checklist will be implemented to govern and control ethical behaviour, ensuring steps and regulations are met and maintained to uphold ethical behaviour and prevent any unethical behaviour.

3.3.6 Constraints

Limitations are the constraints of a study. They are the elements of methodology or study design that influence the interpretation of research findings (Wordvice, 2023). Typical examples of constraints in social science research are subjects, geography, and data (Wordvice, 2023). In this study, the following constraints are relevant:

- There is limited research on the research topic. It can be both a strength and a weakness. A lack of open literature on the topic facilitates the identification of a gap in the optimisation of the application of TMMs in the chrome industry and underlines the need for further research. However, the literature study is hampered by the lack of open literature on the topic.
- In addition to large amounts of data, clients' reluctance to implement modern TMMs could limit the time to study research problems and measure changes over time.
- A correlation or association between variables indicates that their values vary together. However, a change in one variable does not necessarily result in a change in the other. Causation can, therefore, be difficult to prove. Causation is the cause-and-effect relationship between one event or action and the result. It is important because it predicts an event or occurrence. Hill published the following criteria for causality (Hill, 1965:7-12): causality becomes strong when a relationship is statistically significant, the result is repeatable, other explanations can be ruled out, causes precede effects, there is a plausible mechanism that can explain the causal nature of the relationship, the relationship is consistent with related causal relationships that are generally known and accepted as facts, and experiments are randomised.

Price and Murnan (2004:66-67) discuss the following reasons for non-causality:

- There is a threat to internal validity when an instrument lacks one or more psychometric properties, such as validity and reliability. When an instrument is shown to be valid and reliable for a particular population, it does not necessarily mean that it is valid and reliable for all populations. The validity and reliability of the instrument can only be established for populations that are similar to the original sample used for validation. The possibility of a psychometric limitation occurs when researchers conduct assessments of different groups at different points in time.
- Another threat to internal validity is manifested when an intervention is compromised by a concurrent event that contaminates pretest to posttest changes. In this case, the intervention may be mistakenly attributed to the change caused by the confounding variable.

- An inadequate research design, such as the absence of control groups, post-only evaluations, and cross-sectional studies, can also be a limitation of a study. For example, using data from one point in time, called a cross-sectional study, would not be sufficient for establishing a cause-and-effect relationship.
- Small samples and convenience (non-probability sampling, small sample) can also compromise the external validity of a study. For example, convenience sampling will likely show unique trends if compared with the population.

3.4 CONSIDERATIONS IN OPTIMISING THE APPLICATION OF TMMS

Gaining a competitive advantage in the market by adopting new technologies and innovation at a managerial level is decisive for the mining industry (Sánchez & Hartlieb, 2020:1387). To this end, it is necessary to optimise machinery fleets in the mining industry that employs mobile and stationary mining machines (Teplická *et al.,* 2020:2). The optimisation of the equipment is related to its service life; therefore, it is necessary to monitor the time of its use in the mining process (Teplická *et al.,* 2020:2). Mobile surface equipment in mining companies has to be operational because it influences the continual mining process, the health of employees, the safety of the mining process, and the efficiency of mining (Aguayo *et al*., 2021:173; Marklund, 2017:6; Mine Health and Safety Council, 2022).

Automation is the basis of scheduling optimisation because the efficiency of automation equipment is predictable (Wang *et al.,* 2020:7). The type and quantity of mining equipment are usually determined during the design period (Wang *et al.,* 2020:8). With the progress of mine production, the equipment is gradually upgraded in batches, so there is an individual difference in the operating efficiency of each piece of trackless equipment (Wang *et al.,* 2020:8). Therefore, for mining scheduling optimisation, the capacity of each piece of equipment can be considered as known constants (Wang *et al.,* 2020:8). Shortening the completion time is the most direct way to improve production efficiency (Wang *et al.,* 2020:9). The primary objective of mine production scheduling optimisation is to minimise the total completion time (Wang *et al.,* 2020:9).

The replacement strategy for conventional and modern TMMs has increasingly become a crucial part of business operations for optimisation and increasing profitability. This is done through effective fleet management and service delivery through optimal availability. However, the calculation for total optimisation is unclear due to many variables, changing environments, and different business operations. According to Nurock and Porteous (2008:297), the cost increases resulting from older TMMs are poorly understood or quantified, accumulating a large proportion of hidden and direct costs; these authors attributed this to the complex nature of the TMM, the way information is recorded, the type of information recorded, and the nature of the mining cycle.

An under-supply of modern TMMs places strain on supply and replacement strategies (section 3.5 and 3.6). It leads to an array of shortcomings, namely increased life cycle costs, increased downtime (and hence productivity losses) and, given the current supply problems, an extremely long lead time for replacement TMMs (section 3.5).

The intent is to maximise TMM usage in terms of machine life and machine effectiveness, thus increasing overall efficiency. According to Nurock and Porteous (2008:297), the aim of planning a proper replacement strategy is to:

- predict TMM replacements that facilitate capital motivation and planning,
- optimise life cycle costs,
- provide a basis for benchmarking sites.

By using cost-per-ton trends, the total TMM costs are divided by the number of tons a TMM produces (Nurock & Porteous, 2008:298). It is based on the principle that as a TMM ages, the running costs increase, and as the availability of the TMM decreases, the tons produced are reduced, increasing the cost per ton (Nurock & Porteous, 2008:298). The minimum cost per ton is the optimal replacement point (Nurock & Porteous, 2008:298). Almar's business is entirely built on cost per ton, production figures, and invoicing. In this way, the entire business is built and managed according to cost-per-ton KPIs. Therefore, evaluating a replacement strategy based on a cost-per-ton basis would be convenient in establishing optimisation.

An equivalent annuity method is used to assess the cash flows associated with TMMs and the frequency with which they are incurred (Nurock & Porteous, 2008:298). It uses the time value of money to compare different timing alternatives (Nurock & Porteous, 2008:298). It not only ensures the optimal time of replacement but also considers the time value of money, assessing the best possible alternative for replacement.

Vehicle replacement theory is based on the trade-off of decreasing capital cost and increasing running costs with the age of a vehicle (Nurock & Porteous, 2008:298). Due to this, operational TMM availability must be considered alongside overall financial efficiency, where cash flow and capital are not depleted, and only modern TMMs with a high financed value are available, or excess cash can be kept, but services cannot be provided.

The environment is crucial to an effective TMM replacement strategy. The following factors can be considered for replacement within the TMM's environment (Nurock & Porteous, 2008:298):

- The lifespan of the mine,
- TMM availability,

- TMM cost and TMM revenue,
- CAPEX,
- Equipment needs.

Almar’s business is built on a tender basis, and tenders are awarded based on mine requirements and, thus, on the life of the mine because need and requirement would persist as long as the mine exists. Therefore, linking TMM requirements and replacement to the extent of the mine’s lifespan is crucial, as this would ensure optimised usage without excessive downtime. If TMM life exceeds the life of the mine, TMM replacements are not viable (Nurock & Porteous, 2008:298).

TMM availability time is calculated based on the required production hours minus breakdown hours. If the available TMM hours are less than the required production hours, additional or new equipment would be required.

The overall equipment effectiveness can also be used to determine production efficiency. It is a versatile measurement calculated as a ratio between actual and planned production time.

To have a viable business, TMM revenue, or revenue generated from the TMM, needs to cover or exceed the TMM cost. In determining TMM and revenue cost, cost–benefit analysis or payback type methods could be used (Nurock & Porteous, 2008:298).

One method of optimisation can be found in alternative capital outlay solutions, as equipment is one of the most significant cost contributors. Finding alternative solutions, lower TMM costs, better sale prices, or prolonged life can significantly impact CAPEX. Alternatives to replacing conventional TMMs with modern ones, such as upgrading or refurbishing older equipment, can be explored. Besides modern TMM replacements, other options (Figure 9) should be explored (Nurock & Porteous, 2008:298).

Equipment needs are based on client requirements. Therefore, understanding the business, production requirements, and client needs is crucial. It entails finalising the required scope of work in replacing TMMs. Before replacing TMMs and examining production parameters, an assessment should be made to determine whether modern TMMs are needed (Figure 9).

The main purpose for any business is to make money. To this end, an emphasis should be placed on the assets and products that are provided to the market in mining operations. Thus, the most viable option in evaluating TMM replacement would be to consider the TMM's economic life. Establishing and designing TMM life is challenging since TMMs can be repaired, altered, or rebuilt several times to prolong life (Nurock & Porteous, 2008:298). Maintaining a TMM depends on experience, methods, and the accuracy of services and repairs. The maintenance philosophy, methods, expertise, and effectiveness affect the life and operation of many TMM parts and the TMM as a whole (Nurock & Porteous, 2008:298). Areas and working conditions differ, as TMMs are exposed to the natural elements. Different maintenance conditions, operating conditions, practices, and environmental factors also affect the TMM's lifetime (Nurock & Porteous, 2008:298).

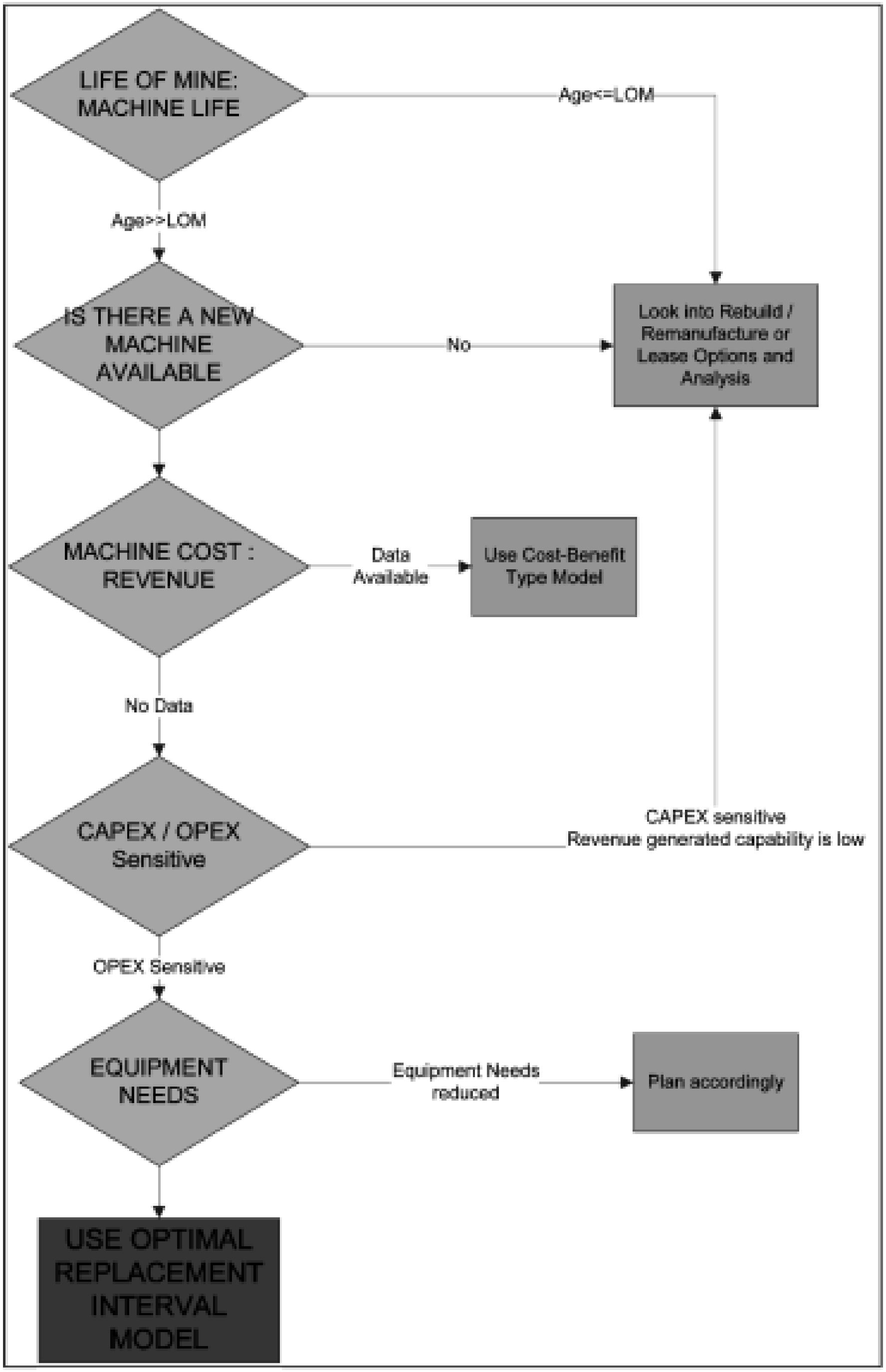

Figure 9 Environment applicable to the optimal replacement interval (Nurock & Porteous, 2008:298).

Factors to consider when replacing conventional TMMs with modern TMMs can be based on three factors that will influence decision-making:

- Operating costs are the most significant contributors that are directly linked to the TMMs and their cost efficiency. Therefore, TMM's maintenance cost (when it rises above a certain threshold), consumables used, and direct labour for repair costs should be considered. If these costs exceed replacement or financing costs, a replacement can be made (Nurock *et al.,* 2008:299).
- Financing costs is ultimately based on a TMM's lifespan. A longer TMM lifespan renders the TMM more economically viable. Therefore, replacement will also be based on financing and the period of financing. The capital cost of the TMM plays a significant role in determining the TMM's lifespan since this cost is spread over the TMM's operating life (Nurock & Porteous*,* 2008:299).
- Availability costs ultimately affect service delivery and client satisfaction. The TMM might become redundant if more TMMs are needed to ensure availability due to increased breakdowns. An increase in the number of TMMs available for the operation will have a cost influence and, thus, an applicable term availability cost. The latter is influenced by the TMM's efficiency, production rate, average utilisation percentage, and effectiveness (Nurock *et al.,* 2008:301).

Other replacement factors to consider are (Nurock & Porteous*,* 2008:301):

- The mine is compelled to employ older TMMs less often due to availability or inefficiency caused by them.
- Malicious damages caused by operators' resistance to using older TMMs, or damages caused by older, less effective, and more defective equipment.
- Various factors such as markets, technological advantages in TMM performance, maintainability, consumption, and operator comfort could require employing modern TMMs (Nurock & Porteous*,* 2008:301).

3.5 APPROACH TO ANALYSE MODERN AND CONVENTIONAL TMMS

Modern and conventional terms are two-way descriptions and discussions for this study. The first part evaluates new and older TMMs in terms of replacement value to optimise TMMs' efficiency. The advantages of replacing an older TMM with a new one is examined in this way. In the short term, this approach ensures organisational sustainability.

The second part evaluates modern and conventional TMMs with regard to the available technology. The evaluation aims to determine whether new technology applies to the current application and whether it will be beneficial to utilise new technology. The current TMMs available in the mining industry are also evaluated. Consequently, the conventional TMMs currently in operation are compared with the modern TMMs that will be available in the future. How emerging technology can improve operational efficiency and ensure organisational sustainability is also assessed.

3.6 RESEARCH APPROACH

Creswell (2014:4) defines a research approach as a collection of assumptions, data collection methods, interpretations, and analyses. The research approach will be derived from the nature of the research problem being addressed and the process of data analysis and reasoning.

As discussed in section 3.3.4, a mixed-method research approach will be followed, employing both quantitative and qualitative research methods. For current conventional and new TMMs, qualitative data will be used to understand concepts, opinions, or experiences currently in the industry, and quantitative data will be used to substantiate findings using statistical information gathered over the years within the organisation.

Qualitative data will also be used to evaluate current operational methods and how new technology can improve overall operations, fuel efficiency, and safer working environments. Quantitative data will be used to highlight trends and support the best possible solutions.

3.6.1 Data collection methods

Quantitative and qualitative data will be obtained from the following Almar databases:

- Almar Investment’s monthly hours summary,
- Almar Investment’s monthly diesel summary,
- Almar Investment’s workflow,
- all daily site snapshots,
- all site availability dashboard,
- site requirements report,
- asset management tool (AMT).

The data will be collected in the following fashions:

- Daily reports for tracking TMM hours and fuel used and comparing data from modern and conventional TMMs with over- and under-projections will be used. In order to ensure profitability, this information will be used to evaluate the company's efficiency.
- TMM availability will be analysed, which provides a picture of the TMM's location within the organisation. It shows how the plant is utilised and how many TMMs are available on each site. Measuring and controlling daily TMM availability and utilisation is vital. TMM availability will be calculated depending on daily usage if a TMM works on a 24-hour shift. Availability calculation will be as follows: Available hour (24 hours) – Availability = Breakdown hours (Standing time)/Available hours. Utilisation is the means of measuring the usage of a TMM and is calculated as follows: Utilisation = Hours worked (TMM worked hours)/Available hours (availability).
- TMM data for the past year will be compiled and analysed, grouped into primary age groups for evaluation.

'Effective utilisation' and 'availability' are the metrics for evaluating the availability and utilisation of the TMM while it is needed for operational requirements. Consequently, a TMM's availability could be 90% for the entire day, but if it is needed at a certain point in time and is unavailable, availability would be 0%.

These samples, techniques, and methods would assist in ultimately evaluating modern and conventional TMMs per site.

According to section 1.2.1.1, different types of TMMs should be considered when conducting the qualitative study.

Continuous or discrete measurements can be used to describe quantitative data (Ali & Bhaskar, 2016:662). In discrete numerical data, the numbers are recorded as whole numbers, whereas continuous data may take any value. Discrete data are observations that can be counted, while continuous data are observations that can be measured. The analysis of Almar data sources will primarily use quantitative data, with qualitative findings to support or verify the findings.

3.6.2 Analysis of data

3.6.2.1 TMM analysis

Based on TMM life hours, TMMs are divided into six primary groups of age. The following are the classifications used to compare conventional and modern TMMs:

A: 0 - 5000 Hours

B: 5000 - 10 000 Hours

C: 10 000 - 15 000 Hours

D: 15 000 - 20 000 Hours

E: 20 000 - 25 000 Hours

F: 25 000 > Hours

Based on these primary categories, the TMMs are classified into groups to determine if the used life of a TMM in a chrome smelting environment would affect TMM availability, utilisation, and breakdowns. It would then support the topic of the research by establishing the optimisation between conventional and modern TMMs because hours are the primary method in all types of measurement for TMMs. To this end, production efficiency, invoiceable values, and other factors of TMM usage will be measured.

3.6.2.2 Breakdowns by TMM category

The purpose is to establish the frequency of breakdowns within age groups for different types of TMMs by evaluating possible downtime and breakdowns of TMMs and the impact of TMM hours on various types of TMMs.

Each breakdown is classified as an event to establish the accuracy of these events and the frequency of TMM breakdowns. These events are logged for each TMM using a component code. Component codes identify assemblies, subassemblies, and parts that can be maintained. The frequency is evaluated to determine which factors would impact TMM availability (impact efficiency), with the intention of eliminating these occurrences and increasing optimisation.

Therefore, the breakdowns are evaluated per the main category, which includes all standing times. Standing times include all breakdowns experienced and logged for the TMM. The top ten breakdowns or standing times are logged to evaluate the correlation between large contributors and total standing time contributions.

3.6.2.3 Standing time per TMM life cycle and TMM category

For this category analysis, the six primary groups are analysed to evaluate the tendency of total standing time per life cycle age, thus evaluating total standing time events for categories (section 3.6.2.1). The component code is reflected in relation to the category.

Further, the analysis is drawn between the component code count and the categorically arranged TMM types; this analysis measures the frequency of downtime for a specific TMM. Since these pieces of equipment all work in different areas and conduct different functions, evaluating downtime per specific TMM helps in understanding the essence of downtime and thus developing a method for optimisation.

For these categories, TMMs' downtime is further evaluated for TRUE and FALSE values. TRUE values are maintenance-related; thus, these downtime tasks are planned and would ensure better TMM availability. FALSE values reflect unplanned component code counts; thus, unplanned breakdowns that impact TMM availability and efficiency directly.

This would contribute to defining which categories can be seen as the TMM age with the most frequent downtime and the contributing reasons.

3.6.2.4 TMM availability and utilisation

Within the primary age group analysed, the availability and utilisation of each TMM are compared to evaluate the correlation between downtime and TMM life. Ultimately, the efficiency of conventional and modern TMMs within the fleet will be compared.

3.6.2.5 TMM breakdowns

Optimising TMMs can be accomplished through efficiency, which requires the availability of efficient TMMs. Consequently, breakdowns and downtime are vital to comparing conventional and modern TMMs and the impact of breakdowns on their availability.

As part of the evaluation, all breakdowns are analysed across all TMMs and categories, and then these breakdowns are compared to determine which types of events result in the longest standing time. The breakdowns are then further analysed using the top ten breakdown component codes.

In order to further analyse breakdowns during TMM lives, breakdown component codes are considered. According to classification evaluation, component codes and their values per primary age group are considered.

The breakdown evaluation will be done in the following segments:

- all breakdowns,
- per category,
- per classification.

3.6.2.6 Breakdown frequency

Breakdown Frequency is a term often used in the discussion in section 4.3. In a given period of time, it is a measure of the number of breakdowns that occur. It is an important metric for assessing the reliability of equipment and systems in maintenance operations. Breakdown Frequency is calculated by dividing the total number of breakdowns by the total number of operating hours. Lower breakdown frequencies indicate higher equipment reliability, while higher breakdown frequencies indicate lower reliability. By identifying breakdown frequency, Almar develops strategies to improve reliability and reduce downtime.

In section 4.3, the TMM breakdown frequency examines the change in downtime frequency as a TMM moves from one category to the next. This evaluation is crucial in determining the optimal lifespan of each TMM because the breakdown hours can be obtained from it. A TMM evaluation not only assists in the replacement strategy but also identifies whether the TMM's efficiency is declining or sufficient for production and use.

3.6.2.7 Fuel consumption comparison: conventional vs modern

A series of TMMs were evaluated with one year of data within the company's history to compare fuel consumption between conventional and modern TMMs. To assess the effects of introducing modern TMMs into operations, fuel consumption is compared for the same-size TMMs working in the same environment and completing the same process. The following equipment was evaluated and monitored for this analysis:

General front-end loaders:

- 938H Series,
- 938K Series,
- 950H Series,
- 950L Series,
- 966H Series,
- 966L Series.

The type of TMM chosen for front-end loaders was Caterpillar (CAT) TMMs. The following TMMs were used for variation:

- CAT-sized.
    - 938 = 2.5 cubic unit TMM,
    - 950 = 3 cubic unit TMM,
    - 966 = 3.5 cubic unit TMM.

- General articulated dump trucks (ADTs) considered are:
  - A30E,
  - A30F,
  - A40F,
  - A40G.
- The type of TMM chosen for articulated dump trucks was only Volvo TMMs. The following Volvo-sized TMMs were considered for variation:
  - A30 = 30ton ADT,
  - A40 = 40ton ADT.
- The TMM age is indicated per plant number in alphabetical order. Historically, TMM numbers started at A and progressed to Z over the years. Looking at TMM age per category plant number, A TMMs will be older and TMMs progressing to Z will be newer. Thus, for the analysed example, H will be older than K and L for FELs. For ADTs, E will be older than F, and F will be older than the newer G.
  - Older FEL TMMs:
    - 938H Series,
    - 950H Series,
    - 966H Series.
  - Newer FEL TMMs:
    - 938K Series,
    - 950L Series,
    - 966L Series.
  - Older ADT TMMs:
    - A30 E,
    - A40 F.,
  - Newer ADT TMMs:
    - A30F,
    - A40G.

3.7 COST-BENEFIT ANALYSIS

The cost-benefit analysis concerns all aspects of production, such as financial issues. Furthermore, it deals with the behaviour of costs in terms of various production criteria, such as prices of factors of production, operational scale, and output size.

Business decisions are based on cost-benefit analysis, by comparing estimated or projected benefits of costs or opportunities and evaluating the cost and benefit for the best possible outcome.

3.7.1 Capital expenditure (CAPEX)

CAPEX, or capital expenditure, is the amount of money invested in the organisation for expansion, upgrading, or acquiring non-consumable, fixed assets (Fernando, 2024). It is primarily a once-off investment for non-consumable assets used to maintain the organisation's current operational requirements and to substitute its future growth from CAPEX.

Benefitting the organisation for more than one year, capital expenditure usually involves money investment in fixed assets. Long-term resources, or fixed assets, are those not easily converted to cash or used up; therefore, they have a long-term use and value for the organisation. Tangible and intangible fixed assets are the two types of assets.

Equipment, buildings, and business units are all the company's fixed assets, and money from CAPEX, or capital expenditure, will be used to update, acquire, improve, or repair them. Therefore, CAPEX is vital for organisational longevity and sustainability.

The same type of TMMs will be used for capital expenditure but considering older and newer models in the same fleet size. Therefore, TMMs such as a front-end loader TMM, Caterpillar 966, Volvo L150, Hitachi ZW310, or similar TMMs will be used for capital expenditure evaluation of the same size TMM purchased, being conventional, modern, or electric.

Capital expenditure is based on the following factors:

3.7.1.1 Current fleet (lower instalment, higher maintenance)

The purchase price will be based on one TMM, such as a front-end loader TMM, Caterpillar 966, Volvo L150, Hitachi ZW310, or similar TMMs. Usually, the purchase price is higher than R3 500 000, the maintenance percentage over the TMM’s life used is 20%, and the life cycle is five years.

3.7.1.2 Purchasing newer TMMs (higher instalment cost, lower maintenance)

The purchase price is R4 500 000 and is based on one TMM such as a front-end loader, Caterpillar 966, Volvo L150, Hitachi ZW310, or similar TMMs. The maintenance percentage over the TMM’s life is 10%, and the life cycle is five years.

3.7.1.3 Purchasing electric TMMs

The purchase price will be based on one TMM, such as a front-end loader TMM, Caterpillar 966, Volvo L150, Hitachi ZW310, or similar TMM. Usually, the purchase price is approximately R5 500 000, the maintenance percentage over the TMM's life is 10%, and the life cycle is five years.

3.7.1.4 Capital expenditure for research and development (R&D)

The capital expenditure for research and development is allocated to simulators, emulators, remote control TMMs, and hot material handling specification equipment development.

3.7.2 Outsourced cost analysis

Outsourced work for a particular task is done through cost-cutting initiatives such as recruitment, training, and development of employees. The latter afforded a decreased need for hiring skilled people to perform outsourced tasks. In this study, the outsourced tasks would refer to TMM rental and TMM or on-site bulk handling services. Thus, outsourcing to people or outside companies already skilled in the trade. This would ultimately boost the quality of work and overall organisational efficiency and effectiveness.

Outsource cost analysis evaluates the benefit of utilising outsourced initiatives and net cost benefits to the organisation (Troacă & Bodislav, 2012:55-56).

It encompasses all outsourcing costs, including contract administration, transition, and bidder costs, minus any new revenue generated from sales, equipment, furniture or even unneeded supplies.

3.7.3 Vehicle investment and finance instalments

In order to compare capital outlay for conventional and modern TMMs, the investment and financing costs between current and future TMMs are compared.

The evaluation of TMM investment cost is crucial in decision-making for an optimised TMM replacement strategy and cash flow calculations.

The three blocks below analyse TMM investment and financing costs compared between current and modern TMMs and future conventional and modern TMMs. The three blocks compare capital outlay and monthly instalment values between conventional and modern TMMs.

Block 1 The evaluation of TMM investment cost for current TMMs.

Current Fleet - Conventional			
Value	-R 3 500 000,00		
Dep	R -		
PV	-R 3 500 000,00		
FV	R -		
PMT			R76 098,48
N	5	60	
I	11%	0,0092	

The current fleet of conventional TMMs was purchased at a lower rate when they were modern compared to the current replacement value of the same modern TMM. These TMMs, however, require a higher maintenance rate, with repair costs increasing as TMMs age. This maintenance cost analysis will be compared to the same modern TMM for replacement decision-making.

Current fleet modern TMMs at replacement value would be higher than current conventional TMMs. These TMMs come at a higher investment cost but with the added benefit of reduced maintenance cost and increased uptime and availability. Thus, they entail higher initial capital outlay but greater support and efficiency.

Future modern TMMs will come at an even higher price. However, the advantage of these TMMs would be seen in their increased efficiency, safety features, and industry compliance. However, availability and uptime would be the same as the current fleet of modern TMMs.

Block 2 The evaluation of TMM investment cost for modern TMMs.

Modern Machines			
Value	-R 4 500 000,00		
Dep	R -		
PV	-R 4 500 000,00		
FV	R -		
PMT			R97 840,90
N	5	60	
I	11%	0,0092	

Block 3 The evaluation of TMM investment cost for future TMMs.

Future - Modern Machines			
Value	-R5 500 000,00		
Dep	R -		
PV	-R5 500 000,00		
FV	R -		
PMT			R119 583,33
N	5	60	
I	11%	0,009167	

3.7.4 Fuel analysis and assumptions

Third-party contract driver's charges and line-haul costs can be influenced by changes in fuel prices. Line-haul charges contribute up to 12% of operating costs, and third-party driver costs up to 24% of operating expenses (Vosloo, 2013). Changes in the fuel price have a high level of influence, influencing almost 40% of expenses.

3.7.5 Nett present value (NPV)

The financial metric referred to as Nett Present Value (NPV) is used to capture the investment opportunity's total value. Projecting all future cash out- and inflows associated with the investment, NPV discounts all future cash flows to the present day and adds it all together. The result of adding all the negatives and positives of the cash flows is the NPV. A positive NPV means that profit will be made after accounting for the time value of money if the investment is made.

After considering various factors such as opportunity costs, risk tolerance through the discount rate (which reflects the investor's cost of capital), future project cash flows, and the time value of money, a value larger than zero achieved for NPV is favourable. Thus, on that basis, even an NPV of one would theoretically be seen as good, simply indicating the worthwhileness of the project. However, in practice, a higher bar for NPV will be set, giving planners an additional margin of safety.

Equation 1 is used to calculate the NPV:

$$NPV = \frac{Cash\ Flow\ 1}{(1+r)^1} + \frac{Cash\ Flow\ 2}{(1+r)^2} + \ldots + \frac{Cash\ Flow\ n}{(1+r)^n} - C_0 \qquad 1$$

Where:

- Cash Flow is the sum of money spent and earned on an investment or project for a given period,
- n is the number of periods,
- r is the discount rate.

Cash flows are any money spent or earned for the sake of the investment, including capital expenditures, interest, and loan payments. Each period's cash flow includes outflows for expenses and inflows for profits, revenue, or dividends.

The number of periods equals how many months or years the project or investment will last.

In most situations, the discount rate is the company's weighted average cost of capital (WACC). A company's WACC is how much money it needs to make to justify the cost of operating. WACC includes the company's interest rate, loan, and dividend payments.

Cash flows need to be discounted because of the *time value of money*. It is the assumption that money today is worth more than money to be received at a later date.

3.7.6 Internal rate of return (IRR)

The internal rate of return (IRR) is the annualised interest rate at which the initial capital investment must have grown to reach the ending value from the beginning value. It measures the return rate on an investment or project without external factors. An investment would be considered successful with higher percentages, normally 10% and higher. Lower investment opportunities would be 5% and lower, which is the percentage where investors would reconsider options for investment.

The internal rate of return is calculated according to equation 2:

$$0 = NPV = \sum_{t=1}^{T} \frac{C_t}{(1+IRR)^t} - C_0 \qquad 2$$

where:

C_t = Nett cash inflow during the period t,

C_0 = Total initial investment costs,

t = The number of time periods.

3.7.7 Profitability index (PI)

A profitability index can be used to prioritize factors such as planning, forecasting, accuracy, and attention to detail. Also, in assessing how the project is performing under various conditions, sensitivity analysis aids as a robustness test of assumptions and scenarios.

Determining the variable with the highest level of risk of all risk factors is one of the focus areas for a sensitivity analysis.

Equation 3 is used for the calculation of PI:

$$\mathrm{PI} = \frac{(\mathrm{NPV} - \mathrm{Initial\ Investment})}{\mathrm{Initial\ Investment}} \tag{3}$$

Below is an explanation of the ranges of profitability index:

- If the profitability index is larger than 1, it shows the project will generate value for a company.
- If the profitability index is less than 1, it shows the project will destroy value.
- If the profitability index equals 1, it shows the project will break even.

3.8 SUMMARY OF THE CHAPTER

In light of the organisation's experience and evaluation of current and future capabilities and resources, it is evident that the organisation can optimise the application of TMMs in its haulage operations, resulting in a competitive advantage in the market and thus ensuring the organisation's sustainability. The description of the calculations of the investment profitability metrics and the approach to obtaining client data from Almar's database form the basis of the evaluation in Chapter 4, where results for the feasibility study will be distilled from the data and the balance between conventional and modern TMMs will be determined.

CHAPTER 4. RESULTS AND DISCUSSION

4.1 INTRODUCTION

Chapter 3 discusses the methods for obtaining quantitative and qualitative data from the Almar database, the analysis of the data, and the approach to optimising the application of traditional and modern TMMs in combination. This chapter presents and discusses the results of the cost-benefit analysis (section 4.2) and trends observed from the Almar database (section 4.3). Finally, the results are discussed in relation to the optimal combination of conventional and modern TMMs in chrome mining processes.

4.2 COST-BENEFIT ANALYSIS

When selecting projects, it is important to consider the NPV, IRR, and PI indicators, as they can represent the project's economic value from different angles and under specific conditions (Zhang, 2022:1212). Based on the calculative interest rate (capital profit sacrifice cost), the NPV is the minimum yield that can be derived from the market (section 3.7.5). It shows the increase in assets created by the investment during its lifetime of use, but it does not provide any information regarding the profitability of the capital investment itself (Juhász, 2011:46-47). The IRR provides information on how the actual yield of long-term engrossed capital is generated (section 3.7.6). PI is a measure of an investment's profitability and can be compared to the profitability of other similar investments (section 3.7.7). This implies that the PI is a capital budgeting tool that helps determine whether a project should be accepted or rejected. Thus, it can be combined with the IIR and NPV to evaluate the profitability of implementing modern TMMs in a mine's hauling operations.

4.2.1 NPV

The NPV's meaning and its calculation are discussed in section 3.7.5. The results of the NPV for TMMs at ages four and five years are given in Tables 2 and 3, respectively. The cash flows and discount rates were obtained from the Almar database.

If the NPV is compared for modern and conventional TMMs for a three-to-four-year period, the NPV of conventional TMMs is larger than that of modern TMMs. This is due to the larger initial investment associated with modern TMMs. Over the three-to-four-year period, the added benefit from using modern TMMs and the cost savings in efficiency, reduced maintenance cost, and the impact thereof are not significant enough to overshadow initial capital outlay to reflect a greater NPV. Therefore, conventional TMMs are better investment opportunities in the short-term business environment than modern TMMs.

Table 2 NPV after four years for conventional and modern TMMs

Net present value (4Year)

Net Cash Flow for Modern and Conventional MAchines (CFt)						
r =	25%					
Conventional Machines						
Year (t)	0	1	2	3	4	5
Cash Flow (Cft)	-R 3 500 000,00	R 1 805 000,00	R 1 735 000,00	R 1 665 000,00	R 1 595 000,00	R -
NPV =	R560 192,00					
Modern Machines						
Year (t)	0	1	2	3	4	5
Cash Flow (Cft)	-R 5 250 000,00	R 2 287 500,00	R 2 392 500,00	R 2 497 500,00	R 2 602 500,00	R -
NPV =	R455 904,00					

ANote: CF0 represents the cash flow experienced at the project's inception

Compared to conventional TMMs, modern TMMs have higher NPVs after five years due to their efficiency and maintenance benefits, suggesting that modern TMMs are better investments at this point. Table 2 further shows that the NPV of modern TMMs exceeds that of conventional TMMs by R283 193.60 NPV over five years, which is significant.

Table 3 NPVs after five years for conventional and modern TMMs.

Net present value (5Year)

Net Cash Flow for Modern and Conventional MAchines (CFt)						
r =	25%					
Conventional Machines						
Year (t)	0	1	2	3	4	5
Cash Flow (Cft)	-R 3 500 000,00	R 1 805 000,00	R 1 735 000,00	R 1 665 000,00	R 1 595 000,00	R 1 525 000,00
NPV =	R1 059 904,00					
Modern Machines						
Year (t)	0	1	2	3	4	5
Cash Flow (Cft)	-R 5 250 000,00	R 2 287 500,00	R 2 392 500,00	R 2 497 500,00	R 2 602 500,00	R 2 707 500,00
NPV =	R1 343 097,60					

ANote: CF0 represents the cash flow experienced at the project's inception

With time, modern TMMs have a more beneficial impact on operations and overall business, making investing in them a better business decision at this stage.

4.2.2 IRR

The meaning of the IRR and how it is calculated are discussed in section 3.7.6. Tables 4, 5, and 6 provide the results for calculating the IRR after four, five, and seven years, respectively.

The internal rate of return (IRR) calculated after four years shows that conventional TMMs exceed that of modern TMMs by one per cent (Table 4). Therefore, considering short-term business operations, conventional TMMs would be better investments than modern TMMs. The IRR values for both conventional and modern TMMs in Table 6 are significantly larger than the 25% required by the organisation, suggesting that both types of TMMs could be very successful investments. Although an IRR larger than 25% is desired, a general guideline is that it should be larger than the cost of capital (Goedhart *et al*., 2015).

Table 4 IRR calculated for investing in conventional and modern TMMs over the shorter term

Internal Rate of Return (4Year)

Internal rate of return for Modern and Conventional MAchines (CFt)								
r =	25%							
Conventional Machines								
Year (t)	0	1	2	3	4	5	6	7
Cash Flow (Cft)	-R 3 500 000,00	R 1 735 000,00	R 1 665 000,00	R 1 595 000,00	R 1 525 000,00	R -	R -	R -
IRR =	31%							
Modern Machines								
Year (t)	0	1	2	3	4	5	6	7
Cash Flow (Cft)	-R 5 250 000,00	R 2 287 500,00	R 2 392 500,00	R 2 497 500,00	R 2 602 500,00	R -	R -	R -
IRR =	30%							

The internal rate of return (IRR) after five years for conventional and modern TMMs is the same, at 37% (Table 5). Therefore, the evaluation turning point is at five years. The long-term benefits of increased efficiency and maintenance costs are evident in Table 6.

Table 5 IRR calculated for investing in conventional and modern TMMs after five years

Internal Rate of Return (5Year)

Internal rate of return for Modern and Conventional MAchines (CFt)								
r =	25%							
Conventional Machines								
Year (t)	0	1	2	3	4	5	6	7
Cash Flow (Cft)	-R 3 500 000,00	R 1 735 000,00	R 1 665 000,00	R 1 595 000,00	R 1 525 000,00	R 1 455 000,00	R -	R -
IRR =	37%							
Modern Machines								
Year (t)	0	1	2	3	4	5	6	7
Cash Flow (Cft)	-R 5 250 000,00	R 2 287 500,00	R 2 392 500,00	R 2 497 500,00	R 2 602 500,00	R 2 707 500,00	R -	R -
IRR =	37%							

The internal rate of return (IRR) after seven years for modern TMMs has a larger IRR than conventional TMMs, with only a one per cent difference between the two options (Table 6). Both options exceed the required IRR of 25%, but modern TMMs have a larger IRR and could be the preferred solution over the long term.

Table 6 IRR calculated for investing in conventional and modern TMMs after seven years

Internal Rate of Return (7Year)

Internal rate of return for Modern and Conventional MAchines (CFt)								
r =	25%							
Conventional Machines								
Year (t)	0	1	2	3	4	5	6	7
Cash Flow (Cft)	-R 3 500 000,00	R 1 735 000,00	R 1 665 000,00	R 1 595 000,00	R 1 525 000,00	R 1 455 000,00	R 1 385 000,00	R 1 315 000,00
IRR =	42%							
Modern Machines								
Year (t)	0	1	2	3	4	5	6	7
Cash Flow (Cft)	-R 5 250 000,00	R 2 287 500,00	R 2 392 500,00	R 2 497 500,00	R 2 602 500,00	R 2 707 500,00	R 2 812 500,00	R 2 917 500,00
IRR =	43%							

4.2.3 PI

The results for the calculation of the PI are given in Tables 7 and 8 for five and seven years, respectively. The profitability index (PI) for conventional and modern TMMs, considered over five years, are both larger than one, and both are viable options. Based on the PI of 1.30 for conventional TMMs compared to 1.26 for modern TMMs in the medium term, conventional TMMs are the better option.

The PI for conventional and modern TMMs considered over seven years is 1.49 for conventional TMMs, compared to modern TMMs, which show a PI of 1.51. Therefore, modern TMMs would be the more favourable option over the long term.

Table 7 PI for modern and conventional TMMs over five years

Profitability Index (5Year)

Profitability Index for Modern and Conventional MAchines (CFt)

r = 25%

Conventional Machines

Year (t)	0	1	2	3	4	5	6	7
Cash Flow (Cft)	-R 3 500 000,00	R 1 805 000,00	R 1 735 000,00	R 1 665 000,00	R 1 595 000,00	R 1 525 000,00	R -	R -

Year	Cash Flow	Discounted Cash Flow
1	R 1 805 000,00	R 1 444 000,00
2	R 1 735 000,00	R 1 110 400,00
3	R 1 665 000,00	R 852 480,00
4	R 1 595 000,00	R 653 312,00
5	R 1 525 000,00	R 499 712,00
		R 4 559 904,00

Discounted Cash Flow	R 4 559 904,00
Investment	R 3 500 000,00
PI =	1,30

Modern Machines

Year (t)	0	1	2	3	4	5	6	7
Cash Flow (Cft)	-R 5 250 000,00	R 2 287 500,00	R 2 392 500,00	R 2 497 500,00	R 2 602 500,00	R 2 707 500,00	R -	R -

Year	Cash Flow	Discounted Cash Flow
1	R 2 287 500,00	R 1 830 000,00
2	R 2 392 500,00	R 1 531 200,00
3	R 2 497 500,00	R 1 278 720,00
4	R 2 602 500,00	R 1 065 984,00
5	R 2 707 500,00	R 887 193,60
		R 6 593 097,60

Discounted Cash Flow	R 6 593 097,60
Investment	R 5 250 000,00
PI =	1,26

Table 8 PI for modern and conventional TMMs over seven years

Profitability Index (7Year)

Profitability Index for Modern and Conventional MAchines (CFt)

r = 25%

Conventional Machines

Year (t)	0	1	2	3	4	5	6	7
Cash Flow (Cft)	-R 3 500 000,00	R 1 805 000,00	R 1 735 000,00	R 1 665 000,00	R 1 595 000,00	R 1 525 000,00	R 1 455 000,00	R 1 385 000,00

Year	Cash Flow	Discounted Cash Flow
1	R 1 805 000,00	R 1 444 000,00
2	R 1 735 000,00	R 1 110 400,00
3	R 1 665 000,00	R 852 480,00
4	R 1 595 000,00	R 653 312,00
5	R 1 525 000,00	R 499 712,00
6	R 1 455 000,00	R 381 419,52
7	R 1 385 000,00	R 290 455,55
		R 5 231 779,07

Discounted Cash Flow	R 5 231 779,07
Investment	R 3 500 000,00
PI =	1,49

Modern Machines

Year (t)	0	1	2	3	4	5	6	7
Cash Flow (Cft)	-R 5 250 000,00	R 2 287 500,00	R 2 392 500,00	R 2 497 500,00	R 2 602 500,00	R 2 707 500,00	R 2 812 500,00	R 2 917 500,00

Year	Cash Flow	Discounted Cash Flow
1	R 2 287 500,00	R 1 830 000,00
2	R 2 392 500,00	R 1 531 200,00
3	R 2 497 500,00	R 1 278 720,00
4	R 2 602 500,00	R 1 065 984,00
5	R 2 707 500,00	R 887 193,60
6	R 2 812 500,00	R 737 280,00
7	R 2 917 500,00	R 611 844,10
		R 7 942 221,70

Discounted Cash Flow	R 7 942 221,70
Investment	R 5 250 000,00
PI =	1,51

4.3 TMM ANALYSIS

The data used for the evaluation was taken over a one-year cycle where various sites and working areas were considered. External factors such as climate, weather conditions, and environment were variables considered. All other aspects were seen as constant changes within one year over the various areas of business operations. The same types of TMMs were analysed and considered across business sectors. For the data evaluated, TMMs were divided into primary age groups and classified as follows:

A: 0 - 5000 Hours

B: 5000 - 10 000 Hours

C: 10 000 - 15 000 Hours

D: 15 000 - 20 000 Hours

E: 20 000 - 25 000 Hours

F: 25 000 > Hours

TMM data was classified by frequency, component code, or category. Modern and conventional TMMs were compared to determine areas for optimisation to ensure relevance.

4.3.1 Breakdowns by TMM category

The component codes for various types of actual downtime reasons were compiled and linked to each type of TMM. The same types of TMMs were then compressed into line items of total TMMs per line to evaluate breakdowns per TMM group and evaluated per age group A to F for age/breakdown tendency.

Table 9 shows the top breakdown reasons per age category. It represents the breakdown type and the corresponding breakdown frequency per age group. This representation of breakdowns per age group ultimately indicates what causes breakdowns and downtime in each age group. This analysis can be used for decision-making in either discontinuing a TMM, removing it from the fleet, implementing a replacement strategy, or identifying trends and causes to aid in prevention at a certain age. Modern TMMs will be closer to primary age group A, and conventional TMMs will be closer to primary group D.

For the analysis in Table 9, Almar data for general FELs (front-end loaders) and general ADTs (articulated dump trucks) were used. They are the largest group of TMMs employed in the client’s mining operations. Typical for these TMMs is the large number of frequencies per component code. Increasing age increases the frequency of maintenance for both types of TMMs. For example, when the general ADTs moved further in their life cycle and accumulated more hours, an apparent increase in breakdowns in primary group D is observed. Higher frequencies in primary group A were caused by greasing, a daily task that resulted in needed downtime but did not influence TMM efficiency. Electrical and engine breakdowns are standout components from this analysis, as the frequency increases at primary age group D. In general, FELs' operation lifetimes fall into age group D, explaining why maintenance frequencies are declining and why no data exists for age group E. Therefore, as the duration of operation for a particular TMM increases, it is replaced by a modern TMM. Replacing the conventional TMM with a modern TMM may be a good investment decision (section 4.4).

Front-end loaders are the workhorses of the client’s mining processes. These TMMs are essential for efficient and fast loading, transporting, turning, and agitating piles of ore and screening and loading large volumes of finished products.

ADTs are more flexible and can be used in narrower, more winding, and steeper roads and extreme weather conditions. However, this lighter vehicle lacks the strength and longevity of FELs.

In terms of appearance, articulated dump trucks have a point of ‘articulation’ behind the cab, which is attached to the vehicle’s tipping body. This increased range of motion and flexibility to pivot makes the truck easy to manoeuvre compared to rigid dump trucks, which are, as their name would suggest, more rigid by design.

The analysis in Table 10 shows that modern TMMs in group A are prone to preventative breakdowns, such as greasing, normally expected from a modern TMM. The evaluation shows that as time progresses and a TMM moves to group D, nearing the end-of-life cycle and being classified as a conventional TMM, breakdowns and larger component issues arise, as indicated by the frequency increase. The top ten breakdowns are presented for all equipment in the company to evaluate the impact of breakdowns on TMM life.

Table 9 Breakdowns by main category (includes all company codes)

Count of Component Code							
Row Labels	A	B	C	D	E	F	Grand Total
General ADT	**1831**	**54**	**534**	**1663**	**1309**	**4923**	**10314**
Grease	1091	1	233	710	470	2204	4709
Electrical	215	14	94	230	247	857	1657
Maintenance	204	13	46	127	89	244	723
Bodywork	99	1	30	116	113	317	676
Hydraulic	49	7	28	128	128	334	674
Engine	67	5	44	116	83	292	607
Tyre	45	2	18	64	43	239	411
AirCon	21	4	22	86	34	198	365
Transmission	15	4	8	20	46	129	222
Suspension	13	3	7	35	32	73	163
Working Element	8		3	31	21	34	97
Fire Suppression System	4		1		3	2	10
General FEL	**4666**	**2224**	**1662**	**4625**	**362**		**13539**
Grease	3304	1222	884	2440	136		7986
Electrical	308	294	218	620	49		1489
Maintenance	364	157	124	307	32		984
Bodywork	259	198	103	300	29		889
Engine	174	77	86	249	41		627
Hydraulic	96	82	82	271	24		555
Suspension	82	57	61	131	25		356
Tyre	46	76	47	94	8		271
AirCon	15	46	38	109	7		215
Transmission	11	11	16	94	5		137
Fire Suppression System	5	3	2	9	4		23
Working Element	2	1	1	1	2		7
Grand Total	6497	2278	2196	6288	1671	4923	23853

Table 10 Top 10 TMM Breakdowns by component code per frequency (Top 10)

Count of Component Code						
Row Labels	A	B	C	D	F	Grand Total
General ADT	**1295**	**13**	**330**	**1003**	**3052**	**5693**
7235 - Grease Service	1087		233	708	2199	4227
8500 - Tyres	45	2	18	64	239	368
6206 - Air Conditioner	10	2	14	49	116	191
7215 - 500 Hrs Service	56	6	12	29	74	177
8312 - Hydraulic Oil	18	1	7	29	100	155
8412 - Coolant	6	2	25	48	64	145
1110 - Engine	20		4	10	76	110
4111 - Batteries	8		8	20	73	109
7000 - Machine	37		3	22	47	109
3106 - Park Brake	8		6	24	64	102
General FEL	**3738**	**1553**	**1159**	**3088**		**9538**
7235 - Grease Service	3303	1215	881	2428		7827
8500 - Tyres	45	76	46	94		261
2501 - Differential	58	36	50	82		226
7215 - 500 Hrs Service	92	46	22	55		215
7214 - 250 Hrs Service	43	12	42	117		214
6308 - Bucket	58	31	26	68		183
4118 - Head Light	25	38	30	79		172
4271 - Globe	41	33	19	68		161
8118 - Half Arrow	66	36	17	37		156
6206 - Air Conditioner	7	30	26	60		123
Grand Total	5033	1566	1489	4091	3052	15231

4.3.2 Standing time per TMM life cycle and TMM category

Table 11 includes all breakdown component frequency codes across all TMMs for the six primary age groups. Age group D has the highest downtime frequency, contributing 23,3% to the total component code frequencies. During age life E to F, TMMs are removed from the fleet, which explains the decrease in frequency counts.

Table 11 Breakdowns by component code frequency per primary age group (All TMMs)

Row Labels	Count of Component Code
A	**11639**
B	**11401**
C	**9662**
D	**13877**
E	**6827**
F	**6150**
Grand Total	59556

Table 12a shows the breakdown frequency per category for modern and conventional general FELs and general ADT TMMs. In the case of the investigated Almar client, the largest contributors to the component code frequencies are general FELs and general ADTs. It is characteristic of these types of TMMs that are mostly used within business operations as far as the TMM count and percentage hours utilised are concerned. In this specific case, general FELs constitute 22,7% of the frequencies and general ADTs constitute 17,3%. The combined total component code frequencies are 40%.

Table 12A Breakdown frequency largest contributors

Row Labels	Count of Component Code	%
General FEL	**13539**	22,7%
General ADT	**10314**	17,3%

Table 12B shows the breakdown frequency count per component code per category for modern and conventional general FEL and general ADT TMMs. The differences between conventional and modern TMMs in Table 15B are in the net power and the operating weight, which increases from conventional to modern TMMs (Construction Equipment Guide, 2023). From Table 12B it is evident that breakdown frequencies decrease from conventional to modern TMMs for the 938 and 950 series. 938H (conventional), at 51 breakdown counts, decreased to 36 compared to its more modern counterpart, 938K. The same occurred with 950H (conventional), at 394 counts, decreasing to 231 breakdown counts compared to the more modern 950L TMM. Therefore, modern TMMs are more reliable than conventional TMMs for the 938 and 950 series. However, in the case of the 966 series, the opposite trend is observed. The breakdown frequency of the 966L series is almost five times higher than that of 966H. Similarly, in the General ADT series the frequency breakdown for modern TMMs is 16 times higher than that for conventional TMMs. These trends occur because there are far more 966L TMMs than 966H TMMs and A40G than A40F within the fleet due to older TMMs already being replaced (Table 13). The average downtime frequency for 966H TMMs is 289, whereas the average downtime frequency for 966L TMMs is 223. Although more in total count, the average downtime occurrence for the modern TMMs is much lower.

Table 12b Breakdown frequency per category for modern and conventional General FEL and General ADT

Row Labels	Count of Component Code
General FEL	**5823**
938H Series I	51
938K Series I	36
950H Series I	394
950L Series I	231
966H Series I	867
966L Series I	4244
General ADT	**1281**
A30G	499
A40F	46
A40G	736
Grand Total	7104

The component codes per age group for nonpreventive reasons (breakdowns/false codes) are shown in Table 14.

To evaluate the impact of planned and unplanned standing time of different TMM categories and the influence of life age per TMM, FALSE (unplanned) component codes will reflect more in older TMM groups, whereas TRUE (planned) downtime component codes will be higher for newer TMMs.

As expected, at 25,3% the primary group D contributes to the largest portion of the unexpected required maintenance, referred to as breakdowns, which is due to the impact of TMMs nearing end-of-life cycle.

Table 13 966H conventional compared to 966L modern TMMs.

966H Series I	867
966H105	451
966H91	127
966H98	289
966L Series I	4244
966L10	198
966L11	159
966L15	132
966L16	188
966L17	183
966L18	89
966L19	147
966L2	331
966L20	172
966L21	216
966L23	134
966L24	207
966L26	249
966L27	403
966L4	321
966L5	426
966L6	198
966L7	244
966L8	247

Table 14 Component codes per age group for non-preventive reasons (breakdowns/false codes)

Row Labels	Count of Component Code
A	3165
B	4970
C	4347
D	6286
E	3333
F	2757
Grand Total	24858

The component codes per age group for non-preventive reasons for modern and conventional TMMs are provided in Table 15. The essence of this evaluation is to understand where a different type of TMM contributes to the larger portion of events in the FALSE, or unexpected, category of breakdown occurrences. In the 938 and 950 series, conventional TMMs show higher breakdown occurrences than modern TMMs, but the opposite trend is observed for the 966 series. Similarly, the modern A40 TMMs show a significantly higher breakdown occurrence than their conventional counterparts. As already mentioned, these trends can be explained by the data in Table 13.

Table 15 Component codes per age group for non-preventive reasons for modern and conventional TMMs

Row Labels	Count of Component Code
General FEL	**2113**
938H Series I	44
938K Series I	28
950H Series I	213
950L Series I	136
966H Series I	437
966L Series I	1255
General ADT	**526**
A30G	80
A40F	31
A40G	415
Grand Total	2639

The component codes per age group for preventative reasons (preventative maintenance/true codes) are given in Table 16. In contrast to unplanned breakdown occurrences, age group A is the highest contributor towards planned maintenance, with 24,4% of true frequencies. It could be linked to the TMM's high availability and the ability to better plan and foresee maintenance, with less downtime between services or planned checks.

Table 16 Component codes per age group for preventative reasons (preventative maintenance/true codes)

Row Labels	Count of Component Code
A	**8474**
B	**6431**
C	**5315**
D	**7591**
E	**3494**
F	**3393**
Grand Total	34698

The component codes per age group for preventative reasons for modern and conventional TMMs are given in Table 17. It shows that the larger TMM count within the fleet is the highest in the planned maintenance field, which are the further analysed values for general FELs and General ADTs.

Table 17 Component codes per age group for preventative reasons for modern and conventional TMMs.

Row Labels	Count of Component Code
General FEL	**3710**
938H Series I	7
938K Series I	8
950H Series I	181
950L Series I	95
966H Series I	430
966L Series I	2989
General ADT	**755**
A30G	419
A40F	15
A40G	321
Grand Total	4465

4.3.3 TMM availability and utilisation

The TMM availability is calculated according to equation 4 and TMM utilisation according to equation 5.

$$\text{TMM availability} = 100 \times \frac{(\text{Planned production time} - \text{Breakdowns})}{\text{Planned production time}} \quad 4$$

$$\text{TMM utilisation} = 100 \times \frac{\text{Run time}}{\text{Planned production time}} \quad 5$$

The results are provided in Table 18.

TMM availability is the hours the TMM is available, calculated after downtime. The more TMMs are available, the more effectively the equipment can be used since there are fewer restrictions and fewer downtimes.

Utilisation refers to the frequency of usage of the TMM during its available hours.

The availability and utilisation percentages in Table 18 show a decrease in availability as the TMMs' age increases. A decrease in TMM efficiency with age is detrimental to the continued application of a particular TMM. As availability decreases to group D or 20000, the option is to either remove the TMM from the fleet or conduct TMM midlife repairs, where the TMM is rebuilt to an almost new state and causes a second increase in TMM availability at age group F. The opposite of availability is utilisation, a minimum at age group C (Table 18), is the age group where service maintenance is no longer done, and TMMs start to age and give unplanned downtime occurrences. It takes some time to evaluate and fix, resulting in lower utilisation. The TMM availability is larger than the TMM utilisation because newer TMMs are readily available. It implies that the hours used for calculating the TMM availability are significantly higher than those used for calculating TMM utilisation. There is an opportunity to take TMMs out of operation for maintenance because the TMM utilisation is relatively low, which prevents the TMMs from being overworked.

When TMMs get older, their availability decreases because of increased downtime. This detrimental operational trend can be attributed to lower downtime of older TMMs, which leaves little time for implementing preventative measures. When a TMM is too old, repairs get increasingly more complex and the TMM maintenance component snowballs.

Table 18 Average percentage of TMM available and utilised

Row Labels	Average of % Hours Available	Average of % Hours Utilized)
A	81%	33%
B	80%	29%
C	78%	23%
D	75%	32%
E	71%	32%
F	81%	39%
Grand Total	**78%**	**31%**

4.3.4 TMM breakdowns

The count of breakdown per main category and the corresponding downtime hours are provided in Table 19. Breakdown's main categories, A to F, are used to evaluate the type of breakdowns and compare to TMM age. It would enable preventative measures to be implemented to reduce or eliminate downtime hours and causes.

The evaluation in Table 19 shows which breakdowns to plan for in advance and ensure parts are on-site to maintain TMMs before these downtimes occur. Hydraulic hoses, tyres, air conditioners, hydraulic oil and batteries form the top five breakdowns. Oil is a significant contributor towards downtime, and either reducing these downtime occurrences by replacing hydraulic hoses earlier or finding methods to replenish hydraulic oil earlier would save time and ensure safer working conditions, resulting in a more effective operation.

Table 19 Count of breakdown per main category and the corresponding downtime hours

Main Categories

Classification	(All)	
Row Labels	**Count of Component Code**	**Sum of Downtime Hours**
4515 - Hydraulic Hoses	1280	19594,38
8500 - Tyres	1043	6797,63
6206 - Air Conditioner	895	2874,30
8312 - Hydraulic Oil	805	8905,72
4111 - Batteries	728	5777,70
4540 - O-Ring	692	2613,92
8412 - Coolant	600	5837,00
4118 - Head Light	569	774,87
6339 - Moil Point	500	603,75
6308 - Bucket	452	67723,22
Grand Total	**7564**	**121502,48**

4.3.5 Availability and breakdown component frequency

In Table 20, frequency determines what happens to a TMM in terms of its availability and breakdown component frequency count when moving from one primary group to another. As expected, higher percentages of modern TMMs are available for operations than for conventional TMMs.

Table 20 Frequency of TMM availability and component breakdown as a function of TMM age.

Row Labels	Count of Bdown Hrs Inc
A-B	34
B-C	21
C-D	24
D-E	24
E-F	8
Grand Total	**111**

4.3.6 Fuel consumption comparison between conventional and modern TMMs

The average fuel consumption is listed for smaller and larger TMMs within the series of older to newer TMMs in Table 21. It shows that front-end loaders with higher production rates have higher average fuel consumption than ADTs. The reason is that ADTs work harder when they haul material where FELs load and form stockpiles.

Table 21 Average fuel consumption for smaller and larger TMMs within the series older to newer TMMs

Row Labels	Classification	Average of Consumption
938H Series I		18,35
938K Series I		11,60
950H Series I		16,59
950L Series I		13,52
966H Series I		18,38
966L Series I		15,86
A30E		7,50
A30F		7,20
A40F		15,20
A40G		13,76
Grand Total		15,83

The average fuel consumption rate is shown for conventional and modern front-end loaders in Figure 10. It shows the fuel consumption efficiency for all TMMs, sizes and types of hauling TMM (FEL and ADT). As TMM sizes differ, newer and older TMMs in larger series TMMs will consume more fuel. Thus, efficiency is not to the extent that a 966L series will be more efficient than a 950H series. However, the efficiency is exploited within the series, where improvement for each series is achieved with newer TMMs purchased and used in production.

For the series CAT 938 FELs, 6.75 litres per hour efficiency is gained going from the old CAT 938H series to the new CAT 938K series. For the series CAT 950 FELs, an efficiency of 3.06 litres per hour is gained going from the old CAT 950H series to the new CAT 950L series. For the series, CAT 966 FELs 2.52 litres per hour efficiency is gained going from the old CAT 966H series to the new CAT 966L series.

The average fuel consumption rate is shown for conventional and modern articulated dump trucks in Figure 11. For the series Volvo A30 ADTs, 0.29 litres per hour efficiency is gained going from the old Volvo A30E series to the new Volvo A30F series. For the series Volvo A40 ADT's, 1.43 litres per hour efficiency is gained, going from 15.20 litres per hour for a Volvo A40F series to 13.76 litres per hour for a Volvo A40G series.

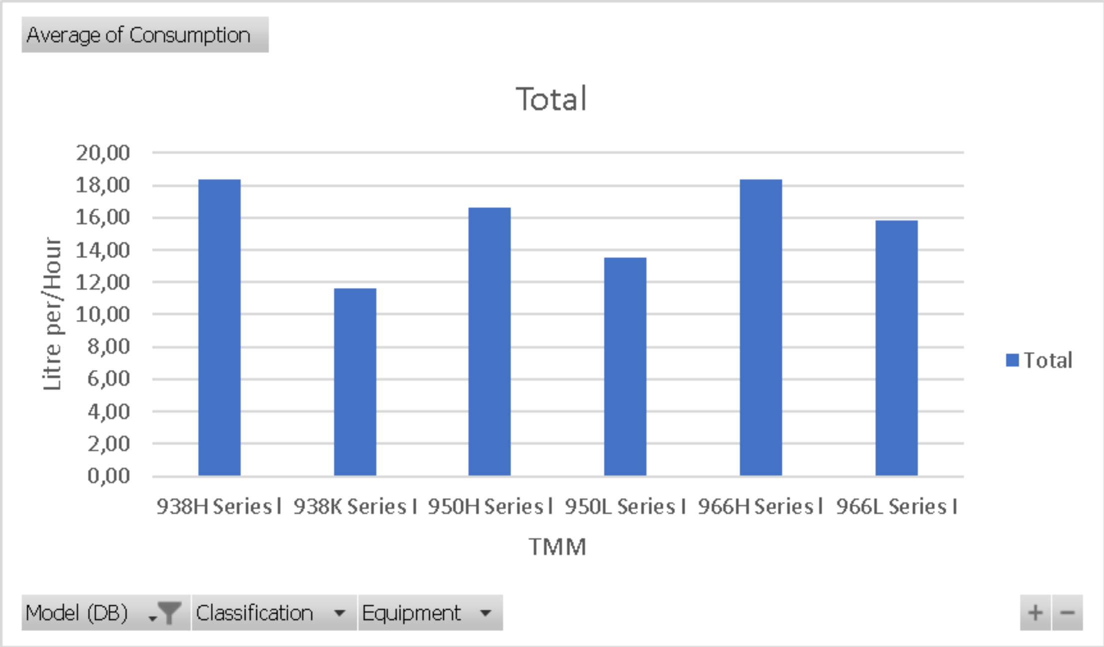

Figure 10 Average fuel consumption rate for conventional and modern front-end loaders

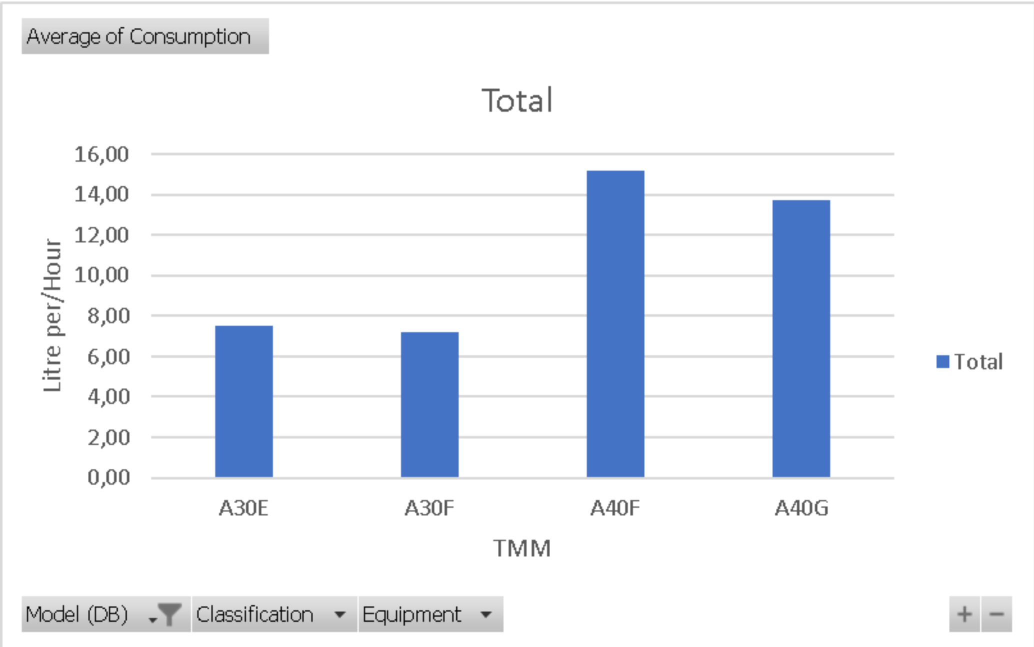

Figure 11 Average fuel consumption rate for conventional and modern articulated dump trucks

4.4 OPTIMISATION OF THE APPLICATION OF TMMs

4.4.1 Investment profitability metrics

In order to reduce a project's investment risk and make profitable decisions for enterprises, NPV, IRR, and PI can be applied. In investment decision-making, the NPV, IRR, and PI methods are widely used (Huang *et al*., 2022:71; Uçtu *et al.*, 2021:25). NPV, IRR, and PI calculations include the time value of money and are widely regarded as useful and practical (Sun, 2022:6; Uçtu *et al.*, 2021:25).

Based on the results presented in sections 4.2.1, 4.2.2 and 4.2.3, Almar will benefit more from investing in modern TMMs over the long-term from both a market and capital investment perspective. However, the results do not indicate at which stage and at which ratio conventional TMMs should be considered over modern TMMs. For this purpose, the fraction that conventional and modern TMMs contribute to the PI at different years was calculated according to equation 6.

$$f_{PI\ conventional,t} + f_{Pimodern,t} = PI_{Tt}; \quad 0 \leq f \leq 1. \qquad 6$$

PI conventional and PI modern indicate the PI at year t for conventional and modern TMMs, respectively. P_{ITt} indicates the total PI at year t ,and t varies from one to seven years. By performing the analysis in this way, the results in Table 22 were obtained. The data in Table 22 can further be used to generate graphs that indicate the optimal ratio, $f_{PI\ conventional,t}/f_{Pimodern,t}$, at a specific year where Pi conventional and PI modern make even contributions to the PI as well as the years where modern TMMs become better investment opportunities. These graphs are shown in Figures 12a and 12b and 13a and 13b, respectively.

Table 22 Calculated PI values at different years and $f_{PI\ conventional.t}/f_{Pimodern.t}$

			Year						
			PI_T						
$f_{PI\ conventional.t}/f_{Pimodern.t}$	$f_{PI\ conventional.t}$	$f_{Pimodern.t}$ a	1	2	3	4	5	6	7
0.11	0.1	0.9	0.355	0.649	0.893	1.09	1.26	1.40	1.51
0.25	0.2	0.8	0.361	0.658	0.902	1.10	1.26	1.40	1.51
0.43	0.3	0.7	0.368	0.667	0.911	1.11	1.27	1.40	1.51
0.67	0.4	0.6	0.374	0.676	0.920	1.12	1.27	1.40	1.50
1.0	0.5	0.5	0.380	0.685	0.928	1.12	1.28	1.40	1.50
1.5	0.6	0.4	0.387	0.694	0.937	1.13	1.28	1.40	1.50
2.33	0.7	0.3	0.394	0.703	0.946	1.14	1.29	1.41	1.50
4.0	0.8	0.2	0.400	0.712	0.955	1.14	1.29	1.41	1.50
9.0	0.9	0.1	0.406	0.721	0.964	1.15	1.30	1.41	1.50

Figure 12a and 12b show that at 6.5 years and a total profitability index of 1.408, the contributions of conventional and modern TMMs to the PI are the same. At year seven, Figures 13a and 13b show that for the whole range of $f_{PI\ conventional,t}/f_{Pimodern}$, and t, the trend is opposite than those at years one to six. It is evident from the calculated PI_T that at different $f_{PI\ conventional,t}/f_{Pimodern,t}$ ratios, the use of more than 50% ($f_{PI\ conventional,t}$ = 0.5 and $f_{Pimodern,t}$ = 0.5) up to 90% ($f_{PI\ conventional,t}$ = 0.1 and $f_{Pimodern,t}$ = 0.9) using modern TMMs in hauling operations is an advantageous investment strategy for Almar's client in year seven. At all the years studied, the PIt becomes constant at fPI conventional,t/fPimodern,t > 4, suggesting that using larger fractions of conventional TMMs at these ratios is more advantageous.

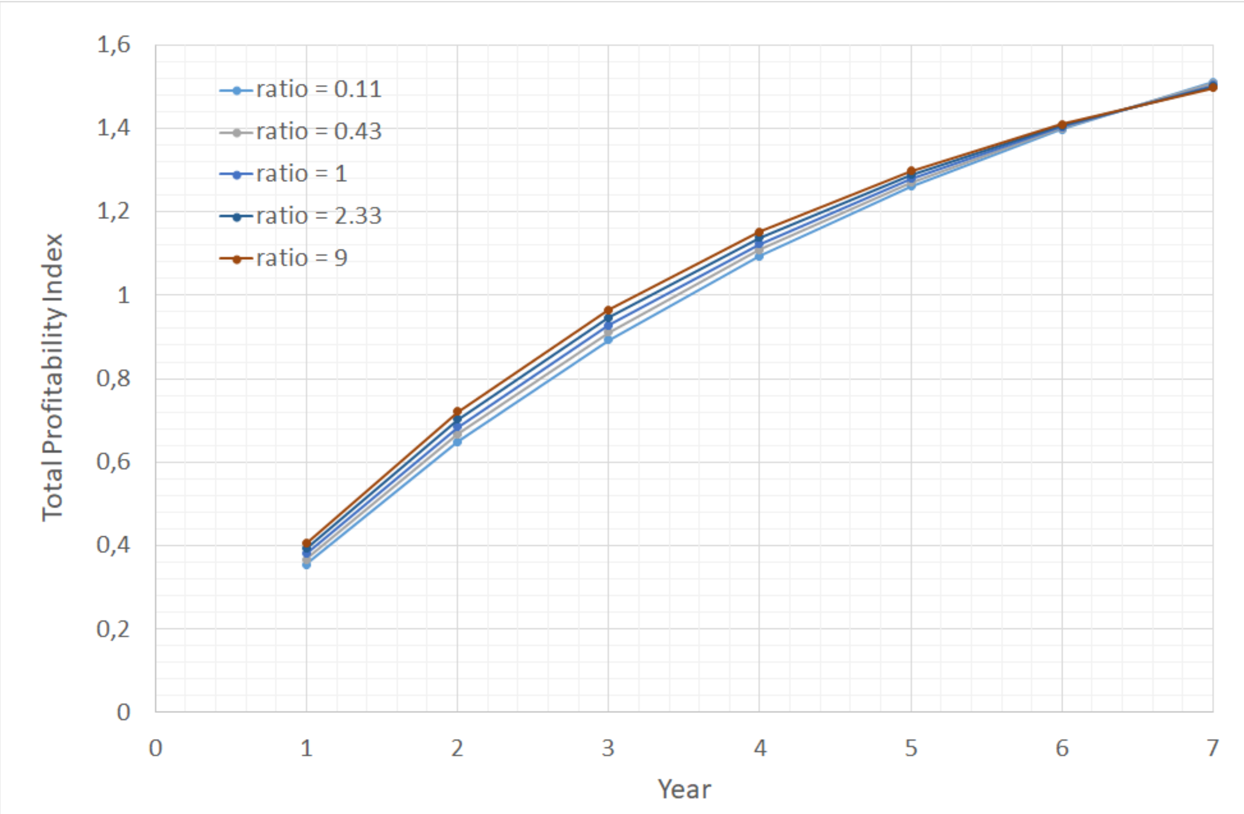

Figure 12a Total profitability index as a function of year. 1 ≤ year ≤ 7.

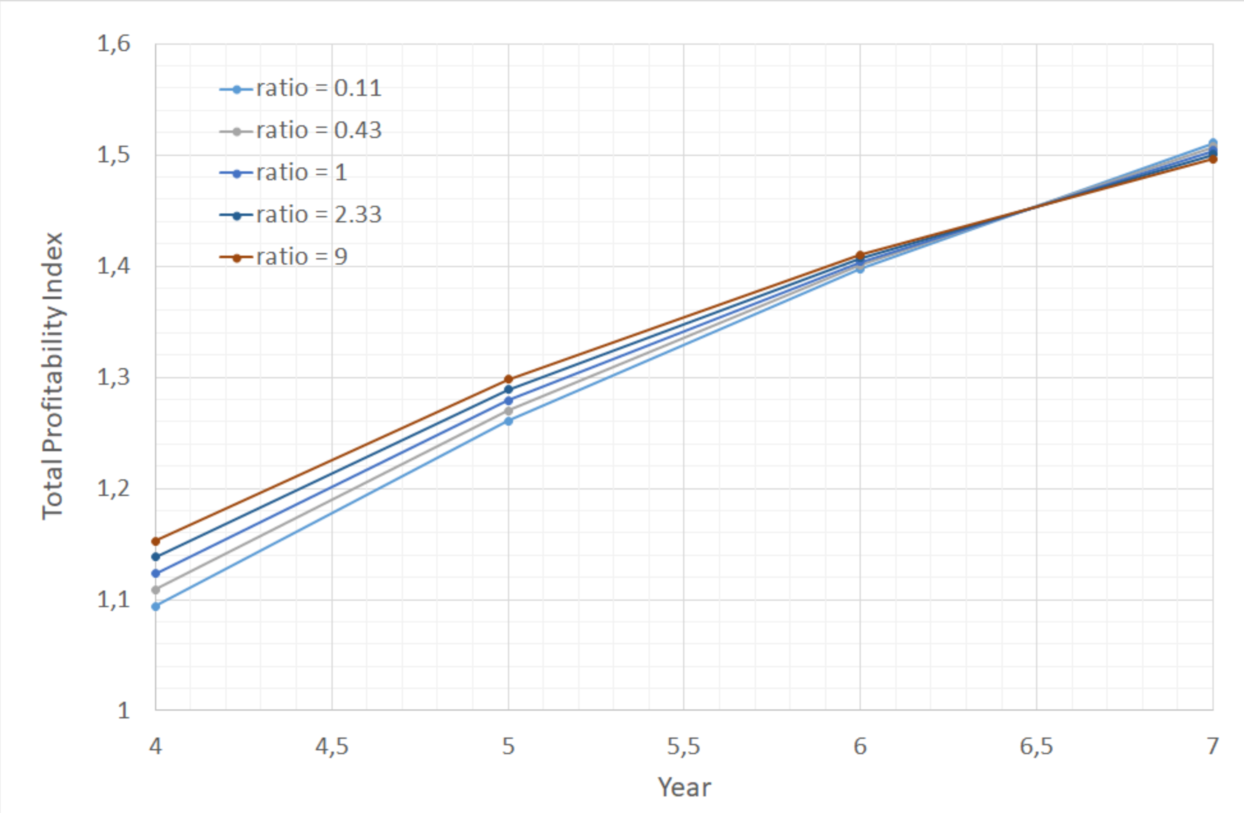

Figure 12b Total profitability index as a function of year. 4 ≤ year ≤ 7.

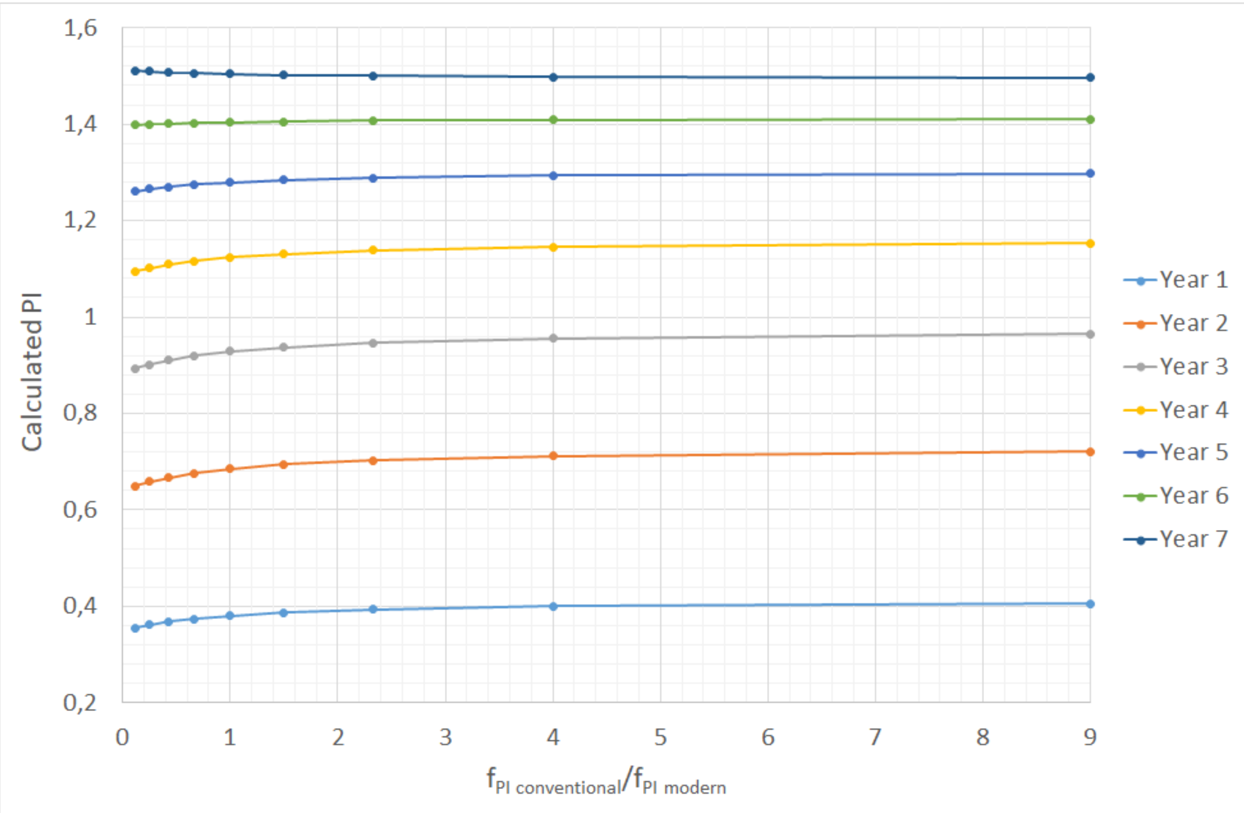

Figure 13a Total profitability index as a function of $f_{PI\ conventional,t}/f_{Pimodern,t.}$ 1 ≤ year ≤ 7.

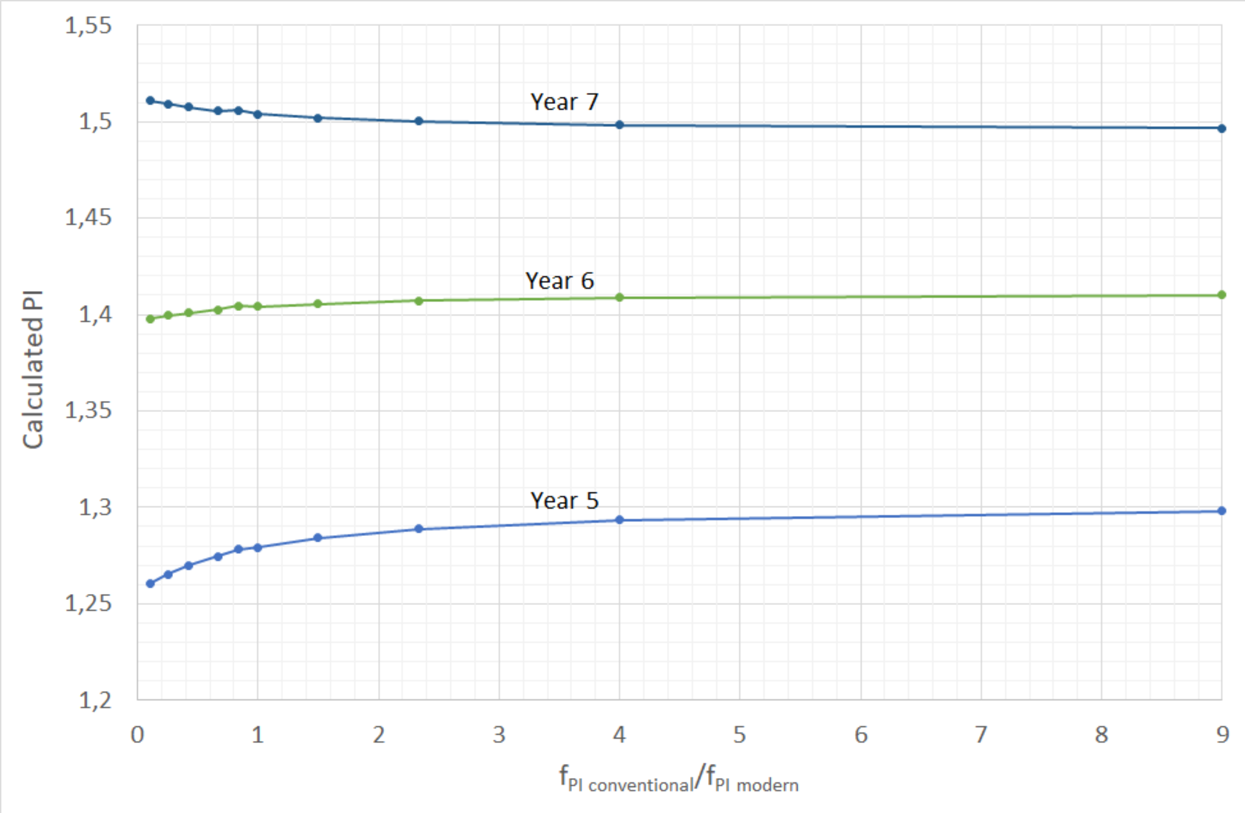

Figure 13b Total profitability index as a function of $f_{PI\ conventional,t}/f_{PImodern,t}$. 5 ≤ year ≤ 7.

4.5 SUMMARY

The data obtained from Almar's database were used to compile tables that showed the TMM age (modern and conventional), where it becomes advantageous to use an increased number of modern TMMs in the client's on-site bulk material handling operations. The data for front-end loaders and articulated dump trucks were employed in the study because these TMMs are used most often in the haulage operations of the client company.

Factors considered in decision-making when modern ones should replace conventional TMMs are the breakdown frequency, standing time per TMM life cycle and TMM category, TMM availability and utilisation, TMM breakdown frequency, availability and breakdown component frequency, and fuel consumption. The results showed that conventional TMMs experience the most breakdowns after 15 000 to 20 000 hours, reaching a maximum frequency of breakdowns at hours more than 25 000 (~ 3 years). If all the TMMs are considered, the downtime frequency reaches a maximum of between 15 000 and 20 000 hours (1.7 to 2.3 years). Breakdown frequencies were 23.7 % and 17.3 % for front-end loaders and articulated dump trucks, respectively. The fuel consumption of conventional TMMs (ADT and FEL) was generally higher than that of modern TMMs (ADT and FEL.

Calculations using the PI index at an increment of one year up to seven years show that at 6.5 years and a total profitability index of 1.408, the contributions of conventional and modern TMMs to the PI are the same. Over long periods (years six and seven), using more than 50% and up to 90% modern TMMs in on-site bulk material handling operations is an advantageous investment strategy for Almar's client.

CHAPTER 5: FINDINGS AND CONCLUSIONS

5.1 INTRODUCTION

This study aims to compare conventional and modern TMMs within a chrome smelting site for the optimisation of hauling operations. The goal is to determine the balance between the application of conventional and modern TMMs in the current fleet in order to optimise productivity. In addition, the current and future technology available to the industry also referred to as conventional and modern TMMs, and the application thereof in the industry was considered.

Consequently, the primary objective of this study is formulated in Chapter 1, which is finding a balance in the application of conventional and modern TMMs for on-site bulk material handling. Furthermore, the aim was to optimise current business operations and investigate new solutions with advances to stay relevant. The literature review in Chapter 2 provides a literature-based analysis of the South African mining industry, chrome smelting operations, and aspects to consider for efficient TMM service delivery. In Chapter 3, details are provided in terms of the research methodology, how information for analysis was gathered, and the process of analysing using the organisation's database. Chapter 3 establishes the basis for analysing the data. Chapter 4 provides the analysis of the data and a cost–benefit analysis, together with a discussion of the results. The current chapter, Chapter 5, concludes the results and discussion in Chapter 4.

Based on the results of this study, conclusions are drawn within this chapter. Additionally, the shortcomings of the study are identified, and recommendations for the optimisation of the application of conventional and modern TMMs in chrome smelting are made. Lastly, the meaning of the results is summarised in terms of managerial implications.

5.2 CONCLUSIONS

5.2.1 Findings from the literature study

A variety of topics were considered for the optimum application of conventional and modern TMMs in the chrome mining industry. The literature study showed the following optimisation considerations:

- It is possible to maximise productivity by exploiting the advantages and disadvantages of conventional and modern TMMs.
- One of the primary considerations when choosing between the application of conventional and modern TMMs is safety issues. Enhanced safety features of modern TMMs make them ideal for use in chrome mine haulage operations.

Optimisation approaches that were distilled from the open literature are the following:

- Gradually replacing conventional TMMs with modern ones when the operation life of the former exceeds that of the latter is advocated.
- Calculating the optimal fraction of conventional and modern TMMs in terms of optimal productivity is necessary.
- Determining an optimum application of conventional and modern TMMs according to the vehicle replacement theory is essential.
- Alternative solutions, such as lower TMM costs, better sale prices or prolonged life, should be considered rather than replacing conventional TMMs with modern ones.
- Automation, maintenance, and training should also be considered when determining the optimum application for conventional and modern TMMs in chrome smelting operations.

Automation increases productivity and, therefore, market competitiveness. Various standards and practices approaches can be distinguished, aiming to achieve a high standard of maintenance procedures and practices for underground mobile mining equipment, essential for high business competition and complying with strict environmental laws and regulations.

A company's on-site bulk material handling operations fall in the realm of value and supply chain management. Supply chain management is important because it plays a role in achieving a competitive advantage. A supply chain management strategy relies on supply chain partners to reduce costs, increase forecast accuracy, increase profits, and improve inventory control.

Supply chain management is important because it manages service delivery or processes that create and deliver a product. Within the value chain, multiple steps are involved, such as research and development, sales, and everything else required to ensure the product is manufactured and delivered or the service is rendered. Porter's Five Forces Strategic Management Framework assists organisations in identifying their competitive advantage within the value chain.

Data obtained from Almar’s database were used to compile tables that showed the TMM age (modern and conventional), where it becomes advantageous to use an increased number of modern TMMs in the client’s haulage operations. Data for front-end loaders and articulated dump trucks were employed in the study because these TMMs are used most often in the haulage operations of the client company.

5.2.2 Findings from the empirical study

Conventional TMMs experience the most breakdowns after 15 000 to 20 000 hours, reaching a maximum frequency of breakdowns at hours larger than 25 000 (~ 3 years). If all the TMMs are considered, downtime frequency reaches a maximum between 15 000 and 20 000 hours (1.7 to 2.3 years). For front-end loaders and articulated dump trucks, breakdown frequencies were 23.7% and 17.3%, respectively. The fuel consumption of conventional TMMs (ADT and FEL) was generally higher than that of modern TMMs (ADT and FEL).

Calculations using the PI index at increments of one to seven years show that at 6.5 years and a total profitability index of 1.408, the contributions of conventional and modern TMMs to the PI are the same. Over long periods (year's six and seven), using more than 50% and up to 90% modern TMMs in hauling operations is an advantageous investment strategy for Almar Investments' clients.

Thus, at this time, there will always be a situation where both conventional and modern TMMs are used in the hauling operations of the chrome mining industry. After two to three years of use, a favourable investment decision would be to replace redundant conventional TMMs with modern ones.

5.3 RECOMMENDATIONS

Although the organisation has many structures, systems, and parameters and effectively makes operational and business decisions, improvements are possible and available. Recommendations that can be made are designing a system based on managerial calculations for TMM replacement when it can be justified in terms of optimal productivity. These calculations would include TMM costs, downtime, and residual and replacement value to optimise TMM application through a calculated replacement of conventional TMMs with modern TMMs to optimise productivity. In this context, residual value refers to the estimated value of a fixed asset at the end of its lease term or useful life.

Further recommendations would be a more detailed analysis of breakdowns and causes, striving to eliminate unnecessary downtime. The results of this study showed that downtime can be minimalised if higher percentages of modern TMMs are employed in hauling operations. If the organisation is in a financial position to purchase more modern TMMs regularly, services and maintenance agreements with OEM suppliers could be made, reducing overhead costs in terms of spares kept in consignment and reducing overhead maintenance labour cost. Further discussions with OEM suppliers regarding buy-back agreements could ensure that fixed buy-back amounts from OEM suppliers can be negotiated. This strategy links to the first recommendation and ensures accurate future capital planning and replacement.

5.4 SHORTCOMINGS OF THE STUDY

The best available resources, knowledge, and methods were applied in developing models and evaluating data in the research. However, considering variables and study shortcomings could contribute to developing a more accurate model.

One of the major shortcomings of this study is the ever-changing environment in the chrome mining and smelting processes, which complicates the set of findings in this study due to ever-changing data. The studied organisation should adapt its TMM hauling operations to these changes because TMM service delivery is production-driven. Data was taken over a relatively long period of seven years, but for more accurate cost-benefit analysis, data over even longer periods should be considered.

There are also shortcomings in terms of data quantity and quality. The fast diversification of TMM types, different TMM operations, different sites and the scale of operations imply that evaluating and presenting all data would be more accurate. The scale of such an endeavour would be more accurate, but it will present challenges to the researcher regarding data presentation and analysis in a mini-dissertation. Therefore, another shortcoming of this study is the insufficient quantity of data to represent the factors mentioned above.

Access to all relevant information from the same organisation also limits the study. The slow adoption of cutting-edge technology within a Third World country constitutes a limitation in the direct evaluation of modern TMMs for future application.

5.5 MEETING RESEARCH OBJECTIVES

Secondary research objective 1: ‘study the relationship between conventional and modern TMMs, which could ultimately improve the equipment's optimisation and sustainability.’ This objective has been reached through both the analysis of Almar’s data that shows the replacement of conventional TMMs with modern ones after ~2 years.

Secondary research objective 2: ‘analyse future technological advancements in the operational field.’ Modern TMMs were included in the analysis strategy followed in this study (section 4.3.2).

Secondary research objective 3: ‘analyse the impact of technological advancement on sustainability.’ This study found that sustainability in the company’s haulage operations is achieved through the timeous implementation of modern TMMs.

Secondary research objective 4: ‘establish the relationship between conventional and modern TMMs and their influence on profitability.’ This has been achieved by calculating investment profitability metrics and using the PI to determine the application of the optimum percentages of conventional and modern TMMs in the client’s haulage operations.

Secondary research objective 5: ‘examine the relationship between conventional and modern TMMs to optimise operation profits.’ This has been achieved by optimising the PI when conventional and modern TMMs are applied at different ratios.

5.6 HYPOTHESIS TESTING

The study established that a blend of conventional and modern TMMs can be optimally applied to increase the productivity of on-site bulk material handling in South African chrome mines.

5.7 SUMMARY OF THE CHAPTER

TMMs are used in various applications. Understanding the essence of the business and the type of service rendered with TMMs within the business is vital for optimisation. A manager can only manage what he/she can measure. Almar Investments has been operating since 1996 and has a good track record. With the large amount of available data, the organisation keeps track of all variables daily. This information can be used in a more detailed structure for daily optimisation if properly analysed.

The ultimate goal of sustainability through optimisation is reached by adopting crucial data analysis to understand when and how conventional TMMs should be replaced with modern ones. As a result, the organisation will be a custodian of this type of business for the future if they utilise modern equipment to the extent of practical business applications.

REFERENCES

Abdalla, M.Y. 2014. *Role of Total Quality Management in Setting Occupational Safety and Health Management System in Small and Medium Size Organizations*. Sudan: Sudan University of Science and Technology. (Thesis - MSc)

Abosede, A. & Onanuga, A.T. 2016. Research design: a review of features and emerging developments. *European Journal of Business and Management*, 8(11):113-118.

Adams, J., Khan, H.T.A. & Raeside, R. 2014. *Research Methods for Business and Social Science Students*. 2nd ed. India, New Delhi: SAGE.

Adams, R., Adeleke, F., Anderson, D., Bawa, A. & Branson, N. 2021. POPIA code of conduct for research. *Discussions on POPIA*, 117(5/6):1-12.

Afonasova, M.A., Panfilova, E.E., Galichkina, M.A. & Ślusarczyk, B. 2019. Digitalization in economy and innovation: the effect on social and economic processes. *Polish Journal of Management Studies*, 19(2):22-32.

Africa Mining. 2017. *Chrome mining in South Africa*. https://projectsiq.co.za/chrome-mining-in-south-africa.htm. Date of access: 20 Nov. 2023.

African Rainbow Minerals (ARM). 2021. *Mineral Resources and Mineral Reserves Report 2021.* https://arm.co.za/wp-content/uploads/2021/10/ARM-MRMR-Report-2021-FINAL..pdf, Date of access: 13 Oct. 2023.

Aguayo, I.A.O., Nehring, M. & Ullah, G.M.W. 2021. Optimising productivity and safety of the open pit loading and haulage system with a surge loader. *Mining*, 1:167-179.

Ahiakwo, N.I., Egwuonwu, A.C. & Okeke, O.C. 2018. A review of the geology and mineral resources of South Africa. *International Journal of Advanced Academic Research*, 4:90-121.

Ahmad, S., Wasim, S., Irfan, S., Gogoi, S., Srivastava, A. & Farheen, Z. 2019. Qualitative v/s Quantitative Research- A Summarized Review. *Journal of Evidence Based Medicine and Healthcare*, 6(43):2828-2832.

Ahsan, A. 2018. The Effect of Cost's on Profitability: An Analysis on Small Manufacturing Businesses. *International Journal of Business and Management Invention*, 7(9):71-81.

Akhter, B., Uddin, M.B. & Jahan, L.B. 2018. Theories of Supply Chain Management: A Critical Analysis. *The Cost and Management*, 46(1):30-39.

Aksoy, S. & Kahraman, M. 2015. A Study of the Effects of Total Quality Management on Occupational Safety Regulations. *European Journal of Social Sciences*, 2(1):146-155.

Ali, A. & Abdelhadi, A. 2022. Condition-Based Monitoring and Maintenance: State of the Art Review. *Applied Sciences*, 12(688):1-18.

Ali, Z. & Bhaskar, S.B. 2016. Basic statistical tools in research and data analysis. *Indian Journal of Anaesthesia*, 60:662-669.

Álvarez-Santos, J., Miguel-Dávila, J-A., Herrera, L. & Nieto, M. 2018. Safety Management System in TQM environments. *Safety Science*, 101:135-143.

Amemba, C.S., Nyaboke, P.G., Osoro, A. & Mburu, M. 2013. Elements of Green Supply Chain Management. *European Journal of Business and Management*, 5(12):51-61.

Anning-Dorson, T., Christian, I.O. & Nyamekye, M.B. 2020. *Customer Service Management in Africa.* New York: Productivity Press.

Antwi, S.K. & Hamza, K. 2015. Qualitative and Quantitative Research Paradigms in Business Research: A Philosophical Reflection. *European Journal of Business and Management*, 7(3):217:225.

Apuke, O.D. 2017. Quantitative research methods: A synopsis approach. *Arabian Journal of Business and Management Review (Kuwait Chapter)*, 6(10):40-47.

Automine. 2020. *Automine® equipment automation and teleoperation systems*. https://www.rocktechnology.sandvik/en/products/automation/automine-equipment-and-teleoperation-systems/?utm_source=google&utm_medium=cpc&utm_campaign=&utm_term=&utm_content=&gclid=Cj0KCQiA8t2eBhDeARIsAAVEga3z8c0P37uXz9ldBz1ZmZIkgm_vIgjHXFX6gz45MR4FqV_7Az3rGLUaAjLQEALw_wcB. Date of access: 30 Jan. 2023.

Baatartogtokh, T. 2014. *State of outsourcing in the mining industry: An overview*. Vancouver: The University of British Columbia. (Thesis – MSc).

Baran, M. & Jones, J. 2017. *Mixed Methods Research for Improved Scientific Study*. USA, Cardinal Strich: IGI Global.

Bartelmus, W. 2014. Object and operation supported maintenance for mining equipment. *Mining Science*, 21:7-21.

Besterfield, D.H., Besterfield, C., Besterfield, G.H., Besterfield, M., Urdhwareshe, H. & Urdhwareshe, R. 2012. *Total Quality Management*. India, Delhi: Dorling Kindersley.

Bick, G. & Sidubi, F. 2018. Mitchell's Brewery: entrepreneurship challenges in the South African craft beer industry. *Emerald Emerging Markets Case Studies*, 8(4):1-35.

Biggemann, S., Maley, J. & Kowalkowski, C. 2014. *Outsourcing core competencies in the mining industry: Reshaping management discourse to achieve impact*. https://www.semanticscholar.org/paper/Outsourcing-core-competencies-in-the-mining-to-Biggemann-Maley/9374891fb8030f93bab7b7ebcf02c98ed00b8713. Date of access: 20 Oct. 2023.

Bisschoff, C. & Liebenberg, P. 2016. *Identifying factors that influence green purchasing behavior in South Africa.* South Africa, Potchefstroom: North West University. (Thesis – MSc)

Blumenthal, M. & Weiche, A. 2017. Build a Better Business Using Customer Complaints. *Get Five Stars*, 1-43.

Boudreault, F. 2019. Electric Vehicles. Electrifying the underground mining industry; The shift to electric vehicles. *Mining Engineering*, 34-39.

Brans, P. 2023. *Markov model*. https://www.techtarget.com/whatis/definition/Markov-model Date of access: 25 Sept. 2023.

Brigham, E.F. & Ehrhardt, M.C. 2016. *Financial management. Theory & Practice*. 15th ed. Boston, Massachusetts, United States: Cengage Learning

Britannica. 2023. *South Africa – Resources, Power, Economy*. https://www.britannica.com/place/South-Africa/Resources-and-power. Date of access: 8 Nov. 2023.

Brundrett, S. 2014. *Industry analysis of autonomous mine haul truck commercialization*. Canada, Vancouver: Simon Fraser University.

Callen, T. 2023. *Gross Domestic Product: An Economy's All*. https://www.imf.org/en/Publications/fandd/issues/Series/Back-to-Basics/gross-domestic-product-GDP. Date of access: 20 Nov. 2023.

Camilleri, M.A., 2017. Market Segmentation, Targeting and Positioning. Camilleri, MA (2018). Market Segmentation, Targeting and Positioning. In Travel Marketing, Tourism Economics and the Airline Product, pp.69-83.

Carter, R.A. 2020. *Moving Ahead in the Material World*. https://www.e-mj.com/features/moving-ahead-in-the-material-world/. Date of access: 6 Feb. 2023.

Cartier, L.E. & Bürge, M. 2011. Agriculture and artisanal gold mining in Sierra Leone: Alternatives or complements? *Journal of International Development*, 23:1080-1099.

Cash, P., Stanković, T. & Štorga, M. 2016. *Experimental Design Research. Approaches, Perspectives, Applications*. Midtown Manhattan, New York City: Springer.

Caterpillar. 2023. *Boost safety and increase machine utilization*. https://www.cat.com/en_US/by-industry/mining/underground-mining/underground-technology/command.html. Date of access: 6 Feb. 2023.

CCICED. 2021. *Global Green Value Chains: China's Opportunities, Challenges and Paths in the Current Economic Context*. https://cciced.eco/wp-content/uploads/2021/09/4-2-Global-Green-Value-Chains.pdf. Date of access: 22 Oct. 2023.

Charumbira, L.T. 2013. The Philosophical and Methodological Approaches Used by Sport and Business Management Student Researchers in Zimbabwe. *Global Journal of Commerce & Management Perspective*, 2(6):51-56.

Chopra, S. & Meindl, P. 2013. *Supply Chain Management. Strategy, Planning, and Operation*. 5th ed. USA, Boston: Pearson.

Collis, J. & Hussey. R. 2014. *Business Research : A practical guide for undergraduate & postgraduate students*. Basingstoke, Hampshire: Palgrave Macmillan.

Construction Equipment Guide.com. 2023. *Catterpillar wheel loaders*. https://www.constructionequipmentguide.com/charts/wheel-loaders/caterpillar. Date of access: 11 Oct. 2023.

Cote, C. 2021a. *What is Diagnostic Analytics? 4 examples.* https://online.hbs.edu/blog/post/diagnostic-analytics. Date of access:14 Nov. 2022.

Cote, C. 2021b. *5 Principles of data ethics for business.* https://online.hbs.edu/blog/post/data-ethics#:~:text=What%20Is%20Data%20Ethics%3F,and%20how%20it%20affects%20individuals. Date of access: 4 Nov. 2022.

Couto, J., Tiago, T., Gil, A., Tiago, F. & Faria, S. 2016. It's hard to be green: Reverse green value chain. *Environmental Research*, 149:302-313.

Creamer Media's Mining Weekly. 2023. *Finding new ways to boost the competitiveness of South African mining*. https://www.miningweekly.com/article/finding-new-ways-to-boost-the-competitiveness-of-south-african-mining-2023-02-17. Date of access: 29 Aug. 2023.

Creswell, J.W. 2002. *Educational research: Planning, conducting, and evaluating quantitative and qualitative research*. 4th ed. London, UK: Pearson Education.

Creswell, J.W. 2013. *Qualitative Inquiry & Research Design. Choosing among five approaches.* 3rd ed. USA, Los Angeles: Sage.

Creswell, J.W. 2014. *Research design. Qualitative, quantitative and mixed methods approaches*. 4th ed. Thousand Oaks, California: SAGE Publications.

DAC.digital. 2023. *The future of autonomous vehicles and autonomous machines*. https://dac.digital/the-future-of-autonomous-vehicles-and-autonomous-machines/. Date of access: 27 Oct. 2023.

Daniela, N. & Ovidiu, R. 2014. Why do logistics and transport matter for development? *Annals of the University of Oradea, Economic Science Series*, 23(1):34-39.

Dash, A.K., Bhattcharjee, R.M., Paul, P.S. and Tikader, M. 2015. Study and analysis of accidents due to wheeled trackless transportation machinery in Indian coal mines – Identification of gap in current investigation system. *Procedia Earth and Planetary Science*, 11:539-547.

Dawadi, S., Shrestha, S., & Giri, R.A. 2021. Mixed-Methods Research: A Discussion on its Types, Challenges, and Criticisms. *Journal of Practical Studies in Education*, 2(2):25-36.

Del Prete, D. & Rungi, A. 2019. *Backward and Forward integration along Global Value Chains*. file:///C:/Users/User/Downloads/RSCAS2019_91.pdf. Date of access: 20 Oct. 2023.

DCED. 2012. *Green Value Chains to Promote Green Growth*. https://www.enterprise-development.org/wp-content/uploads/Green_Value_Chains_to_Promote_Green_Growth.pdf. Date of access: 22 Oct. 2023.

Department of Mineral and Resources. 2015. *Guideline for the compilation of a mandatory code of practice for Trackless Mobile Machines.* https://www.gov.za/sites/default/files/gcis_document/201509/39228gon855.pdf. Date of access: 5 Feb. 2023.

Department: Mineral Resources Republic of South Africa. 2016. South Africa's mineral industry 2014/2015 - SAMI. 32nd ed. Pretoria, South Africa: Director: Mineral Economics, Trevenna Campus.

Department National Treasury, Republic of South Africa. 2023. *2023 Budget Review Economic Outlook*. https://www.treasury.gov.za/documents/mtbps/2023/mtbps/FullMTBPS.pdf. Date of access: 25 Oct. 2023.

De Smith, M.J. 2021. *Statistical Analysis Handbook. A Comprehensive Handbook of Statistical Concepts, Techniques and Software Tools*. Ireland, Limerick: Drumlin Publications.

Dlamini, R. & von Blottnitz, H. 2023. Resource Intensity Trends in the South African Ferrochrome Industry from 2007 to 2020. *Minerals*, 13(44):1-16.

Dolnicar, S., Grün, B. & Leisch, F. 2018. *Market segmentation analysis: Understanding it, doing it, and making it useful*. Gateway East, Singapore: Springer Nature Singapore Pte Ltd.

Doyle, L., Brady, A-M. & Byrne, G. 2009. An overview of mixed methods research. *Journal of Research in Nursing*, 14:175-185.

Doyle, L., Brady, A.M., & Byrne, G. 2016. An overview of mixed methods research – Revisited. *Journal of Research in Nursing*, 21(8):623-635.

Dreschler, B. 2001. Small-scale Mining and Sustainable Development within the SADC Region. *Mining Minerals and Sustainable Development*, 84:1-165.

Dubey, S.K., Singh, R., Singh, S.P., Mishra, A. & Singh, N.V. 2020. *A brief study of value chain and supply chain*. https://www.researchgate.net/publication/344374264_A_BRIEF_STUDY_OF_VALUE_CHAIN_AND_SUPPLY_CHAIN/link/5f6d8afaa6fdcc00863a6f0b/download. Date of access: 22 Oct. 2023.

Du Preez, S.P, Van Kaam, T.P.M., Ringdalen, E. & Tangstad, M. 2023. An Overview of Currently Applied Ferrochrome Production Processes and Their Waste Management Practices. *Minerals*, 13(809):1-35.

Dźwigoł, H. & Barosz, P. 2020. Observation as a research method in social science. *Scientific papers of Silesian University of Technology. Organization and Management Series*, 148:141-149.

EconomicsEssays. 2009. *Importance of Economic Growth.* https://econ.economicshelp.org/2009/11/importance-of-economic-growth.html. Date of access: 11 Oct. 2022.

Economist Intelligence. 2023. *African mining sector looks to the future*. https://country.eiu.com/article.aspx?articleid=1542867137&Country=South+Africa&topic=Economy&subt_1. Date of access: 29 Aug. 2023

Egerton, F.M.G. 2004. Presidential Address: The mechanisation of UG2 mining in the Bushveld Complex. *The Journal of The South African Institute of Mining and Metallurgy*, 439-450.

Egger, P.H.; Erhardt, K. & Masllorens, G. 2021: *Backward Versus Forward Integration of Firms in Global Value Chains*. https://www.econstor.eu/bitstream/10419/236653/1/cesifo1_wp9111.pdf. Date of access: 20 Oct. 2023.

El Nemr, A.M. 2022. Evaluation of The Factors Affecting The Maintenance and Operation Cost of Administrative Buildings in Egypt. *International Journal of Engineering Research & Technology*, 11(2):333-341.

Epiroc. 2020. *Automation and information management underground*. https://www.epiroc.com/en-ba/innovation-and-technology/automation-and-information-management/automation-and-information-management-underground. Date of access: 30 Jan. 2023.

Farida, I. & Setiawan, D. 2022. Business Strategies and Competitive Advantage: The Role of Performance and Innovation. *Journal* of *Open Innovation*: *Technology*, Market, and Complexity, 8(163):1-16.

Feilzer,M.Y. 2010. Doing Mixed Methods Research Pragmatically: Implications for the Rediscovery of Pragmatism as a Research Paradigm. *Journal of Mixed Methods Research*, 4(1):6-16.

Fernando, J. 2024. *Capital Expenditure (CapEx) Definition, Formula, and Examples*. https://www.investopedia.com/terms/c/capitalexpenditure.asp Date of access: 5 Feb. 2024.

Filip, A. 2023. Complaint management: A customer satisfaction learning process. *Procedia - Social and Behavioral Sciences*, 93:271-275.

Gaber, T., El Jazouli, Y., Eldesouky, E. & Ali, A., 2021. Autonomous haulage systems in the mining industry: Cybersecurity, communication and safety issues and challenges. *Electronics*, 10(11):1-13.

Garcia, R., Santos, U.P.D. and Suzigan, W., 2021. Industrial upgrade, economic catch-up and industrial policy in Brazil: general trends and the specific case of the mining industry. *Nova Economia*, 30:1089-1114.

Gautam, A.K. & R. Prabhakar, 2019. Theories of supply chain management: a literature review. *International Journal of Innovative Social Science & Humanities Research*, 6(1):88-98.

Goedhart, M., Levy, P. & Morgan, P. 2015. A better way to understand internal rate of return. https://www.mckinsey.com/capabilities/strategy-and-corporate-finance/our-insights/a-better-way-to-understand-internal-rate-of-return Date of Access: 2 Nov. 2023.

Goodall, N. 2020. Non-Technological Challenges for the Remote Operation of Automated Vehicles. *Transportation Research Part A: Policy and Practice*, 142(2020):14–26,

Govender, J.P. & Govender, T.L. 2016. The influence of green marketing on consumer purchase behavior. *Environmental Economics*, 7(2):77-85.

Gudivada, V.N., Irfan, M.T., Fathi, E. & Raovava, D.L. 2016. Cognitive Analytics: Going Beyond Big Data Analytics and Machine Learning. *Handbook of Statistics*, 35:169-205

Gumede, H., 2018. The socio-economic effects of mechanising and/or modernising hard rock mines in South Africa. *South African Journal of Economic and Management Sciences*, 21(1):1-11.

Gustafson, A. 2013. *Automation of Load Haul Dump Machines. Comparative Performance Analysis and Maintenance Modeling.* Sweden, Lulea: Lulea University of Technology. (Thesis : PhD).

Gustafson, A., Lipsett, M., Schunnesson,H., Galar, D. & Kumar, U. 2014. Development of a Markov model for production performance optimisation. Application for semi-automatic and manual LHD machines in underground mines. *International Journal of Mining, Reclamation and Environment*, 28(5):342-355.

Gustafson, A., Paraszczak, J. Tuleau, J. & Schunnesson, H. 2017. Impact of technical and operational factors on effectiveness of automatic load-haul-dump machines. *Mining Technology*, 126(4):185-190.

Habiyaremye, A., King, N.A. & Tregenna, F. 2022. *Innovation and socio-economic development challenges in South Africa: An overview of indicators and trends. SARChI Industrial Development Working Paper Series, WP 2022-03*. https://www.uj.ac.za/wp-content/uploads/2021/10/sarchi-wp-2022-03-habiyaremye-king-tregenna-march-2022.pdf. Date of access: 10 Oct. 2023

Haecker, R. 2021. The Light of the Leaf: A Theological Critique of Timothy Morton's 'Dark Ecology'. *Religions*, 12(755):1-12.

Halim, A., Lööw, J., Johansson, J., Gustafsson, J., van Wageningen, A. & Kocsis, K. 2022. Improvement of Working Conditions and Opinions of Mine Workers When Battery Electric Vehicles (BEVs) Are Used Instead of Diesel Machines — Results of Field Trial at the Kittilä Mine, Finland. *Mining, Metallurgy & Exploration*, 39:203-219.

Halim, A. 2022. *Recommended practices for battery electric vehicles in underground mining Version 3*. https://gmggroup.org/guidelines-and-publications/https-gmggroup-org-wp-content-uploads-2023-08-2022-06-23_recommended-practices-for-battery-electric-vehicles-in-underground-mining-pdf/. Date of access: 10 Oct. 2023.

Hewis, C.F. 1973. Trackless mining at the International Nickel Company of Canada, Limited. *Journal Of The South African Institute Of Mining And Metallurgy*, 1-10

Hill, A.B. 1965. The Environment and Disease: Association or Causation? *Proceedings of the Royal Society of Medicine*, 7-12.

Hilmi, M. 2021. The Green Food Value Chain Development Approach: Key Lessons Learnt. *Middle East Journal of Agriculture Research*, 10(2):453-471.

Hofstee, E. 2018. *Constructing a good dissertation*: *A practical guide to finishing a Master's, MBA or PhD on Schedule*. South Africa, Johannesburg: EPE.

Horst, R. & Zdziebko, J. 2021. Mechanization and automation in the production processes of Polska Grupa Górnicza S.A. *Mining – Informatics, Automation And Electrical Engineering*, 3(547):7-11.

Howcroft, D. & Trauth, E.M. 2005. *Handbook of Critical Information Systems Research*. UK, Cheltenham: Edward Elgar Publishing Limited.

Huang, J., Tong, J., Wang, P. & Zheng, X. 2022. Application and Comparison of NPV and IRR Methods in the Company Investment Decision. *Advances in Economics, Business and Management Research*, 211:71-78.

Hyman, M.R. & Sierra, J.J. 2016. Observational Methods in Marketing Research. *Business Outlook*, 14(8):1-5.

IFAC. 2020. *Understanding value creation*. https://www.ifac.org/_flysystem/azure-private/publications/files/Understanding-Value-Creation_0.pdf. Date of access: 2 Nov. 2023.

IM (International Mining). 2020. *Underground Load And Haul Sandvik AutoMine development team*. https://im-mining.com/site/wp-content/uploads/2020/06/Underground-Load-and-Haul-1.pdf. Date of access: 4 Feb. 2023.

IM (International Mining). 2023. *MineStar*. https://im-mining.com/tag/minestar/. Date of access: 4 Feb. 2023.

Indeed Editorial Team. 2023. *Defining and Understanding Integration Strategies in Business*. https://www.indeed.com/career-advice/career-development/integration-strategy. Date of access: 21 Nov. 2023.

Intrac. 2017. *Cost benefit analysis*. https://www.intrac.org/wpcms/wp-content/uploads/2017/01/Cost-benefit-analysis.pdf. Date of access: 27 Oct. 2023.

Isac, F.L. & Rusu, S. 2014. Theories Of Consumer's Satisfaction And The Operationalization Of The Expectation Disconfirmation Paradigm. *Annals of the „Constantin Brâncuşi" University of Târgu Jiu, Economy Series*, 2:82-88

Jenkins, A. 2023. *How Does Vertical Integration Work? Pros, Cons and Examples.* https://www.netsuite.com/portal/resource/articles/erp/vertical-integration.shtml. Date of access: 29 July 2023.

Jonathan, G.K. and Mbogo, R.W., 2016. Maintaining Health and Safety at Workplace: Employee and Employer's Role in Ensuring a Safe Working Environment. *Journal of Education and Practice,* 7(29):1-7.

Juhász, L. 2011. Net Present Value versus Internal Rate of Return. *Economics and Sociology*, 4(1):46-53.

Jung, Y.J. & Kim, Y. 2023. Research trends of sustainability and marketing research, 2010–2020: Topic modeling analysis. *Heliyon*, 9:1-18.

Kalinzi, C. 2016. Outsourcing (Logistics) Services and Supply Chain Efficiency - A Critical Review of Outsourcing Function in Mukwano Group of Companies. *Journal of Outsourcing & Organizational Information Management*, 2016:1-22.

Kandal, R.K. 2011. Experimental Research Design: A Play of variable. *Journal of NELTA Surkhet*, 2:34-52.

Kaufmann, H.R., Panni, M.F.A.K. & Orphanidou, Y. 2012. Factors affecting consumers' green purchasing behavior: An integrated conceptual framework. *Amfiteatru Economic Journal,* 14(31):50-69.

Kaushik, V. & Walsh, C.A. 2019. Pragmatism as a Research Paradigm and Its Implications for Social Work Research. *Social Sciences*, 8(255):1-17.

Kenton, W. 2022. *Manufacturing: Definition, Types, Examples, and Use as Indicator*. https://www.investopedia.com/terms/m/manufacturing.asp. Date of access: 20 Nov. 2022.

Khan, S. & Andersson, K. 2011. A design methodology for haptic devices. *Conference proceedings*. In International Conference on Engineering Design, ICED11 15 - 18 August 2011. Denmark: Technical University Of Denmark. pp. 1-12.

Khuluvhe, M., Bhorat, H., Oosthuizen, M., Asmal, Z., Ganyaupfu, E., Netshifhefhe, E. Martin, L., Monnakgotla, J. & Rooney, C. 2022. Skills Supply and Demand in South Africa, Labour Market Intelligence Research Programme. *Department of Higher Education and Training*, 1-126.

Kilian, L. & Zhou, X. 2018. Modeling fluctuations in the global demand for commodities. *Journal of International Money and Finance*, 88:54-78.

Kim, J. 2019. Vertical Integration and the Theory of the Firm. *Oxford Research Encyclopedia of Business and Management*, 1-26.

Kiran, D.R. 2016. *Total Quality Management: Key Concepts and Case Studies*. Amsterdam: Elsevier.

Kirovska, Z., Josifovska, A. & Kiselicki, M. 2016. Efficient management of supply chain in achieving a significant competitive advantage in the market. *Journal of Sustainable Development*, 5(14):5-22.

Klingberg, L. 2023. *The future of Remote Operations for Autonomous Vehicles. Exploring Human-Automation Teamwork and Situational Awareness for SAE Level 4 trucks*. Sweden, Linköping: Linköping University. (Thesis : MSc).

Koçyiğit, Y. & Akkaya, B. 2020. The Role of Organizational Flexibility in Organizational Agility: A Research on SMEs. *Business Management and Strategy*, 11(1):110-123.

Kononov, V.A. 2017. *CSIR Mining Technology. Compendium of Research Project Summaries on Machinery and Transport Systems - 1994 to 2014*. https://mhsc.org.za/wp-content/uploads/2021/02/Thrust-Area-5-Machinery-and-Transport-Systems.pdf Date of access: 10 Oct. 2023.

Korinek, J. 2020. The mining global value chain. *OECD Trade Policy Papers*, 235:1-41.

Kothari, C.R. 2004. *Research Methodology: Methods Techniques.* 2nd ed. India, New Delhi: New Age International (P) Limited.

Kotze, C. 2013. *Mechanised, trackless development improves safety, production rates.* https://www.engineeringnews.co.za/print-version/mechanised-trackless-development-improves-safety-production-rates-2013-03-22. Date of access: 9 Nov. 2022.

Krunić, D.J.; Vujic, S.; Tanaijević, M.; Dimitrijević, B.; Subaranović, T.; Ilic, S. & Maksimovic, S. 2018. Model approaches to life cycle assessment of auxiliary machines based on an example of a coal mine in Serbia. *Journal of Mining Science*, 54:404–413.

Kumar, V, & Garg, M.L. 2018. Predictive Analytics: A Review of Trends and Techniques. *International Journal of Computer Applications*, 182(1):31-37.

Kumar, D. & Rajeev, R. 2004. Value chain: a conceptual framework. *International Journal of Engineering and Management Sciences*, 7(1):74-77.

Lai, F., Chu, Z., Wang, Q. & Fan, C. 2013. Managing dependence in logistics outsourcing relationships: Evidence from China. *International Journal of Production Research*, 51(10):3037-3054.

Leończuk, D. 2016. Categories of supply chain performance indicators: An overview of approaches. *Business Management and Education*, 14(1):103-115.

Li. X. 2014. Operations Management of Logistics and Supply Chain: Issues and Directions. *Discrete Dynamics in Nature and Society*, 2014:1-7.

Longenecker, J.G., Moore, CW. & Petty, J.W. 2007. *Small business management: An entrepreneurial emphasis*. 13th ed. USA, Burgin, KY: Thomson South Western.

Lu, L.X. & Swaminathan, J.M. 2015. Supply Chain Management. *International Encyclopedia of Social and Behavioral Sciences*, 23:709-713.

Lynas, D. & Horberry, T. 2011, ‘Human factor issues with automated mining equipment’. *Ergonomics Open Journal*, 4(1):74–80.

Macfarlane, A.S., 2001. The implementation of new technology in Southern African mines: Pain or panacea. *Journal of the Southern African Institute of Mining and Metallurgy*, 101(3):115-126.

Marklund, S. 2017. *The comparison of automatic and manual loading in an underground mining environment*. Swede, Luleå: Luleå University of Technology. (Degree - Bachelor Programme in Mining and Geotechnical Engineering).

Mann, C.J. 2012. Observational research methods–-Cohort studies, Cross sectional studies, and Case–control studies. *African Journal of Emergency Medicine*, 2:38-46.

Marshall, J., 2014. Mining robotics. 911 Metallurgist. 2016. *Bulk Material Handling – Conveying & Silos*. https://www.911metallurgist.com/blog/bulk-material-handling. Date of access: 20 Nov. 2023.

Merchant, G.E. & Lindor, R.A. 2012. The coming collision between autonomous vehicles and the liability system. *Santa Clara Law Review*, 52:1321-1340.

Meyer, D.F. 2017. An analysis of the short and long-run effects of economic growth on employment in South Africa. *International Journal of Economics and Finance Studies*, 9(1):177-193.

Mine Health and Safety Council. 2022. *Compendium of Research Project Summaries on Machinery and Transport Systems*. https://mhsc.org.za/wp-content/uploads/2021/02/Thrust-Area-9-Special-projects.pdf. Date of access: 28 Oct. 2023

Minerals Council of South Africa. 2023. Media Statement. South Africa’s mine production value remains above R1 trillion despite logistics constraints. Warning lights are flashing. file:///C:/Users/User/Downloads/2023-02-06-media-statement-minerals-council-pubishes-facts-and-figures-2022%20(3).pdf. Date of access: 10 Oct. 2023.

Mining Watch Canada. 2012. *Potential Toxic Effects of Chromium, Chromite Mining and Ferrochrome Production: A Literature Review*. https://miningwatch.ca/sites/default/files/chromite_review.pdf. Date of access: 16 Nov. 2023.

Mkemai, R., 2011. *Maintenance Procedures and Practices for Underground Mobile Mining Equipment*. Swede, Luleå: Luleå University of Technology. (Thesis – MSc).

Moduslink Global Solutions. 2014. *Value Chain Ecosystems of the Future – The Role of Outsourcing in Supply Chain Strategy*. http://www.moduslink.com/wp-content/uploads/2014/07/Value_Chain_Ecosystems_of_the_Future_WhitePaper.pdf Date of access: 20 Oct. 2023.

Mofokeng, T.M. & Chinomona, R. 2019. Supply chain partnership, supply chain collaboration and supply chain integration as the antecedents of supply chain performance. *South African Journal of Business Management*, 50(1):1-10.

Mohape, G. & Zarske, R. 2018. Health and safety on South African mines. A best practice report. *Competence Centre Mineral Resources Southern African–German Chamber Of Commerce And Industry*, 1-68.

Möncks, P., Clearkin, T., Kuipers, H., Laabi, A., Detry, E. & Pocquet, M. 2023. *An untapped goldmine: opportunities for South African mining*. Date of access: 10 Oct. 2023.

Muller, T.F. & Fourie, J.C. 1959. The pioneering of trackless mechanized coal mining in South Africa. *Southern African Institute of Mining and Metallurgy*, 445-460.

Murthy, Y.R., Tripathy, S,K. & Kumar, C.R. 2011. Chrome ore beneficiation challenges & opportunities – A review. *Mineral Engineering*, 24:375-380.

Nardini, D., Andrews, M. & Brooks, G. 2012. A conceptual study into optimizing the delivery of trackbound twin ends through trackless mechanized development. *The Southern African Institute of Mining and Metallurgy Platinum*, 2012:65-90.

Nastjuk, I., Herrenkind, B., Marrone, M., Brendel, A.B. & Kolbe, L.M. 2020. What drives the acceptance of autonomous driving? An investigation of acceptance factors from an end-user's perspective. *Technological Forecasting & Social Change*, 161:1-26.

National Planning Commission. 2012. *National Development Plan: Vision for 2030*. https://www.nationalplanningcommission.org.za/assets/Documents/NDP_Chapters/devplan_ch3_0.pdf. Date of access: 8 Nov. 2023.

NIOSH. 2020. *Haul Truck Research Roadmap Report 2020*. https://www.cdc.gov/niosh/mining/researchprogram/strategicplan/haultruckroadmap2020.html. Date of access: 27 Oct. 2023.

Nishiyama, A., Moteki, M., Fujino, K. & Hashimoto, T., 2013. Research on the comparison of operator viewpoints between manned and remote-control operation in unmanned construction systems. In ISARC. *Conference Proceedings*. Proceedings of the International Symposium on Automation and Robotics in Construction (Vol. 30, p. 1), Montreal, Canada.

Nurock, D. & Porteous, C. 2008. Methodology to determine the optimal replacement age of mobile mining machines. *Conference Proceedings*. In Third International Platinum Conference 'Platinum in Transformation', The Southern African Institute of Mining and Metallurgy, South Africa, Johannesburg. pp. 297–306.

Obeng, M., Mensah, J. & Anim, S.K. 2015. Outsourcing Strategies of Mining Industries: An Empirical Evidence from a Developing Nation. *International Journal of Supply Chain Management*, 4(4):90-101.

O'Connor, E.P. 2014. *Major equipment life cycle cost analysis*. Iowa, Ames: Iowa State University. (Thesis – MSc)

OEC. 2023. *Chromium ore in South Africa*. https://oec.world/en/profile/bilateral-product/chromium-ore/reporter/zaf. Date of access: 29 Aug. 2023.

OECD. 2017. Local Content Policies In Minerals-Exporting Countries: The Case of South Africa. Trade Policy Note*. Organisation for Economic Co-operation and Development*, 1-12.

Olade, M. 2015. *The Haunting Legacy of South Africa's Gold Mines*. https://e360.yale.edu/features/the_haunting_legacy_of_south_africas_gold_mines. Date of access: 31 Jan. 2023.

Olaore, R.A. & Adebisi, N.T. 2013. Accounting, Purchasing and Supply Chain Management Interface. *Journal of Business and Management*, 11(2):80-84.

Omachonu, V.K. & Ross, J.E. 2004. *Principles of Total Quality*. 3rd ed. New York: CRC Press.

Osborne, S. & Hammoud, M.S. 2017. Effective Employee Engagement in the Workplace. *International Journal of Applied Management and Technology*, 16(1):50–67.

Ott, R.L. & Longnecker, M. 2001. *An Introduction to Statistical Methods and Data Analysis*. 5th ed. USA, California: Duxbury.

Pappas, M. 2020. *Viability of business models to promote enterprise development within the South African construction sector.* South Africa, Johannesburg: University of the Witwatersrand. (Thesis - MSc).

Park, Y.S., Konge, L. & Artino, A.R. 2020. The Positivism Paradigm of Research. *Academic Medicine*, 95(5):690-694.

Parker, D. 2022. Epiroc to supply large order of battery-electric mining equipment to Assmang. Creamer Media's Engineering News. https://www.engineeringnews.co.za/print-version/epiroc-to-supply-large-order-of-battery-electric-mining-equipment-to-assmang-2022-04-19. Date of access: 30 Jan. 2023.

Patel, M. & Patel, N. 2019. Exploring Research Methodology: Review Article. *International Journal of Research & Review*, 48(6):48-55.

Patel, J.K. 2021. The Importance of Equipment Maintenance Forecasting. *International Journal of Mechanical Engineering*, 8(5):7-11.

Perenti. 2020. *Critical Standard. Maintenance of mobile equipment*. https://www.perenti.com/wp-content/uploads/2020/06/Maintenance-of-mobile-equipment.pdf. Date of access: 26 Oct. 2023.

Pérez-Lara, M., Saucedo-Martínez, J.A., Marmolejo-Saucedo, J.A., Salais-Fierro, T.E. & Vasant, P. 2019. Vertical and horizontal integration systems in Industry 4.0. *Wireless Networks*, 26(1):1-9.

Peuker, U.A., Kwade, A., Teipel, U., Jäckel, H.-G. Mütze, T. 2012. *Mineral Processing*. Germany, Frankfurt: ProcessNet Subject Divisions.

Podder, S.K. & Harita, M. 2019. *Research Methodology*. India, Mombai: Himalaya Publishing House Pvt. Ltd.

Price, J.H. & Murnan, J. 2004. Limitations and the Necessity of Reporting Them. *American Journal of Health Education*, 35:2,66-67.

Rahman, M.H., Alam, M.J., Hossain, M.Z. & Kabir, M.A. 2020. Mechanical Observation Marketing: How Consumers Behave and Interact in the Food Market. *Acta Scientific Nutritional Health*, 4(3):9-11.

Research Nester. 2023. *Construction equipment rental market*. https://www.researchnester.com/reports/construction-equipment-rental-market/4731. Date of access: 7 Nov. 2023.

Robatto Simard, S., Gamache, M. & Doyon-Poulin, P. 2023. Current Practices for Preventive Maintenance and Expectations for Predictive Maintenance in East-Canadian Mines. *Mining*, 3:26–53.

Rotabroach. 2022. *Commonly Used Power Tools By Contractors*. https://www.rotabroach.co.uk/blog/commonly-used-power-tools-by-contractors/. Date of access: 7 Nov. 2022

Rupprecht, S.M. 2015. Owner versus contract miner — a South African update. *The Journal of the Southern African Institute of Mining and Metallurgy*, 16(115):1021-1025.

Salama, A., 2014. *Haulage system optimization for underground mines: A discrete event simulation and mixed integer programming approach*. Swede, Luleå: Luleå University of Technology (Thesis – PhD).

Sánchez, F. & Hartlieb, P. 2020. Innovation in the Mining Industry: Technological Trends and a Case Study of the Challenges of Disruptive Innovation. *Mining, Metallurgy & Exploration*, 37:1385-1399.

Sánchez, L.A. & Ríos, N.B.Y. 2020. Relationship between total quality management (TQM) and technology R&D management (TM/R&D) in manufacturing companies in Mexico. *Contaduría y Administración*, 65(1):1-22.

Sandvik. 2016. *UG load and haul*. https://mining.komatsu/docs/default-source/non-product-documents/company/joy-global-in-the-news/news-attachments/international-mining---availability-with-attitude-news-article.pdf. Date of access: 28 Oct. 2023.

Sandvik. 2018. *AUTOMINE® Lite2*. file:///C:/Users/User/Downloads/automine-lite-product-sheet-english%20(1).pdf. Date of access: 6 Feb. 2023.

Sattari, S. 2007. *Application of Disconfirmation Theory on Customer Satisfaction Determination Model in Mobile Telecommunication: Case of prepaid mobiles in Iran*. Luleå: Luleå University of Technology. (Thesis: MSc).

Saunders, S. & Tosey, P. 2012/2013. *The layers of research design*. file:///C:/Users/User/Downloads/The_Layers_of_Research_Design.pdf. Date of access: 26 Oct. 2022.

Saunders, M., Lewis, P. & Thornhill, A. 2012. *Research Methods for Business Students.* 6th ed. Essex, Harlow: Pearson Education Ltd.

Sayadi, A.R., Lashgari, A. & Paraszczak, J. 2012. Hard-rock LHD cost estimation using singleand multiple regressions based on principal component analysis. *Tunnelling and underground space technology*, 27(1):133-141

Sepro Mineral Systems, 2019. *The "four types" of mineral processing*. https://minerals.seprosystems.com/the-four-types-of-mineral-processing/ Date of access: 18 OCT. 2023.

Shahandashti, S. M., Pudasaini, B., & McCauley, S. L. 2019. *Autonomous Vehicles and Freight Transportation Analysis*. file:///C:/Users/User/Downloads/NCTCOGFinalReport-AVandFreightTransportation%20(1).pdf Date of access: 23 Oct. 2023

Shan, M., Hwang, B-G., Caldas, C.H., Yin, Z. & Oliveira, D.P. 2020. Towards cleaner and more productive maintenance in petrochemical facilities: Mechanization and an assessment method. *Journal of Cleaner Production*, 259:1-11.

Shukri, F.A.A., Jusoh, R.M., Ramlan, A. & Anuar, M.S.M. 2013. An overview of fleet maintenance and operating cost: Key components and methods. *International Journal of Commerce, Business and Management*, 2(6):443-452.

Singh, N. 2017. Weathering the 'perfect storm' facing the mining sector. *The Journal of the South African Institute of Mining and Metallurgy*, 117:223-229.

SPH (Sandton Plant Hire). 2023. *Almar Investments*. http://www.sandtonplant.co.za/portfolio-view/almar-investments/. Date of access: 28 Jan. 2023.

Strong, H. 2014. *Marketing and management models: A guide to understanding and using business models*. USA, New York: Business Expert Press.

Sri Gurudatta Yadav, S. & Krishnaiah, R.V. 2013. Haptic Science And Technology. *International Journal of Computer Engineering & Applications*, II(I/III):139-146.

Stats SA. 2023a. Statistical Release P0441. Gross domestic product First quarter 2023. *Department Statistics: South Africa*, 1-23.

Stats SA. 2023b. Quarterly Labour Force Survey. *Department Statistics: South Africa*, 1-24.

Steenkamp, C.J.H. & Van Der Lingen, E. 2014. Outsourcing in the mining industry: decision-making framework and critical success factors. *The Journal of The Southern African Institute of Mining and Metallurgy*, 114:845-854.

Strakova, J., Simberova, I., Partlova, P., Vachal, J. & Zich, R. 2021. The Value Chain as the Basis of Business Model Design. *Journal of Competitiveness*, 13(2):135-151.

Strietska-Ilina, O., Hofmann, C., Durán Haro, M. & Jeon, S. 2021. *Skills for green jobs: A global view: Synthesis report based on 21 country studies*. Switzerland, Geneva: International Labour Organization.

Suglo, R.S. 2009. Contract Mining versus Owner Mining – The Way Forward. *Ghana Mining Journal*, 11:61-68.

Sulaiman, H., Saadun, M.N.A. & Yusof, A.A. 2015. Modern manned, unmanned and teleoperated excavator system. *Journal of Mechanical Engineering and Technology*, 7(1):57-58.

Sun, Q. 2022. Application Analysis of Internal Rate of Return Capital Budgeting Method in Project Investment Decision-Making. *BCP Business & Management*, 35:6-10.

Tampier, C., Mascaró, M. & Ruiz-del-Solar, J. 2021. Autonomous loading system for load-haul-dump (LHD) machines used in underground mining. *Applied Sciences*, 11:1-27.

Teoman, S. 2020: Achieving the Customized "Rights" of Logistics by Adopting Novel Tecnologies: A Conceptual Approach and Literature Review. *UTMS Journal of Economics*, 11(2)-231–242.

Teplická, K. and Straka, M., 2020. Sustainability of extraction of raw material by a combination of mobile and stationary mining machines and optimization of machine life cycle. *Sustainability*, 12(24):1-13.

The Economic Times. 2023. *What is outsourcing*. https://economictimes.indiatimes.com/definition/Outsourcing. Date of access: 20 Oct. 2023.

Thiese, M.S. 2015. Observational and interventional study design types; an overview. *Biochemia Medica*, 24(2):199-210.

Tholana, T., Musingwini, C. & Njowa, G. 2013. An algorithm to construct industry cost curves used in analysing cash cost performance. *The Journal of The Southern African Institute of Mining and Metallurgy*, 113:473-484.

Thompson, A.A. & Strickland, A.J. 2001. *Strategic Management*. USA, Boston: McGraw-Hill Irwin.

Thompson, A.A. (Jr.), Peteraf, M.A., Gamble, J.E. & Strickland, A.J. 2012. *Crafting and executing strategy. The quest for competitive advantage: concepts and cases*. 18th ed. Massachusetts, Boston: McGraw-Hill.

Tidd, J. & Bessant, J.R. 2020. *Managing innovation: Integrating technological, market and organizational change*. 7th ed. New Jersey, Hoboken: John Wiley & Sons.

Tilden, E.L. & Snowden, J.M. 2018. The causal inference framework: a primer on concepts and methods for improving the study of well-woman childbearing processes. *Journal of Midwifery & Womens Health*, 63(6):700-709.

Tomlingson, P.D. 2010. *Equipment Management; Key to Equipment Reliability and Productivity in Mining*. 2n ed. USA, Colorado: Society for Mining, Metallurgy, and Exploration, Inc.

Troacă, V-A. & Bodislav, D-A. 2012. Outsourcing. The Concept. *Theoretical and Applied Economics*, XIX(6(571)):51-58.

Tsay, A.A. 2013. Designing and Controlling the Outsourced Supply Chain. Foundations and TrendsR in Technology. *Information and Operations Management*, 7(1-2):1-160.

Tuli, F. 2010. The Basis of Distinction Between Qualitative and Quantitative Research in Social Science: Reflection on Ontological, Epistemological and Methodological Perspectives. *Ethiopian Journal of Education and Sciences*, 6(1):97-108.

Twin, A. 2022. *Outsourcing: How It Works in Business, With Examples*. https://www.investopedia.com/terms/o/outsourcing.asp. Date of access: 20 Oct. 2023.

Uçtu, Ö., Karaca, C. & Uctu, R. 2021. An Evaluation of Investment Project in Gaziantep Footwear Industry: NPV and IRR Approach. *Muhasebe ve Finansman Dergisi – Ocak*, 89:251-272

University of the Witwatersrand. 2022. *The South African mining sector*. https://www.wits.ac.za/wmi/about-us/the-south-african-mining-sector/. Date of access: 29 Aug. 2023.

Van der Hoeven, J., Lohman, B. & Verdegem, R. 2007. Emulation for Digital Preservation in Practice: The Results. *The International Journal of Digital Curation*, 2(2):123-132.

Voronov, Y., Voronov, A. & Makhambayev, D. 2020. Current State and Development Prospects of Autonomous Haulage at Surface Mines. *Conference Proceedings*. E3S Web of Conferences 174, Vth International Innovative Mining Symposium, 1-7.

Vosloo, E. 2013. Courier industry of South Africa [personal interview]. 15 Jul., Pretoria.

Wang, H., Tenorio, V., Li, G., Hou, J. & Hu, N., 2020. Optimization of trackless equipment scheduling in underground mines using genetic algorithms. *Mining, Metallurgy & Exploration*, 37:1-10.

WBCSD. 2011. *What is a value chain? Definitions and characteristics.* https://www.cisl.cam.ac.uk/education/graduate-study/pgcerts/value-chain-defs Date of access: 29 Jul. 2023.

Wennström, J. 2014. *Life Cycle Costing in Road Planning and Management: A Case Study on Collision-free Roads*. Sweden, Stockholm: Royal Institute of Technology. (Technology Licentiate Degree in Bridge Construction).

Wienker, M., Henderson, K. & Volkerts, J. 2016. The Computerized Maintenance Management System An essential Tool for World Class Maintenance. *Procedia Engineering*, 138:413-420.

Wordvice. 2023. *How to Present the Limitations of the Study Examples*. https://blog.wordvice.com/how-to-present-study-limitations-and-alternatives/. Date of access: 15 Sept. 2023.

Xiao, W.; Liu, M. & Chen, X. 2022. Research Status and Development Trend of Underground Intelligent Load-Haul-Dump Vehicle—A Comprehensive Review. *Applied Sciences*, 12(9290):1-24.

Yang, C-L. & Sheu, C. 2011. The effects of environmental regulations on green supply chains. *African Journal of Business Management*, 5(26):10601-10614.

Yun, J.J., Won, D. & Park, K. 2016. Dynamics from open innovation to evolutionary change. *Journal of Open Innovation and Technology*, 2(7):1-22.

Zhang, Y. 2022. The Effectiveness of NPV and IRR Used in Fundamental Financial Markets. *Conference Proceedings*. Proceedings of the 2022 7th International Conference on Financial Innovation and Economic Development (ICFIED 2022). pp. 1208-1212.

ANNEXURE A. Approval letter by Almar management

ALMAR INVESTMENTS (PTY) LTD

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Date:	2023/02/03
Reference Number:	NWU Business School
Area:	Potchefstroom
Attention:	Dr Frans Prinsloo
Reference:	Letter of declaration

Letter of declaration, Acknowledgement of Report receipt

To Whom it may Concern:

Almar Investments hereby acknowledges that Danie Erasmus (22796509) will base his research proposal Report on Almar Investments, information and data for this research proposal will be gathered within Almar Investments structures and existing data base will be used.

Almar Investments management as appointed by the Board of Directors give approval for data collected within its operations as well as secondary data of the the organisation to be used by the researcher for research purposes in the Mini-Dissertation, Optimisation of the application of modern and conventional trackless machines in chrome smelting operations.

Kind Regards

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ANNEXURE B. TYPICAL TMMs

Large mining trucks: these vehicles move materials around a mine site. Among them are powerful mechanical and environmentally friendly electric drive models.

Hydraulic mining shovels: known as excavators, they use hydraulics to power the shovel through rigid materials.

Large mining dozers: they can operate on various surfaces thanks to the choice of vehicles with wheels or tracks. With additional attachments, the dozer can be used for a variety of tasks such as 1) exposing the ground beneath the surface material in order to build mine sites, 2) pushing dirt away from working areas on a mine site, 3) land reclamation around mining sites, 4) extraction of plant matter from the ground, and 5) mine site raking.

Electric rope shovels: they use pulleys and ropes instead of hydraulics to move the shovel at the end of the arm. Electric shovels allow for highly efficient performance over time, unlike hydraulic shovels.

Rotary Drill rigs and rock drills: they create holes through rock or soil, allowing the placement of charges for blasting open mines. When a rotary drill rig is used, the drill bit turns under pressure to cut into the rock. To keep the hole and bit clean, compressed air sends the rock up the drill as the bit turns.

Motor graders: roads are created and maintained using motor graders around mines.

Large wheel loaders: They are used to move material quickly across a site for loading into trucks. Wheel loaders' bucket capacity and load handling increase with their size.

Wheel tractor scrapers: this type of heavy equipment is used for earthmoving.

Underground mining loaders and trucks: The operation of these devices in confined areas is governed by specific parameters. Moreover, these vehicles cannot emit emissions in enclosed environments, such as mines. For this reason, surface mining trucks cannot be used for underground mining.

Fel slag: Front-end loaders are used to break, recover, and load waste products referred to as slag onto slag ADTs. In addition to loading molten slag material, these articulated front-end loaders scoop, break and move molten slag material. These machines are modified and equipped with a specialised function for a specific purpose.

Fel skeleton: front end-loader used to recover and load tapped ferrochrome (final product) from the metal tap floor to metal breaking floors. As soon as the ferrochrome is tapped from the furnace, articulated front-end loaders are used to break, load, and move it. Hence, these machines are specialised, built and equipped for a specific purpose.

Fel general: front-end loaders are used for all other work on the smelting plant, excluding work at the furnaces. It includes all ad-hoc tasks, raw material re-working, the pelletising plant, the chrome recovery plant, and the final product yard. These articulated front-end loaders are used to load, scoop, and move bulk materials.

Adt / tractor general: articulated dump trucks and tractors are used for all other work on the smelting plant, excluding work at the furnaces. It includes all ad-hoc tasks, raw material work, the pelletising plant, the chrome recovery plant, and the final product yard. They are also employed for commodity movement of all other general purposes.

Adt / tractor hot: articulated dump trucks and tractors are used for transporting and hauling all hot material from the furnaces to the chrome recovery plant or slag stockpiles.

Hex hydraulic hammer: excavators are used in breaking the chrome on the metal breaking floors to an acceptable size, normally 300 mm in diameter, that will feed into a primary jaw crushing section.

Hex excavator: excavators are used with a bucket for digging trenches or loading material for transporting and maintaining high walls at stockpiles.

Charge car hot: small front-end loader used for stocking and rabbling of the furnaces; it is almost like a big pot that needs to be stirred in order not to solidify. These machines are used to stir material fed into the hot arching furnaces.

Hex mini hot: small excavators are used at the furnace in preparing tap holes where chrome and slag are split into separate slag and metal pans or runners. These machines are of specialised nature and perform tasks in preparing surface conditions to ensure furnaces are able to open and tap material, also performing tasks where slag and metal/ferrochrome are split.

Water car: water tankers or trucks are used for road and dust suppression on site.

Skid steer general: small bobcats are used for plant maintenance and overall plant housekeeping. These compact machines are able to get into tight and small spaces.

Tlb general: tractor-loader-backhoe used for digging projects and metal recovery. These machines are able to do both scooping and digging functions as they have a loader bucket on the front and a backhoe at the back.

Logger: bar loaders with grab attachments are used in recovering any metal/chrome lying on site

Roller: used for any compacting of surfaces and road maintenance.

Graders: roads are created and maintained using motor graders around mines.