Engineering management concepts for sustainable productivity improvements in small scale mining and minerals processing operations in South Africa

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Abstract

Literature has shown that a number of concerns have been raised with regards to the definition of small scale mining. It has been argued that the formal definition does not capture all the intricacies of small scale mining. The definition does not take into account the level of technology deployed, production output, nature and motivation of miners etc.

The objectives of the research conducted were to firstly develop a formal and scientific definition for Small Scale Mining in South Africa and secondly to use and apply Engineering Management concepts to optimise and improve the productivity of selected Small Scale Mining and Minerals Processing operations in South Africa.

The methodology used involved conducting a literature review of the types of small scale mining and mineral processing operations that exist within South Africa. A case study approach was used and a questionnaire was developed to gather information from selected legal small scale mining and processing operations in South Africa. A survey was developed and submitted to experts/specialists in the field of small scale mining in order to use the Pairwise Comparison Decision Making Tool to develop a scientific definition of small scale mining.

By comparing the information studied in the literature with the data obtained from visiting two small scale operations (semi-precious gemstones and diamonds) and using engineering management concepts it was found that the recommended improvements that one can make to small scale mining and minerals processing operations in South Africa can essentially be categorised into four critical areas namely: Management, Chemical Analysis, Technology and Skills.

These areas are captured in more detail in the Integrated Management Model proposed for Small Scale Mining and Minerals Processing Operations in South Africa within this dissertation. All aims and objectives set-out for the research conducted were achieved. The recommended improvements if implemented by small scale mining and mineral processing operations in South Africa will result in a safer and healthier working environment, increased productivity, higher production rates and improved profitability.

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"True education is not for a mere living, but for a fuller and meaningful life" –
Sri Sathya Sai Baba

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LIST OF ABBREVIATIONS

ASM	Artisanal and Small Scale Mining
ASTM	American Society for Testing and Materials
BMA	Bulk Modal Analysis
BMS	Base Metal Sulphide Search
CASM	Communities and Small Scale Mining
CSR	Corporate social responsibility
DMR	Department of Mineral Resources
FTE	Full time equivalent
HAZOPS	Hazard Operability Studies
MCDM	Multiple-criteria decision-making
MPRDA	Minerals and Petroleum Resources Development Act
MQA	Mining Qualifications Authority
PPE	Personal Protective Equipment
SEM	Scanning Electron Microscopy
SMME	Small, Micro, Medium Enterprises
SSMB	Small Scale Mining & Beneficiation Division (Mintek)
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

CHAPTER 1: INTRODUCTION

1.1. Introduction

Mintek a South African Science Council established in 1934 provides technology, products and services for the minerals processing and metallurgical engineering industries globally. One of Mintek's specific objectives is increasing the level of beneficiation of minerals and mineral commodities as a way of promoting job creation, economic growth and regional development. In terms of the mineral value chain, Mintek's activities cut across minerals processing, smelting, refining and value addition. Mintek is engaged with industrial partners and other research organisations in several technological initiatives in this field (Mintek, 2015).

Mining, metallurgical and infrastructural support for Small, Micro, Medium Enterprises (SMMEs) with respect to downstream beneficiation of minerals is also undertaken by Mintek through its Small Scale Mining & Beneficiation Division (SSMB). The division plays a critical role in fulfilling national priorities relating to advancing rural and marginalised communities within South Africa and promoting mineral beneficiation. This is a programme under which SSMB offers technical support and assistance to small enterprises with no access to in-house consultants and limited financial resources. Other areas covered are extractive technologies in mining on a small scale, beneficiation of resources, sustainability, environmental matters and training. In terms of the mineral value chain, SSMB's activities therefore focus on mining (limited), minerals processing, and value addition (Mintek, 2015).

The government is strongly committed to the promotion of beneficiation (Engineering News, 2005), and the Department of Mineral Resources (DMR) released a beneficiation strategy for South Africa in 2011. South Africa has the ability to further increase beneficiated mineral products and Small Scale Mining and Minerals Processing activities within the country can be used as a driver for this (Department of Mineral Resources, 2015). In the past years technologies have been developed which were relevant to the small scale mining sector, but many of them are currently not implementable due to:

- lower grade ore bodies;
- diversified sources of materials for processing;
- changes directly or indirectly related to the environment of operations.

1.2. What is Small Scale Mining

Small scale mining offers a means of survival and in some cases of enrichment for many in South Africa especially in rural areas where job opportunities are scarce. However whilst small scale mining is an opportunity to help reduce poverty and create sustainable livelihoods, it is associated with a number of negatives including health and safety hazards, environmental degradation, use of child labour and conflict amongst communities. The negative impacts mentioned occur where mining is conducted on an informal or illegal basis (CASM, 2004).

Small scale mining operations can be described as either semi-industrial or fully industrial. For the later, the level of mechanization (technology or equipment used), operational structure and degree of compliance as compared to international standards is advanced. These types of operations are predominantly funded and managed by business owners and stakeholders from countries that are themselves industrialized. They produce products that are niche even though in small quantities but utilise high grade mineral deposits. These require complex extraction and concentration techniques. This scenario tends to be found in countries with a positive investment climate and due to this, these types of operations generate fewer problems (social, environmental and operational). The rest of the small scale mining community then look to these as positive examples (Hentschel, et al., 2003).

A growing small business sector will result in an increase in the competitiveness of the economy and is a way to create more much needed jobs. The drop in the price of several minerals over the years has resulted in the closure of a number large scale mining and processing operations. Improved management of small scale mining operations therefore have the ability to take over and mine more economically where certain large scale mining operations are not able to do so successfully. Small scale mining operations can hence increase both their local and total global production. Small scale mining and minerals processing already takes place at a considerable scale in South Africa. There are several opportunities for small scale mining and processing operations in gold, diamonds, coal and industrial minerals (South African Government, 1998).

1.3. Problem Statement

The problem statement of the research undertaken is as follows:

Improved management of small scale mining and minerals processing operations in South Africa have the potential to contribute significantly to both local and global production and in certain instances take over and mine more economically where certain large scale mining operations are not able to do so successfully.

1.4. Research Objectives

A summary of the objectives of this research is as follows:

a) To develop a formal and scientific definition for Small Scale Mining in South Africa.
b) To use and apply Engineering Management Concepts to optimise and improve the productivity of selected Small Scale Mining and Minerals Processing Operations in South Africa.

1.5. Research Questions

The following questions were investigated during the research:

a) How can one improve the productivity of existing Small Scale Mining and Minerals Processing Operations in South Africa?
b) Does the definition of artisanal and small scale mining impact the sustainability and productivity of these operations?

1.6. Papers and Presentations

The following papers (unpublished) and/or presentations were compiled during the course of the research undertaken:

- Small Scale Minerals Processing and Value Addition – Study of Methods used for the concentration and upgrading of feeds (Presented at the MinProc 2015 Conference) – *N. Singh, A.F. Mulaba-Bafubiandi*

- The formulation of a scientific definition for artisanal and small scale mining using the Pairwise Comparison Decision Making Tool (2016) – *N. Singh, A.F. Mulaba-Bafubiandi*

- Climate Change and Biodiversity: Possible Impacts of Small Scale Mining Activities in South Africa (Presented at the 2nd Univen-WSU Research Conference 2016) – *N. Singh, A.F. Mulaba-Bafubiandi*

- Prospects in the Industrialisation of Mineral Related SMEs in South Africa (2016 – Submitted to Engineering Institute of Zambia Symposium Conference 2017) – *N. Singh, A.F. Mulaba-Bafubiandi, J.H.C. Pretorius*

- Strategy for Sustainability of Small Scale Mining Operations in South Africa (2016) – *N. Singh, A.F. Mulaba-Bafubiandi, J.H.C. Pretorius*

1.7. Layout of the Research Report

Chapter 2 is a literature study of selected work published related to the small scale mining sector both in South Africa and globally, the existing definitions used and the importance thereof, challenges faced and existing techniques utilised to achieve productivity improvement.

Chapter 3 provides the research methodology and design used to conduct the research in order to achieve its objectives. The methods and tools (questionnaires and surveys) used for data collection are explained in detail. The technique used for developing the definition of small scale mining and determining how to improve productivity using Engineering Management concepts is also highlighted.

Chapter 4 presents the results obtained from the questionnaires and surveys used. It then discusses the data collected together with the findings from the literature study and then provides solutions to the research objectives.

Chapter 5 summarizes the research conducted and concludes with the results obtained.

1.8. Conclusion

This research undertaken provides a status quo of the current small scale mining and minerals processing activities within South Africa. It will also give an overview of the existing definitions of small scale mining together with the challenges and gaps faced by this sector and look at developing a new scientific definition. The research will recommend methods that can be used to increase the productivity of selected small scale mining and minerals processing operations (while reducing environmental impact) by using Engineering Management Concepts.

CHAPTER 2: LITERATURE STUDY

2.1. Introduction

The purpose of this chapter is to study selected literature that has been published previously. The literature study needed to answer the following questions:

- What is the history and current state of mining and small scale mining in South Africa and what commodities are mined?
- What are the existing definitions used for small scale mining in South Africa and globally.
- What are the challenges faced by the small scale mining sector in South Africa and globally.
- Are there currently techniques or processes being used globally to improve productivity of small scale mining operations?

2.2. Mining in South Africa

Mining and minerals is the backbone of the South African economy. South Africa is a leading producer of gold, platinum group metals, chromium and vanadium. It is also a leading producer of aluminium, diamonds, iron ore, manganese, coal, titanium, and zirconium. South Africa's mineral resources are estimated at a value of approximately US$2.5 trillion (Citi Bank, 2011). In the mining sector the term beneficiation is defined as the different processes used to extract valuable minerals from mined ore and separate it into mineral and gangue (waste), the former suitable for further processing or direct use (CTI Reviews, 2015). The term beneficiation is used very often in conjunction with the term value-addition. Based on the definition described above, the term beneficiation has been used within a context of economic development and corporate social responsibility (CSR) to describe the amount of value derived from the exploitation of mineral assets which remain in the country and benefits locals including communities (Citi Bank, 2011).

2.3. Defining the Small Scale Mining Sector in South Africa

Artisanal and small scale mining or ASM is defined as mining undertaken by individuals, groups, families or cooperatives that have either no mechanization or minimal mechanization and found mostly in the informal (usually illegal) sector (Hentschel, et al., 2003). Although attempts have been made, a common or even scientific definition of ASM has not yet been developed. In certain countries a distinction is made between artisanal mining and small scale mining. Artisanal mining is described as mining done manually (labour intensive) and on a very small scale. Small scale mining is described as mining done with some mechanization and on a slightly bigger scale (Hentschel, et al., 2003).

A few of the criteria used to categorise the ASM operations include:

- Volume of production
- Number of people (labour)
- Capital Cost (equipment)
- Size of the mineral resource

The characteristics of ASM include (Hentschel, et al., 2003):

- Lack of or limited use of mechanization (manual labour)
- Low levels of occupational safety and health care
- Low qualifications or education level of staff
- Inefficient mining and processing of minerals that result in low recoveries
- Mining of small deposits, which are not economically viable using mechanized techniques
- Low levels of productivity
- Low levels of income
- Insufficient consideration for the environment
- Lack of capital investment

Artisanal mining and small scale mining are sometimes used together which leads to confusion. According to other definitions, artisanal mining includes both micro and very small mining categories. A clear distinction is however made using the level of technology deployed, and also the profitability of the operation. Artisanal mining is rudimentary in nature; it involves no mechanization. It is conducted purely as a means of survival. On the other hand, small- scale activities are profit-orientated, and usually involve the use of mechanization (Hentschel, et al., 2003).

In South Africa the definition of artisanal mining and small scale mining is based on the broader definition of small businesses as set out in the (Government Gazette, 2003). Table 1 below summarises these classifications:

Table 1: Mining and quarrying operations classifications in South Africa based on the National Small Business Development Act (Government Gazette, 2003)

Size of class	Total full time equivalent of paid employees	Total annual turnover	Total gross asset value (fixed property excluded)
Micro	< 5	< R 200 000	< R 100 000
Very small	< 20	< R 4 million	< R 2 million
Small	< 50	< R 10 million	< R 6 million
Junior	< 200	< R 39 million	< R 23 million

In a feasibility study conducted for the Lepelle-Nkumpi municipality (Lepelle-Nkumpi Local Municipality & Kayamandi Development Services (PTY) LTD, 2006), it was reported that small scale mining refers to mining done by peasants without training and mining knowledge as individuals or as groups (of four to eight individuals) or as co-operatives (of ten or more individuals) which are financed by limited resources using traditional techniques and low level equipment. The report stated that there are also highly organised small scale mining operations with higher levels of employment (up to 50 employees), technology and capital.

There is no set definition of what is meant by small scale mining (Heath , et al., 2004). The definition of small scale mining varies amongst researchers depending on the purpose of its use. The definition used in their study conducted in 2004 was based on the:

- Amount of raw material (unprocessed) moved per annum.
- Number of people employed.
- Level of mechanization used.

In their study (Heath , et al., 2004) included all types of small scale mining that range from artisanal mines to small businesses but excluded junior mining companies. They defined a junior mining company as one that employs between 50 and 200 employees. They included companies that are classified as follows:

- Micro which employs < 5 employees.
- Very small which employs <20 employees.
- Small which employs <50 employees.

The level of mechanisation used was also considered by (Heath , et al., 2004). Micro scale mining (which is associated to artisanal mining), involves no mechanisation and its primary motivation for existence is subsistence. Small to medium scale mining was defined as mining that is not subsistence orientated and involves limited mechanisation. This mechanisation for example would include one truck, one front end loader and one piece of mechanical equipment for the processing of ore. Large scale mining is defined as mining that is not subsistence driven and involves the use of extensive mechanisation. This includes for example many trucks, many front end loaders and many mechanical equipment for the processing of ore. Their definition was aligned to that set-out by the National Small Business Development Act of 1996 which was then revised in 2003 and illustrated in Table 1.

Several concerns have been raised in the past with respect to the definition (Scott, et al., 1998) (Mutemeri & Petersen, 2002). They argued that the formal definition does not capture all the intricacies of small scale mining. The definition does not take into account the level of technology deployed, production output, nature and motivation of miners etc. These characteristics are believed to form an important part of artisanal and small scale mining in the country.

The White Paper of Local Government of 1998 states the following challenges as key policy requirements for the subsector:

- access to mineral rights
- access to finance
- institutional support
- access to markets
- skills and training

These five key requirements have been the main focus of government-led interventions for the past 20 years.

The South African Government Green Paper on Mineral and Mining Policy of 1998 indicates that small scale mining operators entering the sector face a number of technical challenges that do not allow them to participate in mining activities. These include inadequate skills in dealing with complex minerals processing, practical mining related problems and business management skills.

It was further stated by (Mutemeri & Petersen, 2002), that the activities of those miners that have entered the sector due to desperation have resulted in their operations not being safe, not being efficient and not being environmentally friendly. However it was also noted that the introduction of new government policies (since 1994), has led to new and specialized programmes being developed to assist and also promote the sector. Part of the strategy developed for the support of the small scale mining sector in the country include initiatives for promoting mineral beneficiation and value addition, research and development of relevant technologies, skills development and transfer of appropriate technology.

The Department of Mineral Resources (DMR) (previously called the Department of Minerals and Energy) had established a Small Scale Mining Directorate to deal with the major challenges faced by the small scale mining sector in South Africa since the establishment of the Minerals and Petroleum Resources Development Act (MPRDA) in 2002. The DMR has found that many previously disadvantaged South Africans see small scale mining as an opportunity for a new way of life. The DMR is working to legalise small scale mining operations that are in existence, and find ways that are affordable and understandable and will help to make them economically viable (Department of Mineral Resources, 2015). The DMR refers to the Artisanal and Small Scale Mining sector collectively as “small scale mining” and defines the following categories (Department of Mineral Resources, 2015) (Love, 2015):

- Artisanal or subsistence mining operations, also classified as new entrants;
- Formal mining operations that are sub-optimal; and
- Entrepreneurs that have upfront capital.

Mintek which is a South African Science Council is a provider of products and services for the minerals processing and metallurgical engineering industries globally. It established the Small Scale Mining and Beneficiation division (SSMB) to provide support to the small scale mining and processing sector through the research and development of appropriate/affordable technologies, and by providing training and marketing support. SSMB have established programmes for the training of small scale miners under the auspices of the Mining Qualifications Authority (MQA). Over 2500 people have been trained in these programmes in subjects including legal and regulatory requirements, basic geology, beneficiation, minerals processing, health and safety and business skills. Training courses on minerals (e.g. gold, diamonds and dimension stone) are held in the areas of the country or communities where the trainees/miners come from. The main aim of the training school is to assist small scale miners to operate more efficiently so that their operations can be economically viable and sustainable (Mintek, 2015).

2.4. Types of commodities mined and processed by the Small Scale Mining sector in South Africa

Small Scale mining and processing activities are wide spread across the country and they occur in all nine provinces in South Africa. These activities are predominantly conducted in the rural parts of the country but mineral availability is a key determining factor (Mahlatsi, et al., 2011). Table 2 shows the different mineral categories exploited by this sector.

Table 2: Mineral commodities exploited by Small Scale Processing Operations in South Africa (Mahlatsi, et al., 2011)

Category	Commodity type	Location
Precious minerals	Gold	Gauteng, North West, Mpumalanga
	Diamonds	Northern Cape, North West, Free State
Semi-precious minerals	Tiger's eye, rose quartz, amethyst, feldspar, jasper	Northern Cape
Energy Related minerals	Coal	Mpumalanga, KwaZulu Natal

Other Industrial minerals	Granite, sandstone, slate, aggregate, clay, gypsum etc.	All nine provinces

NB. Uranium bearing minerals are not exploited by the small scale mining and processing sector

The literature study will hence focus on the above mentioned mineral commodities mined and processed by small scale operations.

2.4.1. Precious Minerals

2.4.1.1. Gold

In 1886 the Witwatersrand Goldfields was discovered and this led to the establishment of South Africa's gold mining industry. This industry has been a global leader in gold mining production for 120 years. Small scale mining of gold however took place in the South African greenstone belt areas for some period of time prior to the start of what is now termed the "modern" gold mining industry. There is very little history for the period prior to the 1830s. South Africa is still one of the world's largest gold producers, but the country's output has been declining for more than thirty years which is a significant decrease from the 1000 tons produced in 1970. At that point in time this was equivalent to two-thirds of the global supply (AngloGold Ashanti Limited, 2013).

While most of the gold mining and processing operations are done on a large scale there exist small operations as well. The small operators utilise mercury to amalgamate with the metal in order to extract the gold. The gold that is produced is a result of the boiling away of the mercury from the amalgam that is formed. Even though mercury is effective in extracting gold particles the process is hazardous due to the toxicity of mercury vapour (Wikipedia, 2015b).

Mintek developed the iGoli mercury-free gold extraction process especially for use by small scale gold miners to eliminate the use of the mercury amalgamation process. A small scale plant has been designed, which makes the process easy to operate and use. iGoli has been transferred to small scale mining operations in countries like South Africa (Gauteng), Tanzania, DRC, Mozambique and Peru. The research is on-going in order to ensure that the waste product streams from each operation are not hazardous and are neutralised. Upstream processing equipment has also been developed to assist the miners in the pre-processing of their raw material in preparation for feeding to the iGoli process (Mintek, 2015).

Prior to the amalgamation process however, several pre-processing steps need to be followed in order reduce the size of the gold bearing ore. According to (Mitchell, et al., 1997) the methods considered, mostly involve the physical separation of gold from gangue using gravity-based processing methods. These gravity-based processing methods include the use of sluice boxes, jigs, shaking tables, spirals, rotating cones and bowl concentrators.

An outline of the various mineral processing methods commonly used to recover gold which indicates the size range of material being processed and the typical gold recovery figures was given by (Mitchell, et al., 1997). It was also stated that the mineralogical character of gold is often not considered when planning the processing flowsheet to be used.

Table 3: Particle size range and typical efficiencies of gravity and chemical gold recovery methods (Mitchell, et al., 1997)

Method	Effective size range	Recovery efficiency
Sluice boxes (+ Reichert cones)	2500 to 100 µm	As low as 20% for -<100 µm gold to 96% for <1000 µm gold
Jigs	2500 to 75 µm	As low as 50% for 100 µm gold to 98% for 1000 µm gold
Shaking tables	3000 to 15 µm	As low as 20% for 20 to 40 µm gold up to 90% for gold >40 µm
Spirals	3000 to 75 µm	65 to 80 %
Rotating cones & Bowl concentrators	6000 to 30 µm	Up to 99%
Amalgamation	1500 to 70 µm	As low as 65% for <75 µm gold up to 98% for <500 µm gold
Cyanidation	Finer than 200 µm	At least 80% to 99%

N.B. Recovery data are specific to particle-size, ore nature and processing operation.

A comparison of cost and environmental impacts of the gold recovery methods is shown in Table 4 below (Mitchell, et al., 1997).

Table 4: Relative cost and environmental impact of gold recovery methods (Mitchell, et al., 1997)

Recovery method	Cost	Environmental impact
Sluice box	1	1
Jig	3	1
Shaking table	2	1
Spiral	3	1
Rotating cone	2	1
Bowl	4	1
Drum	4	1
Magnetic separation	4	1
Electrostatic separation	4	1
Hydrocycloning	2	1
Froth flotation	3 - 4	4
Amalgamation (mercury)	2	4
Cyanidation	3 - 4	4

N.B. Ranking from low (1) to high (4).

A gold mining operation in Graskop was visited by (Ledwaba & Moeletsi, 2015), had stopped operations in 2012 after the mining permit expired. The company lodged an application for a mining right with the DMR. The mining area is an abandoned mine with a total of five shafts. It was further stated that the company will only resume operations once the mining right has been granted. The equipment currently onsite is old and the recommendation made by (Ledwaba & Moeletsi, 2015) was that new equipment will be required for the new production capacity required. The existing equipment is shown in Figure 1.

Figure 1: Gold processing equipment remaining at abandoned operation in Graskop, Mpumalanga Province (Ledwaba & Moeletsi, 2015)

From a second visit to a gold mining and processing facility in Barberton (Moeletsi, 2016) noted that the operation had stopped a year ago due to equipment being removed by a co-owner and all that was left at the site was a screen shown in Figure 2. The purpose of the visit was to collect a sample of gold ore for analytical and mineralogical analysis.

Figure 2: Non-operational gold processing facility in Barberton, Mpumalanga Province (Moeletsi, 2016)

The gold mining and processing operations in Graskop and Barberton which are both non-operational are the only ones currently known to Mintek.

2.4.1.2. Diamonds

Large scale mining which was deemed to be “profitable mining” started in 1867 when the first diamond was discovered on the banks of the Orange River. This then led to the discovery and mining of the Kimberley pipes a few years later. The primary sources of diamonds in South Africa include seven large diamond mines that are controlled by the De Beers Consolidated Mines Company (Cape Town Diamond Museum, 2015).

Diamonds are recovered from ore in five stages (Cape Town Diamond Museum, 2015).

Stage 1 - Crushing:

The diamond bearing ore and gravel is collected and transported to a primary crusher. The purpose of the primary crusher is to reduce the size of the ore into smaller pieces that are less than 150mm in size. A secondary crusher which is known as a roll-crusher can also be used to reduce the size of the ore further if required.

Stage 2 – Scrubbing:

The ore from stage one is scrubbed to remove loose excess material and is then screened. The cut off size is 1.5mm and material that is smaller than this is discarded as it is too expensive to extract diamonds from pieces of ore that are too small.

Stage 3 – Cyclonic separation plant:

The ore is mixed with a solution that contains ferrosilicon powder and water. The solution is measured to a specific relative density and is fed into a cyclone. This results in a separation where materials with a high density sink to the bottom which contains a layer of diamond rich concentrate.

Stage 4 – Recovery:

The concentrate from stage 3 is put through a series of processes which involve steps that include magnetic susceptibility, X-Ray luminescence and crystallographic laser fluorescence. These are calculated based on the specific properties of diamonds. This series of processes are designed to separate the rough diamond from any other heavy density materials that are collected by the cyclonic separation plant in stage 3.

Stage 5 – Cleaning, weighing and packaging:

Cleaning of the diamonds collected from the recovery process are cleaned in an acid solution then washed, weighed and packaged in sealed containers ready for transport. In compliance with the Kimberley Process, the containers have to be sealed with a tamper resistant seal, numbered on site and must contain certificate of origin.

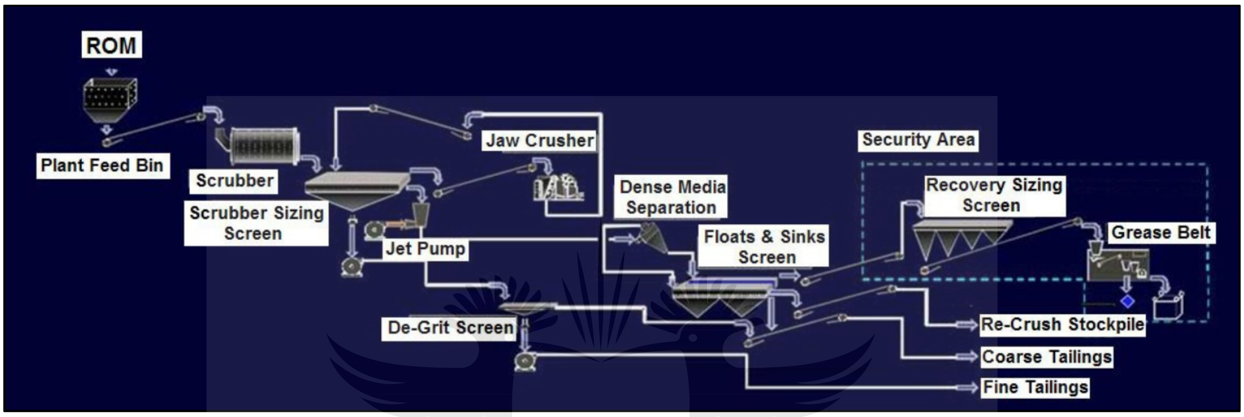


Figure 3: Typical Diamond Recovery Flowsheet (DiamondCor Mining Inc, 2015)

The days of stock standard diamond beneficiation are gone and there is opportunity to streamline existing diamond processing operations or develop simpler more efficient and more economical plants. New technologies are not always appropriate and may not always be the solution. Various simple quantifications of potential efficiency improvements versus capital savings has to be included in decision making (van der Westhuyzen, et al., 2014).

The approach used by (Pan, 2013) to achieve balanced and optimal production for a diamond operation was to firstly have an optimal production plan including targets and secondly to ensure that these targets are met using all the resources that are available. It is claimed that the system developed can potentially help improve production throughput up to 30% at processing plants.

2.4.2. Semi-precious Minerals

The Northern Cape Province is well endowed with large mineral resources which can be translated into sustainable economic development. Amongst the economic mineral resources found in the province are the semi-precious gem minerals. The province has significant deposits of (but not limited to); tiger's eye, rose quartz, amethyst, feldspar, jasper and agate. Some of these deposits are ranked high (world-wide ranking) in terms of their economic potential. However, this potential has not been realised because they are mined on a small scale level, and most are unregulated (sold illegally). There is also little known or formally documented research regarding the locality, quality and value of reserves of the Northern Cape gem minerals (Mintek, 2011).

The production of semi-precious gemstones involves mining, processing and enhancement. In the small scale mining of gemstones the processes involved are breaking of the rock, crushing to smaller sizes, concentration (picking by hand), washing followed by screening or jigging. In larger operations which include mechanization and operational staff, the process involves standard gravity methods, grease belts, separation (electrostatic, magnetic), skin-flotation, optical sorting etc. and is similar to that of diamond processing (Gordan, 1995).

The process of enhancement involves sawing, grinding, sanding and polishing. Diamond saws or blades are used to cut a slice of a required thickness. Grinding of the gemstone may be done with impregnated diamond, silicon carbide, aluminium oxide wheels or coated abrasive disks. Disk and belt sanders use abrasives that are either bonded to cloth or reinforced paper that is waterproof. The final polish is done using leather laps with a polishing agent. The polished shapes which are usually irregular can be further polished. This is achieved by tumbling them in a rubber lined drum and using a grinding and polishing medium. This can be done with or without water (Gordan, 1995).

2.4.3. Energy Related Minerals

2.4.3.1. Coal

According to the (Department of Energy, 2015), coal dominates South Africa's energy resource base and internationally is the most widely used source of fuel. Coal accounts for 36% of the total fuel consumption of the world's electricity production. It also accounts for about 77% of South Africa's primary energy needs. This trend is unlikely to change in the next two decades as there are inadequate suitable alternatives to coal as an energy source. A large coal mining industry has therefore resulted in South Africa and there are a number of deposits that can be economically exploited. About 28% of South Africa's coal production is exported and this passes mainly through the Richards Bay Coal Terminal. This ranks South Africa at number four in terms of the largest coal exporters in the world. South Africa's coal is mined from both large scale operations some of which are the biggest in the world right down to small scale producers. Coal mining operations in South Africa consist of 51% underground mining of and about 49% open-cast (Mahumapelo, 2015).

Coal mining activities on opencast and underground mines include a number of contracting services and these require a high skills set, capital investment and experienced staff. The mining industry is highly regulated. It is therefore very important for entrants to familiarise themselves and comply with all legislation. This is a requirement in order to obtain and retain prospecting and mining rights (Coaltech, 2015) (Mahumapelo, 2015).

Coal beneficiation is defined as the process of removing contaminants from the lower grade coal in order to achieve a product quality that is required for the application of the consumer or end user. This can be either as an energy source, chemical agent or as a feedstock. This process is commonly referred to as coal "washing" or coal "cleaning". Coal processing on the other hand is defined as the complete process of sizing (crushing), screening and washing of the run-of-mine coal (Portaclone, 2015).

Coal preparation requires one to understand all of the classification methods used and the properties of coal. The important properties are the relative density distribution of the raw material and its relationship to ash, the volatile matter and the proximate analysis which is the moisture content and amount of fixed carbon. The calorific value and sulphur content are also important properties as this relates to the relative density distribution (Portaclone, 2015).

The research done by (Mahumapelo, 2015) and interviews conducted with small scale coal mining and processing companies showed that it is a major challenge to gain entry into the sector because of the lack of skilled staff and the lack of finance to apply for the prospecting/mining permits and for procurement of the necessary equipment. To become a supplier of coal to Eskom is also a huge challenge for up and coming suppliers due to the stringent requirements. A comparison was also done by (Mahumapelo, 2015) on coal samples which are used as the feed to these small scale coal mining and processing operations versus Eskom's coal specification and the feed did not meet the requirements. The cost of upgrading this feed using existing technology and processes would not be economically viable for small scale operators.

The opportunity however that does exist for small scale operators that have access to these types of coal feed material is with respect to briquetting of the coal and the sale of these briquettes for the purposes of steam generation in boilers, heating, drying processes and for the replacement of conventional liquid fuel and wood. (Berkowitz, 1979) indicated that suitably prepared pulverised coal can be compacted into strong, homogeneous briquettes and with various refinements this technique has been used since the mid-1800s to upgrade a variety of low-rank coals and coal fines that would otherwise have little commercial value. The briquetting process is however linked to the nature of the coal feed and a clear distinction is made between briquetting with and without binders.

The process of briquetting of coal without the use of a binder according to (Berkowitz, 1979):

- Is restricted to soft unconsolidated lignites or brown coals where careful attention needs to be paid to size and moisture content.
- Requires high pressures for satisfactory compaction, specially designed moulds and fairly complex mould charging and discharging which therefore makes it uneconomical.

For small scale operators the process of briquetting coal with the use of the binder is simpler and this is illustrated in Figure 4 below.

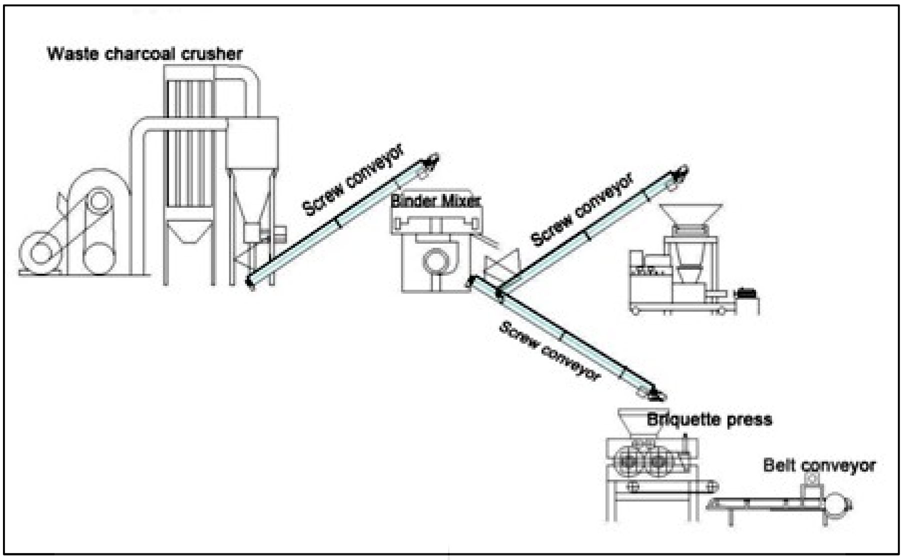


Figure 4: Typical Coal Briquetting (with Binder) Process (Agico Group, 2012)

From literature and several internet searches one is however not able to trace any small scale operators in South Africa currently utilising the above processing technology.

2.4.4. Other Industrial Minerals

Industrial minerals are defined as commodities or materials that are mined mainly for their commercial value and it excludes fuel minerals and sources of metals (industrial minerals are non-metallic). They are used in their natural state or after processing either as raw materials or as additives in a number of applications. Some examples of applications for industrial minerals include ceramics, construction, paint manufacturing, electronics, filtration, plastics, glass, detergents and paper (Wikipedia, 2015c). Industrial minerals are also often referred to as low value bulk commodities where basic demand is relatively inelastic as far as the market is concerned and price changes are a result of shortages or surpluses. (Coulson, 2009).

The building industry is the major consumer for construction materials. The need for mineral raw materials makes quarrying activities strategically important in the global economy. Construction materials which are either aggregates (e.g. sand, gravel and crushed stone) or dimension stone are used in developing built-up environments, road construction, civil engineering works and other infrastructure development (Furcas & Balletto, 2013)

2.4.4.1. Dimension Stone Quarrying and Processing

Industrial minerals such as granite, sandstone and slate can be classified under dimension stone. According to (Ashmole & Motloung, 2008a) the dimension stone industry is larger in value when compared to non-fuel minerals and the consumption of natural stone is growing at a rate that is significantly faster that other mineral products. Since 1986 the dimension stone industry has grown at an average rate of over 7% per annum (Ashmole & Motloung, 2008b).

Table 5: World production of dimension stones, thousand cubic meters from 2003-2010 (Furcas & Balletto, 2013).

	Gross quarrying	Quarrying waste	Raw production	Processing waste	Processed production	Processed production as a % of gross quarrying	Total production of stone waste	Total waste production as a % of gross quarrying
2003	57,000	29,222	27,778	11,400	16,400	29	40,622	71
2004	61,650	31,557	30,093	12,300	17,800	29	43,857	71
2005	64,750	33,176	31,574	12,950	18,650	29	46,126	71
2006	70,450	36,098	34,352	14,100	20,250	29	50,198	71
2007	78,500	40,167	38,333	15,750	22,550	29	55,917	71
2008	79,600	40,711	38,889	15,950	22,950	29	56,661	71
2009	79,150	40,446	38,704	15,900	22,800	29	56,346	71
2010	84,450	43,161	41,289	12,350	28,950	34	55,511	66

Table 5 shows the world production of dimension stone for the period 2003-2010 and it is then subdivided into gross and raw production. It can be seen that the processed production, which shows the final product of the quarrying industry, is a surprisingly low percentage of the total volume extracted. It is around 30% of the gross quarrying. The total production of waste stone that accounts for both the quarrying and processing is the largest output of this sector. The waste accounts for about 70% of the total extracted volume of stone (Furcas & Balletto, 2013).

Previously the quarrying of dimension stone was carried out using traditional methods that were developed over a number of centuries. This is however becoming exceedingly challenging from a technical perspective, requiring inputs from geology, mining engineering, blasting technology, non-explosive rock breaking, rock mechanics, mine design and reserve evaluation. One therefore has to be very well trained in a variety of cutting and splitting techniques as well as having an understanding of both geology and the physical properties of the material (Ashmole & Motloung, 2008a).

The processing operation of dimension stone shows more variation than the extraction phase. The procedure is depicted in Figure 5 below:

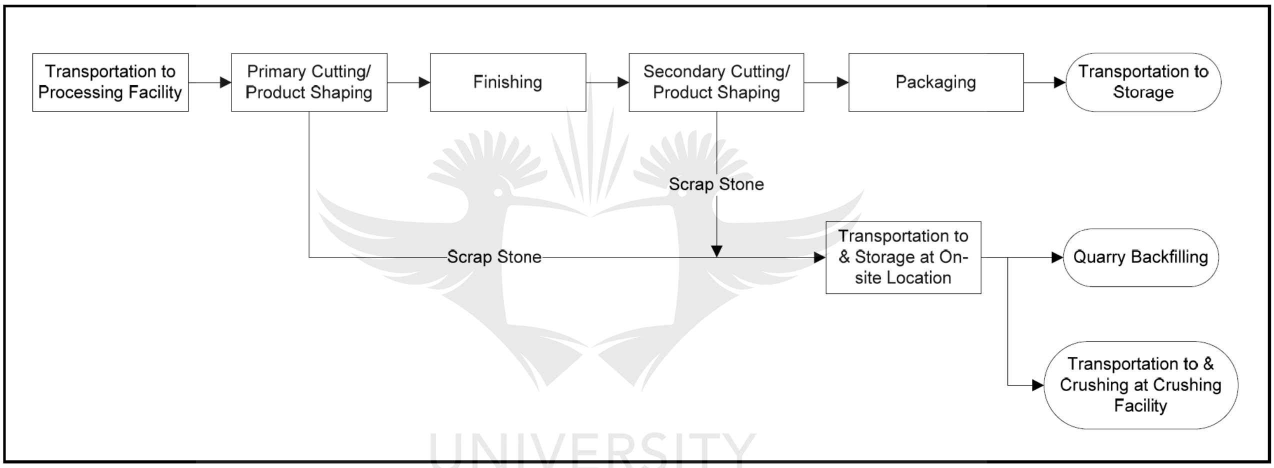


Figure 5: Process flow diagram for dimension stone operations (University of Tennessee, Center for Clean Products, 2008)

Although the environmental impacts of dimension stone are generally not significant and can be managed effectively, most stone operators are relatively small scale and they tend to be less well equipped to respond to the increasing environmental demands because of the lack of resources and training (Ashmole & Motloung, 2008b).

The following methods for improving dimension stone operations were suggested by (Domaracka & Muchova, 2013):

- Including a Quality Management Process - Performing inspections that begin at the moment of excavation and also regular inspections throughout the production process.

- Innovation – Use of obsolete processing technology and physically demanding machinery that cause damage to the dimension stone should be replaced by modern technology. It has however been noted that new technology is expensive especially for small operators.
- Production Management – reduction in costs on poor quality, optimising costs, optimal use of resources (human, material and technology).

Solving the problem of a Pakistan dimension stone operation that in spite of having sufficient quantity of machinery and skilled labour were unable to produce sufficient volume of product to meet the demands of the market, (Jalil, et al., 2014) proposed the following solution for improving the operation:

- A change in the processing plan with additional focus on the proper utilization of workers and machinery.
- Optimal reduction in the quantity of machinery utilized and the distribution of workers into three shifts of seven hours. This optimized not only machine utilization but also the number of hours worked by staff.
- Production improvement plan – workers were also motivated through the accomplishment of their fiscal and social needs.

2.5. Conclusion

The literature study has given a good understanding of the small scale mining sector both in South Africa and globally. One is also now able to focus on selected commodities that include gold, diamonds, semi-precious gemstones, coal and dimension stone as minerals of strategic importance to the small scale mining sector in South Africa. The existing definitions of small scale mining are seen to be confusing and it is used in conjunction with artisanal mining. Literature has shown that there is no formal or scientific definition available. There is also evidence that management techniques are being used to an extent to improve productivity of certain operations.

The next chapter will hence focus on the research methodology used to address the research objectives.

CHAPTER 3: RESEARCH METHODOLOGY

3.1. Introduction

A summary of the objectives of this research is as follows:

a. To develop a formal and scientific definition for Small Scale Mining in South Africa.
b. To use and apply Engineering Management Concepts to optimise and improve the productivity of selected Small Scale Mining and Minerals Processing Operations in South Africa.

3.2. Research Design

According to (Saunders & Tosey, 2013), most researchers design their research to either answer a question or to find a solution to a problem. They introduced the metaphor and concept of a 'Research Onion" shown in Figure 6 which assists researchers in the selection of technique/s used to obtain data along with procedures to analyse the data.

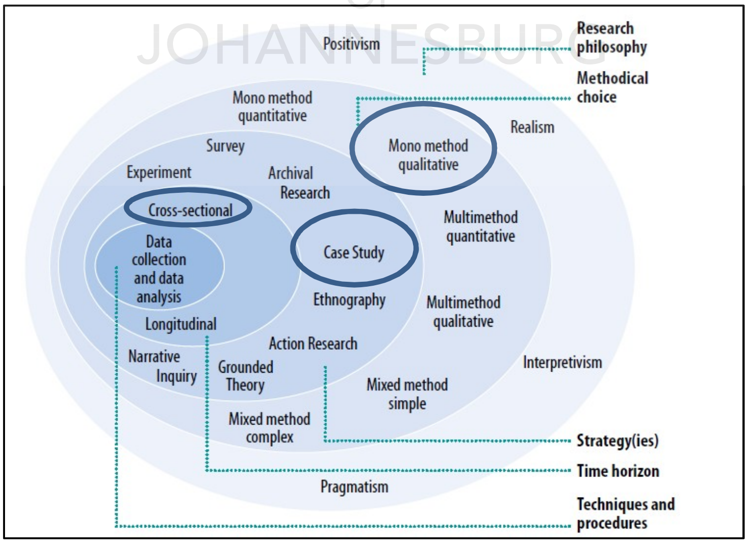


Figure 6: The Research Onion highlighting techniques to be used (Saunders & Tosey, 2013)

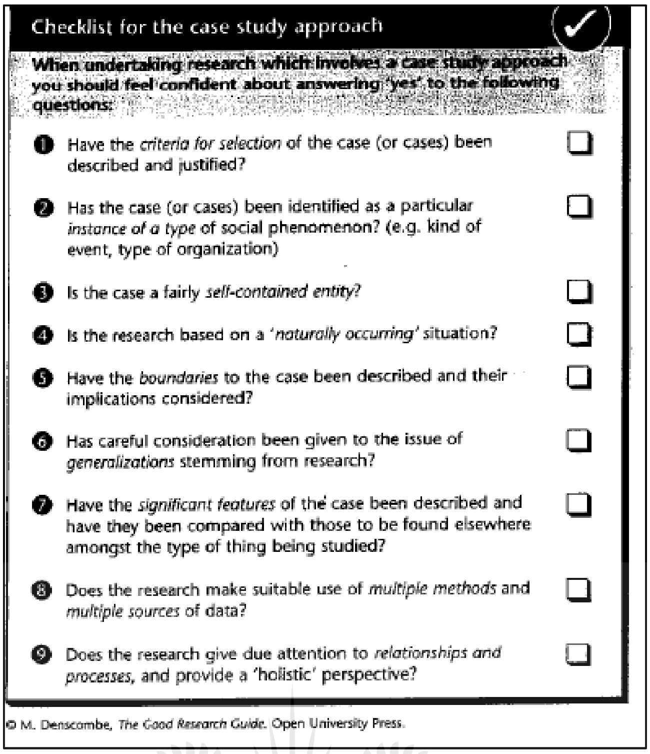
For this particular research using the concept of the Research Onion the following methods will be used:

- Mono method qualitative (Methodological Choice) – data collected through detailed interviews and then analysed as narratives.
- Case Study (Strategy) – this approach is described in section 3.3.
- Cross-sectional (Time Horizon) – research undertaken to answer a question at a particular time (snapshot) and makes use of a survey or case study.

3.3. A Case Study Approach to Research

According to (Denscombe, 1998) case studies are used widely particularly with small scale research. It is further explained that a case study approach focuses on individual instances rather than a wide spectrum. The case study approach is the opposite of a mass study. The rationale behind the case study approach and focussing efforts on one case rather than many cases is that there may be insights gained from looking at the single case that can have broader implications that would not have come to the forefront through the use of a research strategy that tries to cover a large number of instances i.e. a survey approach. "What a case study can do that a normal survey cannot do is study things in detail" (Denscombe, 1998).

"Case studies focus on one instance (or a few instances) of a particular phenomenon with a view to providing an in-depth account of events, relationships, experiences or processes occurring in that particular instance" (Denscombe, 1998).



Checklist for the case study approach ✓

When undertaking research which involves a case study approach you should feel confident about answering 'yes' to the following questions:

1. Have the *criteria for selection* of the case (or cases) been described and justified? ☐
2. Has the case (or cases) been identified as a particular *instance of a type* of social phenomenon? (e.g. kind of event, type of organization) ☐
3. Is the case a fairly *self-contained entity*? ☐
4. Is the research based on a *'naturally occurring'* situation? ☐
5. Have the *boundaries* to the case been described and their implications considered? ☐
6. Has careful consideration been given to the issue of *generalizations* stemming from research? ☐
7. Have the *significant features* of the case been described and have they been compared with those to be found elsewhere amongst the type of thing being studied? ☐
8. Does the research make suitable use of *multiple methods* and *multiple sources* of data? ☐
9. Does the research give due attention to *relationships and processes*, and provide a 'holistic' perspective? ☐

Figure 7: Checklist for the case study approach (Denscombe, 1998)

3.4. Engineering Management Concepts

3.4.1. Definition of Engineering Management

There are several definitions of Engineering Management. Engineering Management is a form of management that is specialised and centres on the application of engineering principles to business practices. It is a career that brings together the technological problem-solving savvy of engineering together with management (organizational, administrative, and planning) (Wikipedia, 2015a).

Engineering Management is a field that concentrates on the application of engineering principles for the purpose of effective planning and efficient management of manufacturing or industrial operations (Businessdictionary.com, 2015).

Engineering Management covers the following areas of engineering and projects (American Society for Engineering Management, 2015):

- Management of projects and the design process

- Skills for engineers (both Personal and Communication)
- Management of scientific methods
- Human resources
- Variation, quality, and reliability

3.4.2. Tools and Concepts used in Engineering Management

3.4.2.1. Decision Making Methods

In his paper (Fulop, 2000) taken from (Harris, 1980) stated that decision making is the study of firstly identifying and secondly selecting alternatives based on the values and preferences of the decision maker/s. In making a decision there are alternative choices that have to be considered and one needs to choose the alternative that fits best with ones goals and objectives (Fulop, 2000).

Decision making should start with the identification of the decision maker/s together with stakeholder/s involved in the decision thereby reducing the possible disagreement regarding the definition of the problem, its requirements, goals and criteria. The decision making process has the following steps (Baker, et al., 2002):

1. Defining the problem
2. Determining the requirements
3. Establishing the goals
4. Identifying the alternatives
5. Defining the criteria
6. Selecting a suitable decision making tool
7. Evaluating the alternatives against the criteria
8. Validating the solutions against the problem statement

3.4.2.1.1. Pairwise Comparison

Pairwise Comparison is a decision making tool to firstly rank a set of decision making criteria and secondly to rate the criteria on a scale of importance that is relative. If there are more than two criteria involved then determining which one of the criteria is more important poses a problem hence one would need to be able to rank the criteria in order of importance. To each criterion one needs to assign some sort of a relative ranking. This ranking must indicate the degree of importance of each of the criterion with respect to the other criterion that is defined (DesignWIKI, 2016).

It can be very difficult to rank and weight criteria especially in complex problems where every criterion must be weighted in comparison to every other criterion simultaneously. This results in the problem growing arithmetically. An example is for 4 criteria where there are 3 + 2 + 1 = 6 relationships and similarly for 8 criteria there would be 28 relationships to consider (DesignWIKI, 2016).

The Pairwise Comparison is one of the ways to determine how to evaluate alternatives. It is done by providing a simple but reliable means to rate and rank decision making criteria (DesignWIKI, 2016). The Pairwise Comparison is implemented in two stages:

- Stage 1: One has to determine qualitatively which criteria are more important in comparison to the others. A rank order of the criteria needs to be established.
- Stage 2: One has to assign to each criterion a quantitative weight thus ensuring that the qualitative rank order is then satisfied.

3.4.2.1.1.1. Identification of the criteria to be ranked

A suitable technique for identifying the criteria needs to be used.

3.4.2.1.1.2. Arranging the criteria in a square matrix

Table 6: Arranging the criteria in a square matrix using the Pairwise Comparison

Criteria No		A	B	C	D	E
1	A					
2	B					
3	C					
4	D					
5	E					

Each cell in the matrix corresponds to a comparison of a pair of items. The cell will contain the item that is considered the most important of the pair. Since comparing A to B is the same as comparing B to A there is only a need for one triangle of the matrix. One triangle of the matrix will contain a mirror image of the other. The diagonal of the matrix is hence irrelevant since you will just be comparing the criteria to itself (DesignWIKI, 2016).

Table 7: Matrix after the criteria are mirrored

Criteria No		A	B	C	D	E
1	A	-				
2	B	-	-			
3	C	-	-	-		
4	D	-	-	-	-	
5	E	-	-	-	-	-

3.4.2.1.1.3. Comparing pairs of criteria across rows

For every row one needs to now consider the criterion in the row with respect to each criterion in the rest of that row. The letter corresponding to the criteria that one feels is more important must then be written down in the cell. If one feels that both criteria are equally important then both letters need to be written down in the cell.

Table 8: Example of resultant matrix after comparisons are done

Criteria No		**A**	**B**	**C**	**D**	**E**
1	**A**	**-**	**A**	**A**	**D**	**AE**
2	**B**	**-**	**-**	**B**	**BD**	**E**
3	**C**	**-**	**-**	**-**	**C**	**E**
4	**D**	**-**	**-**	**-**	**-**	**D**
5	**E**	**-**	**-**	**-**	**-**	**-**

3.4.2.1.1.4. Creating the Ranking

In order to create the ranking one must draw up an ordered list of the criteria ranked relatively by the number of cells containing the corresponding letter or flag.

For example based on Table 8:

- Criteria 1 - A – rank value = 3
- Criteria 2 - B – rank value = 2
- Criteria 3 - C – rank value = 1
- Criteria 4 - D – rank value = 3

One can see that Criteria 1 = Criteria 4 = rank value = 3

3.4.2.1.1.5. Assigning Weights

The two basic constraints are:

- The total sum of the weights = 100%
- The weights must abide by the relative ranking given using the pairwise comparison

The calculation of x in the above example is therefore as follows:

$$3x + 2x + x + 3x = 100\%$$

$$9x = 100\%$$

$$x = 11.11\%$$

hence the weightings are:

- Criteria 1 = 3x = 33.33%
- Criteria 2 = 2x = 22.22%
- Criteria 3 = x = 11.11%
- Criteria 4 = 3x = 33.33%

3.4.2.2. Use of Six-Sigma for Problem Solving in Small Businesses

Six Sigma is a set of techniques and tools developed for process improvement. Its purpose is to improve the quality of the outputs of a particular process by firstly identifying and secondly removing the causes of defects or errors. This then results in the minimisation of the variability in manufacturing and business processes. (Wikipedia, 2015d)

Through engineering management, one will be able to confront any issues directly by following the steps below (**DMAIC**):

- **D**efine the problem and the goals of a project
- **M**easure key areas of the existing process and collect appropriate data.
- **A**nalyse the data collected to investigate and then verify cause and effect relationships.
- **I**mprove the existing process to create either a future state process.
- **C**ontrol the future state process. This will ensure that any deviations from the targets set are corrected proactively before they result in defects.

Even though there is some doubt, Six Sigma can be used with great effect in small and medium sized businesses (Pyzdek, 2016). The key to successful implementation is in the modification of the way it is deployed. A small business can use Six Sigma provided it has at least one person that can spend one day per week on it. If a work day or shift contains eight hours, this time spent is reached when total employment equals 20 full time equivalents (FTEs). Commitment is required and training is necessary on educating both management and operational staff (Pyzdek, 2016).

A case is made by (Ware , 2012) that small businesses need to look into Six Sigma methodologies. It was further stated that every business needs to incorporate some type of quality assurance management as reject products are very costly. Businesses need process and product control systems. Six Sigma can help make decisions and improve the workings of the operations of small businesses.

According to (Sustaining Edge Solutions Inc, 2016), small businesses were led to believe that the Six Sigma process is complicated and very expensive. This is however not the case. Small businesses require a simple process that can be repeated which one can use to identify, analyse, measure, and improve its existing processes. This can be achieved using simply tools and methods. Easy to understand process templates have been designed which help make business improvements.

3.4.2.3. Production and Operations Management

Production and Operations Management is described as a process that combines and transforms various resources within an organisation into value added outputs in a controlled manner having the required level of quality. Production management are the set of interrelated management activities involved in manufacturing products whereas operations management is the same concept extended to services management. The objective of production management is to manufacture products of both the correct quality and quantity at the right time and cost (Stevenson, 1998).

The general model for managing operations is indicated in Figure 8 below

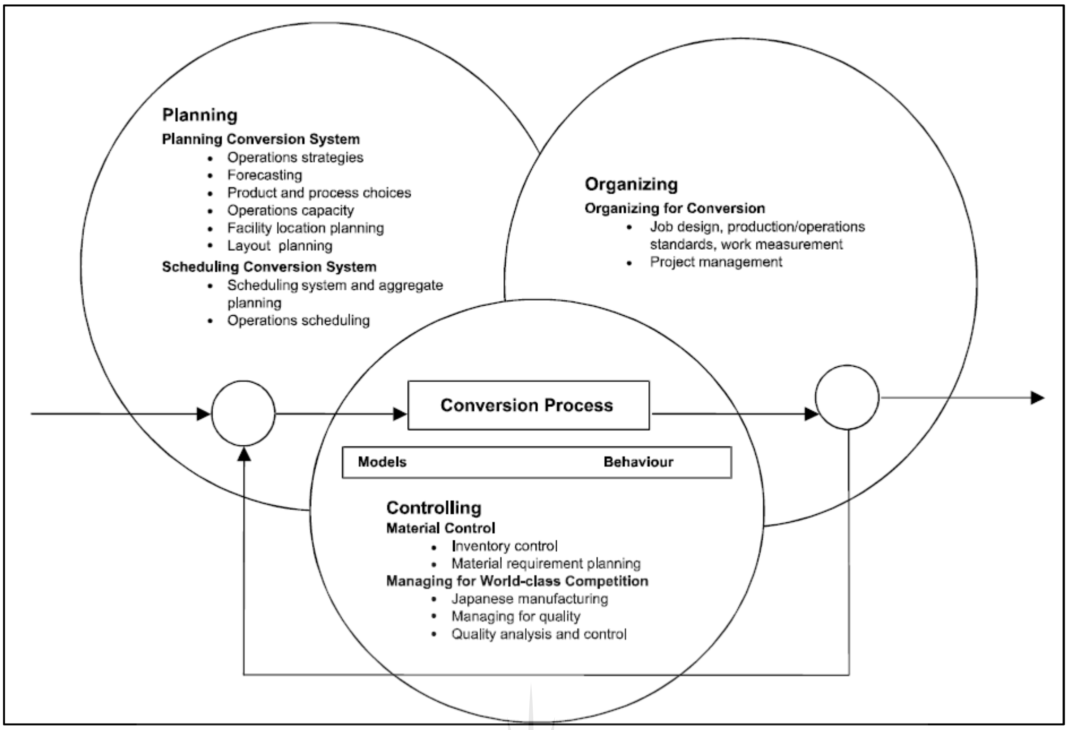


Figure 8: Model for managing operations (Stevenson, 1998)

Operations management is concerned with the utilisation of resources through planning, organising and controlling to obtain the maximum effect or minimising their loss or underutilisation (Stevenson, 1998). This is shown in Figure 9 below.

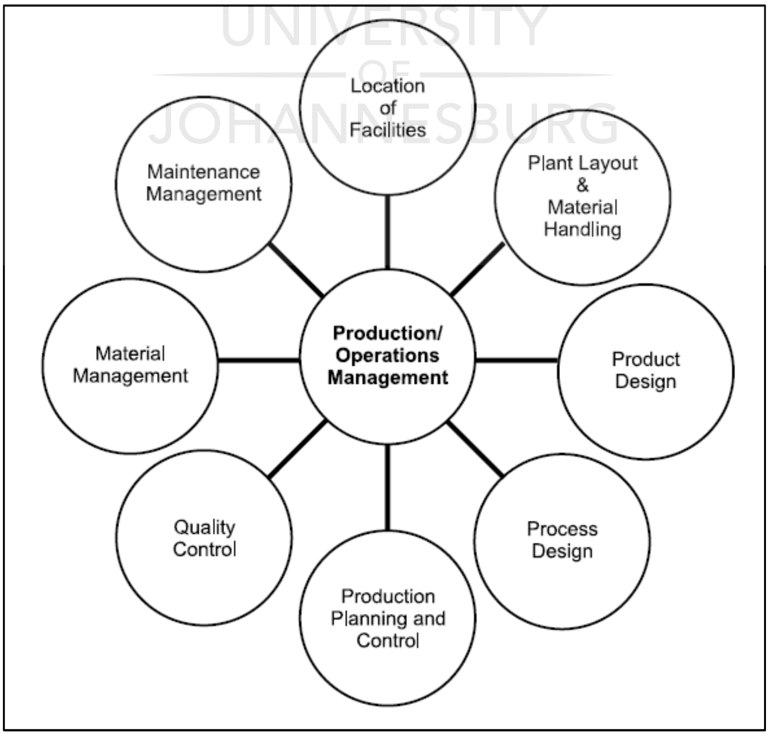


Figure 9: Scope of production and operations management (Stevenson, 1998)

3.4.2.4. *Risk Analysis and Management*

Risk management is described as the process of identifying risks, assessing risks, and then taking appropriate steps to reduce the risks to a level that is acceptable. The risk management approach used will determine the processes, techniques, tools, and team member's roles and responsibilities. The risk management plan developed must describe how risk management will be structured and how it will be performed (Mitre , 2015) .

A model and process for Risk Management is shown in Figure 10 below.

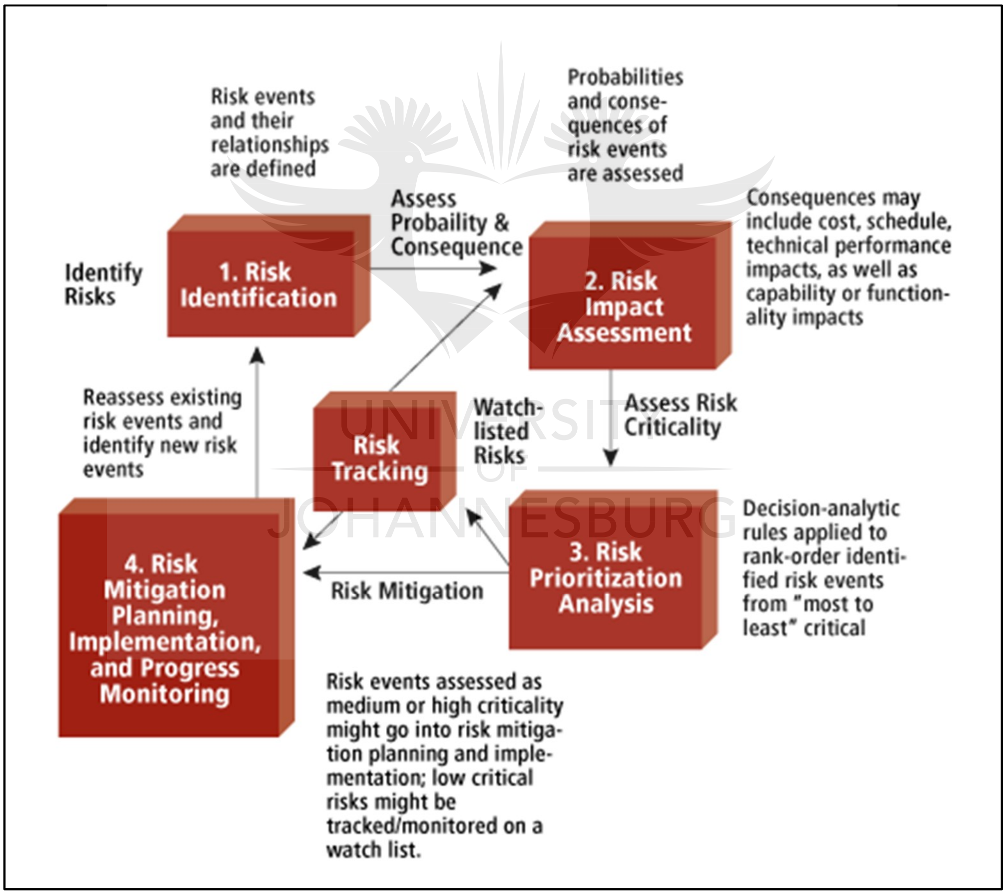


Figure 10: Steps involved in Risk Management (Mitre , 2015)

3.4.2.5. Environmental Management

Environmental Management is defined as the management of the interactions and also impacts of human activities on the natural environment. Environmental management identifies the factors that have a stake or impact in the conflicts that may arise between meeting ones needs and protecting the environment below (West Cost District Municipality, 2015).

The process to be followed is described below (West Cost District Municipality, 2015) :

- Identification of the problem: This is done via complaints/concerns received from the community which will result in identifying a certain environmental problem.
- Evaluation of the problem: This includes inspections that need to be performed in conjunction with relevant Provincial and National Government Departments to determine the extent of the problem.
- Controlling the problem: The problem must be brought to the attention of the transgressor/polluter and the person/company who is informed to stop their activities and address the problem or concerns which include the rehabilitation of the affected area/s.

3.5. Collection of data

3.5.1. Developing a Definition for Small Scale mining

In order to develop a definition for Small Scale Mining one will utilise the Pairwise Comparison Decision Making Tool described in section 3.4.2.1.1. The variables or criteria (from literature) to be compared are:

- Volume of production **Variable = A**
- Number of people (labour) employed **Variable = B**

- Capital Cost (equipment, technology level) **Variable = C**
- Size of the mineral resource **Variable = D**

As discussed in section 3.4.2.1.1, four criteria result in six comparisons. These comparisons are summarised as - Which is more important:

1. Volume of production (A) or No of people Employed (B)
2. Volume of production (A) or Capital Cost (C)
3. Volume of production (A) or Size of the mineral resource (D)
4. No of people Employed (B) or Capital Cost (C)
5. No of people Employed (B) or Size of the mineral resource (D)
6. Capital Cost (C) or Size of the mineral resource (D)

A survey will be designed based on the above comparisons that will be sent to at least 10 specialists/experts in the field of small scale mining in order to determine the relative weights and hence importance/rank of the abovementioned variables.

A specialist/expert in Small Scale Mining will be defined as a person that:

- Is knowledgeable in the area.
- Has worked in the sector for a number of years.
- Is highly skilled in the areas of geology, mining or minerals processing.

These specialists/experts can reside in academia, government departments, science councils, mining sector or can be employed as consultants.

3.5.2. Visits to selected small scale mining and minerals processing operations

The primary source of information used for the research is from literature. The second source of information would be data collected from selected legalised small scale mining and processing operations within South Africa.

These operations would need to be identified using information collected from literature, databases/lists available from the Department of Mineral Resources (DMR) and also word of mouth i.e. from reliable sources/people that work within the field of small scale mining and processing. The operations visited would need to be confined to the commodities identified during the literature review as ones currently being mined and processed by legalised small scale operators. These commodities can be summarised as follows: diamonds, semi-precious gemstones, gold, coal and industrial minerals.

3.5.3. Questionnaire and Survey Design

In order to collect the data from selected small scale mining and minerals processing operations one would need to develop a structured questionnaire or survey.

In questionnaire design, questionnaires can take two forms. The first is a self-administered questionnaire where the respondents are required to complete the questionnaire in their own time. The second is a structured interview where the interviewer (usually the person conducting the research) writes down the answers of the respondent and this can be done either telephonically or through a face-to-face interview (Eiselen, et al., 2005). Due to that fact that the number of legal small scale processing operations in South Africa that could be visited may be limited the approach to be used would be a face-to-face interview with owners or mine managers which would require a structured questionnaire.

The development of the questionnaire would involve:

a. Formulating once again the objectives of the research and the intended goals (stated in section 3.1).
b. Providing a clear and concise formulation of who the target audience is (owners and mine managers of legal small scale mining and processing operations in South Africa).
c. Listing all questions and information required to answer the research question.
d. Organising the questions in a logical order and also categorising them so that they follow a sequence that is understandable to the person being interviewed.
e. Consulting with experts (research supervisor) to ensure that questions are relevant to the target audience and that the information collected will indeed answer the research question.

The questionnaire and survey developed can be found in APPENDIX A: Questionnaire used for gathering of information and APPENDIX B: Survey - Defining the Artisanal & Small Scale Mining Sector.

3.6. Analysis of Data

The data obtained from these selected small scale mining and minerals processing operations would then be used:

a. To compare actual practices (processing techniques, production, operations etc.) with those studied in the literature and then draw recommendations for improvement to productivity.

3.7. Applying Engineering Management Principles to Small Scale Mining and Minerals Processing Operations

3.7.1 Determining focus areas for improvement of productivity

Qualitative Data Analysis (Cross-Case Displays) was described by (Miles & Huberman, 1994) as "Variable-orientated Strategies" where researchers look for themes that cut across different cases. Recurring themes can be found after analysis and comparison of the data.

The technique to be used will therefore be a comparison of suggested methods of improving productivity from literature with the data collected from the visits to selected small scale mining and processing operations. The list of suggested improvements will then be categorised in a number of themes or in this case focus areas. The methodology is shown in Figure 11 below.

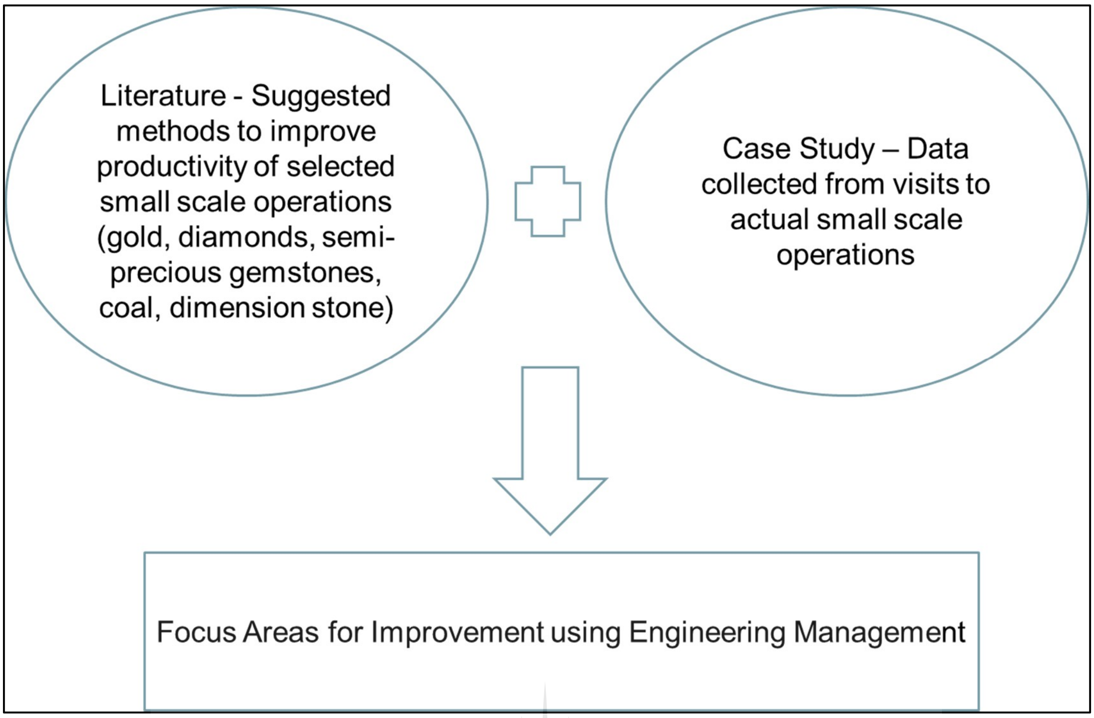


Figure 11: Methodology used to determine focus areas for productivity improvement

3.7.2. Developing appropriate models and recommendations for improving productivity

This will involve the application of Engineering Management described in section 3.4 on the Focus Areas identified in section 3.7.1. Depending on the findings of 3.7.1, literature would need to be further consulted to look at recommended ways in which each focus area can be expanded and also practically implemented.

CHAPTER 4: PRESENTATION OF RESULTS IN LIGHT OF THE LITERATURE

4.1. Introduction

The challenge faced with this part of the research was finding suitable legal operations that could be visited. Even though the Department of Minerals Resources (DMR) have lists of small scale operations, a number of the companies on the list are not operational anymore and the contact details of the owners are out dated. Extensive searches were also done on the internet to look for contact details for various small scale operations in South Africa. On making contact with a number of these operations it was found that they were closed down and certain respondents did not reply to email or telephone. Due to this one was unable to find suitable operations in gold, coal and quarrying. A gold operation was identified (discussed in the literature study section 2.4.1.1) but the operation has shut down.

On the 25 November 2015 a trip was made to Prieska which is about 250km from Kimberley in the Northern Cape Province of South Africa. Two sites were visited, namely a Diamond Mining & Processing Operation (AAA Mining) and a Semi-precious Gemstone Processing Operation (PP Gemstones Mining & Export). The purpose of the trip was to observe the processing operations and conduct interviews with staff and management of the operations. The questionnaire used can be found in APPENDIX A: Questionnaire used for gathering of information

4.1.1. Case Study A: Visit to a Diamond Mining and Processing Operation in Prieska, Northern Cape

AAA Mining was established in 2004 and has employed 42 staff. They are a legal entity with the appropriate permits for mining diamonds. The production capacity is approximately 40 tons per hour (per diamond pan) of processed diamonds. Figure 12 shows the size of the processing plant which is equipped with six 16 feet diamond pans (Figure 15) which one was told by the mine manager is a distinct technology advantage for the operation. The layout of the plant follows the process outlined in the literature and section 2.4.1.2. The final stage of processing (recovery) is enclosed (Figure 16) and one was not able to view this. The final product is transported by truck to the Diamond House in Kimberley.

Figure 12: Diamond Processing Operation in Prieska, Northern Cape

Figure 13: Screening of material

Figure 14: Washing of material

Figure 15: 16 feet diamond pans

Figure 16: Enclosed Diamond Recovery Stage

The average age of the staff employed is 35 years. The educational level of the staff varies and range between Grades 10-12 and Artisans that include boilermakers, electricians, mechanics and drivers. All training is done onsite and certification received from the Transvaal Training Centre. The operator level staff salaries range between R5, 000 and R10, 000 per month.

The shift times are from 6am to 6pm (12 hours, single shift) from Monday to Thursday. The exception is Friday when the shift ends a 3pm. Even though this can be considered as three hours of lost productivity the staff is taken into consideration as many of them need to travel over the weekends to see their families. Keeping staff happy is very important.

In terms of Health and Safety there are 6 safety reps and 6 first aiders. All staff have to wear the prescribed Personal Protective Equipment (PPE) and Hazard Operability Studies (HAZOPS) together with Risk Assessments are done regularly hence the Mine Manager indicated that injury is not a concern.

The main environmental concerns are the disposal of oil (from machines and equipment), dust (evident in the photos taken), noise and extreme heat (46-48 degrees Celsius) which is typical for the Northern Cape Province especially during summer seasons.

The main cost drivers for this diamond mining and processing operation is:

- Diesel (60 000 L/month)
- Water
- Electricity (Eskom)

4.1.2. Case Study B: Visit to a Semi-precious Gemstone Cutting & Polishing in Prieska, Northern Cape

PP Gemstones Mining & Export is a very small business established in 2014 and employing only 10 staff. They are a legal entity with the appropriate permits for mining Tiger's eye. The business has three operations namely mining, processing and export. The visit undertaken was to see the storage and processing facility in Prieska. The company mines a number of semi-precious gemstones within the Northern Cape area but specialises in Tiger's Eye which is available in the Prieska area. The raw material is firstly sorted by hand (Figure 18), graded (visually) and then packaged (Figure 17) and ready for sale or export in large bags. The output of the business is only 20kg per day but this is also impacted by the mining operations.

Figure 17: Graded and packaged semi-precious gemstones for sale or export

Figure 18: Different types of semi-precious gemstones

Not all the raw material is packaged for sale or export. Some of the material is beneficiated locally and the business has equipment for cutting (Figure 19), sanding and polishing (Figure 20). The process followed is the same as described in the literature in section 2.4.2. A range of products are manufactured in small quantities and an example of tiles is shown in Figure 21. The equipment used is however old but still serves the purpose.

Figure 19: Gemstone cutting equipment

Figure 20: Gemstone sanding and polishing (wet) equipment

Figure 21: Tiles made using different semi-precious gemstones

4.1.3. Additional challenges faced during interview process

Besides the first challenge of not being able to find suitable legal operations for all five commodities studied; it was also very difficult to obtain all information required as per the structured questionnaire (APPENDIX A). Some of the people interviewed did not have all the answers and one struggled to get all the information required in details. A considerable amount of information had to be acquired from visual inspections which are shown in the photos. Some information was requested via email after the site visits but responses were not received.

4.1.4. Summary of major difference between operations visited (Case Study A and B)

Even though based on the current definition both operations visited are classified as small scale they have significant differences in terms of number of people employed, production rates, capital investment and type of equipment (technology) used. Table 9 below show the major differences highlighted.

Table 9: Comparison of a Semi-precious Gemstone Operation and a Diamond Mining and Processing Operation which are both considered "Small Scale"

	Semi-precious Gemstone Operation	**Diamond Mining and Processing Operation**
No of People employed	10	42
Estimated Value of equipment (technology used)	< R2M	>R6M
Production	20kg per day (output)	40 tons per hour per diamond pan (throughput)

4.2. Discussion of Results

4.2.1. The Formulation of a Definition for Small Scale Mining

From the literature review one can see that developing an exact definition of small scale mining can be rather complicated and complex. The four key variables that determine if an operation is artisanal or small are:

1)	Volume of production	**Variable = A**
2)	Number of people (labour) employed	**Variable = B**
3)	Capital Cost (equipment, technology level)	**Variable = C**
4)	Size of the mineral resource	**Variable = D**

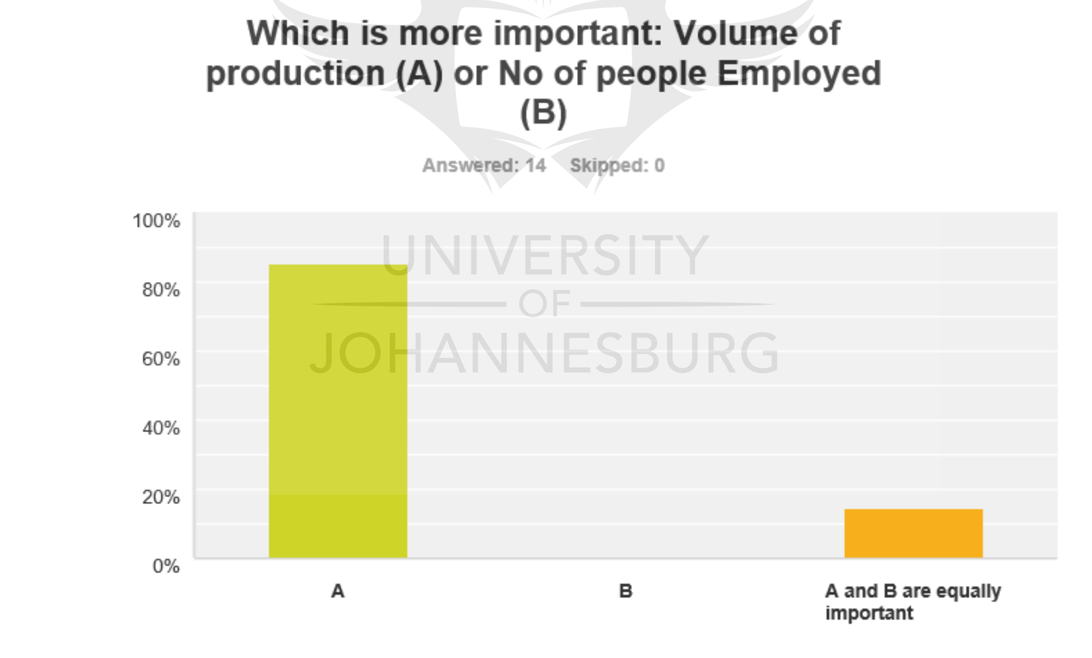
There may however be further contradiction and confusion caused with some of these variables used for classification especially on the side of production (which affects turnover) and the business management of the operation. An operation that has many staff but is not well managed and therefore has a low turnover may be classified incorrectly. The opposite may also be applicable in the case where an operation has fewer staff but is well managed and these result in a higher turnover. The level of production is also influenced by the type of mineral being processed and different commodities may have different production outputs e.g. diamond processing versus quarrying.

One is also able to see from the two sites visited (diamond and semi-precious gemstones) in section 4.1 that the scale/size of operations, number of employees, type of equipment used are vastly different but based on the current definition both operations are classified as “small scale”.

The determination of whether an operation is artisanal or small scale is essentially a matrix of the four above mentioned variables.

Classification of type of operation = ∑ (Volume of production)*(Weight), (Number of people employed)*(Weight), (Capital Cost)*(Weight), (Size of the mineral resource)*(Weight) …………………………………………………….. (1)

In order to determine the weights of the criteria the Pairwise Comparison tool was used as described in section 3.4.2.1.1. A survey (APPENDIX B: Survey - Defining the Artisanal & Small Scale Mining Sector) was conducted and the number of surveys submitted to experts/specialists in the field of small scale mining was thirty three (33). The number of responses received was fourteen (14). This was a 42% response rate which is low but the number received (14) was higher than the required amount of 10. A response rate of >60% would have been required in order to generalise the results. The results obtained were as follows where the criteria was numbered as Volume of production (A) , Number of people employed (B), Capital Cost (C) and Size of the mineral resource (D).

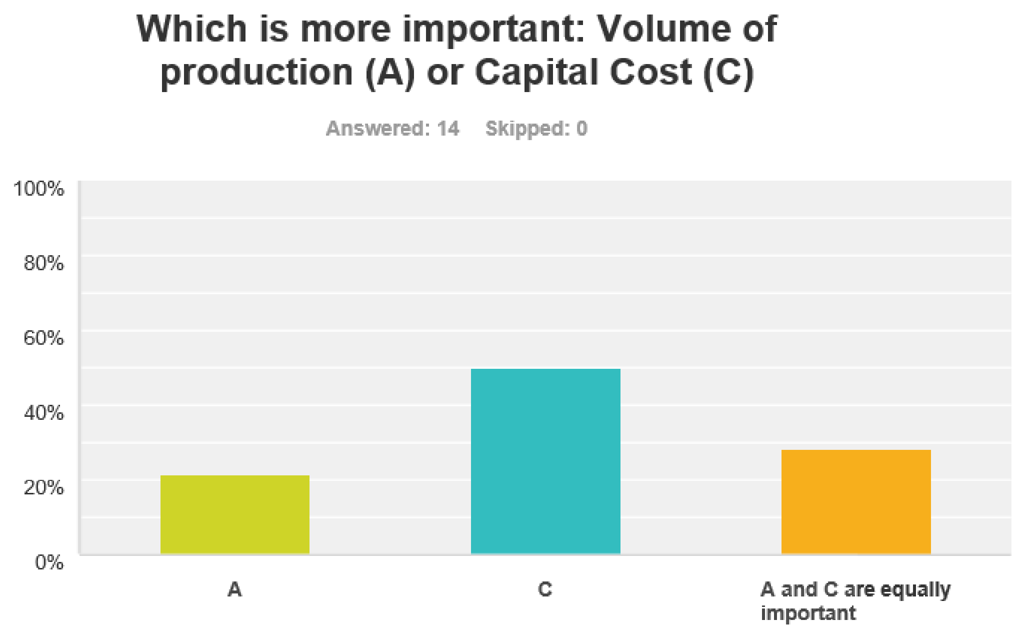


Answer Choices	Responses	
A	85.71%	12
B	0.00%	0
A and B are equally important	14.29%	2
Total		14

Figure 22: Results of Question 1 of survey

Almost 86% of experts/specialists surveyed felt that Volume of production (A) was far more important a criteria than the No of people Employed (B). 14% felt that Volume of production (A) and No of people Employed (B) were equally important. Some of the reasons given for the choices are summarised below:

- Some small scale mining projects give employment to large numbers of people, yet all are basically in subsistence type of work. Some highly mechanised operations employ very few people and yet are not considered as small scale mining operations.
- The number of people employed depends on the level of technology deployed. Operations could employ the same number of people but could have different production volumes.
- Mechanisation and automation can produce more but employ less.
- The number of people employed is not a true indication of the type of operation.
- Large volumes of production may be due to mechanisation and not necessarily due to the number of people employed.

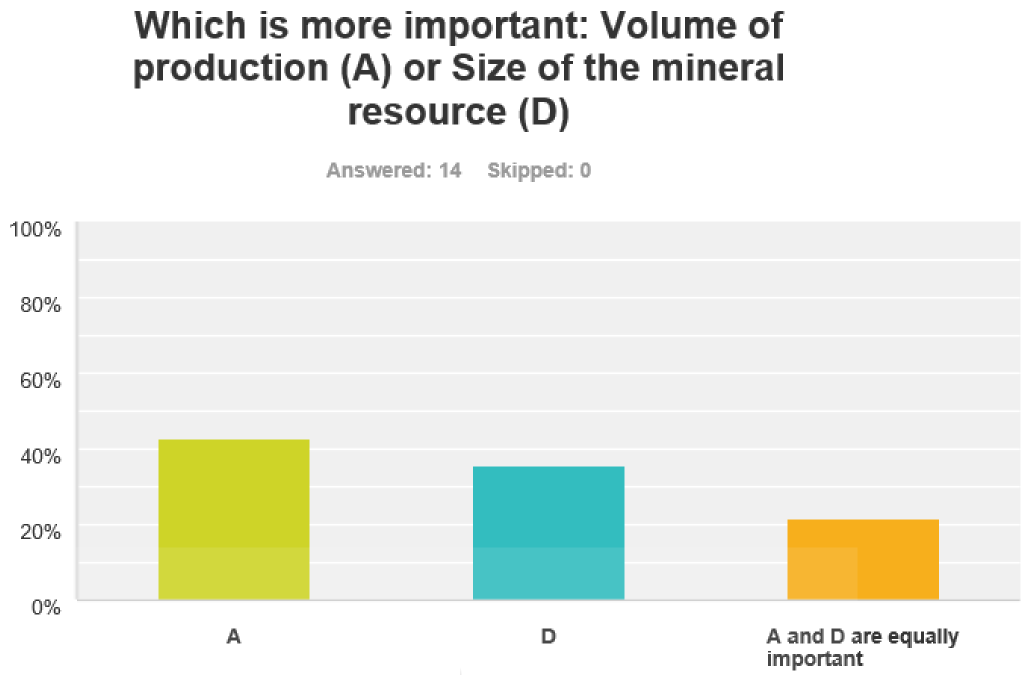


Answer Choices	Responses	
A	21.43%	3
C	50.00%	7
A and C are equally important	28.57%	4
Total		14

Figure 23: Results of Question 2 of survey

50% of the experts/specialists surveyed felt that Capital Cost (C) was more important a criteria than Volume of Production (A). Almost 29% felt that Capital Cost (C) and Volume of Production (A) were equally important with 21% indicating that Volume of Production (A) was more important than Capital Cost (C). Some of the reasons given for the choices are summarised below:

- One can achieve a higher volume of production with more capital investment or alternatively the amount of capital invested is directly dependent on the volume or scale of production that one wants to achieve.



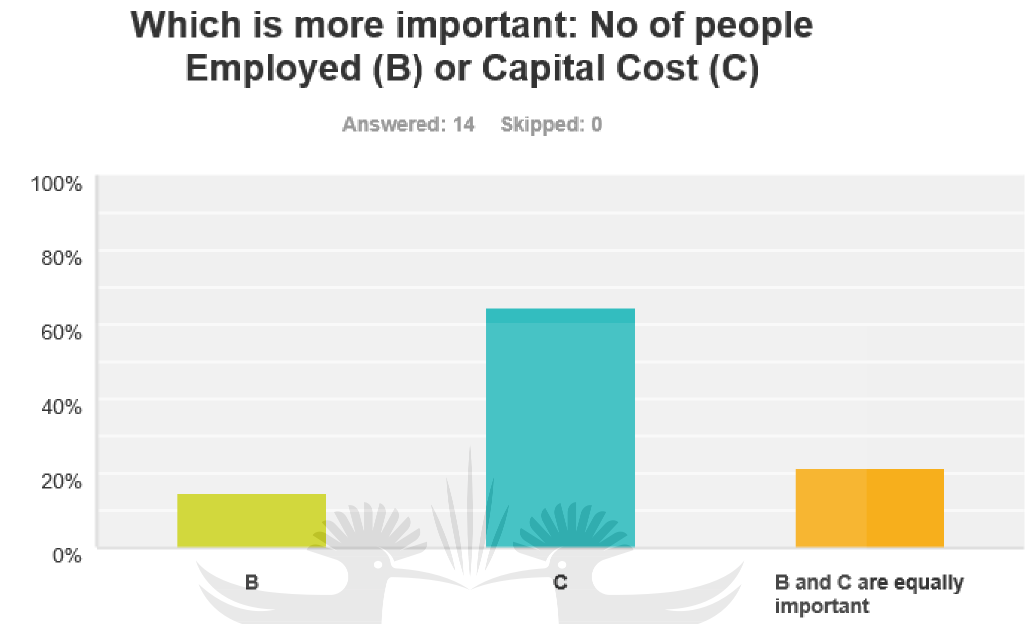
Answer Choices	Responses	
A	42.86%	6
D	35.71%	5
A and D are equally important	21.43%	3
Total		14

Figure 24: Results of Question 3 of survey

The results obtained for Question 3 of the survey were much closer that Questions 1 and 2. Almost 43% of the experts/specialists surveyed felt that Volume of Production (A) was more important than Size of the Mineral Deposit (D). Almost 36% felt that Size of the Mineral Deposit (D) was more important than the Volume of Production (A). 21% felt that Volume of Production (A) and the Size of the Mineral Deposit (D) were equally important. Some of the reasons given for the choices are summarised below:

- For both artisanal and small scale miners the size of the mineral deposit does not matter as long as they are able to meet the production demands.
- The size of the mineral deposit determines the scale of operation.
- The lifespan of the operation is dependent on the size of the mineral deposit and type of equipment used for mining/processing.

- Larger mineral deposits would not be considered as small scale operations anymore.

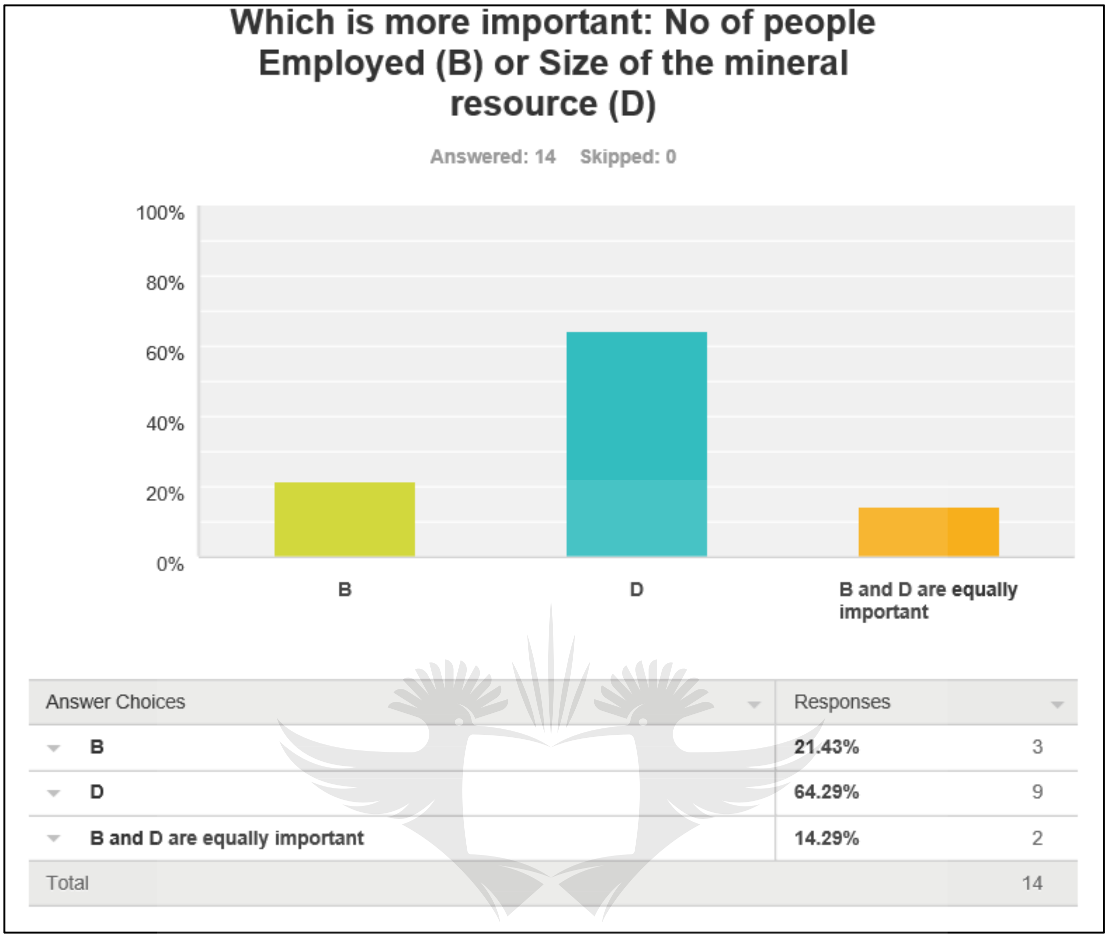


Answer Choices	Responses	
B	14.29%	2
C	64.29%	9
B and C are equally important	21.43%	3
Total		14

Figure 25: Results of Question 4 of survey

64% of the experts/specialists surveyed felt Capital Cost (C) was far more important a criteria than the No of people Employed (B). Only 14% felt that No of people Employed (B) was more important than Capital Cost (C) with 21% feeling that they are of equal importance. Some of the reasons given for the choices are summarised below:

- The amount of capital invested determines both the level of technology deployed and the size of the operation.
- The number of people employed is a result of the combination of technology deployed, capital cost and the rate of resource extraction, rather than the resource volume.

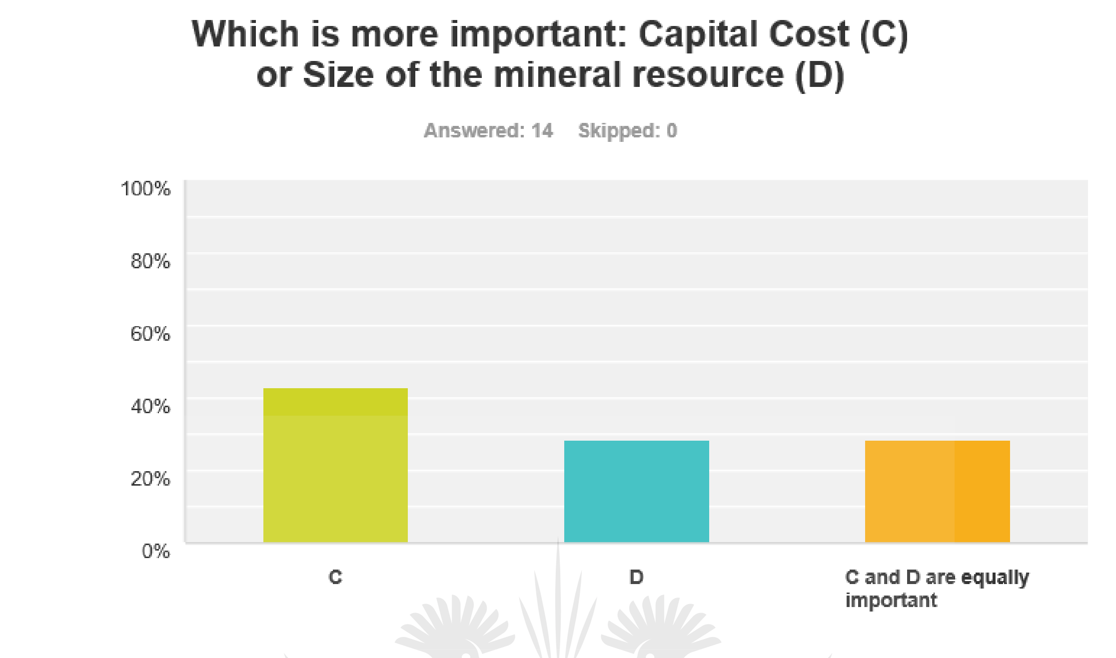


Answer Choices	Responses	
B	21.43%	3
D	64.29%	9
B and D are equally important	14.29%	2
Total		14

Figure 26: Results of Question 5 of survey

64% of the experts/specialists surveyed felt that the Size of the Mineral Resource (D) was far more important a criteria than the No of people Employed (B). 21% felt that the No of people Employed (B) was more important than the Size of the Mineral Resource (D) with 14% feeling that they are of equal importance. Some of the reasons given for the choices are summarised below:

- It's not the size of the mineral deposit, but rather the grade/quality of the deposit that is important.
- The size of the mineral deposit is not relevant it's the capacity (capital, technology, people) to be able to mine or process the deposit that is important.
- The size of the mineral deposit will determine how many people are required.



Answer Choices	Responses	
C	42.86%	6
D	28.57%	4
C and D are equally important	28.57%	4
Total		14

Figure 27: Results of Question 6 of survey

Question 6 of the survey yielded the closest comparison. Almost 43% of the experts/specialists surveyed felt Capital Cost (C) was more important than the Size of the Mineral Resource (D). Almost 29% were split between the option of the Size of the Mineral Resource (D) being more important than the Capital Cost (C) and the option of both criteria being of equal importance. Some of the reasons given for the choices are summarised below:

- The capital cost somewhat determines the profitability of the operations.
- The size, type of mineral mined/processed and geology will determine the capital cost.
- From a geological perspective the resource size and mining cost plays a huge role in governing the mineral reserve. i.e. mineable ore

The individual results of the questions of the survey were then tabulated using the Pairwise Comparison in section 3.4.2.1.1. The results of the 14 surveys received are shown in Table 10 below.

Table 10: Table showing results of survey conducted for determining weights of the importance for the selected criteria using the Pairwise Comparison tool.

	Production	People	Capital	Size of Resource
Survey No	A	B	C	D
1	16.67	0.00	50.00	33.33
2	42.86	0.00	14.29	42.86
3	28.57	0.00	28.57	42.86
4	16.67	0.00	50.00	33.33
5	50.00	33.33	16.67	0.00
6	33.33	0.00	33.33	33.33
7	25.00	25.00	12.50	37.50
8	22.22	33.33	33.33	11.11
9	37.50	25.00	25.00	12.50
10	42.86	0.00	42.86	14.29
11	25.00	37.50	37.50	0.00
12	16.67	0.00	33.33	50.00
13	25.00	0.00	37.50	37.50
14	28.57	0.00	42.86	28.57
Average	29.35	11.01	32.70	26.94

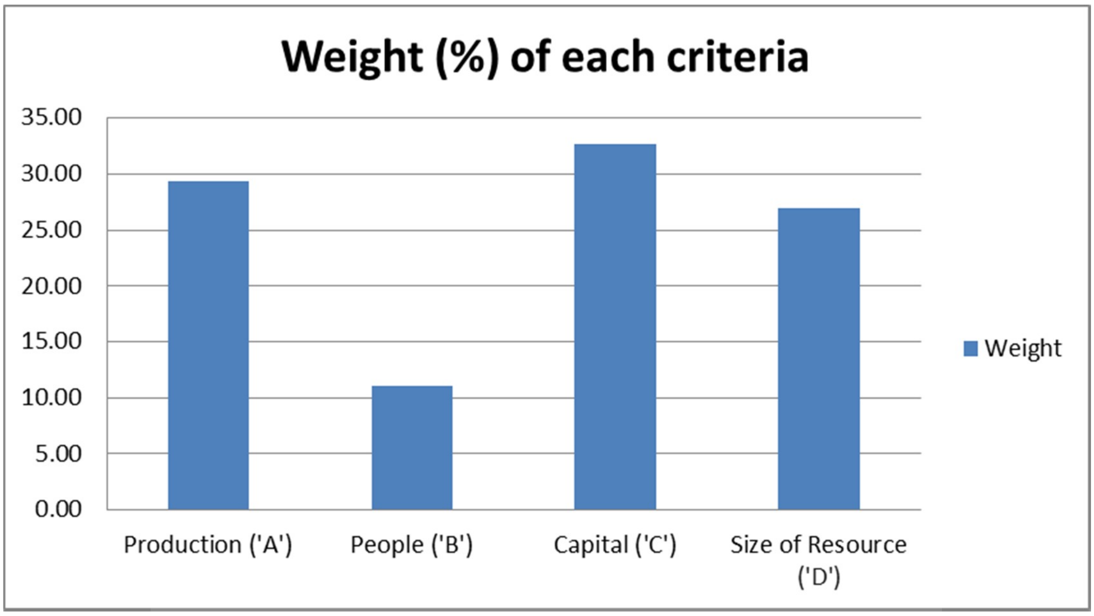


Figure 28: Graphical representation of the results of the survey using the Pairwise Comparison Tool.

Using the Pairwise comparison and the survey conducted one can clearly see that the No of People Employed (B) is the least important criteria and is only weighted at 11%. The comparison is however very close between the other three criteria. Capital Cost (C) is the most important at 32.70% followed closely by Volume of Production (A) at 29.35% and then Size of the Mineral Resource (D) at 26.94%. The classification of a small scale mining operation based on the Pairwise Comparison tool and the 14 surveys received can therefore be expressed as:

Classification of type of operation = 29.35*(Volume of Production) + 11.01*(No of people employed) + 32.70*(Capital Cost) + 26.94*(Size of the mineral resource) ……………………………………………………………………………… (2)

In the literature review it was found that the common perception of the characterisation of Artisanal and Small Scale Mining (ASM) was that there is (Hentschel, et al., 2003):

- Lack of or limited use of mechanization (manual labour)
- Low levels of occupational safety and health care
- Low qualifications or education level of staff
- Inefficient mining and processing of minerals that result in low recoveries
- Mining of small deposits, which are not economically viable using mechanized techniques
- Low levels of productivity

- Low levels of income
- Insufficient consideration for the environment
- Lack of capital investment

From the definition developed and the selected operations visits one can see that the perception of “lack”, “low level”, “poor” and “insufficient” is mainly from artisanal operations and not operations that would be classified as small scale. The Diamond Mining and Processing operation visited which is classified as “Small Scale” does not suffer from any of the challenges above that is found in literature whereas the Semi-precious Gemstone operation tends to display more of the artisanal type of characteristics.

The definition developed therefore clearly indicates that if an operation does not have enough capital, does not have adequate production volumes and mineral resources it cannot be classified as small scale but rather should be classified as artisanal. It also emphasises the point that artisanal and small scale mining should not be interchangeably used but should rather have unique definitions to avoid the confusion that it has caused for several years within the sector.

4.2.2. The Factors that affect Productivity of Small Scale Mining and Minerals Processing Operations and Recommendations for Improvement

From the literature and selected small scale mining and minerals processing operations studied (visited) the general methods for improvement of operations is summarised as follows:

Table 11: Table summarising the recommended improvements that can be made to existing small scale processing operations obtained from literature and selected site visits.

Type of Operation	Summary of recommended improvements	Category of recommended improvement
Gold	• Use of the correct processing equipment and methods for gold extraction. • Education and Training of small scale operators on the processing methods to be used and also health/safety. • Testing and analysis of the ore/feed prior to selection of the processing method	• Technology • Skills • Chemical Analysis
Diamonds	• Utilisation of optimal production plan including targets and potential efficiency improvements. • Minimisation of the amount of dust produced during processing.	• Management (Production) • Management (Environmental)
Semi-precious Gemstones	• Mechanisation of the recovery and processing techniques used.	• Technology
Coal	• Optimization of the existing techniques used for sizing, screening, washing and briquetting of low calorific value coals.	• Technology

Quarrying (Dimension Stone)	• Introduction of Quality Management Process from excavation to production • Innovation and the use of new technology for processing • Production Management – reduction of costs and optimal use of resources (people, technology, raw material)	• Management (Quality) • Technology • Management (Production, Operations)

The recommended improvements can essentially be categorised into four focus areas namely:

- Management
- Chemical Analysis
- Technology
- Skills

These are shown in Figure 29 below and this has been termed the "The Small Scale Mining and Minerals Processing Productivity Improvement Pyramid"

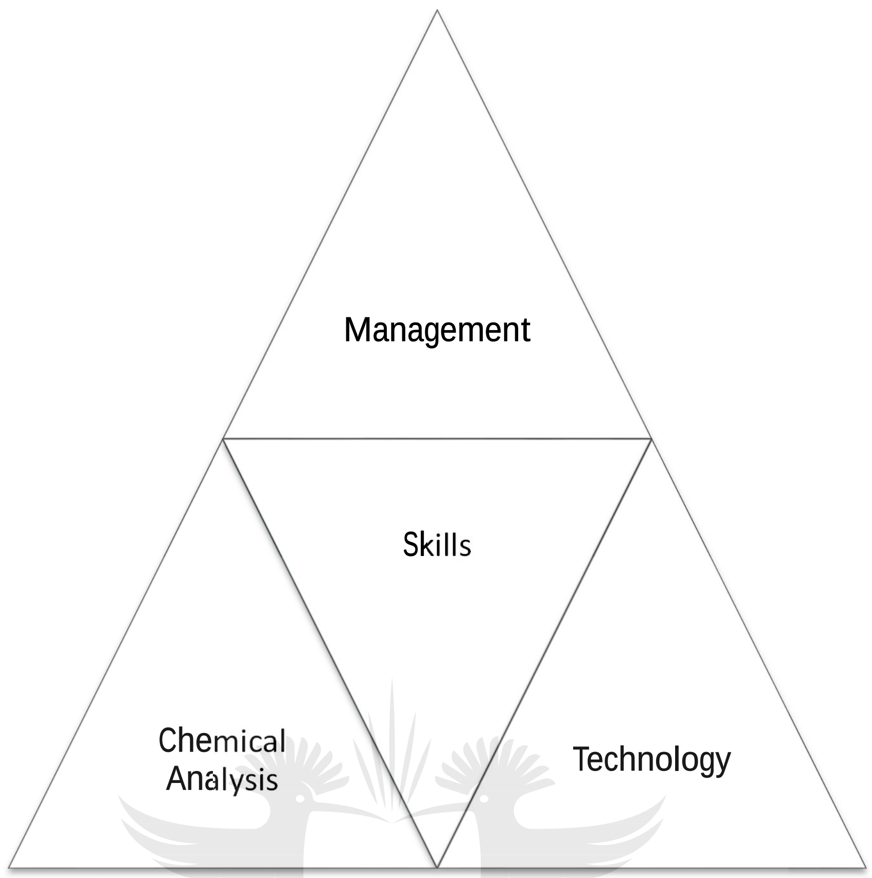


Figure 29: The four focus areas required to improve productivity of selected small scale mining and processing operations in South Africa – The Small Scale Mining and Minerals Processing Productivity Improvement Pyramid

Even though each of the four areas can be looked at individually and one can determine what improvements can be made that would yield positive results in terms of productivity, one needs to ensure that a holistic approach is used since improvements in productivity requires all four areas and there may also be certain areas that are interdependent. Interdependence is the mutual reliance between two or more groups (Wikipedia, 2016). One example of interdependence would be if the feed material was not properly analysed then one would be unable to determine the best processing flowsheet to be used and hence would not have the suitable technology required to achieve the best productivity.

4.2.2.1. Management

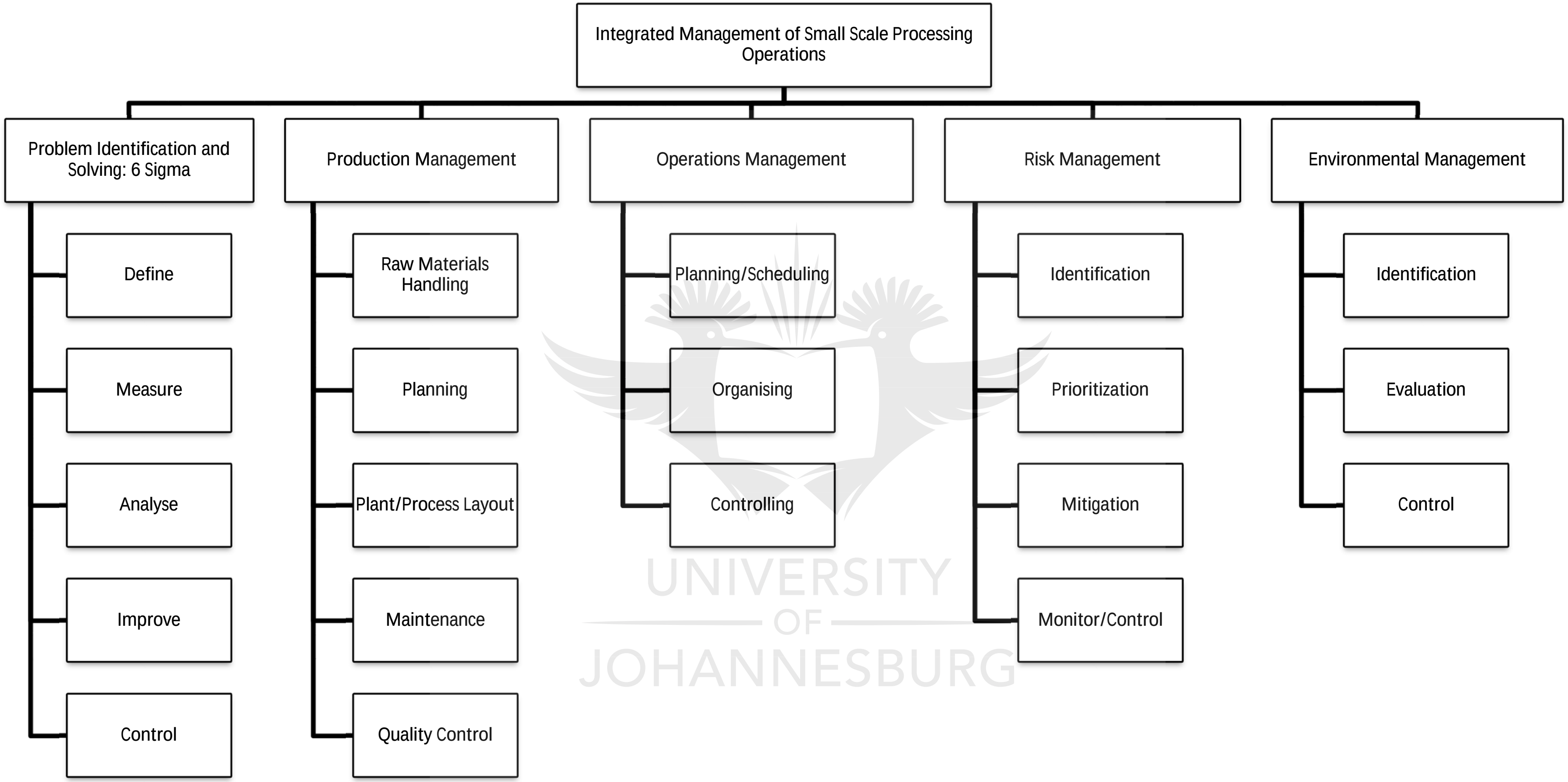


Figure 30: Integrated Management Model proposed for Small Scale Mining and Minerals Processing Operations

Figure 30 shows the proposed integrated Management model that should be used by Small Scale Mining and Minerals Processing operations. The proposed models takes all the concepts discussed in section 3.4 and combines them into a single model.

Six Sigma is an invaluable tool that should be used by all small scale mining and minerals processing operations for identification and solving of problems related to production, operations, environment and risk. All of these management tools require one to be able to measure identified variables and be able to have systems in place to monitor and control these variables for improved productivity and efficiency. Literature has shown that Six Sigma is equally applicable to small businesses/operations and not only used for larger operations. Management and staff will however need to be trained on its use and application for problem solving and also to improve the quality of the final product.

4.2.2.2. Chemical Analysis

Chemical analysis is defined as the study of the chemical composition of substances and its structure. Analytical chemistry is divided into qualitative analysis and quantitative analysis. Qualitative chemical analysis is the determination of elements and compounds that are present within a sample of unknown material. Quantitative chemical analysis is the determination of the amount (by weight) of each element or compound present (The Columbia Electronic Encyclopedia, 6th Edition, 2012).

In the context of small scale mining and minerals processing it refers to the chemical or mineral composition, mineralogy, particle size distribution and any other characteristics of the feed material that one needs to know at the onset in order to determine the optimal recovery/extraction method to be used. This will require samples to be sent to recognised laboratories for analysis. Even though this has cost implications, which is why it is an area neglected by small scale operators, the benefit of improved recovery will most likely outweigh the cost incurred for analysis.

Chemical analysis is essential in ensuring not only the mineral's safety but also to ensure quality, productivity, control and consistency (Case Chemicals, 2016).

Table 12 below shows the proposed tests and analysis required for small scale mining and minerals processing operations

Table 12: Table showing proposed tests and analysis required for selected small scale mining and minerals processing operations

Type of Operation	**Proposed tests and analysis required**
Gold	*Source:* www.mintek.co.za Full gold mineralogical characterisation can be conducted to determine the bulk modal mineralogy, minerals present, their relative abundances, gold (Au), silver (Ag) and copper (Cu) minerals present, their relative abundances, Au, Ag, Cu, deportment, liberation characteristics, grain size of Au, Ag, Cu and gangue mineral association. Samples normally submitted are -1mm (top size) and not pulverised. The following analysis are performed on gold samples: • Fire assay – this is used to determine the gold grade • X-Ray Diffraction (XRD) – Used to determine mineral composition (reports relative proportions) • Scanning Electron Microscopy (SEM) – Determine the relationship between minerals (how they are distributed /interlock) • Qualitative Energy Dispersive XRF – Used to determine elemental composition. • Gold search - In order to understand the different gold species an Au mineral deportment study is undertaken. Only discrete Au-bearing minerals will be targeted, in this instance. Solid solution of gold in pyrite and arsenopyrite crystal structure cannot be determined by this method. • Bulk modal analyses (BMA) & Base metal sulphide Search (BMS). The polished sections are analysed using an AutoSEM. The data will be supported by X-Ray diffraction. From the data generated the relative proportions of all the different minerals will be quantified.

Table 12 continued….

Diamonds and Semi-precious Gemstones	*Source:* (Geologycafe.com, 2016) A summary of the tests done on both diamonds and semi-precious gemstones include: • Weighing - Gemstone rough may be sold by weight. The units of measurement include ounce, pound, gram or kilogram, and metric carat. • Testing Gemstones Using a Conductivity Meter – this refers to the heat conduction and some gem materials such as diamonds are excellent conductors. • Diamond Lite and Colour Grading of Gemstones - The main purpose of the unit is for colour grading diamonds, but it also can be used to compare coloured stones under controlled and repeatable lighting conditions that can be important. • The Diamond Microscope - The diamond microscope used is called a stereo microscope and is similar to pair of binoculars. The diamond microscope uses a darkfield base and divert the light from inclusions or flaws in the diamond.
Coal	*Source:* (Zhu, 2014) Coal sample analysis is done to determine the quality (or rank) of the coal and also to determine its characteristics which are termed intrinsic. General coal analysis and testing include the following: • Proximate analysis – This analysis tests for moisture content, ash content, volatile matter and fixed carbon. • Ultimate analysis - This analysis tests for carbon, hydrogen, oxygen, nitrogen and sulphur content. • Ash analysis – This analysis tests for major and minor elements in both coal and coal ash. • Calorific value - This is also defined as the heating value or specific energy of coal.

Table 12 continued….

Quarrying (Dimension Stone)	*Source:* (Marble Institute of America (MIA), 2014), (Marble Institute of America (MIA), 2016) For different types of dimension stone, tests have to be conducted to determine the suitability of the stone for a particular use or application. Strength tests are performed to determine if the dimension stone is resistant to crushing and bending. Density (also known as specific gravity) is tested so that one is able to design appropriate supports systems that can carry the weight of the particular dimension stone. The absorption rate of water also needs to be tested in order to determine its resistance especially to staining and freezing. For applications involving flooring (e.g. tiles) the dimension stone wear and slip resistance is critical. Type of tests conducted include: • Petrography – this is a technique used to determine the description and classification of the stone. • X-ray diffraction (XRD) analysis • Lithogeochemistry – this is the chemical analysis of stone • American Society for Testing and Materials (ASTM) standard tests. These include o checking the uniformity of the stone o wet and dry tests o testing parallel and perpendicular with the rift o horizontal applications and limitations of thin stone.

4.2.2.3. Technology

The development of a minerals processing flowsheet using the appropriate recovery methods (technology) based on the results of the analysis, the financial standing (capital at hand for investment) of the small scale operator and the environmental impact (similar to what was proposed for gold processing in Table 4) will all need to be considered.

The Centre for Mechanised Mining Systems at Wits University have drafted a document entitled "Addressing the Technology Challenges of the Mining Industry". The potential benefits of mechanisation and automation in mining are highlighted by (The Centre for Mechanised Mining (CMMS), Wits University, 2012):

- both a safer and healthier working environment
- more opportunities for employment including attracting females into the industry
- improved profitability and productivity
- improved production rates
- improved attraction and retention of skilled staff

These benefits are both applicable to small scale and large scale operations. It was observed during the site visits conducted that none of the operations employed females.

4.2.2.4. Skills

Training the engineering and operational staff on the optimum use of the equipment (technology) and ensuring that all the management concepts referred to in section 4.2.2.1 are adhered to must be of utmost importance.

In their paper (Motsoeneng, et al., 2013) eloquently captured the skills required by engineering staff within the platinum mining sector and this is equally applicable to small scale mining and processing operations as well, also bearing in mind the shift to new technology. It was stated that the lack of engineering skills which include both technical and management will have a serious negative impact on the capacity of the mining industry to ensure that improved productivity and high safety standards are maintained. A summary of the skills required noted from this paper are as follows:

- Core technical skills – More focused and specialised skills are now required in light of the fact that new technologies are being used that will transform the mining processes used.
- Soft skills – these skills include mathematics, computation, reading and writing, interpersonal skills, an understanding of systems (technology used), coping with change in the workplace.
- Project management skills
- Communication skills
- Environmental management skills – it is stated that ore extraction must be performed according to an economical, safe and environmentally acceptable standard. This is applicable to both large and small scale mining sectors. (Motsoeneng, et al., 2013) also very importantly stated that the identification of the environmental risks associated with mining and quarrying requires a knowledge of not only the methods of extracting and processing but also that of the environment.
- Leadership skills - These include problem solving and decision making skills.

One of the objectives of (The Centre for Mechanised Mining (CMMS), Wits University, 2012) is the development of short courses and programs to ensure more effective management training within the implementation of mining technology. This can be utilised by small scale operations to up skill their staff.

4.3. Conclusion

This chapter has highlighted the results of the two Case Studies which are operations that are both classified currently as small scale but have vastly different characteristics. This has highlighted the problem and inconsistency with the existing definition of small scale mining. The Pairwise Comparison decision making tool was then used to develop a formal and scientific definition of small scale mining and a technique that in future could be used to distinguish between artisanal and small scale mining operations.

Focus areas for productivity improvement have also been identified and recommendation and models have also been proposed. The next chapter will summarise the findings and conclusions of the research.

CHAPTER 5: CONCLUSIONS

Literature has shown that a number of concerns have been raised with regards to the definition of small scale mining. It has been stated that the formal definition does not capture all the complexities of small scale mining. The definition does not take into account the level of technology deployed, production output, nature and motivation of miners etc. These characteristics are believed to form an important part of artisanal and small scale mining in the country.

The objectives of the research conducted were hence twofold; firstly to develop a formal and scientific definition for Small Scale Mining in South Africa and secondly to use and apply Engineering Management Concepts to optimise and improve the productivity of selected Small Scale Mining and Minerals Processing Operations in South Africa.

The methodology used was firstly to conduct a literature review of the types of small scale mining and processing operations that exist within South Africa, to understand how these types of operations are run and to look at the current approaches used to improve productivity both in South Africa and also across the world. The literature review indicated that the types of small scale mining and processing operations predominant in South Africa include gold, diamonds, semi-precious gemstones, coal and quarrying of dimension stone. There was also a sense obtained that there have been strides made in terms of increasing productivity of certain operations by improving the management of operations.

Secondly a questionnaire was developed to be used for visiting selected legal small scale mining and processing operations in South Africa to gather information as a basis of a case study. A survey had to also be developed to be submitted to experts/specialists in the fields of small scale mining in order to use the Pairwise Comparison Decision Making Tool to develop a formal and scientific definition of small scale mining and processing.

A challenge was experienced finding suitable operations to visit as the majority of the operations on the list of the Department of Mineral Resources (DMR) were not in existence anymore. Eventually one was only able to visit a diamond and semi-precious gemstone operation in Prieska, Northern Cape. These visits were very insightful as they had clearly shown the confusion caused by the existing definition of Small Scale Mining as both operations were vastly different but under the current definition both are classified as small scale.

A survey was conducted and responses received from 14 experts/specialists in the field of small scale mining and using the Pairwise Comparison Decision Making Tool a formal and scientific definition was successfully developed. The definition of a small scale mining operation can be expressed as:

Classification of type of operation = 29.35*(Volume of Production) + 11.01*(No of people employed) + 32.70*(Capital Cost) + 26.94*(Size of the mineral resource) ……………………………………………………………………………… (2)

The definition developed clearly indicates that if an operation does not have enough capital, does not have adequate production volumes and mineral resources it cannot be classified as small scale but rather should be classified as artisanal. It also emphasises the point that artisanal and small scale mining should not be interchangeably used and should rather have exact definitions to avoid the confusion that it has caused for several years within the sector. *It is recommended that further research be undertaken to expand this definition using Multiple-criteria decision-making (MCDM) as it becomes a multi variable problem with a number of options (matrix) and would require statistical methods to analyse fully and if achieved would give one an enhanced scientific definition.*

From the literature, analysis of the selected small scale mining and minerals processing operations studied (visited) and using engineering management concepts the recommended improvements to optimise and improve the productivity can essentially be categorised into four critical areas namely:

- Management
- Chemical Analysis
- Technology
- Skills

This is captured in the Integrated Management Model proposed for Small Scale Mining and Processing Operations in Figure 30. Even though each of the four areas can be looked at individually and one can determine what improvements can be made that would yield positive results in terms of productivity, one needs to ensure that a holistic approach is used since productivity requires all four areas to be optimised and there may also be certain areas that are interdependent.

All aims and objectives set-out for the research conducted was achieved. The recommended improvements if implemented by small scale mining and minerals processing operations in South Africa will result in safer and healthier operating environments, increased productivity, higher production rates and improved profitability.

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APPENDIX A: Questionnaire used for gathering of information

Date	
Name of Business	
Name of Person Interviewed and Designation	
Physical Location/Address of Business	
GPS Co-ordinates (if available for mapping purposes)	
Type of commodity/mineral processed	
Type of operation	Only Mining Only Processing Both
Number of years in operation	
Number of staff employed (include operational structure if available) Gender, Age, Experience and Race of the operators Family composition of the operators. Are they the breadwinners or not?	
Skills/Educational level/Age of staff employed Educational needs and requirements. Do the operators need to be educated?	
Overall rating of skills level of operation (based on above information)	Require a rating scale
Average Annual/Monthly salary of staff • Ranges for revenue and income	
Annual/Monthly turnover in Rand Value	
Annual/Monthly production rate (tons)	
Description of the market for the end product	

Schematic of Minerals Processing flowsheet used	
List of equipment used for processing and indicative value (Rands) • Do the operators understand the technology?	
Is there chemical analysis available of raw material and end product?	
Does the staff work shifts? What are the operating hours?	
List of expenditure incurred during processing e.g. Raw material, water, electricity, transport, diesel, petrol etc	
Health and Safety processes in place (PPE, signage, documentation, HAZOP etc) • The operators understanding of the impact to the environment	
Processes put in place to eliminate environmental issues (waste disposal)	

Challenges faced by the company	
Suggested improvements that can be made	
Awareness or need for the operation to be registered or legal	
Overall level of technology used by operation for processing (based on above information)	Require a rating scale
Overall classification of the operation in terms of the definition of Small Scale Processing	
General: • What is the domestic cost of living and what fraction of small scale mining income addresses this. • Are they satisfied that the income addressed their cost of living?	

APPENDIX B: Survey - Defining the Artisanal & Small Scale Mining Sector

Title:	Name:	Surname:
Job Title:	Institution:	
Date:		

Background:

Artisanal and small scale mining are sometimes used interchangeably. Despite many attempts, a common definition of Artisanal and Small Scale Mining (ASM) has yet to be established. In some countries a distinction is made between 'artisanal mining' that is purely manual and on a very small scale, and 'small-scale mining' that has some mechanization and is on a larger scale. A number of concerns have been raised with regards to the definition (Scott, Rockey, & Hudson, 1998) (Mutemeri & Petersen, 2002). It has been argued that the formal definition does not capture all the intricacies of small scale mining.

Some of the criteria used to categorise the ASM operations include:

- Volume of production
- Number of people (labour) employed
- Capital Cost (equipment, technology level)
- Size of the mineral resource

Purpose of the Survey:

To assign some relative ranking and to determine the degree of importance of each of the above criteria with respect to the other criterion. The technique to be used is the Pairwise Comparison. All information will be kept confidential and no names or institutions will be disclosed in the analysis of the results.

Instructions for completing the survey:

(Source: DesignWIKI, Pairwise Comparison, http://deseng.ryerson.ca/dokuwiki/design:pairwise_comparison)

Please complete the following based on which criteria you feel is more important:

Comparison	**Which is more important (Letter)**	**Equal Importance (tick or cross)**	**Why? Brief reason for your choice**
Volume of production (A) or No of people Employed (B)			
Volume of production (A) or Capital Cost (C)			
Volume of production (A) or Size of the mineral resource (D)			
No of people Employed (B) or Capital Cost (C)			
No of people Employed (B) or Size of the mineral resource (D)			
Capital Cost (C) or Size of the mineral resource (D)			

Please return the survey to:

Nirdesh Singh (011 709 4335)

nirdeshs@mintek.co.za

Survey Monkey Design

Defining the Artisanal & Small Scale Mining Sector

Background

Artisanal and small scale mining are sometimes used interchangeably. Despite many attempts, a common definition of Artisanal and Small Scale Mining (ASM) has yet to be established. In some countries a distinction is made between 'artisanal mining' that is purely manual and on a very small scale, and 'small-scale mining' that has some mechanization and is on a larger scale. A number of concerns have been raised with regards to the definition (Scott, Rockey, & Hudson, 1998) (Mutemeri & Petersen, 2002). It has been argued that the formal definition does not capture all the intricacies of small scale mining.

Some of the criteria used to categorise the ASM operations include:

- Volume of production
- Number of people (labour) employed
- Capital Cost (equipment, technology level)
- Size of the mineral resource

Edit

Purpose of the Survey:

To assign some relative ranking and to determine the degree of importance of each of the above criteria with respect to the other criterion. The technique to be used is the Pairwise Comparison. All information will be kept confidential and no names or institutions will be disclosed in the analysis of the results for the research undertaken for the qualification of M.Eng (Engineering Management).

Nirdesh Singh
University of Johannesburg
nirdeshs@gmail.com

1. Which is more important: Volume of production (A) or No of people Employed (B)

- ○ A
- ○ B
- ○ A and B are equally important

2. Which is more important: Volume of production (A) or Capital Cost (C)

- ○ A
- ○ C
- ○ A and C are equally important

3. Which is more important: Volume of production (A) or Size of the mineral resource (D)

- ◯ A
- ◯ D
- ◯ A and D are equally important

4. Which is more important: No of people Employed (B) or Capital Cost (C)

- ◯ B
- ◯ C
- ◯ B and C are equally important

5. Which is more important: No of people Employed (B) or Size of the mineral resource (D)

- ◯ B
- ◯ D
- ◯ B and D are equally important

6. Which is more important: Capital Cost (C) or Size of the mineral resource (D)

- ◯ C
- ◯ D
- ◯ C and D are equally important

7. Optional - Please help us understand why you selected some of the answers above:

8. Address

Name	
Company	
Email Address	
Phone Number	