EMPIRICAL CHARACTERISATION OF A MINING PRODUCTION SYSTEM

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DECLARATION

I declare that this dissertation is my own, unaided work. Where use has been made of the work of others, it has been duly acknowledged. It is being submitted for the Degree of Master of Science in the University of the Witwatersrand, Johannesburg. It has not been submitted before in any form for any degree or examination in any other University.

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ABSTRACT

The primary objective of any mining business unit is to make profit by extracting, processing and selling minerals from a particular mineral deposit. It is important to optimise the extraction of the mineral resource given time, space and resource constraints. The mineral extraction process is often associated with uncertainty due to variable technical and human factors. Technical factors such as grade distribution, ground conditions and equipment reliability influence the performance of the mining production system (MPS). The performance of the MPS is also impacted by human factors such as employee skills, health and attendance. Uncertainty associated with technical and human factors often leads to planned output being different to actuals obtained. Therefore an in-depth analysis of the significant causes of deviations from the planned outcomes becomes a very important exercise.

This research investigated the empirical relationships between inputs and outputs in a MPS in order assist management in directing efforts at key production drivers. A literature review revealed that production output is an end result of a chain of processes dependent and directly linked to each other, often referred to as the Mining Value Chain. The processes can be seen as milestones to be achieved within a production project. The process requires technical and human factors as resources. The literature review also highlighted that the production stage is the most obvious stage for investors to realise their return on investment. The production stage which constitutes a MPS was chosen as a relevant research area for the reason mentioned. Once a MPS has been empirically characterised, more effort and resources can be focused on the key decision making variables (DMVs) in order to meet the planned outcomes. A production function was developed accordingly, based on the production logic and historical data.

The research concludes that for a typical platinum mine the face advance, face length mined, number of teams, and team size (independent variables) have a statistically significant relationship with the centares (m^2) (dependent variable / response variable) produced which is a key performance indicator (KPI) for a platinum mine. A statistically significant regression equation with a coefficient of determination $R^2 = 0.99835$ was obtained for the MPS. The production function can be used to align the physical, technical and human factors together to predict the optimal output level. The production function also highlights that the most significant production lever of the MPS is the face advance, contrary to a commonly held sentiment that lost blasts are the most significant.

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- Lastly to God Almighty for the good health and a steady heart.

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MPS	Mine production system
DMVs	Decision making variables
KPI	Key performance indicators
MRM	Mineral resource management
TOC	Theory of constraints
SA	South Africa
PwC	Pricewaterhousecoppers
RCA	Root cause analysis
FY	Financial year
PGMS	Platinum group metals
GDP	Gross domestic product
JSE	Johannesburg stock exchange
FDI	Foreign direct investment
BP	Business plan
SMART	Specific measurable achievable realistic time bound
BC	Bushveld complex
EY	Ernst & Young
FI	Flexibility index
SQDB	Safe Quality daily blast
AE	Advance efficiency
BF	Blast frequency
GPME	Ground people material Equipment
RDO	Rock drill operator
TE	Technical efficiency
FA	Face advance

SPP	Survey production profile
FLM	Face length mined
AB	Achieved blasts
T	Teams
TL	Total labour
TC	Team compliment
OMD	Off reef main development
RPD	Re & pre -development
DTM	Development to mill
BME	Basic mining equation

1 INTRODUCTION

1.1 Chapter overview

This chapter presents an overview of a mine production system (MPS), the relevant challenges and its contribution to the entire mining value chain. It justifies the decision to particularly want to empirically examine and characterise the MPS in an effort to fully understand it and manage it better. The objectives indicate that to empirically describe the MPS, regression techniques are the most applicable analysis tool, the preview of the structure of the dissertation is given at the end of the chapter to show how the various components of the research are related**.**

1.2 South African (SA) mining background

Since the discovery of precious metals in 1886, mining has been the backbone of the South African economy. Mining has been the fore-runner to many industries and continues to be a key catalyst to many side line economies (Chamber of Mines, 2016). The basket of mainstream commodities includes coal, diamond, platinum group metals (PGMs), iron ore and gold. With reference to Figure 1.1 South Africa holds the biggest reserve base of PGMs at about 80% and accounts for nearly 50% of the world’s PGMs production**.**

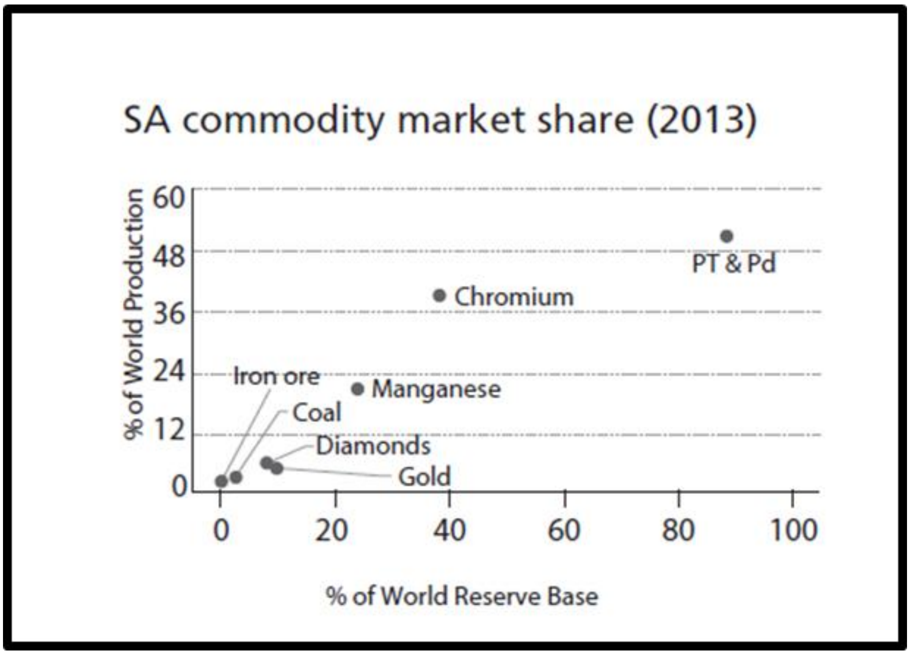

Figure 1.1 SA commodity market share as at 2013 (Chamber of Mines, 2016)

The South African mining sector, has contributed in the following manner to the economy in 2014 (Baxter , 2015):

- 7.6% to the gross domestic product (GDP)
- 26% worth of merchandise exports
- 12% of the Johannesburg Securities Exchange (JSE)
- 14% of the foreign direct investment (FDI)
- 495 000 direct jobs
- 1.3 Million jobs directly and indirectly.

It is perhaps relevant and important to single out one mining sector (PGMs) from the mining commodity basket at this stage simply because of the following facts as illustrated in Figure 1.2 to 1.5**.**

- They account for 21.85% share of the mineral sales exports, second to gold

- It is the biggest mining industry employer

- It has had the largest share of the mining GDP post 2010 only to be overtaken by coal and other metal ores combined.

- The second largest contributor of the mining sector revenue

- It has the largest world reserve base as mentioned earlier in this section.

Mineral	Export value (Rbn)	Percent of total mineral exports
PGMs	60.92	21.85%
Platinum	45.00	16.14%
Palladium	9.13	3.27%
Gold	71.96	25.81%
Iron ore	59.04	21.18%
Coal	51.98	18.65%

Figure 1.2 SA commodities comparison (Chamber of Mines SA, 2014)

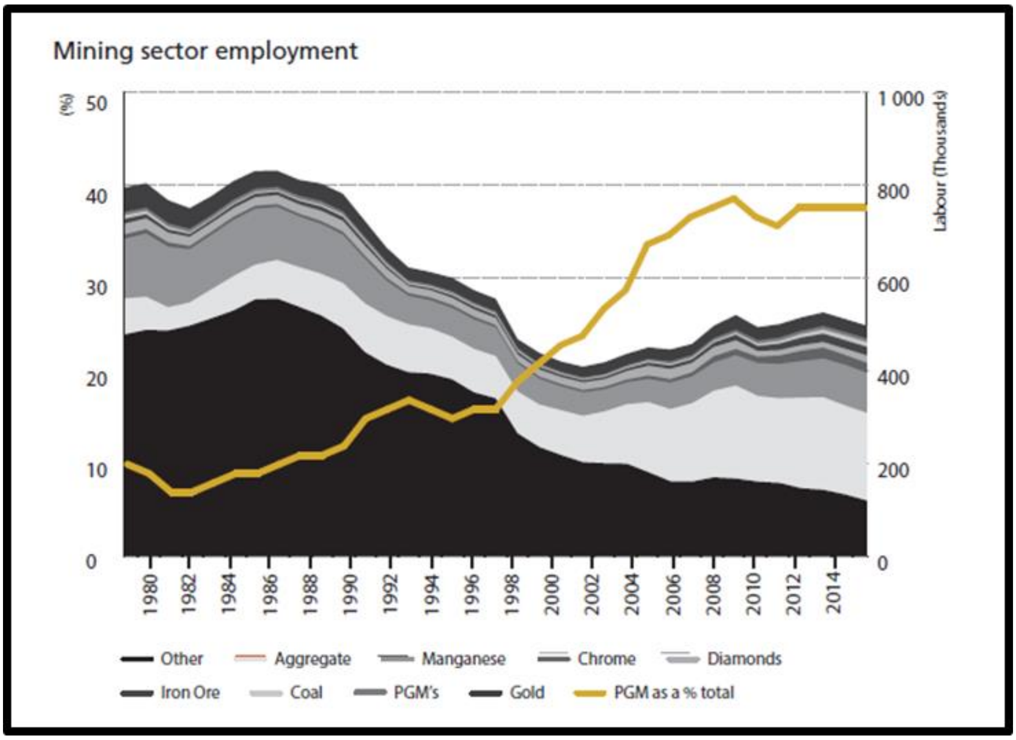

Figure 1.3 SA commodities employment figures (Chamber of Mines, 2016)

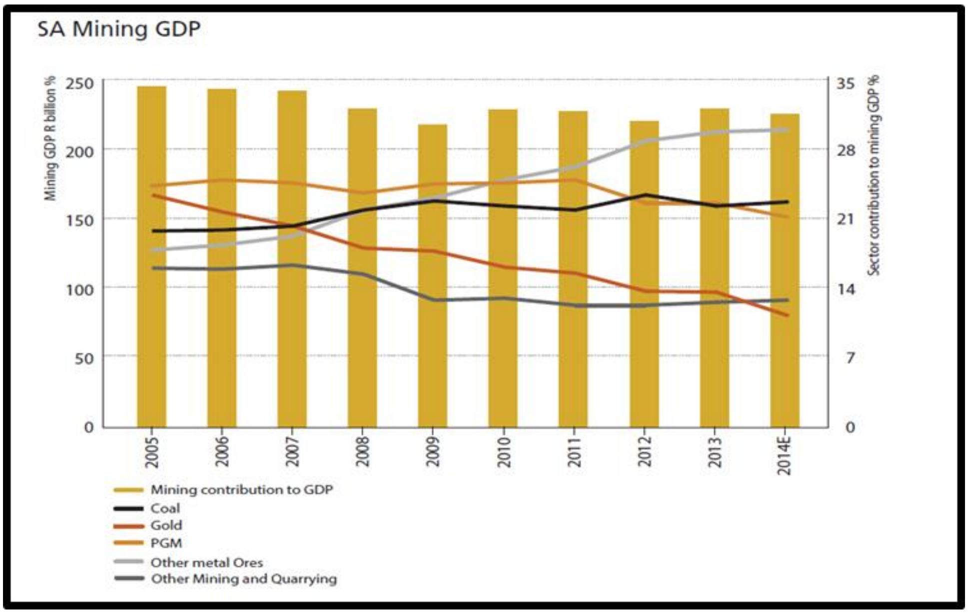

Figure 1.4 SA commodities GDP contribution (Chamber of Mines, 2016)

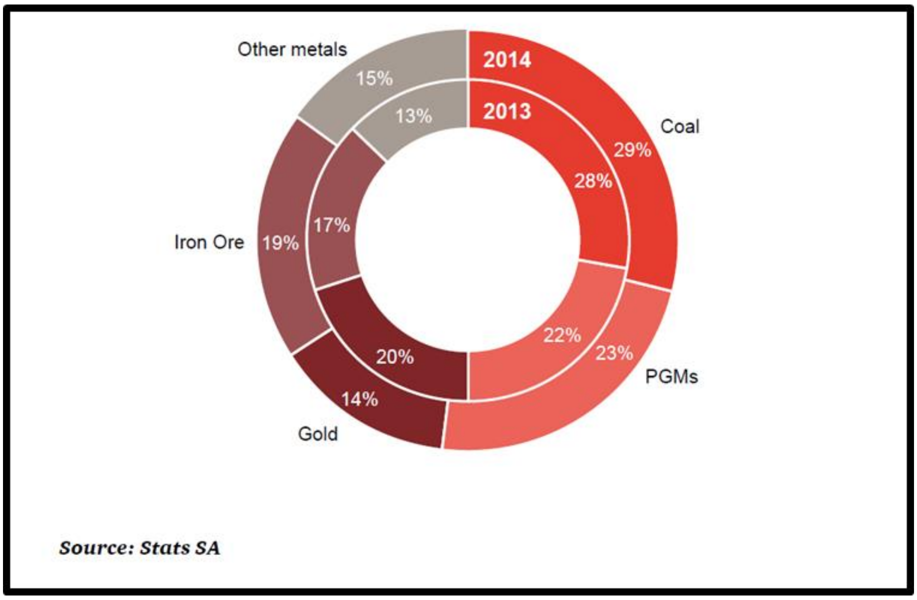

Figure 1.5 SA commodities revenue contribution (PWC, 2014)

It is against the above background of the significance of the PGMs sector that the productivity and sustainability of the sector is relevant and worth examining in an effort to understand its characteristics. This is why a platinum case study is considered in this dissertation.

Despite the positive effects of the mining sector it has of recent times experienced certain challenges that threaten and affect its profitability. According to Baxter (2015), the following are some of the challenges that the miners have to deal with:

- Falling trend of metal prices
- Labour market instability
- Binding infrastructure constraints
- Inappropriate application of regulatory tools

- Policy and regulations uncertainty
- Declining productivity and rapidly escalating costs.

1.3 Background on a Mining Production System (MPS)

A mine production system (MPS) is a result of an iterative process of design, planning and optimisation of mining input variables and decision making variables (DMVs). The MPS exists within the mineral extraction link of the complete mining value chain. It represents the stage where mining companies have the opportunity through production to start generating returns on the investments undertaken. Returns on shareholders' investments can be realised at this stage.

More often the resultant MPS behaves somewhat different from the optimised MPS plan. This behaviour or character is observed in an ensemble of output results of the key performance indicators (KPIs). These results are sometimes above target, on target or below target. The first two circumstances are perhaps the most desired. However, in most cases the MPS, especially of mature mines, tends to deliver below target. The variability of the KPIs of interest is influenced by internal variables or decision making variables (DMVs). The uncertainty associated with technical and human factors is probably the factor generating this array of different results. The variable factors or DMVs can either be controllable or uncontrollable. It is therefore important to understand and know to what degree one can control the controllable variables to achieve the desired output and to minimise the effects of the uncontrollable variables.

1.4 Problem statement and motivation

The premise of any mining business unit is to make profit by extracting, processing and selling minerals from a particular ore deposit under uncertain and complex conditions. The degree of uncertainty and complexity is influenced largely by external factors and internal factors. External factors include amongst others, the metal product price variation, exchange rates, political climate, legislative and policy matters. Internal factors would include mineral grade distribution, ground conditions, equipment reliability, infrastructure needs and the mine design criteria selected for the mining method. The interaction between these factors affect the premise, thus, yielding an ensemble of different outputs (desired and sometimes not desired).

The research problem stems from the fact that for a period spanning about eight business plan (BP) years (i.e. financial year (FY) 2008 to 2015), there has been a consistent decline of desired output of planned key performance indicators (KPIs) at the platinum mine case study. While the reviews and management reports always indicate this departure merely in terms of percentage variances and the effect on profitability, the relationship of all mining variables responsible for yielding those results has not been quantitatively described or characterised collectively in one scientific format. The systemic decline in productivity against the rapidly escalating costs indicated in Figure 1.6 results in aggressively eroded profit margins. This research attempts to scientifically characterise the internal factors affecting the mine production system (MPS). The envisaged output is an empirical formula that expresses the most important or influential KPI (dependent variable) in terms of its independent variables. The relationship can be used as a management tool to determine which variables to focus on and manage in order to influence the MPS to yield the desired result.

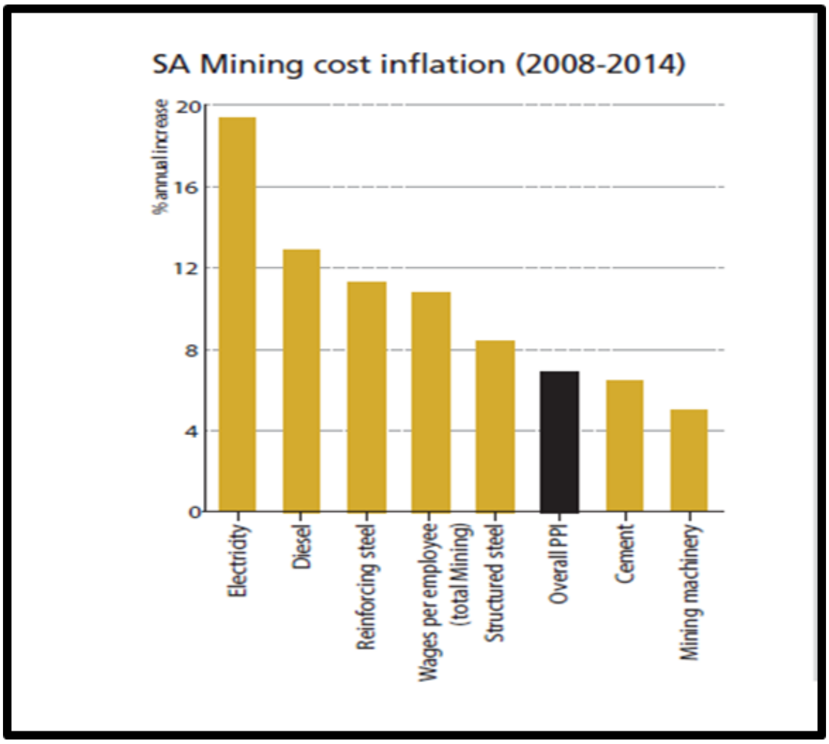

Figure 1.6 SA mining cost inflation illustration (Chamber of Mines, 2016)

1.5 Significance of research

Commentary on the mining industry's declining productivity has been topical in the last decade due to the declining productivity trends across several commodities. Research, analysis and publications from institutions like the Chamber of Mines, Statistics South Africa, Ernst and Young (EY), McKinsey & Company, DuPont, PricewaterhouseCoopers (PwC) and many independent market analysts have highlighted this trend. Common to all the reports is the declining labour productivity versus increasing wage bills, rising input costs due to inflation, decreasing revenues, falling metal prices, declining throughput and instability of the labour markets.

Several solutions are proposed to resolve the declining productivity problem. The following are some of the suggested solutions which are relevant to the management of a MPS:

- Reduce costs
- Increase face time/utilisation
- Improve mine safety
- Optimise mine development
- Increase and optimise production
- Comply with mining plans and performance targets
- Increase control on the mining operation.

The solutions listed above are in principle relevant and make sense. However the challenge is whether they are specific enough, measurable, achievable, realistic and time-bound (SMART). The practicality of implementing them all at once is the biggest challenge. The platinum mining industry in no exception to the challenges discussed above.

Cawood and Neingo (2014) commented that while the Bushveld Complex (BC) provides South Africa with comparative advantages, platinum prices are set on global markets based on free market principles. This fact brings about the need to monitor the production efficiency to ensure that the platinum sector remains sustainable and competitive.

An empirically characterised MPS will specifically and quantitatively define a complete relationship between the KPIs and the DMVs. With those relationships in place the inherent nature of the system can be optimised by focusing on the significant DMVs as these result in the most deviations from planned output. An empirically characterised system highlights the contribution or impact of individual DMVs related to the KPI. This will help in re-directing the optimisation efforts to the DMVs with the highest impact as opposed to generic efforts to try to resolve the system as a whole.

1.6 Objective of the dissertation

In order to achieve the aim of this dissertation, the following objectives had to be realised:

1. Compile the production KPIs for the period in review (BP 08 – BP 15)
2. Compile the production data of variables that influence the KPIs
3. Analyse the data using quantitative techniques
4. Test the deterministic planning inputs
5. Present the results and analysis
6. Test the application of the results derived.

In summary the objective is to delineate, quantify, relate and analyse the factors that influence the MPS productivity and present the resulting relationship.

1.7 Structure of the dissertation

In addition to Chapter 1, there are other five chapters. Chapter 2 presents the literature survey, the background information and concepts relevant to the study. Chapter 3 discusses the methodology approach in examining the problem and all assumptions made. Chapter 4 presents the data analysis and empirical modelling outputs. Chapter 5 presents the observations. The last chapter concludes and makes recommendations. It highlights what was achieved, presents the limitations that affect the research problem and suggests further direction for more research work.

1.8 Summary

This chapter introduced the reader to this dissertation by providing some of the background information to the research problem, the main research question, motivation and structure of the dissertation. The next chapter focuses on the survey of the literature on topics relevant to the research.

2 LITERATURE REVIEW

2.1 Chapter overview

Chapter 2 provides a review of the literature research related to a MPS design, nature, and productivity. The chapter is divided into sections that cover the following:

a) The MPS and the mining value chain

b) The MPS variables or factors

c) Performance measure of the MPS

d) The MPS management tools and review

e) The MPS productivity challenge.

2.2 The MPS and the mining value chain

The MPS represents a specific set of activities within the mineral extraction link of the mining value chain (Figure 2.1). Just like a steel chain with links, the links of the mining value chain represent distinct processes that are dependent horizontally on each other whether upstream or downstream. Each unit contains within itself processes that must be complete for that unit to function and service other units upstream or downstream of it.

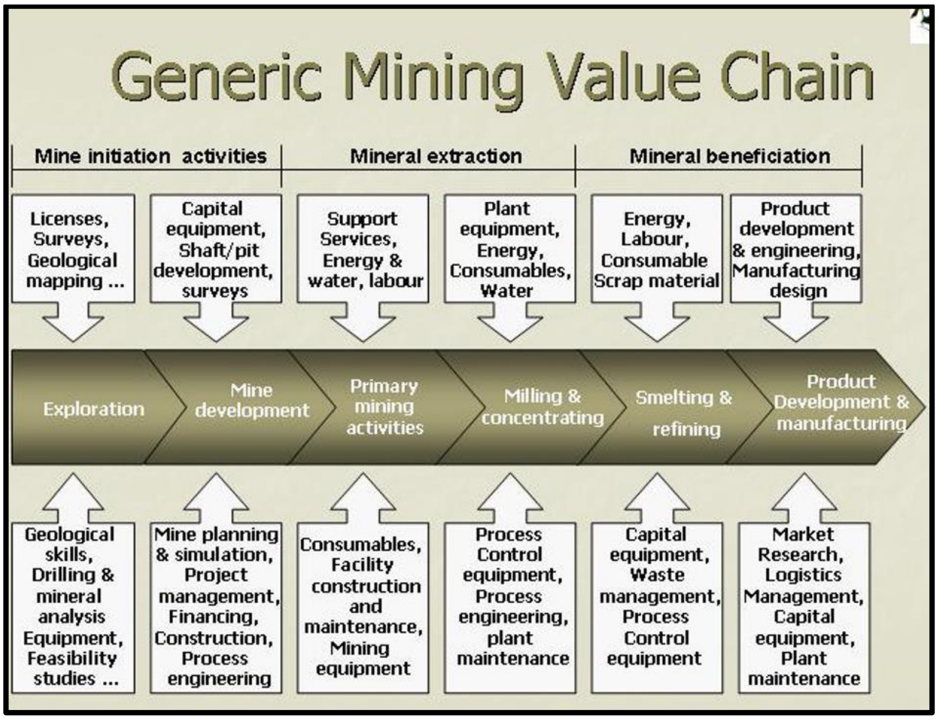

Figure 2.1 An elementary illustration of the mining value chain (Glen Steyn and Associates, 2015)

The mineral extraction link is perhaps the most important link depicted in the mining value chain. From this link the mine gets the volumes of total throughput (Figure 2.1). Cambitsis (2013:769) commented that “While cost management and improvement are crucial to running an effective and profitable organisation, the greatest gains can generally be obtained by increasing production volumes or throughput”. According to Song *et al* (2013), mining has four basic stages namely, exploration, development, production and closure. Of these four Song *et al* (2013) noted that production / exploitation / extraction of the ore is the only obvious stage for stakeholders to recover investments and take profits. It therefore follows that improvement in production volume has a significantly higher impact on the bottom line and is the most impactful profit lever. The study by Cambitsis

(2013) compared the impact on profit by a 10% decrease in cost and 10% increase in throughput. The study found that for the same percentage change, the response of profit to the change in throughput was far higher. If the mineral extraction stage malfunctions, it chokes the other stages downstream of it resulting in an underperforming mining value chain. It is therefore important that this stage is well designed, planned, optimized and managed properly. On the other hand if the stage preceding the mineral extraction malfunctions, delayed production ensues resulting in delayed recovery of capital and money invested. It is therefore imperative to manage the mining value chain in totality and optimize each stage.

Optimization involves the process of making anything such as a design, system, activity or decision, functional or effective as possible. The *Business Dictionary* (2017) (Business Dictionary, 2017) defines optimization as “finding an alternative with the most cost effective or highest achievable performance under the given constraints, by maximizing desired factors and minimizing undesired ones”. In mining terms optimization translates into the process of finding the maximum value and worth of a mineral deposit (Gardner, 1986). This can be achieved by obtaining the maximum centares (m^2), tonnage and grade, while maintaining the lowest cost per unit of production as possible. This is the role / function of the mine production system.

Within the mineral extraction stage domain exists the primary mining activity (Figure 2.1). This is the physical exploitation of the mineral deposit and consists of cyclic activities that are dependent on each other. The panel planned must be cleaned, supported, drilled, charged up and blasted. The cycle is repetitive day by day and the consistency and the quality of this cyclic process is a huge productivity lever. This is the process that must produce the required throughput. It consists of a set of factors and parameters that must be satisfied and which must interact to form a productive Mining Production System. The primary mining activity is dependent mainly on the following initial conditions:

- Ore reserve availability
- Labour (direct production and support services)
- Material (consumables) and utilities
- Equipment.

2.3 The MPS initial factors

The MPS consists of initial conditions which are technical and human in nature (Figure 2.2 and Figure 2.3). These conditions are required as the backbone of the system (inputs). They form the internal capacity or the production engine of the MPS. The production parameters are applied to the initial conditions to plan and yield a desired outcome of the system (a safe quality daily blast). The production parameters are a set of measurable and controllable variables that determine, define and restrict the operation of the MPS. They are a result of an iterative process of design, planning and optimisation. Conveniently, they can be referred to as the decision-making variables (DMVs) and the optimum value or condition of each can be found.

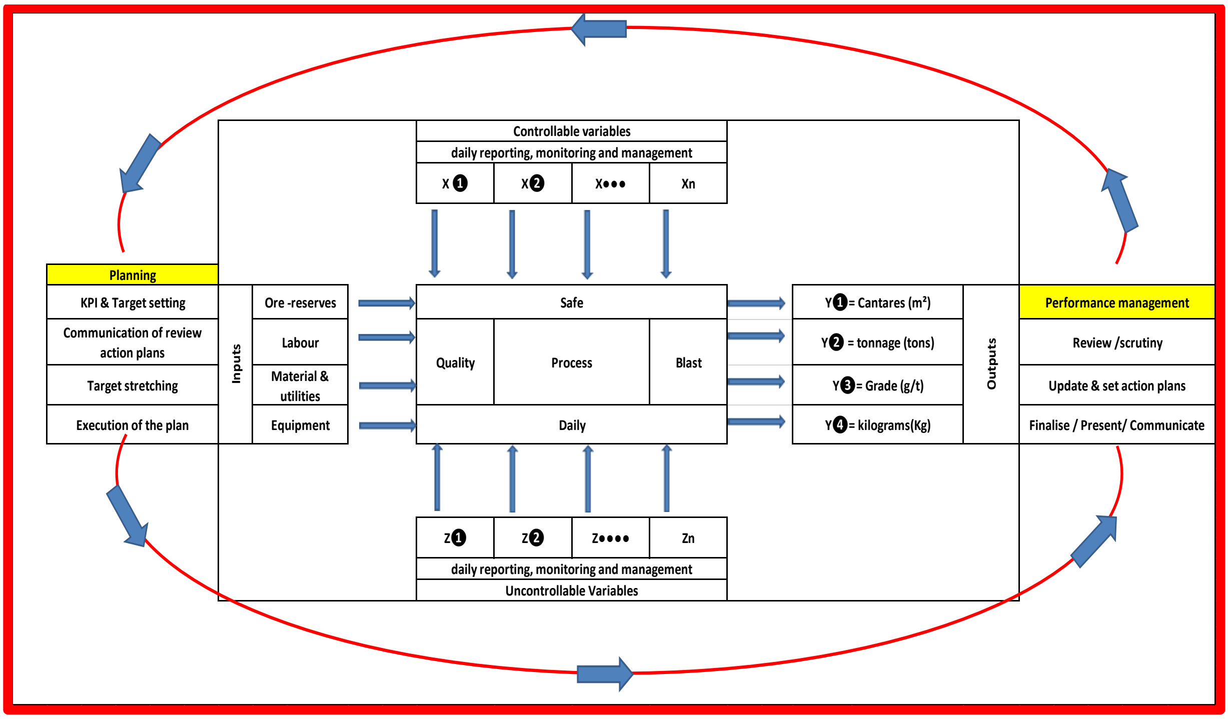

Figure 2.2 Representation of the model of the MPS

However downstream of these are random variables which affect the system's desired outcome. The random variables present themselves in the form of constraints, break downs and nuisance variables resulting in a lost blast (Figure 2.3) .The inherent randomness of these variables affects the production parameters and the initial conditions resulting in an array of different outputs of the system. The objective of the mining production system is to constantly deliver production at the right quantity, quality and consistency as planned. This can be achieved by minimizing the risk of falling short by actively managing the system in totality.

A mine production system						
Class/Type	**Initial Conditions**	**Production parameters**	**Desired outcome**	**Random Variables**	**un-desired outcome**	**Output**
technical factor	ore reserves	availability flexibility advance/blast face length/ panel Cut off Grade	**SAFE QUALITY DAILY BLAST**	geo-technical conditions, ore body geology	**LOST BLAST**	centares mined, tonnage produced, metal recovered, production efficiencies.
human factor	People (direct production and support services)	medical fitness (red ticket) skill experience flexibility presenteeism motivation		absenteeism, health, attitude, injuries, labour disputes, labour unrest, union matters		
technical factor	material and utilities	vailabilbity variable budget (costs) flexibility reliability		supply chain constraints, poor planning, wastage, logistics, lack of material / buffers		
technical factor	equipment	reliability flexibility availability quantity size ergonomics		break downs, supply chain constraints, logistics		

Figure 2.3 An illustration of a MPS

2.3.1 Mineral reserves (ground)

The ore reserves of the MPS in discussion are set in the famous Bushveld Complex (BC). The complex comprises of a suite of igneous rocks of a wide range of composition occupying a saucer shaped area in the Central Transvaal. (Figure 2.4). Despite the great academic interest in the complex in consequence and form, it is also of great economic importance and is referred as the greatest repository of magmatic ores known in South Africa. It contains the world’s largest known reserves of platinum (Lurie, 1994).

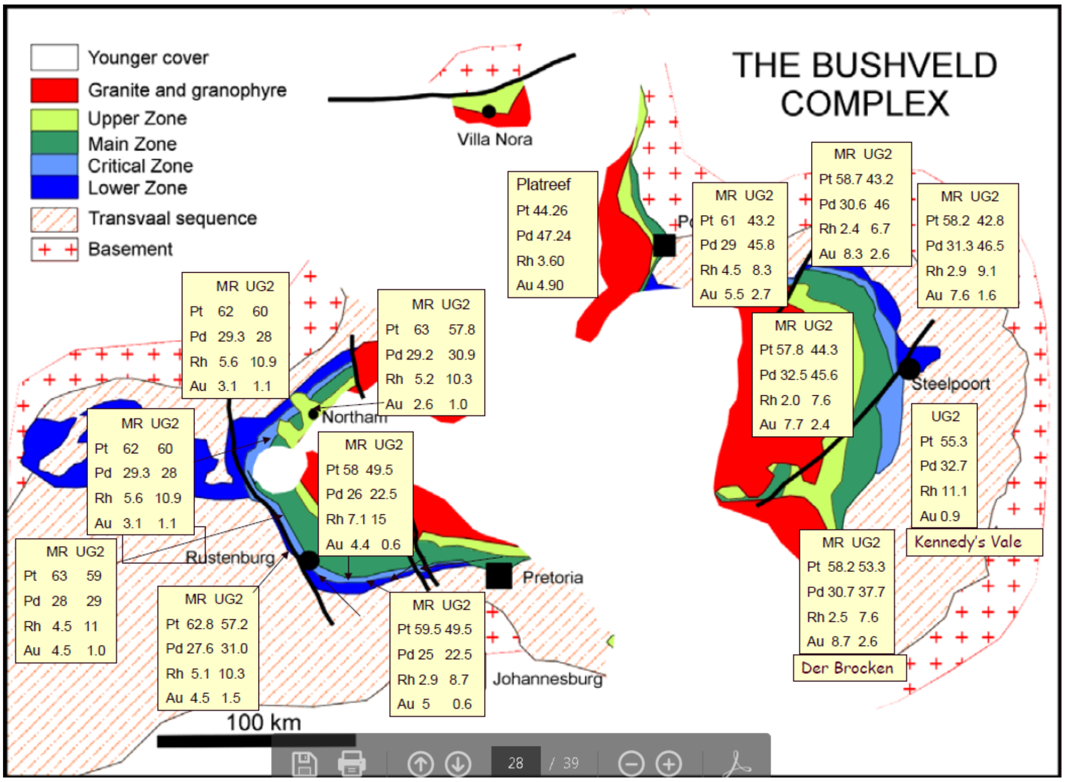

Figure 2.4 The Bushveld Complex illustrated (Kinnard, n.d.)

Central to the technical factor of ore reserves is the concept of availability and flexibility. Mineral reserves' availability is perhaps the most important and the only reason for a mining project to exist. The mineral is first explored, classified, quantified and modelled before any decision is made to exploit it. Mohloki and Musingwini (2010:309) commented that "ore reserves are the foundation of any mining project or producing mine as these are expected to be exploited over the life of mine". A mineral deposit in its in-*situ* state is useless unless it is accessed and exposed for physical exploitation. It must be developed and generated at a faster rate than the mining rate to ensure that there is no shortage of places to be mined or lack of operating flexibility which may result in production shortfalls (Mohloki & Musingwini, 2010). The shortage or lack of reserves constrains the MPS.

While it is evident that ore reserves must be available as an initial technical factor or condition, the plan to exploit the reserves must also be flexible. Musingwini, *et al*., (2006) suggested that flexibility is needed so that any mining plan can accommodate financial, technical, and social changes that are a reality in the dynamic mine business operating environment. At an operating level, flexibility is seen as the ability to swiftly move the mining operations to different production faces when the issues of grade control, or unpredicted geological structures (random variables) require it. The level of availability of ore reserves and flexibility of a mining production system is a vital technical factor to an achievable and sustained mine production plan. The shortage or lack of operating flexibility is a constraint to the MPS.

The degree of availability and flexibility is governed by the concept of a mining life cycle. According to Woodhall (2002), the cycle represents the production process commencing with waste development and ending in sealing off the mined out areas after the payable ore reserves are exhausted. It comprises strictly of a set of sequential mining phases. The mining lifecycle consists of eight distinct mining process namely (Woodhall, 2002):

1. Non mineral reserve generating development (waste development)
2. Mineral reserve generating development
3. Ledging
4. Equipping
5. Resourcing
6. Vamping

7. Reclaiming
8. Sealing.

It is in the third and fourth stages of the mining life cycle where ore reserve availability and flexibility is realized. Resourcing simply follows as the production process where the drilling, blasting and removal of broken rock takes place from an equipped working face (Woodhall 2002). Woodhall (2002:40) defined flexibility as “the provision of sufficient equipped mining face to make alternative, profitable workplaces available to sustain a planned production level”. It is often required that a production team must have two working places available thus, defining the flexibility as two. An integrated metric for measuring technical operating flexibility (FI) is defined by Musingwini *et al* (2006) as:

FI = {available fully equipped stopes + stopes already in production} / production stopes required to meet the planned production targets.

From the above function if FI <1, the system is said to be inflexible, if FI>1 then the system is flexible the case of FI=1 represents a marginal flexible status.

Ore availability on the other hand is measure of how far development has been kept ahead of stoping operations. It is the amount of ore available for stoping with little or no further development required expressed in years of production. A typical rule of thumb suggests two years as a safe practical figure (Storrar, 1977). Low ore availability implies reduced flexibility while a higher ore availability implies increased flexibility.

The most important aspect of ore-reserve availability and flexibility is that ore reserves are translated into the centares (m^2) mined with the primary input as face length mineable in metres. The multiplicative nature of this KPI function suggests that if the face length to be mined is zero, then no production can happen at all. This is a huge risk to any business or mining plan. This risk has been highlighted also by MacFarlane (2006) that sometimes creation of flexibility is compromised at the expense of quick profit returns. He commented that flexibility is important to manage the economic cycles and to mitigate the inherent risk source. Therefore, if flexibility in mine plans has not been created as a value adding decision, reactive planning has to be undertaken which is value destroying.

2.3.2 Labour

The MPS initial conditions require that labour must be allocated to exploit the available ore reserves. A typical underground platinum MPS is capital intensive and labour intensive due to the conventional mining method employed. Figure 2.5 highlights that the total labour cost can be estimated to be about 40% of the mines' total production cost. The human capital employed is therefore required to be healthy, fit, trainable, and skilled enough to support the mining business. It is therefore very important that the labour assigned must be utilized and be productive. The lack of skill and shortage of labour is a constraint to the MPS.

Optimum labour planning and management systems must be in place and are very important to ensure that there is no oversupply or undersupply of labour. There should be a constant demand and supply of labour on a daily basis.

Meyer (2010) observed that to achieve a safe quality daily blast (SQDB) (these blasts are proportionate to the amount of rock extracted from the mine and therefore the amount of product produced), it is important that every employee completes his or her daily tasks. Therefore, it is important to have a formalised labour planning system to ensure maximised profit and an effective workforce. However, for the labour to be correctly planned the production plan must be solid and realistic before labour resources are called for. Only the correct number of people in the stope will ensure a quality blast. The production output will also increase due to the number of blasts increased. Meyer (2010) criticised the conventional labour planning methods which are based on efficiencies (m^2/employee, or m/ employee) and suggested improvement of them citing that the labour plan is not optimised and is often wasted because it excludes a concept called technical efficiency which will be explored later in more detail.

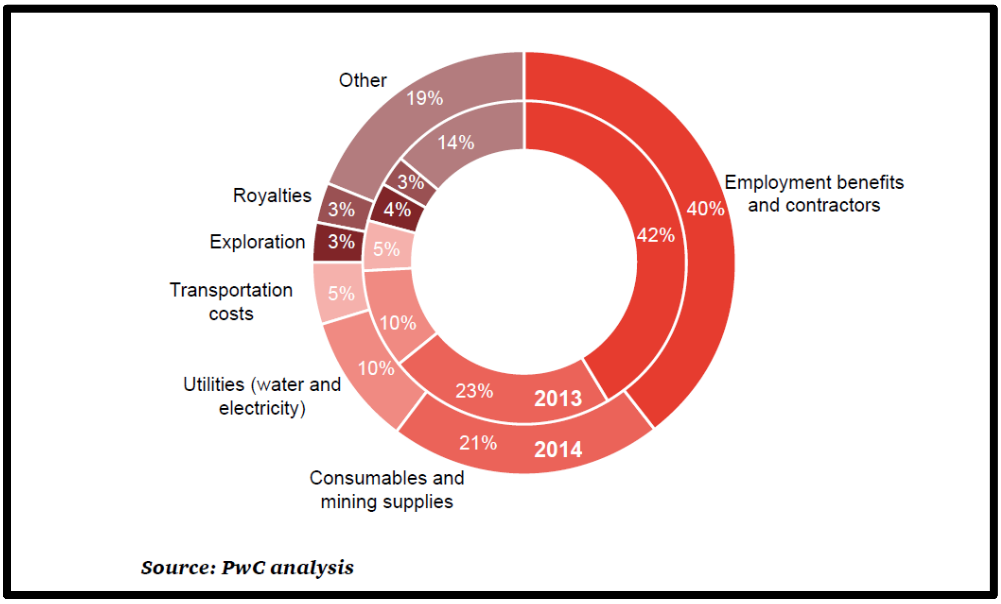

Figure 2.5 South African mining costs distribution (PWC, 2014)

Historically there has been a decline in platinum mining productivity (Figure 2.6). Baxter (2014) highlighted that the total factor productivity had decreased over the past 13 years and that a mine worker produces about 46% less platinum. Mohloki (2009) commented that labour costs will not increase with extra tonnes produced within the labour force's capability, while producing less than the labour force capacity will erode the profitability of the organisation. Hence an over–recovery is more desirable than an under-recovery which backs the argument that labour should be productive at all times when deployed.

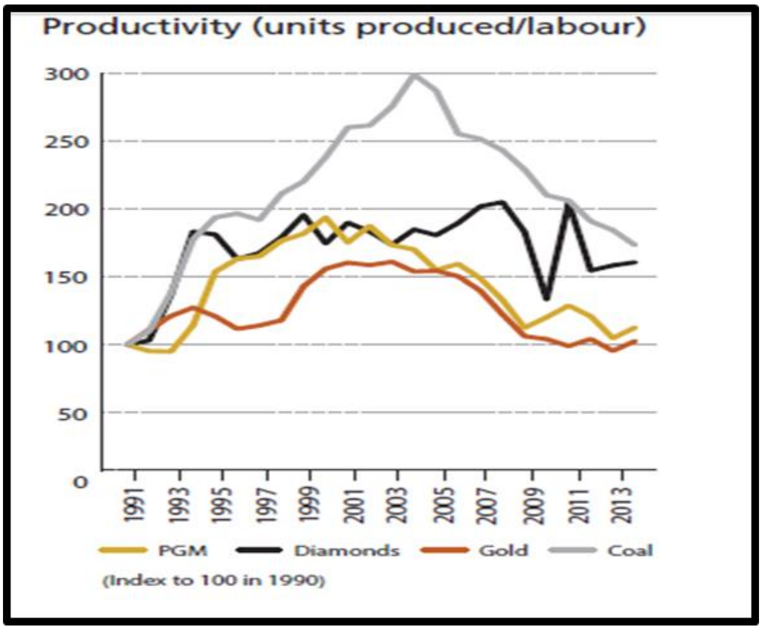

Figure 2.6 Labour productivity vs. labour costs (Baxter, 2014)

The decline in MPS productivity can be due to any of the technical factors and the human factors of the MPS. Baxter (2014) noted that the decline in mining productivity is also due to the industry not getting enough productive blasts per year. This means that fixed costs are not being covered due to an increased number of lost blasts and the unit production cost is also affected. The labour element of the MPS, thus, introduces a set of random human factors that affect mining productivity.

2.3.3 Mining equipment

Mining uses various types of complex and sophisticated equipment whose reliability, maintainability and safety are very important. Equipment selection is typically a function of the mining method. A typical conventional platinum mine requires a specific set of equipment (scraper winches, rail bound locomotives, etc.) for its operation. The functionality and reliability of the equipment is very important in determining whether or not the mining production targets can be met.

2.3.4 Material and utilities

Consumable material is one of the initial technical factors that the MPS cannot survive without. Phillis and Gumede (2011) stated that, “the management of critical resource inventories is an important productivity lever and a significant risk factor—risk in the sense that poor resource availability lends itself to disempowerment of workers, unsafe work practices, wasted spending (high unit costs), and poor quality of work (including mining waste/rework)”. Most underground platinum mines experience lost blasts that directly lead to reduced productivity. In their study, Phillis and Gumede (2011) established that in most surveyed shafts, 30% of lost blasts can be attributed to shortages of critical material and/or equipment. The availability of critical consumables makes the concept of supply chain management important for a productive MPS.

2.3.5 Support services

The support services structure in the form of personnel for rock mechanics, ventilation, human resources, engineering, finance, mine planning and mine management, is also required to support the MPS. The expertise and contribution of the employees in these departments is directly linked to whether or not a safe quality daily blast will be achieved.

2.3.6 Interaction and interdependency of MPS initial factors

Central and common to the initial conditions required for the MPS to function is the concept of flexibility required by both the technical and human factors. Mohloki and Musingwini (2010) pointed out that the level of flexibility required will depend on geological losses, logistical problems such as employee absenteeism, unclean panels, incompletely clean panels, poorly blasted faces, falls of ground and the slow development rates due to poor advance rates. This interaction of the random variables and their impact on the MPS will be examined in detail later in the report.

The MPS can clearly be viewed against the background of a chain with links which can only break at its weakest link called the constraint. Breaking in this context means failure to achieve the system's goal (maximum throughput) due to the presence of the constraint (McNeese, 2014). The links are represented by initial conditions, production parameters and the random variables. The constraints within the links mentioned will be those parts or elements of the MPS that will constrain the objective function of the system. In the case of the MPS, constraints will more than likely to be lack of operating flexibility, lack of equipment, lack of material, and lack of employee skill and knowledge.

It becomes the management's daily duty to find and eliminate the constraints. A systematic approach, be it root cause analysis (RCA) or theory of constraints (TOC) methodology, can be used to eliminate the constraints, break downs or nuisance variables in order to achieve the objective of the MPS

2.4 Performance measure of the MPS

The premise of a mining business unit is to make profits and maximise shareholder return or wealth. Therefore revenue and profit are very important indicators to monitor and observe. Cost management and improvement have a direct impact on the bottom line and are sometimes an area of focus in improving productivity. However an observation by Cambitsis (2013) suggests that while cost management and improvement are crucial in the running of a profitable organisation, the greatest gains can generally be obtained by increasing volumes or throughput. He further observed that a 10% change on costs had a lower impact on the bottom line compared to a 10% change on the volumes or throughput. It is against this background that costs have not been selected as a KPIs for this research study. The attention is therefore directed to the KPIs and DMVs that determine the MPS volumes or throughput.

The critical variables that determine the performance of a MPS can be expressed by a basic mining equation (BME). A BME is simply an operation combining the critical variables in order to determine the expected profit (De Jager, 2005). In its form it provides a means of measuring the impact of changes in the variables on the value of the mine. The BME in Section 2.4.2 indicates the metal content produced which is sold at a certain price to yield revenue. The revenue generated minus the cost of producing the metal is the profit contribution of the mine. The ultimate measure of the performance a MPS is the return on the investment it yields on the investment undertaken. The critical variables of the BME are discussed in sections 2.4.1 to 2.4.4.

2.4.1 Centares mined (m^2)

The primary input into throughput calculation is the centares mined. This factor represents an area mined by a stoping team, i.e. a predetermined face length after geotechnical considerations is advanced forward by means of blasting. The total square metres mined is the product of the face length mined (m) and the advance realised (m). The total centares mined is therefore a function of face length mined (m), advance per blast (m), number of blasts, and the number of teams planned to blast. This relationship is represented by the equation below:

Centares mined (m^2) = face length mined per team (m) x advance per blast (m) x number of blasts x number of teams

The ratio between the achieved advance per blast and the planned advance per blast is called advance efficiency (AE) and the ratio between the number of blasts achieved and the number of blasts planned is called the blast frequency (BF). The product of AE and BF is called the technical efficiency. It is therefore logical that to get the maximum amount of centares, the DMVs must be at their optimal values. The centares mined becomes a DMV in the calculation of tonnage produced.

2.4.2 Tonnage mined (t)

The blocks of ground mined are mined at a pre-determined height or cut called the stoping width. The stoping width is a result of grade distribution and some practical considerations. Ideally only the payable portion of the face length must be mined. However because people and equipment must fit into the cut certain portions of lower values of grade are included resulting in a practical stoping width. The stoping width is measured in metres. This relationship can be represented by the equation below, where the specific gravity represents an inherent property of the ore-body being mined:

Tonnage (t) = centares mine (m^2) x stoping width (m) x the specific gravity (t/m^3).

2.4.3 Grade produced (g/t)

Grade represents an inherent property of the ore deposit. It is a measure of the mineral content in the ore-deposit often expressed in grams per tonne (g/t). Higher values of grade imply higher metal content and ore quality. Ideally miners would want to mine only blocks with the highest values of grade, however, sometimes the lower values have to be taken out concurrently with the payable grade due to ore-body characteristics and geological discontinuities. This parameter is determined through accurate sampling and assay methods. Grade is a DMV in the determination of the mineral product produced. The grade that will be discussed in this report is the hammer sample grade. The hammer sample grade is the head grade of ore before milling takes place. The mill grade was not considered due to the lack of reliable data.

2.4.4 Platinum kilograms produced (kg)

This KPI represents mineral content in the ore delivered to the plant. It represents the finished product delivered by the mining department to the plant. It is a function of centares mined, tonnage mined, and grade achieved. The equation below represents this relationship:

Metal content produced (kg) = volume of ore mined (m^3) x specific gravity (t/m^3) x grade (g/t)

2.5 The MPS management tools (what to manage)

The ultimate goal of the MPS is to achieve the production targets through the achievement of a safe quality daily blast. The four main initial conditions which are, ground, people, material and equipment (GPME) become the most important variables that can make the achievement of the goal possible. Line management has direct control over these factors and therefore the responsibility lies with them to control and manage them in a manner that will add value to the mining business. All the variables (DMVs) that determine the KPIs in Section 2.4 above must be managed accordingly to influence the achievement of the desired KPI target.

2.5.1 The MPS and lost blasts

It has been mentioned in the previous section that for an MPS to produce the four initial factors GPME must be present (Figure 2.2 and Figure 2.3). It is not sufficient to have these factors only. There is a single most important event that must occur to initiate the generation of the required centares called a blast. The multiplicative nature of the variables indicates that if any of the variables is zero, then no production will be realised. More often than not the four factors are always available and only require a blast event to occur. A blast can be seen as an impetus that starts a chain reaction of events that will eventually lead to the generation of platinum kilograms to be sold. A lost blast is an undesired event which results in a planned panel failing to generate the planned channel tonnes at a required grade, thus, failing to generate the required metal content on the day. The problem with a lost blast is that on the day, all the labour allocated to that workplace have themselves earned a salary. The effect of a zero revenue minus the cost of labour at work has obviously a negative effect to the bottom line. In most cases the lost blast is repetitive in the same workplace which translates into a failure of line supervision and line management to eliminate the cause of the lost blast. It is a platinum mining norm in South Africa to plan a production month at an average of 23 shifts for conventional mining. The full potential capacity of a team is the ability to produce on every single planned shift. However for practicality and proper allowance the business plan (BP) targets are set at an average 60% of the full potential. The implication here is that an allowance has already been made for potential genuine lost blast effects. It is very surprising that the occurrence of lost blasts even exceeds the allowed levels for as per the BP.

The labour factor is the most important decision making variable (DMV) in the above relationship. It uses the resources (inputs) (ore-reserves, material & utilities and equipment to generate one single primary output of the MPS objective function (centares mined) by initiating the blast event. The labour in the MPS controls further down the line the following, tonnes mined and quality achieved (grade). If any of the four variables prevents the MPS from achieving its objective then it becomes a constraint to the system and it must be fixed so that it is no longer a limiting factor.

It is not sufficient to only identify a constraint within the MPS. Further analysis of why the constraint exists must be done. The root cause of the constraint behaviour must be identified. A root cause is the highest level of a problem. It is the evil at the bottom that sets the entire cause and effect chain causing all sorts of problem (ASQ, n.d.). A root cause is defined as a factor that causes non-conformance and should be permanently eliminated through process improvement (ASQ, n.d.). The concept of Root Cause Analysis (RCA) becomes applicable. RCA is defined as a tool and technique to be used to uncover the causes of problems. RCA helps to identify not only what and how but also why something happened.

For the purpose of this research, RCA has been used to analyse constraints as captured by the allowed lost blast reasons booked on the mineral resource management system (MRM). The application of RCA in lost blast analysis is demonstrated in Appendix A.

2.5.2 Root Cause Analysis (RCA) of blasts (constraint analysis)

For the purpose of RCA application the four initial conditions (GPME) were allocated codes (1 – 4) as follows (appendix A):

- Ground (ore reserves); 1
- People; 2
- Material & services; 3
- Equipment; 4.

For example the following lost blast reasons were given for failure to achieve a safe quality daily blast at four different working places:

- **DMI: Day shift miner absent**

A miner is a legally appointed person and only him can see the team members in, declare the workplace safe and prepare the face with the team for blasting. If he/she is not at work and there is no miner to cover him within the Mine, Health and Safety Act (MHSA) legal bounds, then that results in a lost blast booked against people (code 2).

- **DEW: Team establish workplace**

If this booking on the MRM is made against a stoping team which is planned to blast and not establish workplaces, this means the team currently has no place to mine. Therefore there is no flexibility, hence the constraint is ground (code1).

- **IWE: winch electrical**

A breakdown of a winch on day shift or night shift can prevent a planned panel from being blasted. The breakdown is a constraint that is classified under equipment failure (code 4). Of course if there was a person planned and assigned to respond to break down timeously and that person fails to respond then the constraint becomes a person and the lost blast reason changes further to people (code 2) instead of equipment failure (code 4).

- **DRB: roof bolter break down**

A roof bolter in conventional mining is used to install active roof bolt support on the immediate face in the hanging wall as permanent support before a blast is taken. Conveniently the reason is a breakdown of the bolter (equipment break down). However, by applying RCA the reason changes to shortage of spares in the store (shortage of equipment). With further analysis it can be revealed that someone is responsible for making sure that there is enough material at the face to achieve a blast and that there is enough buffer at the stores to ensure an uninterrupted mining process. The final RCA indicates that a person (people) (code 2) is a constraint. The failure of a supervisor to provide for enough material to achieve a blast has resulted in a lost blast hence loss of production for that day.

Figure 2.7 and Figure 2.8 will show the distribution of lost blast analysis for a mine for a period of a month of production. The lost blasts filtered here are only stoping lost blasts.

In total the MPS MRM system has provided for nearly 77 (Appendix A) lost blast reasons grouped under the following categories:

- Labour (day shift and night shift)
- Engineering
- Finance
- Rock Engineering
- Geology and ventilation.

The RCA methodology facilitates the grouping of lost blasts into only four categories hence minimising ambiguity in classification and therefore directing the controlled action to the actual cause. Figure 2.7 depicts the lost blast reasons before application of RCA while Figure 2.8 depicts the same distribution only after RCA was done.

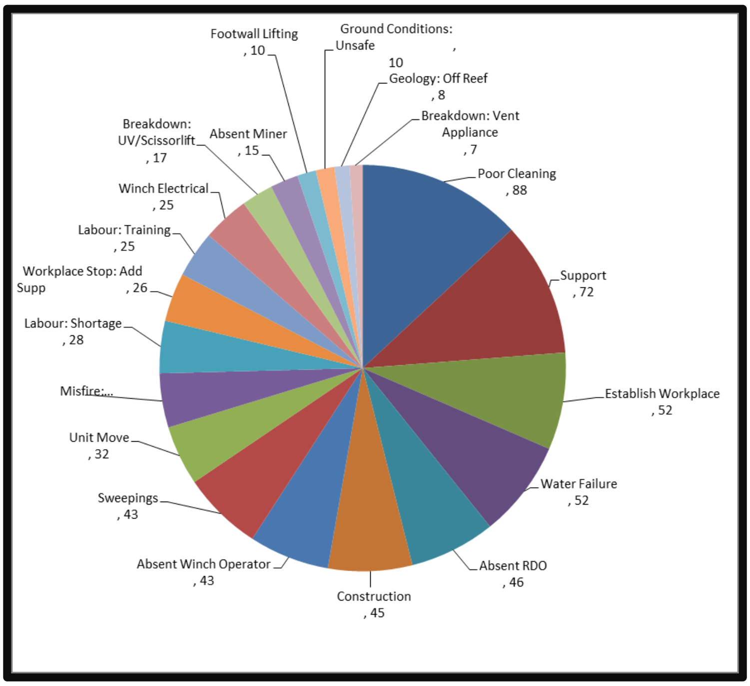

Figure 2.7 Stoping lost blasts distribution before RCA analysis

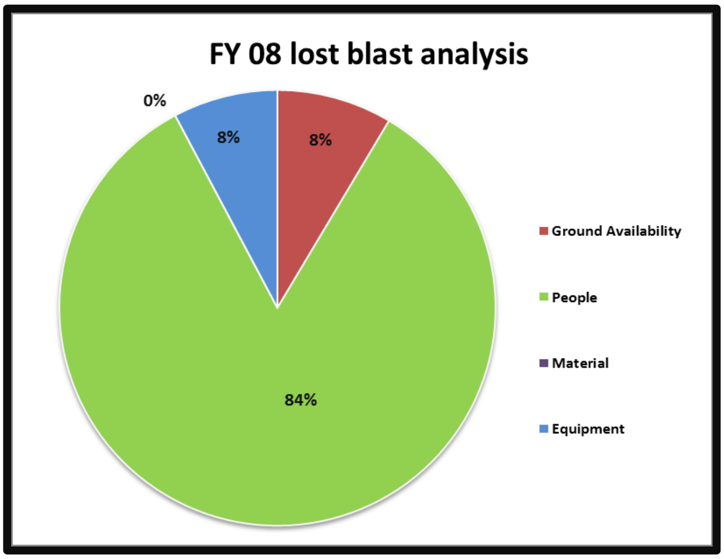

Figure 2.8 Stoping lost blasts distribution after RCA analysis

If one considers for example the poor cleaning lost blast reason as indicated in Figure 2.7, a total of 88 times a workplace could not be blasted because the team that was supposed to properly clean the work place and hand it over to the blasting shift did not do so. The team has a supervisor who is a legally appointed miner who is assumed to be trained and competent. The miner is overseen by a shift supervisor who is also overseen by a mine overseer. The interaction between these people is daily hence a question comes up, why is it impossible to eliminate the poor cleaning lost blast after the first occurrence.

In RCA, the following lost blast reasons , absent rock drill operator (RDO), absent winch operator, absent miner, labour training, labour shortage, misfire mining, sweepings, support are grouped under code 2 (people). When the mining cycle is correct, sweepings must be done concurrently with the daily production cycle. Sweepings may or cannot interrupt a blast. Support on the on the other hand is a cyclic activity and must be systematically installed with the production cycle. It must not constitute a lost blast. Only additional support due to adverse ground conditions can interrupt a blast for safety reasons and is considered a legitimate lost blast. It is also not surprising that any lost blast related to material (consumables) is grouped under ID code 2 (people) because it is directly under the control of a human being. This fact is demonstrated in Figure 2.8 where the lost blast due to material rarely occurs if not at all.

2.5.3 Theory of constraints (TOC) application

The MPS activities are sequential and cyclic in nature. A safe quality daily blast can be seen as a project delivered on any particular day while the activities that yield a safe quality daily blast can be seen as milestones within the blasting project. The sequential flow of these activities is important to the achievement of the objective. When the upstream activities do not occur, the objective is missed and the system fails or is constrained. The theory of constraints (TOC) is available to deal with a system of this nature. The theory of constraints (TOC) is a systems-management philosophy developed by Eliyahu M. Goldratt in the early 1980s (Institute of Management Accountants, 1999). It is a management tool that assists managers to achieve the bottom line and capacity improvement quickly and at little or no cost at all. The main objective of TOC is to identify a constraint in the system. In the example of a safe quality daily blast the value chain would be drill-blast-clean-support. If any of the four events does not occur the cycle cannot be completed or repeated. It then becomes necessary to identify where the problem is. The RCA process will generally lead to identification of the real cause of the problem. When the problem (constraint) is identified, the TOC methodology suggests further critical steps to solve the problem. There is a five step focusing process in TOC that helps to manage the change based on the work of Eliyahu Goldratt.

The mining stages that precede the production from a panel characterise the specific events that follow on each other. For example, an equipped panel ready for mining is a result of four distinct sequential mining phases namely (Woodhall 2002):

a) Waste development (non-mineral reserve generating development)
b) Mineral reserve generating development
c) Ledging

d) Equipping.

The level of interdependency of the sequential mining phases is very high. It therefore follows that the execution of these processes must flow continuously and consistently. A very important concept in managing systems that are characteristic or dependent on sequential execution is the theory of constraints (TOC). If the preceding phases are not completed or done on schedule, the desired product (an equipped panel for mining) will not be realised. The preceding steps are therefore said to be constraining the system. The RCA process will generally lead to identification of the real cause of the problem. When the problem is found (constraint) then the TOC methodology suggests a further four critical steps to solve the problem which are:

- Identify (RCA)
- Exploit the bottle neck
- Subordinate all other elements to the bottle neck
- Elevate the bottle neck to get more from it
- Prevent inertia.

The history of TOC application suggests that it was extensively used in the manufacturing industry. The success stories indicate how much impact the theory made on throughput, inventory levels, operating expenses and net operating profit. The mining industry has not been left behind in the adoption of this concept. A company called Stratflow indicated that since 2000 and in over 70 interventions, they have successfully implemented the TOC methodology or concept (Startflow, 2016). Some mining success productivity improvements are as follows:

- Underground narrow reef platinum mine shaft x: 35% increase in output within one month.
- Underground gold mine shaft no 4# (+60%)
- Underground gold mine shaft no 7# (+55%)
- Underground gold mine shaft no 5# (+50%)
- Open cast chrome mine (+30%).

Sasol Mining a division of Sasol Limited also applied TOC in determining the capacity constraint resource in an underground coal production section. In applying the TOC theory, it was established that the constraint in the underground mining section was the three shuttle cars in the production process (Van Heerden, n.d.). Mathu (2014) found through the application of TOC that constraints are experienced in all stages of the coal supply chain and exposed all the vulnerable areas. Solutions were therefore implemented to targeting identified vulnerable areas. The theory of constraints is the best technique to handle interdependency and variability in a complex and random environment like mining.

2.6 The MPS productivity challenge

An extremely important responsibility of the mining industry is to grow the economy by extracting minerals as efficiently as possible. Platinum metal groups are fungible and traded on international markets with the need to remain competitive in the market (Cawood and Neingo, 2014). It is therefore essential to measure the productivity of any mining business and weigh it against the business plan bench marks.

During the planning stage all DMVs are set at their optimal values to yield a desired output, however, productivity decline is an indicator of a systemic problem intrinsic of the industry lately. The original plans have failed in most mining business cases. The original internal capacity is not being realised. The mining plans are exhibiting a different character contrary to the planned. The approach to fix the problem targets the assumed optimised plan, whereas the system now has an inherent character. As the system operates an ensemble of different values of DMVs yield outputs different to some extent to the desired output. In essence the DMVs are defining a different system. It is therefore important to define this new character as a function of its DMVs. This characterisation will quantitatively define a complete relationship between the KPI and the DMVs. With this relationship in place the inherent nature of the system can be optimised by manipulating the DMVs as desired. An empirically characterised system highlights the contribution or impact of individual DMVs related to the KPI. This will help in re-directing the optimisation efforts to the most significant DMVs as opposed to a generic effort to resolve the system as whole.

The MPS productivity challenge over time is demonstrated in Figure 2.9, Figure 2.11, Figure 2.11, Figure 2.12 and Figure 2.13. The period considered spans 8 business plan years. For sensible analysis of the data the industrial action periods where no mining occurred have been excluded in the output results.

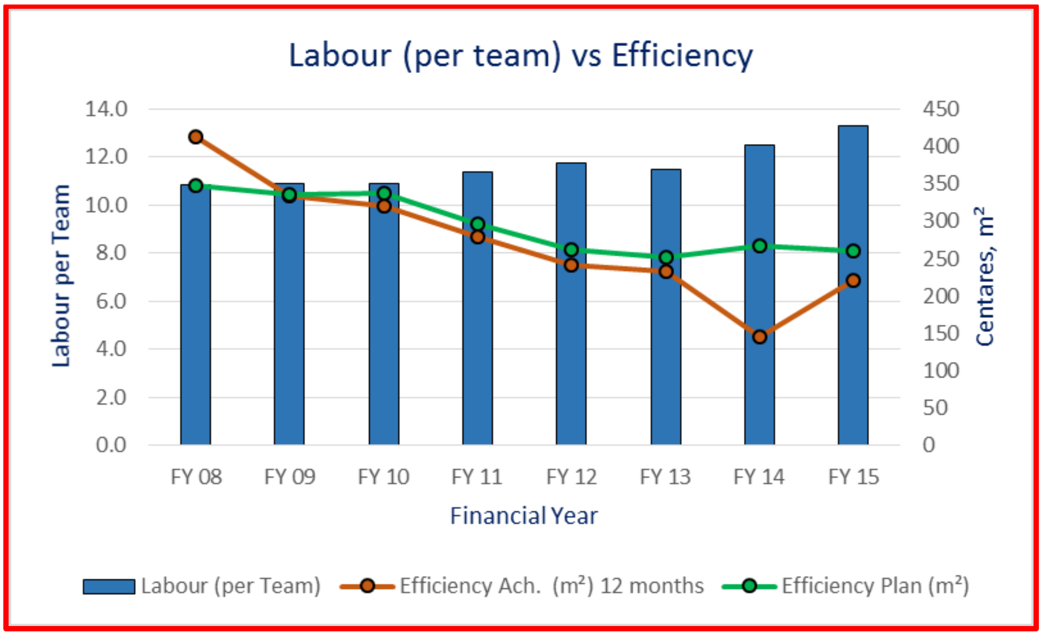

Figure 2.9 Team efficiencies vs labour per team for period FY 08 to FY 15

Figure 2.9 above depicts a gradual increase in the labour size per team. While the labour per team has increased from an average of 10 men/team to 13.3 men / team the output or efficiencies have themselves declined. The increase in labour has been due to additional stope activities like netting and bolting. While the increase in the team size was good in respect of safety it would seem it has had an impact on the efficiencies per team. This comment however does not exclude the effect of the human or technical factors that could impact the efficiencies. The most worrying observation is that while the planned efficiencies were also adjusted over time (Figure 2.10), the achieved efficiencies also declined and were below the reduced planned efficiencies.

Centares planned per panel team								
BP	BP09	BP10	BP11	BP12	BP13	BP14	BP15	BP16
m^2/team	398	389	386	310	324	242	242	323

Figure 2.10 Efficiencies planned for the years under review

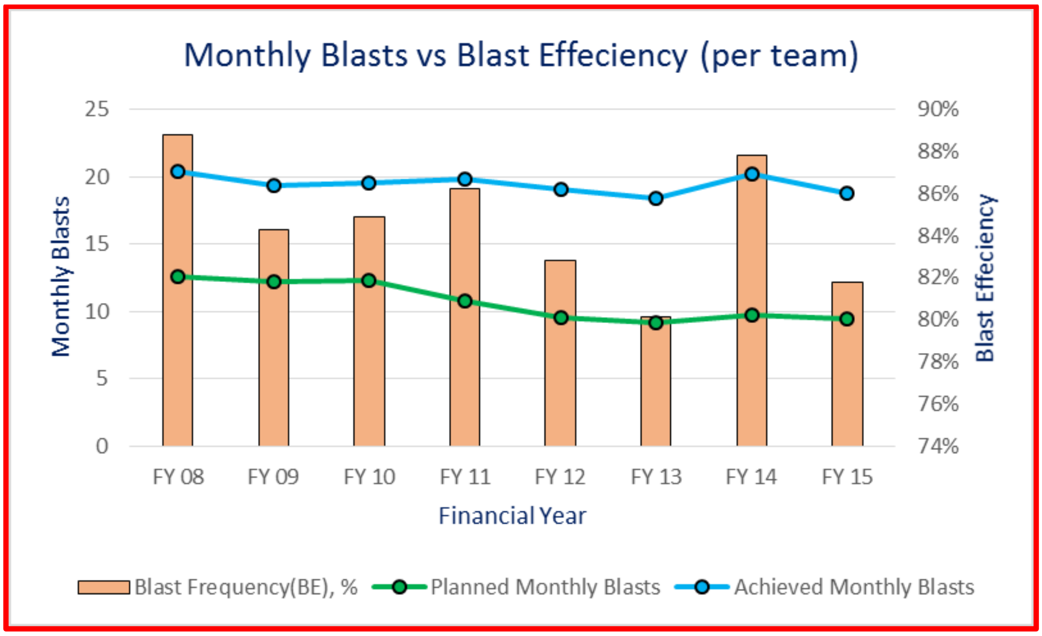

Figure 2.11 Monthly blasts, blast efficiencies for period FY 08 to FY 15

Figure 2.11 indicates that in general, the teams have achieved more blasts per month on average than the actual planned blasts. It would however be expected that the efficiencies would have stayed relatively the same for the period FY 08 to FY 15 because the achieved blasts are fairly constant over time. There are two possible causes here, one, there could be a problem with the quality of the blasts booked or recorded if the blasts really occurred or two, recorded blasts have not occurred at all as recorded on the MRM system.

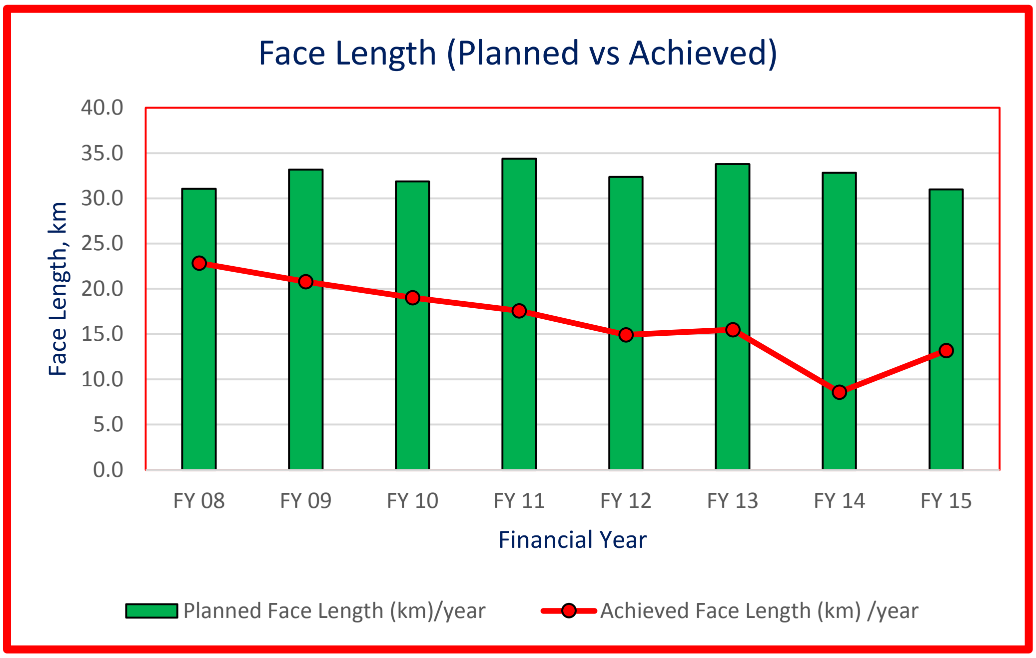

Figure 2.12 Face length planned vs mined for period FY 08 to FY 15

Figure 2.12 depicts a gradual decline in the actual mined face length over the years. In the FY 08 although the face length mined was less than planned, the target m² and the efficiencies were achieved. This is indicative of the quality of the blasts that occurred as indicated in Figure 2.13. The concept of technical efficiency (TE) becomes obvious here. The planned face length to be mined was not achieved, but the achieved mined face length yielded the planned output. One can deduce that the advance efficiency (AE) was high and the Blast Frequency (BF) was also high. The combination of AE and BF yield a technically efficient MPS. The FY 08 was the best year as indicated.

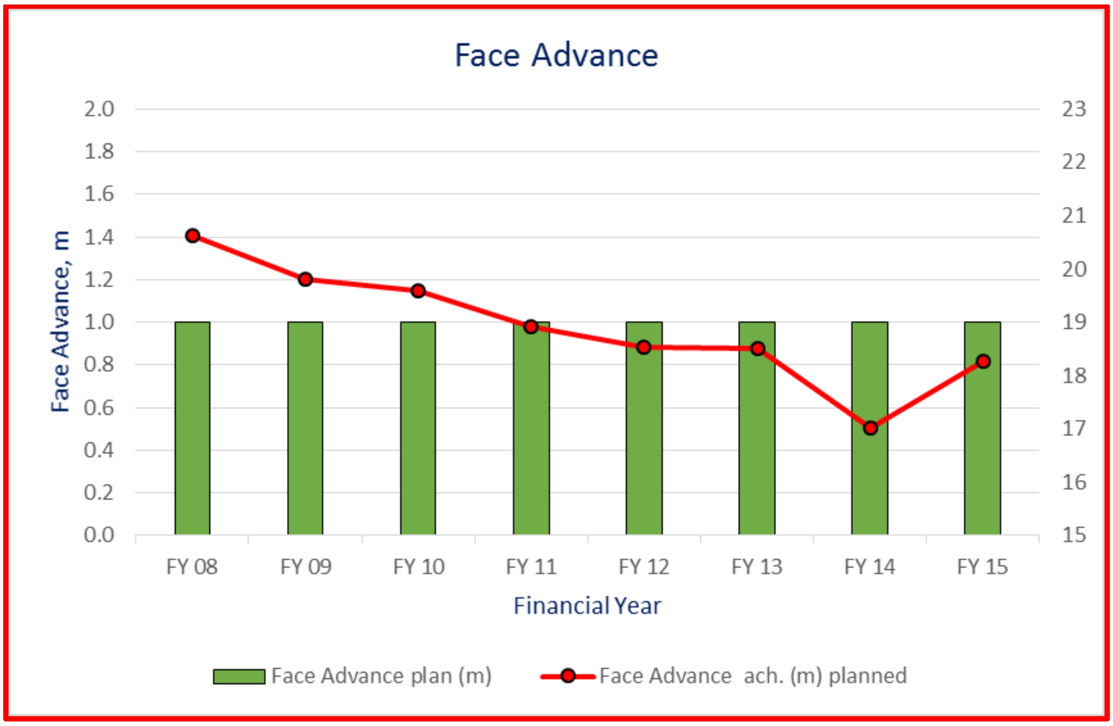

Figure 2.13 Face advance for the period FY 08 to FY 15

No detailed analysis or record can be found where the MPS has been empirically defined except the analysis of its variance from the desired operating capacity. It is the objective of this research to fill that gap. This research study attempts to characterise the inherent structure of the MPS and check for opportunistic leverage factors by targeting the most significant DMVs.

2.7 Summary

This chapter presented the findings of the survey of literature on topics relevant to the dissertation. It started by identifying the MPS in the context of the mining value chain. This was done to establish the relevance of the unit itself. Secondly, the variables or initial factors of the MPS were defined. The purpose was to show the complexity of the mining production system and the level of interdependency that exists. The key performance indicators were highlighted in the third section together with their associated DMVs. The management tools available and their application in the industry were then presented. The final part discussed the declining productivity status in the mining industry and the attempts to solve it. The aim of this section was to highlight the shortfall or the ambiguity of the suggested solutions, thus, justifying the relevance of the research study.

3 HYPOTHETICAL PLATINUM MINE CASE STUDY AND METHODOLOGY

3.1 Chapter overview

This chapter focuses on the research methodology used in the study. The chapter begins with the description of the case study mine then the method chosen for the research. The data utilised is then discussed along with the data limitations.

3.2 The platinum case study

The MPS case study is designed as an underground platinum mine consisting of a vertical shaft system (main shaft and ventilation shaft) to access the ore body. The ore body comprises of two distinct reef planes, the Merensky and the UG2 reefs dipping gently at about 9 degrees east and strike roughly north-south. The average platinum group metal (PGM) grade is about 3.71 g/t over a 1.1m stoping width on average. The two reef planes are scheduled to be mined concurrently. Underground mining operations follow traditional narrow reef, tabular mining practices. The ore body is mined on a conventional breast layout grid of 180m raise lines and 300m back lengths. This layout gives a total of about 18 stopes with in-stope grid pillars accounted for. Access to these stopes is by means of off-reef haulages leading to secondary development to reef. Based on geological and other conditions certain portions of ground are left unmined. A stoping team mining about 27m of available face length has a potential to achieve 621 m^2/month. For practical reasons the business plan (BP) target is 373 m^2/month which is 60% of the full potential in order to account for production disruptions. This equates to about 13 blasts at an assumed face advance of 1m/blast.

The production data used for the case study spans a period of 8 BP years. It is based on direct evidence collected or reported over the 8-year period. Standardised statistical methods were used to enhance the accuracy of the analysis and to validate empirical conclusions about the data. The data was chosen specifically because it spans the highs and the lows of the MPS in question.

3.3 Brief description of the research methodology

The research is empirical in nature. Direct evidence in the form of data collected over a period eight years was quantitatively analysed. The methodology attempts to describe accurately the interaction or relationship between the dependent and independent variables of interest in the data collected. A standardised statistical method was used to enhance the accuracy of the analysis of the data and to validate the empirical conclusions about the data. In summary the observed relationship was compiled in the database. An inductive analysis of the data involved the formulating of the relationships as a hypothesis. Deduction involved analysing the data to find testable predictions or relationships. Finally the derived empirical relationship was tested.

3.4 Data utilised

The study focusses on a hypothetical platinum mine for eight business plan (BP) years starting in July 2007 (BP 08) to June (BP 15). The business plan financial year for this particular mine starts in July and ends in June the following year (e.g. BP 08 starts in July 2007 and ends in June 2008). The data utilised is derived from the survey production profile (SPP). The SPP is the summary of all key measurable parameters that are measured against a planned target. These parameters are presented in Appendix B. Of all the measurable parameters listed in the SPP, centares were selected for the purpose of this research because they form the core of the MPS objective function, therefore, their analysis can give a better understanding of the characteristics of the MPS under study. It was also described earlier that centares are the key DMV in the determination of the tonnage throughput achieved.

3.5 Results presentation

The results were presented in the following manner:

- The empirically derived relationships defining the selected KPIs were presented and discussed.

3.6 Summary

This chapter discussed and clarified the methodology used in the research. It highlighted the details of the data utilised and why it was specifically chosen. The chapter finally discussed the manner in which the results were presented as outlined in the next chapter.

4 EMPIRICAL MODELLING OF THE CASE STUDY MINE PRODUCTION SYSTEM

4.1 Introduction

The critical parameters that are assumed to influence or predict the value of the target KPI (centares) were identified and are briefly described below. The parameters represent monthly figures that were used in the regression analysis for a total of 84 mining months over the 8 years as follows (Appendix C):

- **Face advance (FA)**: this parameter represents the distance that the total face length mined has been advanced forward by mining teams underground.
- **Face length mined (FLM)**: this parameter represents the mineable face length perpendicular to direction of advance that the teams accessed and worked on.
- **Ach. Blasts (AB)**: this parameter represents the number of blasts booked (achieved) on the MRM system against all the mining teams.
- **Teams (T)**: this parameter represents the number of mining teams planned to mine.
- **Total Labour (TL)**: this parameter represents the total number of production labour in the stopes.
- **Team Eff (TE).** This parameter represents the team efficiencies, i.e. the average m^2 that a team achieves per month.
- **Team size (TC)**: this parameter represents the number persons at work assigned to a team per panel.

- **Off Main Dev (OMD)**: this parameter represents the off-reef main development done to access the ore body to be mined.
- **Re & Pre Dev (RPD)**: this parameters represents the in-stope development that is done to re-establish existing panels.
- **Dev. To Mill (DTM)**: this parameter represents the material from development (main and secondary) that are trammed to the mill.

In statistical terms, the inference is that the above parameters influence or are good predictors of the dependent variable (centares). This suggestion is called a hypothesis and it must be tested. The choice of variables is purely based on experience and knowledge of the mining environment, e.g. the tonnage produced is recorded in the SPP, but it has not been included as a variable that predicts centares because it does not. Conversely, centares would be included as predictor variable of the tonnage produced. The independent variables were selected based on the nature of the research problem and the experience of the author. The total SPP variables are shown in Appendix B. Only 10 variables have been selected to start the analysis as indicated in run 1. The SPP is the record of all KPIs planned against the achieved results. Note that the centares form the first entry of the SPP parameters. The SPP can be seen and an ore flow type of process starting with centares generated and resulting in the platinum kilograms produced. Of course after the application of other internal modifying variables. The hypothesis states that the independent variables have some effect or predictive value with respect to the future values of the dependent variable (centares).

The variables that are included in the final regression model are those variables that have statistical significance in describing or predicting the dependent variable. In other words, they are the variables that pass the significance test by rejecting the null hypothesis

Table 4.1 depicts the correlation coefficients between the variables selected for the regression run 1 from data in Appendix C. Run 1 represents the first analysis of the 10 variables assumed to have significant influence on centares. The correlation coefficient measures the strength of the linear relationship between two variables. The coefficient is measured on a relative scale of -1 to +1. A positive correlation indicates that the variables move in the same direction while a negative correlation indicates that the variables move in opposite directions. The team size in Table 4.1 has a negative correlation to the total m^2 while all other variables have a positive correlation. The variables with the a strong correlation (>50%) at run 1 in descending order are, TE, FLM, FA ,OMD, DTM, AB,T,RPD,TL,SDT, and TC.

Table 4.1 Correlation coefficients @ run 1

	Y1 (M²)	X1 (FA)	X2 (FLM)	X3 (AB)	X4 (T)	X6 (TL)	X7 (TE)	X8 (TC)	X9 (OMD)	X10 (SDT)	X11 (RPD)	X12 (DTM)
Y1 (M²)	1											
X1 (FA)	0.8647862	1										
X2 (FLM)	0.8774466	0.5402864	1									
X3 (AB)	0.4194869	0.4070942	0.3749064	1								
X4 (T)	0.2361809	0.2964296	0.1937479	0.9239633	1							
X6 (TL)	0.0963931	0.2628918	0.0261537	0.5024373	0.6153406	1						
X7 (TE)	0.9056886	0.7410688	0.8032207	0.0257617	-0.191727	-0.160113	1					
X8 (TC)	-0.237893	-0.187709	-0.217729	-0.637345	-0.608253	0.1768095	0.0453308	1				
X9 (OMD)	0.7946338	0.7083677	0.6848584	0.4222324	0.2579495	0.0883054	0.6988498	-0.223961	1			
X10 (SDT)	0.0631305	0.0630236	0.0599204	0.0100455	0.0253267	0.2023813	0.0398251	0.0978187	0.032213	1		
X11 (RPD)	0.1622779	0.2684286	0.0887172	0.1796301	0.2160764	0.4003289	0.0734508	0.0923101	0.2645758	0.0104969	1	
X12 (DTM)	0.677202	0.6735049	0.5525811	0.368505	0.3121713	0.2255467	0.5591445	-0.140197	0.5979525	0.0352561	0.3892149	1

Table 4.1 also measures the inter-correlation strength between the independent variables themselves. An inter-correlation of >50% among the variable would indicate a strong correlation within the variables. Such circumstances tend to bring noise and affect the regression results to a very large extent, e.g. TE has about 74% and 80% correlation to the FA and FLM respectively. This is true because TE is a function of FA and FLM. Care was taken to eliminate this problem carefully in order to arrive at the correct and sensible regression results.

Table 4.2 indicates the regression statistics results at run 1. The R^2 value is equal to 0.985 meaning that 98.5% of the variation within the centares analysis is explained.

Table 4.2 Regression statistics @ run 1

Regression Statistics	
Multiple R	0.99963787
R Square	0.999275872
Adjusted R Square	0.985478046
Standard Error	902.145428
Observations	84

Table 4.3 highlights the significance level test of the variables used in the regression analysis. A predetermined confidence level of 95% has been selected for the purpose of testing. The implication here is that a P-value higher than 0.05 for any variable indicates that the variable has little influence in terms of predicting the dependent variable. AB, TL, SDT and RPD were the first to be eliminated.

Table 4.3 Regression statistics @ run 1

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0	#N/A	#N/A	#N/A
X1 (FA)	536.1179882	328.9407524	1.6298	0.1074
X2 (FLM)	1.922178294	0.91304495	2.1052	0.0387
X3 (AB)	1.360854023	1.281638086	1.0618	0.2918
X4 (T)	-71.55492162	37.50188081	-1.908	0.0603
X6 (TL)	13.56280402	1.629279093	8.3244	3E-12
X7 (TE)	70.89594067	10.50861085	6.7465	3E-09
X8 (TC)	-1292.706158	97.05751832	-13.319	3E-21
X9 (OMD)	1.284319439	0.916350808	1.4016	0.1653
X10 (SDT)	-0.462076796	1.68473519	-0.2743	0.7846
X11 (RPD)	-0.530445561	0.499930775	-1.061	0.2922
X12 (DTM)	1.613974538	0.818186357	1.9726	0.0523

The predictive production function at run 1 would not make sense due to the number of variables that must be removed from the test first due to their insignificance.

Table 4.4 depicts the correlation coefficients between the variables selected for the regression run 2. The data used at run 2 analysis is in Appendix D. The team size (TC) in Table 4.4 has a negative correlation to the total m² while all other variables have a positive correlation.

Table 4.4 Correlation coefficients @ run 2

	Y1 (M²)	X1 (FA)	X2 (FLM)	X4 (T)	X7 (TE)	X8 (TC)	X9 (OMD)	X12 (DTM)
Y1 (M²)	1							
X1 (FA)	0.864786	1						
X2 (FLM)	0.877447	0.540286	1					
X4 (T)	0.236181	0.29643	0.193748	1				
X7 (TE)	0.905689	0.741069	0.803221	-0.19173	1			
X8 (TC)	-0.23789	-0.18771	-0.21773	-0.60825	0.045331	1		
X9 (OMD)	0.794634	0.708368	0.684858	0.257949	0.69885	-0.22396	1	
X12 (DTM)	0.677202	0.673505	0.552581	0.312171	0.559145	-0.1402	0.597952	1

Table 4.5 indicates the regression statistics results at run 2. The R² value is equal to 0.985 meaning that 98.5% of the variation within the centares analysis is explained.

Table 4.5 Regression statistics @ run 2

Regression Statistics	
Multiple R	0.9992321
R Square	0.9984647
Adjusted R Square	0.9851856
Standard Error	1286.0502
Observations	84

Table 4.6 highlights the significance level test of the variables used in the regression analysis. A predetermined confidence level of 95% has been selected for the purpose of testing. The coefficients of the variables are indicated along with the P-value. The P-value indicates that the variables are all significant and relevant in predicting the future values of the dependent variable Total m² except for TE, OMD and DTM. These variables were eliminated for the next regression run 3.

Table 4.6 Regression statistics @ run 2

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0	#N/A	#N/A	#N/A
X1 (FA)	2415.3692	319.8135176	7.55243	0.000000
X2 (FLM)	6.6968092	0.986758982	6.7866716	0.000000
X4 (T)	-110.17662	32.09981938	-3.4323126	0.000971
X7 (TE)	11.668757	10.03958749	1.1622746	0.248761
X8 (TC)	-710.45008	64.96467838	-10.935944	0.000000
X9 (OMD)	1.9168065	1.249913889	1.5335508	0.129293
X12(DTM)	1.286752	1.118730161	1.1501897	0.253672

The resultant production function from Table 4.6 is shown below by Equation 1:

Total M² = (2415 x FA) + (6.69 x FLM) - (110.17x T) + (11.67 x TE) - (710.45 x TC) + (1.9 x OMD) + (1.2 x DTM).

Equation 1

Table 4.7 depicts the correlation coefficients between the variables selected for the regression run 3. The data used at run 3 analysis is in appendix E. Team size in Table 4.7 has a negative correlation to the total m² while all other variables have a positive correlation.

Table 4.7 Correlation coefficients @ run 3

	Y1	*X1*	*X2*	*X4*	*X8*
Y1 (M^2)	1				
X1 (FA)	0.8648	1			
X2 (FLM)	0.8774	0.5403	1		
X4 (T)	0.2362	0.2964	0.1937	1	
X8 (TC)	-0.2379	-0.1877	-0.2177	-0.6083	1

Table 4.8 indicates the regression statistics results at run 3. The R^2 value is equal to 0.985 meaning that 98.5% of the variation within the centares analysis is explained.

Table 4.8 Regression statistics @ run 3

Regression Statistics	
Multiple R	0.9991744
R Square	0.9983495
Adjusted R Square	0.9857877
Standard Error	1301.0291
Observations	84

Table 4.9 highlights the significance level test of the variables used in the regression analysis. A predetermined confidence level of 95% has been selected for the purpose of testing. The coefficients of the variables are indicated along with the P-value. The P-value indicates that the variables

are all significant and relevant in predicting the future values of the dependent variable total m².

Table 4.9 Regression statistics @ run 3

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0	#N/A	#N/A	#N/A
X1 (FA)	2910.1778	102.7298384	28.32845719	0.0000
X2 (FLM)	8.0927577	0.282826347	28.61387484	0.0000
X4 (T)	-148.2509	9.263123142	-16.0044182	0.0000
X8 (TC)	-693.14535	50.71330513	-13.667919	0.0000

The resultant production function from Table 4.9 is shown below by Equation 2

$$\text{Total } M^2 = (2910.18 \times FA) + (8.09 \times FLM) - (148.25 \times T) - (693.14 \times TC)$$

<u>Equation 2</u>

5 OBSERVATIONS AND DISCUSSION

5.1 General observations

The following observations are noted from results presented:

- The number of blasts reported on the MRM system are not really important in determining the amount of centares produced. The AB (achieved blasts) variable was eliminated in the final regression analysis due to its insignificance. The quality of the blast if it happened is the most important predictor in respect of the centares generated.

- An increase of 1m of face advance will result in an increase of 2910 m^2
- An increase in 1m of face length mined will result in an increase of 8.09 m^2
- An increase in 1 team will result in a decrease of 148.25 m^2. This coefficient can be interpreted as the average efficiency of the teams in the mine. More teams do not necessarily equate to higher production. It can either be that the teams do not have place to mine or the productivity declines in line with the Law of Diminishing Returns.
- An increase in 1 employee per team will result in a decrease of 693 m^2, this fact has been observed lately with the decline in productivity per worker, while the employees per team has increased in the panels. The amount of centares produced has decreased and is a

problem facing platinum mines lately. This fact weighed against the remuneration per worker reduces the profitability of a MPS.

At the business stage the coefficients of all the variables are set at optimal positive values. As the system operates and matures it seems that the coefficients behave rather differently as depicted in Equation 2. The two negative coefficients of T and TC will result in the sub-optimal output centares.

In predicting what a MPS must produce in any given month during the drafting of the Business Plan, the production function (Equation 2) can be used to align the physical, technical and human factors together to predict the optimal output level. The production function also highlights that the most significant production lever of the MPS is the face advance. The production function characterises the mine's monthly production output. It can also be broken down further if a daily output prediction is required.

The research indicates that the problem lies with the people as in the case on teams and team compliment. The lost blast analysis concurs with the resultant function highlighting the problem around the labour force. But pertinent questions arise in relation to the findings. The following are a few:

- Is the team compliment set correctly to achieve the target?
- Can the team members complete the mining cycle as desired?

- Can the team members physically and technically achieve what is required of them?
- Is the current mining environment and procedures too difficult for the people currently in service?
- Is the current labour force skilled and competent enough to operate in the current mining environment?
- Are the skills properly replaced to maintain continuity?
- Is there a knowledge gap?
- Is there a relationship gap (employer vs employee)?
- Why is the MPS exhibiting so much variability?
- Is the infrastructure supporting the teams?
- Is the mine design and layout optimal?
- Is the supervision adequate and competent?
- Is there may be other factors that render the labour force inefficient?
- What has exactly changed?

5.2 The variability challenge

It is assumed at the planning stage that every employee must add about 30m². The resultant state of the MPS indicates that 1 extra employee takes away about 693 m². This results in a variability of about negative 124%

It is also assumed that at the planning stage every extra team must add about 373m² on average. The resultant state of the MPS indicated that 1 extra team takes away about 148m². The variance of the system over time clearly indicates a problem centred on the people.

5.3 The optimization challenge

The production objective function is additive in nature. In the case of centares produced the DMVs are or must positive coefficients. Taking equation 2 to account, the maximum values of the teams (T) and team compliment (TC) can only be set at zero because they have negative coefficients. The face advance required and the face length to be mimed which represent the most significant production variables cannot be achieved if the two variables are set at zero. A team full of the compliment labour is required to initiate a safe quality daily blast.

6 CONCLUSION AND RECOMMEDATIONS

6.1 Research conclusion

This research study has presented an estimation of a mining production function. It was suggested that other parameters (face *advance, face length mined, achieved blasts, team efficiency, pre- & re-development, off-reef development, development to mill, team size*) could be quite important in the estimation of the production function. The result of the regression analysis shows that face advance (FA), face length mined (FLM), number of teams (T), and team size (TC) have a statistically significant relationship with the centares (m^2) produced, contrary to a widely accepted view that lost blasts are the key DMV to focus on. Platinum mines should in fact be focusing on the quality of the blast, more specifically, the advance. The first two variables have a positive significant relationship with centares, while the last parameters T and TC have a negative significant relationship with centares produced. Finally, the results confirm the existence and concept of the economic principle of diminishing marginal returns which seem to be directly applicable to team sizes.

Three of the initial conditions required for a successful mining operation have been confirmed in the resultant regression equation except for material and equipment which are directly controlled by people (supervisors or line mine management). The literature survey has indicated the importance of ore availability and the flexibility to exploit it. The resultant regression equation has confirmed that in respect of face length to be mined being significant. Face advance is directly in control of the people actually doing the job.

6.2 Research limitations

The data used in this research is collected personally by service departments during underground visits. It may be possible that some measurements have been over or under reported, however the mineral reserves system is able to reconcile the measurements to check for any discrepancies where the errors were not picked up, the human element took precedence.

6.3 Recommendations for future research work

It would seem that labour utilization and efficiency are becoming increasingly important and problematic in the workplace in the mines. Unfortunately with the people intensiveness due to conventional mining methods being used, the platinum industry is faced with a dilemma. Further research into the root cause of the declining labour productivity is recommended by many experts. The author also agrees that this must be a point of focus for as long the mining technology and methods are not changed.

The mining business is inherently prone to a lot of uncertainty as indicated earlier. It would therefore be in the interest of the mining employers to focus on the parts that they can control and let the markets predict the profitability. Perhaps the biggest motivation to conduct further research on declining labour productivity is due to the information depicted in the Figure 6.1 and

Figure 6.2. Figure 6.1 indicates a consistent demand forecast for the metal platinum for at least 6 years.

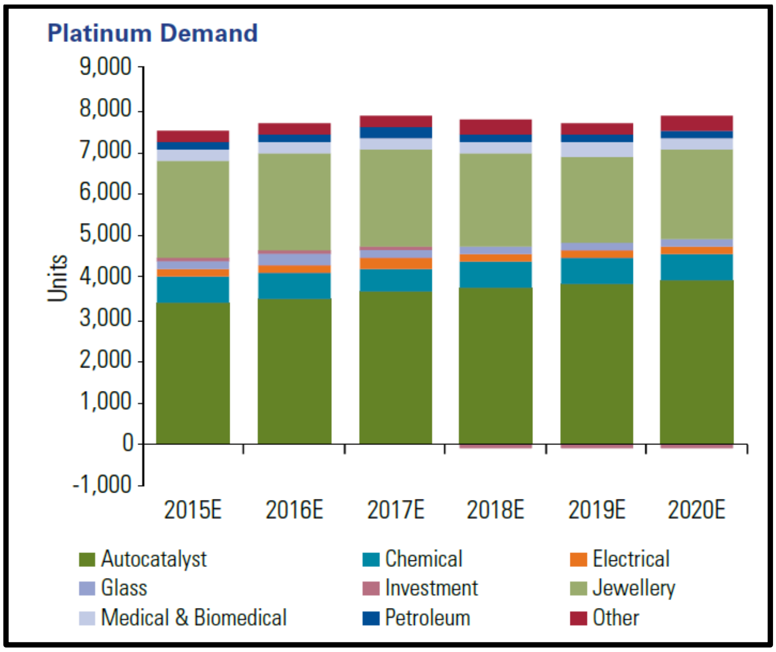

Figure 6.1 Platinum demand forecast figures (Van der Lith, 2015)

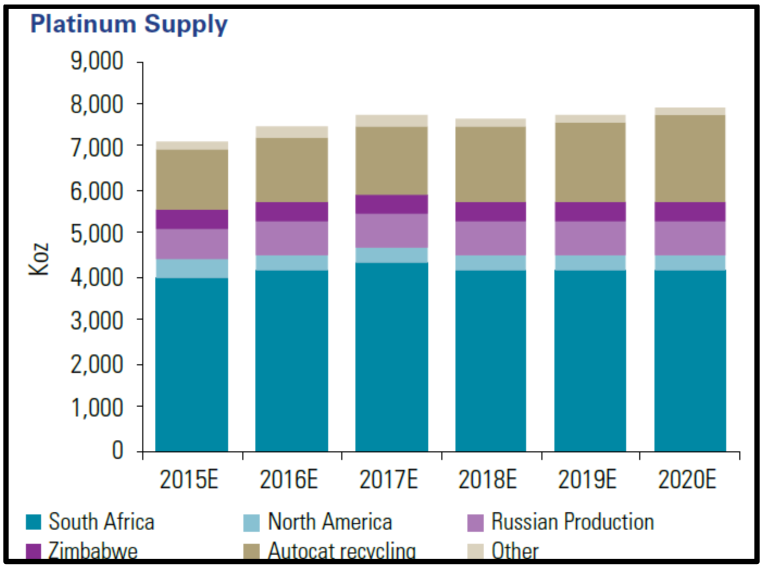

Figure 6.2 Platinum supply forecast figures (Van der Lith, 2015)

Figure 6.2 indicates that South Africa is still in position to be biggest platinum supplier for a few years to come.

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Appendix A

This is the root cause analysis (RCA) methodology used to define the exact cause of the lost blasts as recorded or booked on the MRM system.

Lost blast (LB) Root cause analysis and RCA interpretation						
#	LB CODE	LB Reason	LB RCA (compromised parameters)	Random Variable compromising the parameters	MPS Initial Conditions Compromised (GPME)	ID code
1	DLD	absent loader driver	HF, People	absenteeism	P	2
2	DLO	absent loco operator	HF, People	absenteeism	P	2
3	DMI	absent miner	HF, People	absenteeism	P	2
4	DPO	absent panel operator	HF, People	absenteeism	P	2
5	DRD	absent	HF, People	absenteeism	P	2
6	DWO	absent winch operator	HF, People	absenteeism	P	2
7	DAC	ASG not clean	HF, People	poor cleaning practice	P	2
8	DCS	coaching skills	HF, People	absenteeism	P	2

9	DCO	construction	TF, reserves	Flexibility/availability	R	1
10	D54	DMR section 54	HF, People	compliance	P	2
11	DEW	establish workplace	TF, reserves	Flexibility/availability	R	1
12	DFS	fixing face shape	HF, People	poor mining practice	P	2
13	DFL	Flooded workplace	HF, People	poor compliance	P	2
14	DMS	material shortage logistics	HF, People	planning	P	2
15	DMF	misfire mining	HF, People	poor execution	P	2
16	DCW	no contingency workplace	TF, reserves	Flexibility/availability	R	1
17	DPC	poor cleaning	HF, People	poor cleaning practice	P	2
18	DRB	roof bolter	HF, People	poor planning	P	2
19	DSU	support	HF, People	poor mining practice	P	2
20	DSW	sweepings	HF, People	poor mining cycle	P	2
21	DUM	unit move	HF, People	poor planning	P	2
22	NLD	absent loader driver	HF, People	absenteeism	P	2
23	NLO	absent loco operator	HF, People	absenteeism	P	2
24	NMI	absent miner	HF, People	absenteeism	P	2

25	NPO	absent panel operator	HF, People	absenteeism	P	2
26	NRD	absent RDO	HF, People	absenteeism	P	2
27	NOW	absent winch operator	HF, People	absenteeism	P	2
28	NAB	ASG behind	HF, People	poor mining practice	P	2
29	NLS	coaching skills	HF, People	poor labour skills	P	2
30	N54	DMR section 54	HF, People	non compliance	P	2
31	NMS	material shortage logistics	HF, People	poor planning	P	2
32	NPB	poor breaking	HF, People	poor mining practices	P	2
33	NFS	poor face shape	HF, People	poor mining practices	P	2
34	NRH	no rig holes	HF, People	poor mining practices	P	2
35	NSW	sweepings	HF, People	poor mining cycle	P	2
36	IDR	break down drill rig	TF, Equipment	break down	E	4
37	ILH	break down LHD	TF, Equipment	break down	E	4
38	ILD	break down loader	TF, Equipment	break down	E	4
39	ILO	break down loco	TF, Equipment	break down	E	4
40	ICT	cable theft	HF, People	poor discipline	P	2
41	ICA	compressed air	TF, Material & Services	break down	M&S	4

42	IMF	misfire engineering	TF, Material & Services	break down	M&S	4
43	IPF	power failure	TF, Material & Services	break down	M&S	4
44	IWA	water failure	TF, Material & Services	break down	M&S	4
45	IWE	winch electrical	TF, Equipment	break down	E	4
46	IWM	winch mechanical	TF, Equipment	break down	E	4
47	RFO	ground conditions fog	TF, reserves	Flexibility/availability	R	1
48	RUN	ground conditions unsafe	TF, reserves	Flexibility/availability	R	1
49	RML	rehab, mesh and lace	TF, reserves	Flexibility/availability	R	1
50	RSI	rehab, set installation	TF, reserves	Flexibility/availability	R	1
51	RSC	rehab, shot-creting	TF, reserves	Flexibility/availability	R	1
52	RSU	start-up rock engineering	HF, People	planning	P	2
53	RAS	work place stop, add support	TF, reserves	flexibility/ ground	R	1
54	RSS	work place stop, std. support	HF, People	poor compliance	P	2
55	VVA	break down vent appliance	TF, Equipment	break down	E	2
56	VSU	start-up Ventilation	HF, People	planning	P	2
57	VGP	vent gases present	TF, reserves	Flexibility/availability	R	1

58	VHO	vent holing	HF, People	poor work execution	P	2
59	VLO	vent layout required	HF, People	poor planning	P	2
60	VPG	vent, potential gas area	TF, reserves	Flexibility/ availability	R	1
61	VUS	vent, unsafe conditions	TF, reserves	Flexibility/availability	R	1
62	HIA	labour industrial action	HF, People	labour issues	P	2
63	HME	labour meetings	HF, People	labour issues	P	2
64	HSH	labour shortage	HF, People	poor planning	P	2
65	HTR	labour training	HF, People	poor planning	P	2
66	HUP	labour unscheduled parade	HF, People	poor planning	P	2
67	FAD	material shortage admin	HF, People	poor planning	P	2
68	FOO	material shortage no stock	HF, People	poor planning	P	2
69	FOB	material shortage budget	HF, People	poor planning	P	2
70	SNL	survey no layout	HF, People	poor planning	P	2
71	SNP	survey no pegs	HF, People	poor planning	P	2
72	SNN	survey no survey note	HF, People	poor planning	P	2
73	GOR	geology off reef	TF, reserves	Flexibility/availability	R	1

74	GPH	geology pothole	TF, reserves	Flexibility/availability	R	1
75	GWI	geology water intersection	TF, reserves	Flexibility/availability	R	1
76	GSU	start-up geology	HF, People	poor planning	P	2
77	GWS	work place stop geology	TF, reserves	Flexibility/availability	R	1

Appendix B

This appendix shows all the variables recorded in the SPP. It indicates centares as the first entry in the ore flow process as a most significant variable in determining the resultant platinum kilogram produced. The ore flow process starts with the generation of centares (m^2).

Variable	Unit
Total Eq m^2	m^2
Total Eq m^2 On	m^2
Total Eq m^2 Off	m^2
Eq m^2 (Excl Re/Pre)	m^2
Total Straight m^2	m^2
Straight m^2 On	m^2
Straight m^2 Off	m^2
White Areas	m^2
On Main Dev	m
Off Main Dev	m
On Reef Sec Dev	m
Off Reef Sec Dev	m
Sec Dev Total	m
Dev Total	m
Re & Pre Dev	m
Cap-Dev on	m
Cap-Dev off	m
Dev to mill	m

Channel Width	cm
Allow O/B	cm
Error O/B	cm
Allow U/B	cm
Error U/B	cm
3m width	cm
Off reef	cm
Ext width	cm
Ore remaining	cm
Sweepings	cm
Special sweepings	cm
Channel Width	Tons
Allow O/B	Tons
Error O/B	Tons
Allow U/B	Tons
Error U/B	Tons
3m width	Tons
Off reef	Tons
Ext width	Tons
Cuttings	Tons
Prospects	Tons
Ore remaining	Tons
Current Sweepings	Tons
Special Sweepings	Tons
Vamping	Tons
Re - sweepings	Tons
Re-Vamping	Tons

Sundries	Tons
Trammed from Stopes	Tons
Dev to mill	Tons
Ore to sludge	Tons
Calc tons Hoisted	Tons
To stockpile	Tons
From Stockpile	Tons
Survey Call	Tons
Survey Call/Wline Diff	Tons
Weighline	Tons
MBD Plus to LOS	Tons
Mill	Tons
Channel Width	(g/t)
Allow O/B	(g/t)
Error O/B	(g/t)
Allow U/B	(g/t)
Error U/B	(g/t)
3m width	(g/t)
Off reef	(g/t)
Ext width	(g/t)
Cuttings	(g/t)
Ore remaining	(g/t)
Current Sweepings	(g/t)
Special Sweepings	(g/t)
Vamping	(g/t)
Re - sweepings	(g/t)
Re-Vamping	(g/t)

Sundries	(g/t)
Trammed from Stopes	(g/t)
Dev to mill	(g/t)
Ore to sludge	(g/t)
Calc Hoisted	(g/t)
To stockpile	(g/t)
From Stockpile	(g/t)
Survey Call	(g/t)
Weighline	(g/t)
MBD Plus to LOS	(g/t)
Mill	(g/t)
Channel Width	Kg
Allow O/B	Kg
Error O/B	Kg
Allow U/B	Kg
Error U/B	Kg
3m width	Kg
Off reef	Kg
Ext width	Kg
Cuttings	Kg
Prospects	Kg
Ore remaining	Kg
Current Sweepings	Kg
Special Sweepings	Kg
Vamping	Kg
Re - sweepings	Kg
Re-Vamping	Kg

Sundries	Kg
Trammed from Stopes	Kg
Dev to mill	Kg
Ore to sludge	Kg
Calc Kg Hoisted	Kg
To stockpile	Kg
From Stockpile	Kg
Survey Call	Kg
Weighline	Kg
MBD kg plus to LOS	Kg
Mill kg	Kg
Tonnage Discrepancy	Tons
Weighline (Ratio) tons	%
Mill (Mcf)	%
Current Sweepings	m^2
Special sweepings	m^2
Ledging	m^2
Cubics (Stope & Dev)	m^3
Eq. Swept Excl. Ledg	%
Total Eq Swept m^2	m^2
Stope Width	cm
MIll Width	cm
Tons/m^2	t/m^2
m^2 yield	g/m^2
Sweepings - Str %	%
Sweepings - total Eq %	%
Replacement factor	

Off reef %	%
Channel Extraction	%
Stope Dilution on g/t	%
Drives/RefBays (wc)	m
Laybyes (wc)	m
T/ways (wc)	m
Boxholes (wc)	m
Raises/Winzes (wc)	m
X/Cuts (wc)	m
Others (wc)	m
Capital Development	m
Channel cmg/t	cmg/t
Channel Dilution (%)	Tons
Error O/B Dilution (%)	Tons
Error U/B Dilution (%)	Tons
3m Width Dilution (%)	Tons
Off Reef Dilution (%)	Tons
Ext Width Dilution (%)	Tons

Appendix C

The variables in this appendix were selected for regression analysis run 1 based on the experience and logic of the mining operation and their expected influence on the dependent variable being examined which is centares (Y1).

variable		Total Eq m²	Face Advance	Face Length Mined	Achieved Blasts	Teams	Total Labour	Team Efficiency	Team Compliment	Off Main Dev	Sec Dev Total	Re & Pre Dev	Dev to mill
Date		Y1	X1	X2	X3	X4	X6	X7	X8	X9	X10	X11	X12
1	Jul-07	44347.69	12.32	3601.00	2093	98	1045	452.53	10.66	807.00	23.90	312.20	481.60
2	Aug-07	43815.66	10.17	4307.00	1932	98	1107	447.10	11.29	789.90	172.80	406.20	591.20
3	Sep-07	37786.12	9.37	4034.00	1913	96	1013	393.61	10.56	764.60	136.50	402.40	623.20
4	Oct-07	41787.83	11.76	3552.00	1968	96	1005	435.29	10.47	821.70	55.60	460.00	602.80
5	Nov-07	39801.97	10.80	3685.00	2010	97	1024	410.33	10.55	1088.30	147.40	414.20	554.40
6	Dec-07	38276.00	9.84	3891.00	1890	96	1009	398.71	10.51	869.30	80.40	377.20	554.40
7	Jan-08	25569.62	7.35	3480.00	1684	85	969	300.82	11.40	511.50	45.60	243.60	332.00
8	Feb-08	37973.00	9.40	4039.00	1792	87	913	436.47	10.49	706.20	73.50	321.00	624.20
9	Mar-08	41811.82	10.39	4023.00	1742	86	955	486.18	11.10	788.20	40.80	385.00	685.70
10	Apr-08	39154.03	10.21	3836.00	1952	97	1067	403.65	11.00	652.00	79.00	182.70	539.00
11	May-08	42398.27	10.30	4118.00	2086	97	1034	437.10	10.66	828.90	75.30	286.20	680.50
12	Jun-08	39484.80	11.17	3535.00	2005	97	1120	407.06	11.55	637.60	109.90	253.20	661.40
13	Jul-08	20850.62	6.66	3129.00	1961	98	1053	212.76	10.74	379.30	101.00	229.30	470.90
14	Aug-08	34401.33	10.09	3410.00	1926	101	1155	340.61	11.43	610.10	72.00	299.30	665.30
15	Sep-08	41707.69	10.76	3875.00	1964	101	1078	412.95	10.68	731.50	128.40	264.80	653.60
16	Oct-08	38686.18	10.59	3652.00	2008	102	1110	379.28	10.88	540.80	92.30	316.50	730.30
17	Nov-08	38154.87	10.69	3569.00	1964	102	1047	374.07	10.26	638.50	139.90	305.80	577.70
18	Dec-08	41449.90	10.48	3954.00	2008	102	1089	406.37	10.67	599.80	189.40	343.10	892.00
19	Jan-09	30061.65	9.03	3329.00	2025	102	1183	294.72	11.60	485.40	112.70	281.50	613.20

20	**Feb-09**	28780.69	8.65	3328.00	1949	100	1080	287.81	10.80	540.60	183.90	225.80	740.40
21	**Mar-09**	34579.20	10.97	3153.00	1886	99	1058	349.28	10.68	510.60	0.00	299.30	903.00
22	**Apr-09**	30819.42	9.12	3380.00	1878	99	1075	311.31	10.86	513.40	0.00	286.10	774.10
23	**May-09**	32066.69	10.08	3181.00	1856	100	1105	320.67	11.05	480.20	0.00	309.60	678.60
24	**Jun-09**	36416.82	10.46	3482.00	1967	101	1091	360.56	10.80	592.50	0.00	523.60	694.20
25	**Jul-09**	38752.61	10.83	3577.44	1856	98	978	395.43	9.98	519.80	11.30	485.90	796.60
26	**Aug-09**	35095.55	10.00	3508.82	1792	95	1111	369.43	11.70	463.40	0.00	727.60	690.60
27	**Sep-09**	10981.74	4.51	2433.64	1743	95	643	115.60	6.77	107.40	0.00	277.30	275.10
28	**Oct-09**	40930.14	11.32	3615.41	1841	93	1098	440.11	11.80	685.60	0.00	1314.50	901.40
29	**Nov-09**	27278.56	8.79	3102.49	1766	93	1011	293.32	10.87	719.50	0.00	913.50	842.20
30	**Dec-09**	40975.72	11.19	3660.29	1865	93	1066	440.60	11.46	791.30	16.30	1029.80	899.40
31	**Jan-10**	21813.36	7.69	2835.32	1896	100	1151	218.13	11.51	383.00	0.00	534.80	304.30
32	**Feb-10**	35871.64	9.05	3965.67	1899	99	1141	362.34	11.52	662.20	5.30	715.10	667.20
33	**Mar-10**	34617.37	8.88	3896.96	1968	99	1083	349.67	10.94	688.10	58.90	734.90	770.90
34	**Apr-10**	29899.37	8.64	3462.01	1878	99	1108	302.01	11.19	590.10	46.80	692.00	544.60
35	**May-10**	32727.33	9.69	3377.44	2192	98	1134	333.95	11.57	800.20	31.70	886.20	704.50
36	**Jun-10**	35814.82	9.14	3916.94	1926	97	1099	369.22	11.33	753.30	47.50	936.20	657.80
37	**Jul-10**	38100.02	9.55	3988.33	1986	98	1127	388.78	11.50	677.10	47.20	1011.80	595.30
38	**Aug-10**	35600.05	9.94	3581.34	2076	102	1167	349.02	11.44	814.40	51.70	816.70	769.60
39	**Sep-10**	37290.10	10.93	3411.34	2119	103	1124	362.04	10.92	710.40	41.70	751.60	717.10
40	**Oct-10**	35434.71	11.26	3147.63	2043	102	1168	347.40	11.45	756.50	87.60	866.80	683.90
41	**Nov-10**	21709.46	7.36	2950.51	1842	102	1196	212.84	11.73	454.70	63.30	563.80	472.60
42	**Dec-10**	26635.19	8.69	3066.56	1924	103	1231	258.59	11.95	579.80	74.40	729.10	609.00
43	**Jan-11**	16808.55	6.71	2504.26	2010	102	1186	164.79	11.63	392.60	59.10	393.10	403.20
44	**Feb-11**	30420.03	9.01	3377.16	2021	102	1174	298.24	11.51	592.70	115.20	736.40	784.50
45	**Mar-11**	28789.53	9.45	3046.96	2036	103	1247	279.51	12.10	574.00	92.30	760.90	797.19
46	**Apr-11**	30953.35	9.15	3384.58	2169	107	1230	289.28	11.50	773.92	153.37	742.20	654.87
47	**May-11**	23730.01	6.72	3533.63	2251	111	1226	213.78	11.04	378.05	29.50	575.20	426.26

48	**Jun-11**	34625.80	8.61	4020.96	2220	111	1278	311.94	11.51	611.17	40.10	628.50	617.82
49	**Jul-11**	33939.18	8.07	4203.27	2221	112	1265	303.03	11.29	544.87	37.38	557.80	542.20
50	**Aug-11**	39394.14	8.94	4408.30	2259	112	1178	351.73	10.52	779.31	31.50	763.10	716.03
51	**Sep-11**	36060.73	9.94	3626.79	2275	112	1217	321.97	10.86	739.66	61.00	692.50	802.45
52	**Oct-11**	33344.81	10.31	3234.19	2236	112	1291	297.72	11.52	645.53	65.05	599.40	837.05
53	**Nov-11**	30205.83	9.51	3177.58	1919	113	1262	267.31	11.17	596.35	18.87	659.70	932.89
54	**Dec-11**	20957.50	6.90	3038.14	2108	113	1342	185.46	11.88	389.50	30.66	434.90	634.01
55	**Jan-12**	18014.00	7.52	2396.50	1166	68	739	264.91	10.86	301.80	32.29	267.30	417.04
56	**Feb-12**	8248.87	3.70	2230.78	112	22	565	374.95	25.70	215.05	24.50	224.10	275.08
58	**Apr-12**	22345.93	9.48	2358.13	2140	108	1407	206.91	13.03	401.07	33.51	558.80	643.50
59	**May-12**	25651.42	10.23	2508.60	2082	108	1211	237.51	11.21	782.89	49.35	711.20	838.03
60	**Jun-12**	25424.81	10.24	2483.25	2037	107	1295	237.62	12.11	668.43	43.77	651.30	669.60
61	**Jul-12**	30858.62	10.32	2989.50	2188	111	1357	278.01	12.22	663.20	22.50	965.60	675.51
62	**Aug-12**	32931.04	9.62	3422.80	1966	103	1133	319.72	11.00	711.40	32.00	839.10	770.60
63	**Sep-12**	24188.70	8.37	2888.30	1803	101	1121	239.49	11.10	520.20	40.30	637.00	568.60
64	**Oct-12**	29692.97	9.27	3202.41	1783	100	1142	296.93	11.42	632.40	29.60	640.90	510.40
65	**Nov-12**	23074.33	8.54	2702.20	1777	101	1167	228.46	11.55	529.20	52.90	721.20	450.60
66	**Dec-12**	28370.21	9.99	2839.45	1802	101	1114	280.89	11.03	710.00	65.90	738.80	573.20
67	**Jan-13**	7641.22	4.13	1849.11	1935	101	1172	75.66	11.60	301.70	23.90	194.10	224.60
68	**Feb-13**	27875.11	9.84	2833.44	1912	102	1215	273.29	11.91	663.20	42.70	633.90	468.50
69	**Mar-13**	25017.27	8.85	2825.76	1898	102	1130	245.27	11.08	653.87	29.50	613.70	396.40
70	**Apr-13**	20197.48	7.67	2631.90	1769	100	1119	201.97	11.19	597.00	28.70	429.00	388.70
71	**May-13**	23556.74	8.95	2633.49	1792	99	1141	237.95	11.53	484.00	77.60	475.70	495.10
72	**Jun-13**	24455.98	8.12	3013.27	1795	98	1171	249.55	11.95	476.10	65.40	592.20	509.50
73	**Jul-13**	30072.67	9.66	3113.57	1849	99	1175	303.76	11.86	492.10	130.94	698.00	833.79
74	**Aug-13**	28164.88	8.15	3457.60	1856	99	1206	284.49	12.18	555.90	114.40	676.60	644.40
75	**Sep-13**	31260.44	8.62	3625.78	1797	100	1268	312.60	12.68	555.50	219.70	790.70	765.40
76	**Oct-13**	30771.98	8.13	3782.92	1875	100	1243	307.72	12.43	653.20	192.90	712.40	674.90

77	**Nov-13**	30225.75	9.73	3107.73	1857	100	1255	302.26	12.55	768.20	260.90	830.00	713.60
78	**Dec-13**	22686.45	8.93	2541.49	1812	100	1384	226.86	13.84	417.30	253.90	777.50	593.20
79	**Jan-14**	8611.35	4.58	1879.92	1918	100	424	86.11	4.24	252.20	84.00	317.40	218.30
80	**Aug-14**	20318.67	8.72	2330.40	1870	99	1254	205.24	12.67	180.00	158.80	564.11	258.70
81	**Sep-14**	18282.08	7.57	2415.88	1632	96	1328	190.44	13.83	193.70	65.00	450.06	166.00
82	**Oct-14**	13068.71	6.10	2142.95	1660	93	1303	140.52	14.01	188.80	140.00	532.35	257.40
83	**Nov-14**	29924.24	11.07	2704.40	1666	90	1256	332.49	13.96	367.10	117.90	838.52	473.10
84	**Dec-14**	29000.12	9.34	3103.67	1641	89	1110	325.84	12.47	382.10	213.50	1059.49	642.10
85	**Jan-15**	13169.20	5.94	2216.48	1792	92	1208	143.14	13.13	170.50	75.40	481.49	213.40

Appendix D

The variables in this appendix were selected for regression analysis run 2 after elimination of insignificant variables after run 1.

variable		Total Eq m²	Face advance	Face length mined	Teams	Team efficiency	Team compliment	Off. Main Dev.	Dev to mill
Date		Y1	X1	X2	X4	X7	X8	X9	X12
1	Jul-07	44347.69	12.32	3601.00	98	452.53	10.66	807.00	481.60
2	Aug-07	43815.66	10.17	4307.00	98	447.10	11.29	789.90	591.20
3	Sep-07	37786.12	9.37	4034.00	96	393.61	10.56	764.60	623.20
4	Oct-07	41787.83	11.76	3552.00	96	435.29	10.47	821.70	602.80
5	Nov-07	39801.97	10.80	3685.00	97	410.33	10.55	1088.30	554.40
6	Dec-07	38276.00	9.84	3891.00	96	398.71	10.51	869.30	554.40
7	Jan-08	25569.62	7.35	3480.00	85	300.82	11.40	511.50	332.00
8	Feb-08	37973.00	9.40	4039.00	87	436.47	10.49	706.20	624.20
9	Mar-08	41811.82	10.39	4023.00	86	486.18	11.10	788.20	685.70
10	Apr-08	39154.03	10.21	3836.00	97	403.65	11.00	652.00	539.00
11	May-08	42398.27	10.30	4118.00	97	437.10	10.66	828.90	680.50
12	Jun-08	39484.80	11.17	3535.00	97	407.06	11.55	637.60	661.40
13	Jul-08	20850.62	6.66	3129.00	98	212.76	10.74	379.30	470.90
14	Aug-08	34401.33	10.09	3410.00	101	340.61	11.43	610.10	665.30
15	Sep-08	41707.69	10.76	3875.00	101	412.95	10.68	731.50	653.60
16	Oct-08	38686.18	10.59	3652.00	102	379.28	10.88	540.80	730.30
17	Nov-08	38154.87	10.69	3569.00	102	374.07	10.26	638.50	577.70
18	Dec-08	41449.90	10.48	3954.00	102	406.37	10.67	599.80	892.00
19	Jan-09	30061.65	9.03	3329.00	102	294.72	11.60	485.40	613.20

20	**Feb-09**	28780.69	8.65	3328.00	100	287.81	10.80	540.60	740.40
21	**Mar-09**	34579.20	10.97	3153.00	99	349.28	10.68	510.60	903.00
22	**Apr-09**	30819.42	9.12	3380.00	99	311.31	10.86	513.40	774.10
23	**May-09**	32066.69	10.08	3181.00	100	320.67	11.05	480.20	678.60
24	**Jun-09**	36416.82	10.46	3482.00	101	360.56	10.80	592.50	694.20
25	**Jul-09**	38752.61	10.83	3577.44	98	395.43	9.98	519.80	796.60
26	**Aug-09**	35095.55	10.00	3508.82	95	369.43	11.70	463.40	690.60
27	**Sep-09**	10981.74	4.51	2433.64	95	115.60	6.77	107.40	275.10
28	**Oct-09**	40930.14	11.32	3615.41	93	440.11	11.80	685.60	901.40
29	**Nov-09**	27278.56	8.79	3102.49	93	293.32	10.87	719.50	842.20
30	**Dec-09**	40975.72	11.19	3660.29	93	440.60	11.46	791.30	899.40
31	**Jan-10**	21813.36	7.69	2835.32	100	218.13	11.51	383.00	304.30
32	**Feb-10**	35871.64	9.05	3965.67	99	362.34	11.52	662.20	667.20
33	**Mar-10**	34617.37	8.88	3896.96	99	349.67	10.94	688.10	770.90
34	**Apr-10**	29899.37	8.64	3462.01	99	302.01	11.19	590.10	544.60
35	**May-10**	32727.33	9.69	3377.44	98	333.95	11.57	800.20	704.50
36	**Jun-10**	35814.82	9.14	3916.94	97	369.22	11.33	753.30	657.80
37	**Jul-10**	38100.02	9.55	3988.33	98	388.78	11.50	677.10	595.30
38	**Aug-10**	35600.05	9.94	3581.34	102	349.02	11.44	814.40	769.60
39	**Sep-10**	37290.10	10.93	3411.34	103	362.04	10.92	710.40	717.10
40	**Oct-10**	35434.71	11.26	3147.63	102	347.40	11.45	756.50	683.90
41	**Nov-10**	21709.46	7.36	2950.51	102	212.84	11.73	454.70	472.60
42	**Dec-10**	26635.19	8.69	3066.56	103	258.59	11.95	579.80	609.00
43	**Jan-11**	16808.55	6.71	2504.26	102	164.79	11.63	392.60	403.20
44	**Feb-11**	30420.03	9.01	3377.16	102	298.24	11.51	592.70	784.50
45	**Mar-11**	28789.53	9.45	3046.96	103	279.51	12.10	574.00	797.19
46	**Apr-11**	30953.35	9.15	3384.58	107	289.28	11.50	773.92	654.87
47	**May-11**	23730.01	6.72	3533.63	111	213.78	11.04	378.05	426.26

48	**Jun-11**	34625.80	8.61	4020.96	111	311.94	11.51	611.17	617.82
49	**Jul-11**	33939.18	8.07	4203.27	112	303.03	11.29	544.87	542.20
50	**Aug-11**	39394.14	8.94	4408.30	112	351.73	10.52	779.31	716.03
51	**Sep-11**	36060.73	9.94	3626.79	112	321.97	10.86	739.66	802.45
52	**Oct-11**	33344.81	10.31	3234.19	112	297.72	11.52	645.53	837.05
53	**Nov-11**	30205.83	9.51	3177.58	113	267.31	11.17	596.35	932.89
54	**Dec-11**	20957.50	6.90	3038.14	113	185.46	11.88	389.50	634.01
55	**Jan-12**	18014.00	7.52	2396.50	68	264.91	10.86	301.80	417.04
56	**Feb-12**	8248.87	3.70	2230.78	22	374.95	25.70	215.05	275.08
58	**Apr-12**	22345.93	9.48	2358.13	108	206.91	13.03	401.07	643.50
59	**May-12**	25651.42	10.23	2508.60	108	237.51	11.21	782.89	838.03
60	**Jun-12**	25424.81	10.24	2483.25	107	237.62	12.11	668.43	669.60
61	**Jul-12**	30858.62	10.32	2989.50	111	278.01	12.22	663.20	675.51
62	**Aug-12**	32931.04	9.62	3422.80	103	319.72	11.00	711.40	770.60
63	**Sep-12**	24188.70	8.37	2888.30	101	239.49	11.10	520.20	568.60
64	**Oct-12**	29692.97	9.27	3202.41	100	296.93	11.42	632.40	510.40
65	**Nov-12**	23074.33	8.54	2702.20	101	228.46	11.55	529.20	450.60
66	**Dec-12**	28370.21	9.99	2839.45	101	280.89	11.03	710.00	573.20
67	**Jan-13**	7641.22	4.13	1849.11	101	75.66	11.60	301.70	224.60
68	**Feb-13**	27875.11	9.84	2833.44	102	273.29	11.91	663.20	468.50
69	**Mar-13**	25017.27	8.85	2825.76	102	245.27	11.08	653.87	396.40
70	**Apr-13**	20197.48	7.67	2631.90	100	201.97	11.19	597.00	388.70
71	**May-13**	23556.74	8.95	2633.49	99	237.95	11.53	484.00	495.10
72	**Jun-13**	24455.98	8.12	3013.27	98	249.55	11.95	476.10	509.50
73	**Jul-13**	30072.67	9.66	3113.57	99	303.76	11.86	492.10	833.79
74	**Aug-13**	28164.88	8.15	3457.60	99	284.49	12.18	555.90	644.40
75	**Sep-13**	31260.44	8.62	3625.78	100	312.60	12.68	555.50	765.40
76	**Oct-13**	30771.98	8.13	3782.92	100	307.72	12.43	653.20	674.90

77	**Nov-13**	30225.75	9.73	3107.73	100	302.26	12.55	768.20	713.60
78	**Dec-13**	22686.45	8.93	2541.49	100	226.86	13.84	417.30	593.20
79	**Jan-14**	8611.35	4.58	1879.92	100	86.11	4.24	252.20	218.30
80	**Aug-14**	20318.67	8.72	2330.40	99	205.24	12.67	180.00	258.70
81	**Sep-14**	18282.08	7.57	2415.88	96	190.44	13.83	193.70	166.00
82	**Oct-14**	13068.71	6.10	2142.95	93	140.52	14.01	188.80	257.40
83	**Nov-14**	29924.24	11.07	2704.40	90	332.49	13.96	367.10	473.10
84	**Dec-14**	29000.12	9.34	3103.67	89	325.84	12.47	382.10	642.10
85	**Jan-15**	21216.23	8.02	2216.48	92	143.14	13.13	170.50	213.40

Appendix E

The variables in this appendix were selected for regression analysis run 3 after elimination of insignificant variables after run 2. All the variables passed the significance test and are included in the final regression equation generated.

variable		Total Eq m²	Face advance	Face length mined	Teams	Team compliment
Date		Y1	X1	X2	X4	X8
1	Jul-07	44347.69	12.32	3601.00	98	10.66
2	Aug-07	43815.66	10.17	4307.00	98	11.29
3	Sep-07	37786.12	9.37	4034.00	96	10.56
4	Oct-07	41787.83	11.76	3552.00	96	10.47
5	Nov-07	39801.97	10.80	3685.00	97	10.55
6	Dec-07	38276.00	9.84	3891.00	96	10.51
7	Jan-08	25569.62	7.35	3480.00	85	11.40
8	Feb-08	37973.00	9.40	4039.00	87	10.49
9	Mar-08	41811.82	10.39	4023.00	86	11.10
10	Apr-08	39154.03	10.21	3836.00	97	11.00
11	May-08	42398.27	10.30	4118.00	97	10.66
12	Jun-08	39484.80	11.17	3535.00	97	11.55
13	Jul-08	20850.62	6.66	3129.00	98	10.74
14	Aug-08	34401.33	10.09	3410.00	101	11.43
15	Sep-08	41707.69	10.76	3875.00	101	10.68
16	Oct-08	38686.18	10.59	3652.00	102	10.88
17	Nov-08	38154.87	10.69	3569.00	102	10.26
18	Dec-08	41449.90	10.48	3954.00	102	10.67
19	Jan-09	30061.65	9.03	3329.00	102	11.60

20	**Feb-09**	28780.69	8.65	3328.00	100	10.80
21	**Mar-09**	34579.20	10.97	3153.00	99	10.68
22	**Apr-09**	30819.42	9.12	3380.00	99	10.86
23	**May-09**	32066.69	10.08	3181.00	100	11.05
24	**Jun-09**	36416.82	10.46	3482.00	101	10.80
25	**Jul-09**	38752.61	10.83	3577.44	98	9.98
26	**Aug-09**	35095.55	10.00	3508.82	95	11.70
27	**Sep-09**	10981.74	4.51	2433.64	95	6.77
28	**Oct-09**	40930.14	11.32	3615.41	93	11.80
29	**Nov-09**	27278.56	8.79	3102.49	93	10.87
30	**Dec-09**	40975.72	11.19	3660.29	93	11.46
31	**Jan-10**	21813.36	7.69	2835.32	100	11.51
32	**Feb-10**	35871.64	9.05	3965.67	99	11.52
33	**Mar-10**	34617.37	8.88	3896.96	99	10.94
34	**Apr-10**	29899.37	8.64	3462.01	99	11.19
35	**May-10**	32727.33	9.69	3377.44	98	11.57
36	**Jun-10**	35814.82	9.14	3916.94	97	11.33
37	**Jul-10**	38100.02	9.55	3988.33	98	11.50
38	**Aug-10**	35600.05	9.94	3581.34	102	11.44
39	**Sep-10**	37290.10	10.93	3411.34	103	10.92
40	**Oct-10**	35434.71	11.26	3147.63	102	11.45
41	**Nov-10**	21709.46	7.36	2950.51	102	11.73
42	**Dec-10**	26635.19	8.69	3066.56	103	11.95
43	**Jan-11**	16808.55	6.71	2504.26	102	11.63
44	**Feb-11**	30420.03	9.01	3377.16	102	11.51
45	**Mar-11**	28789.53	9.45	3046.96	103	12.10
46	**Apr-11**	30953.35	9.15	3384.58	107	11.50
47	**May-11**	23730.01	6.72	3533.63	111	11.04

48	**Jun-11**	34625.80	8.61	4020.96	111	11.51
49	**Jul-11**	33939.18	8.07	4203.27	112	11.29
50	**Aug-11**	39394.14	8.94	4408.30	112	10.52
51	**Sep-11**	36060.73	9.94	3626.79	112	10.86
52	**Oct-11**	33344.81	10.31	3234.19	112	11.52
53	**Nov-11**	30205.83	9.51	3177.58	113	11.17
54	**Dec-11**	20957.50	6.90	3038.14	113	11.88
55	**Jan-12**	18014.00	7.52	2396.50	68	10.86
56	**Feb-12**	8248.87	3.70	2230.78	22	25.70
58	**Apr-12**	22345.93	9.48	2358.13	108	13.03
59	**May-12**	25651.42	10.23	2508.60	108	11.21
60	**Jun-12**	25424.81	10.24	2483.25	107	12.11
61	**Jul-12**	30858.62	10.32	2989.50	111	12.22
62	**Aug-12**	32931.04	9.62	3422.80	103	11.00
63	**Sep-12**	24188.70	8.37	2888.30	101	11.10
64	**Oct-12**	29692.97	9.27	3202.41	100	11.42
65	**Nov-12**	23074.33	8.54	2702.20	101	11.55
66	**Dec-12**	28370.21	9.99	2839.45	101	11.03
67	**Jan-13**	7641.22	4.13	1849.11	101	11.60
68	**Feb-13**	27875.11	9.84	2833.44	102	11.91
69	**Mar-13**	25017.27	8.85	2825.76	102	11.08
70	**Apr-13**	20197.48	7.67	2631.90	100	11.19
71	**May-13**	23556.74	8.95	2633.49	99	11.53
72	**Jun-13**	24455.98	8.12	3013.27	98	11.95
73	**Jul-13**	30072.67	9.66	3113.57	99	11.86
74	**Aug-13**	28164.88	8.15	3457.60	99	12.18
75	**Sep-13**	31260.44	8.62	3625.78	100	12.68
76	**Oct-13**	30771.98	8.13	3782.92	100	12.43

77	**Nov-13**	30225.75	9.73	3107.73	100	12.55
78	**Dec-13**	22686.45	8.93	2541.49	100	13.84
79	**Jan-14**	8611.35	4.58	1879.92	100	4.24
80	**Aug-14**	20318.67	8.72	2330.40	99	12.67
81	**Sep-14**	18282.08	7.57	2415.88	96	13.83
82	**Oct-14**	13068.71	6.10	2142.95	93	14.01
83	**Nov-14**	29924.24	11.07	2704.40	90	13.96
84	**Dec-14**	29000.12	9.34	3103.67	89	12.47
85	**Jan-15**	13169.20	5.94	2216.48	92	13.13