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Estimating mine planning software utilization for decision-making strategies in the South African platinum group metals mining sector

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This paper discuses a new methodology to define and measure mine planning software utilization in the South African platinum group metals (PGM) mining sector within an evolving data-set framework. An initial data-set showing the mine planning software providers, their corresponding software solutions, as well as the software capabilities and information on the number of licences was collected and compiled in 2012 in an online database for software utilized in the South African mining industry. The database development and implementation was published in the *Journal of the Southern African Institute of Mining and Metallurgy* in 2013. In 2014 the data-set was updated with additional and new information.

Using the 2012 and 2014 timestamps, a methodology for estimating the software utilization was developed. In this methodology, three variables, namely commodity (i), functionality (l), and time factor (t) were used to define and measure the software utilization in order to ultimately inform decision-making strategies for software utilization by various stakeholders. Using six different functionalities – namely geological data management, geological modelling and resource estimation, design and layout, scheduling, financial valuation, and optimization, utilization for PGMs was measured. This paper presents the methodology employed for measuring the mine planning software utilization. The work presented in this paper is part of a PhD research study in the School of Mining Engineering at the University of the Witwatersrand.

Keywords: PGM sector mine planning software utilization, database, South African mining industry.

Introduction

This paper outlines the development of a new methodology to define and measure mine planning software utilization in the South African platinum group metal (PGM) mining sector. Although the calculations can be done for any commodity, in this paper the calculations were restricted to PGMs as South Africa is the world's number one platinum producer, producing 73 per cent (4.12 million ounces) of the annual global platinum output in 2013 (Johnson Matthey, 2014). According to Statistics South Africa (2014), PGMs generated almost 23% of South Africa's mining income during 2013.

An initial data-set showing the mine planning software providers, their corresponding software solutions, as well as the software capabilities and information on the number of licences was collected and compiled in 2012 in an online database. The database development and implementation was published in the *Journal of the Southern African Institute of Mining and Metallurgy* in 2013 (Katakwa, *et al*., 2013). In 2014 the data-set was updated with additional and new information. Using the updated data-set, a methodology was developed to measure mine planning software utilization for PGMs in order to ultimately inform decision-making strategies for utilization of the software in the PGM sector.

Utilization is a well-known word within the mining industry because of its ties with the level of productivity. Higher utilization is often leads to higher productivity, hence better profit margins. From this point of view, utilization is an important factor regardless of the size of any operation including those in the PGM sector. The root of the word 'utilization' comes from the word 'utilize', meaning to 'make practical and effective use of' (Oxford English Dictionaries, 2014). By using this definition, software utilization can be defined as the effective use of mine planning software in South Africa, but in general, utilization is associated with overall equipment effectiveness, which is one of the key performance-based metrics. It is important to understand the fundamentals behind these metrics.

Overall equipment effectiveness

In the literature, utilization is associated with time in such a way that it can be defined as the measurement of time used to perform effective work. In the mining industry, in both surface and underground operations, better equipment utilization often leads to higher of productivity, hence greater profitability.

Although there are a number of ways to measure performance against the various metrics, the most widely used measure to determine performance against capability of the equipment is Overall Equipment Effectiveness (OEE). OEE measurement is also commonly used as a key performance indicator (KPI) in Total Productive Maintenance (TPM) and Lean Manufacturing programmes for measuring production efficiency (Vorne Industries, 2008).

There are six factors, also known as the 'Six Big Losses', which are the main causes of production losses. TPM and OEE programmes aim to control these six factors. (Nakajima, 1998) listed these six factors effecting equipment utilization as:

- Breakdown loss
- Setup and adjustment loss
- Idling and minor stoppages
- Reduced speed loss
- Quality defects and rework
- Start-up loss.

In the TPM model, Nakajima (1998) furthermore formulated utilization using availability, performance rate, and quality rate as shown in the following formula:

$$\textit{Equipment effectiveness} = \textit{Availability} \times \textit{Performance rate} \times \textit{Quality rate}$$

In this formula, equipment effectiveness defines the meaning of equipment utilization and is calculated by multiplying equipment availability by performance rate and quality rate. Figure 1 shows time factors effecting equipment utilization. In Figure 1, operation time is associated with total available time for a given period, as this can be anything from a shift of the day to a whole month. As shown in Figure 1, loading time can be calculated by deducting downtime from the operation time.

Availability can be calculated by dividing loading time by operation time. As the loading time calculation is already given, the availability formula then is (Shirose, 2013):

$$\textit{Availability} = \frac{\textit{Operation time} - \textit{Planned downtime} - \textit{Unplanned downtime}}{\textit{Operation time}}$$

Furthermore, speed loss time is the lost time caused by operating below the planned speed, and can be calculated by using the actual time to make the production quantity minus the design time to make the same quantity as formulated below (Shirose, 2013):

$$\textit{Speed loss time} = \textit{Parts produced} \times (\textit{Design cycle time} - \textit{Actual cycle time})$$

Cycle time is the time taken to produce one unit. Design cycle time used to calculate the equipment's designed production rate, and actual cycle time used to calculate the equipment's actual production rate. Design operating time is the time the equipment should have taken to produce the units and is the difference between the loading time and the speed loss time. Performance rate is the ratio of the design operating time to loading time (Shirose, 2013) as shown below:

$$\textit{Performance rate} = \frac{\textit{Design operating time}}{\textit{Loading time}} = \frac{\textit{Loading time} - \textit{Speed lost time}}{\textit{Loading time}}$$

Operation Time			
Loading Time			Downtime
Design Operating Time		Speed Loss Time	
Valuable Operating Time	Quality Loss Time		

Figure 1. Time factors effecting equipment utilization (after Shirose, 2013)

Quality loss time is the time lost making nonconforming material. Valuable operating time is the time the equipment spends making conforming material. Quality rate is the ratio of conforming units produced to total units produced (Shirose, 2013), as shown below:

$$\textit{Quality loss time} = \textit{Nonconforming units} \times \textit{Actual cycle time}$$

Although OEE is a very powerful tool to measure efficiency, hence utilization; it is fundamentally designed for equipment utilization, which can be defined as hardware utilization. The aim of this study is to define *software utilization* in the South African mining industry. Although OEE gives some ideas regarding utilization, it is not designed to establish a framework that can bring a new approach towards mine planning software utilization.

El-Ramly and Stroulia (2004) tried to explain software utilization. They stated that there are a number of techniques available to understand how often the software is being used as well as to what degree it is being used. Many software systems collect, or can be set up to collect, data about how users use them, i.e. system-user interaction data. Such data can be of great value for program understanding and re-engineering purposes. Sequential data mining methods can be applied to identify patterns of user activities from system-user interaction traces (El-Ramly and Stroulia, 2004).

Despite the fact that user data may be available in some instances, using the data mining methods based on the user behaviour to measure mine planning software utilization is inappropriate when considering the size of the South African PGM sector and user privacy. By selecting the number of targeted mining sites, limited research output could be possible but most probably would not be sufficient to satisfy the whole PGM mining industry in South Africa.

To achieve a successful research initiative that covers the entire South African PGM mining sector, a methodology was developed in such a way that utilization of the mine planning software that is used in PGM mining sector could be measured. The next section defines this measurement framework.

Software utilization

By using an analogy to the one given earlier, software utilization can also be defined by associating many-to-many, one-to-many, and many-to-one relationships between entity types. In this association, the relationships between software vendors, commodity, functionality, and time factor were used to develop the following terminology:

$$\{C_i, F_l\} \rightarrow S_{k=\{i,l\}}$$

where S_k is the software that performs tasks on commodity (i) and functionality (l). In the market there is usually more than one software solution specifically designed for commodity (i) and functionality (l). In order to identify and evaluate each particular software solution, a new index (m) is used so that $S_k^{(m)}$ is defined to represent a unique software solution whereas $k=\{i,l\}$ is an index which is a specific combination of $\{i,l\}$, and

Table I
Number of software solutions by company

Name of software company	Company X			Company Y	Company Z	
Name of software solution	X_1	X_2	X_3	Y_1	Z_1	Z_2
m	1	2	3	4	5	6

$m=1, 2, 3 \ldots M$

where M is the total number of software solutions. For example, assume there are three software companies namely X, Y, and Z. Each of these three companies might have a number of software solutions, i.e. software company X has three types of software namely; X_1, X_2, and X_3; company Y has only one type, namely Y_1; and company Z has two types of software, namely Z_1 and Z_2. Table I shows how to find M.

From Table I, the total number of available software solutions, M, is 6.

Using a similar approach, the utilization of the software solutions can also be defined as such:

$u_{i,l}^{(m)}$ is the utilization of the software that performs task on commodity (i) and functionality (l) by using software (m). Although there is no rigid definition of the software utilization, it is defined as a numeric value that falls into the range between 0 and 1 inclusive, *i.e.*

$$u_{i,l}^{(m)} \in [0,1]$$

By doing so, performing further analytic development on the software utilization can be accomplished. Furthermore, the utilization formula can be extended by considering time factor (t) to the following:

$$u_{i,l}^{(m,t)} = f_{i,l}^{(m,t)} . w_{i,l}^{(m,t)}$$

where $f_{i,l}^{(m,t)}$ is a quantity factor that relates to the software that performs a specific task on commodity (i) and functionality (l) using software (m) at a specific time (t), and $w_{i,l}^{(m,t)}$ is the weighing factor, which will handle the missing data-related issues and/or other factors such as market capitalization of the companies. For instance, $f_{i,l}^{(m,t)}$ can be defined as the total number of sites. For example, if the market capitalization of the software companies X and Y are US$1 million and US$100 million respectively, but if both companies have a software solution with the same functionality, then the weighing factor for the small company will be higher than that for the larger company. Furthermore, the price of the mine planning software as well as support availability plays an important role when considering the weighing factor.

Software utilization is already defined in a generic way. However, the software utilization can also be defined in a specific way, i.e. the relative utilization (r). Relative utilization can be considered as a weighed software utilization and can be formulated as:

$$r_{i,l}^{(m,t)} = \frac{u_{i,l}^{(m,t)}}{\sum_{n=1}^{M} u_{i,l}^{(n,t)}}$$

Calculating relative utilization leads to a weighed market share of the software utilization. In the calculation of relative utilization, three variables were used to generate the results, namely:

- Commodity (i)
- Functionality (l)
- Time factor (t).

For example, the following results calculated for only one commodity, (i) namely PGMs, using six different functionalities (l) (Katakwa *et al*., 2013) namely:

1. Geological data management
2. Geological modelling and resource estimation
3. Design and layout
4. Scheduling
5. Financial valuation
6. Optimization.

Six functionalities listed by Katakwa *et al*. (2013) originated from the Open Group's Business Reference Model, which categorizes not only the functionalities of mine planning software, but also mine value chain stages and mining methods (The Open Group, 2010). The Open Group's Business Reference Model illustrates how the various software solutions interact with each other. Figure 2 shows the names of available mine planning software solutions and their functionalities along the mining value chain.

The time (t) factor has two timestamp indicators showing different data collection dates, namely:

- September 2012, t=1
- April 2014, t=2.

By using all three variables, the weighed software utilization, hence the market share of each participating mine planning software solution, was calculated. The dataset was extracted from the updated database, and the programming language *GNU Octave* was used for the data analysis and the calculation of the software utilization per functionality for the selected PGM commodity using two different timestamps as mentioned previously.

It is important to note that if $f_{i,l}^{(m,t)}$ is 0, it means that the subject software either does not support the specific functionality or does not support the specific commodity. Furthermore, when calculating $u_{i,l}^{(m,t)}$ and $w_{i,l}^{(m,t)}$, the value is set to 1 as at this stage of the calculation it was decided that the weighed software utilization did not have any impact on the calculation of the relative software utilization. The software_identities, which uniquely identify each particular software solution, are not named in this research work, and the solutions have been numbered randomly.

Results for PGMs

In this section, mine planning software utilization for commodity (i) PGMs was calculated. Six functionalities (l) with two timestamps (t) were used for the calculations and the results for each functionality with two timestamps are presented as tables and figures, respectively. Accordingly, a total number of {6(l) x 2(t) = 12} tables for each commodity was created. According to the functionality list provided earlier, the first functionality, 'Geological Data Management' was used with two different timestamps to produce the first sets of two tables. After generating the tables, pie charts were created for each table for easy interpretation of the results. Consequently, using the functionality list, the remaining tables and figures were created in a similar manner.

	Geological Data Management	Geological Modelling and Resource Estimation	Design and Layout	Scheduling	Financial Valuation	Optimisation
Bentley Evaluation				■	■	
Bentley Scheduler				■		
BLOCK AGG	■			■		
CADSMine		■	■	■		
Carbon 14 Mine Scheduler				■		
Carbon Economics					■	■
Carbon Micro Scheduler				■		
Carbon Performance Manager					■	
Carbon Processing				■	■	
Carbon Risk					■	■
Carbon V						■
Chronos				■		
Dragsim				■		■
Enhanced Production Scheduler (CAE)				■		■
EPS (MineRP)				■		
EPS Viz (Visualizer)				■		
EPS-PCBC Interface				■		
EPSOT (EPS Schedule Optimization Tool)				■		■
GEMS	■	■	■			
Geological Data Management Solution	■					
HAULNET				■		
Interactive Short Term Scheduler			■	■		
LoM Economics					■	■
Maptek I-Site	■					
Maxipit					■	■
Mine 2-4D			■	■		
Mine Scenario Planning			■	■		
Mineable Layout Optimizer			■			
Mineable Reserves Optimizer (CAE)			■	■		
Mineable Shape Optimizer			■	■		■
mineCAD			■			
mineCAVE			■			
mineHAUL			■			
mineMARKUP	■					
Mineral Beneficiation					■	■
MineSched				■		
mineSERV			■			
mineSTRUCTURE		■	■			
Minex	■	■	■			
MKP (Mining Knowledge Platform)	■	■				
MRM	■	■	■	■	■	■
NPV Scheduler (CAE)				■	■	■
NPV Scheduler (MineRP)				■	■	
Open Pit Metals				■		
PCBC				■		
Pegs Lite	■					
Performance Diagnostics						■
Portfolio Modelling					■	
Qerent Modeller					■	■
Sable Data Warehouse	■					
Services and Logistics			■	■		■
Sirovision	■	■				
Strat 3D		■				
Studio 3 - Engineering			■			
Studio 3 - Geology		■				■
Studio 5D Planner			■	■		
Studio3 - Basics						■
Surpac	■	■	■			
Talpac			■			
Underground Coal				■		
Ventsim Visual (Advanced)			■			
Vulcan	■	■	■			
Whittle					■	■
Workforce Planning					■	■
Xact				■		
Xeras					■	■
Xpac				■		

Figure 2. Available mine planning software solutions and their functionalities along the mining value chain

Table II Software providers and their locations	
Software provider	**Location of headquarters**
CAE Mining	Saint-Laurent, Canada
Cyest Corporation	Johannesburg, South Africa
Geovia	Paris, France
Maptek	Adelaide, Australia
MineRP Solutions	Centurion, South Africa
RungePincockMinarco	Brisbane, Australia
Sable	Johannesburg, South Africa

Table II shows the names of the software providers that participated in this study, as well as the locations of their headquarters. Note that data on CAE Mining was only made available in the April 2014 data-set. The results presented here do not cater for either the mining methods or the type of mine (whether it is a surface or an underground operation).

Geological data management software results for PGMs

Table III shows the market share of the individual software solutions for commodityPGMs using the functionality Geological Data Management as at September, 2012, while Table IV shows the same results using the second timestamp, i.e. April 2014. Figure 3 illustrates the data from both tables in graphical format. Note that $f_{i,l}^{(m,t)}$, $w_{i,l}^{(m,t)}$, $u_{i,l}^{(m,t)}$, and $r_{i,l}^{(m,t)}$ in the column headings in Tables III to XIII were defined in the previous section.

There is a significant difference between the two pie charts in Figure 3; CAE Mining's Geological Data Management Solution software with a 47% market share in the April 2014 chart is clearly visible. Pegs Lite and MRM have each a 16% market share in this field.

Geological modelling and resource estimation software results for PGMs

Table V shows the market share of the individual software solutions for the commodity PGMs using the Geological Modelling and Resource Estimation functionality as at September 2012, while Table VI shows the results using the second timestamp, April 2014. Figure 4 is a graphical representation of both tables.

When comparing the diagrams in Figure 4, similar to the previous results, there is huge difference between the two pie charts; Studio 3 - Geology is the leading software with a 50% market share in the April 2014 chart. MRM and CADSMine software have a 19% and 18% market share in this field, respectively.

Table III
Geological Data Management functionality software utilization for PGMs as of September 2012

m	software_id	$f_{i,l}^{(m,t)}$	$w_{i,l}^{(m,t)}$	$u_{i,l}^{(m,t)}$	$r_{i,l}^{(m,t)}$
1	9	2	1	2	0.0290
2	10	6	1	6	0.0870
3	13	4	1	4	0.0580
4	38	1	1	1	0.0145
5	68	1	1	1	0.0145
6	72	0	1	0	0.0000
7	83	12	1	12	0.1739
8	93	0	1	0	0.0000
9	95	0	1	0	0.0000
10	97	22	1	22	0.3188
11	98	21	1	21	0.3043
12	100	0	1	0	0.0000
13	113	0	1	0	0.0000

Table IV
Geological Data Management functionality software utilization for PGMs as of April 2014

m	software_id	$f_{i,l}^{(m,t)}$	$w_{i,l}^{(m,t)}$	$u_{i,l}^{(m,t)}$	$r_{i,l}^{(m,t)}$
1	9	2	1	2	0.0148
2	10	6	1	6	0.0444
3	13	4	1	4	0.0296
4	38	1	1	1	0.0074
5	68	1	1	1	0.0074
6	72	0	1	0	0.0000
7	83	12	1	12	0.0889
8	93	0	1	0	0.0000
9	95	64	1	64	0.4741
10	97	22	1	22	0.1630
11	98	21	1	21	0.1556
12	100	2	1	2	0.0148
13	113	0	1	0	0.0000

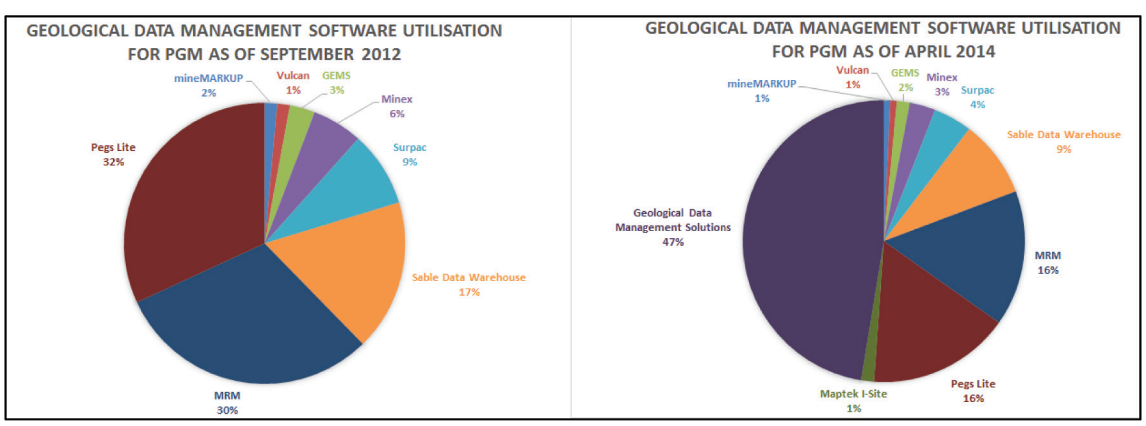

Figure 3. Geological Data Management functionality software utilization for PGMs

Table V
Geological Modelling and Resource Estimation functionality software utilization for PGMs as of September 2012

m	software_id	$f_{i,l}^{(m,t)}$	$w_{i,l}^{(m,t)}$	$u_{i,l}^{(m,t)}$	$r_{i,l}^{(m,t)}$
1	9	2	1	2	0.0370
2	10	6	1	6	0.1111
3	13	4	1	4	0.0741
4	48	0	1	0	0.0000
5	68	1	1	1	0.0185
6	72	0	1	0	0.0000
7	84	0	1	0	0.0000
8	93	0	1	0	0.0000
9	94	0	1	0	0.0000
10	98	21	1	21	0.3889
11	99	20	1	20	0.3704

Table VI
Geological Modelling and Resource Estimation functionality software utilization for PGMs as of April 2014

m	software_id	$f_{i,l}^{(m,t)}$	$w_{i,l}^{(m,t)}$	$u_{i,l}^{(m,t)}$	$r_{i,l}^{(m,t)}$
1	9	2	1	2	0.0183
2	10	6	1	6	0.0550
3	13	4	1	4	0.0367
4	48	0	1	0	0.0000
5	68	1	1	1	0.0092
6	72	0	1	0	0.0000
7	84	55	1	55	0.5046
8	93	0	1	0	0.0000
9	94	0	1	0	0.0000
10	98	21	1	21	0.1927
11	99	20	1	20	0.1835

Design and layout software results for PGMs

Table VII shows the market share of the individual software solutions for the commodity PGMs using the Design and Layout functionality as at September, 2012 while Table VIII shows the same results using the second timestamp, April 2014. Figure 5 illustrates the graphical representation of both tables.

There are some differences between the two pie charts in Figure 5. Although MRM and CADSMine software still has the biggest slices from the pie, with a 25% and 24% market share respectively in the Design and Layout software field,

Table VII
Design and Layout functionality software utilization for PGMs as of September 2012

m	software_id	$f_{i,l}^{(m,t)}$	$w_{i,l}^{(m,t)}$	$u_{i,l}^{(m,t)}$	$r_{i,l}^{(m,t)}$
1	2	6	1	6	0.0857
2	5	2	1	2	0.0286
3	9	2	1	2	0.0286
4	10	6	1	6	0.0857
5	13	4	1	4	0.0571
6	31	0	1	0	0.0000
7	32	0	1	0	0.0000
8	46	0	1	0	0.0000
9	48	0	1	0	0.0000
10	49	0	1	0	0.0000
11	68	1	1	1	0.0143
12	70	2	1	2	0.0286
13	85	0	1	0	0.0000
14	86	0	1	0	0.0000
15	88	0	1	0	0.0000
16	89	0	1	0	0.0000
17	90	0	1	0	0.0000
18	96	0	1	0	0.0000
19	98	21	1	21	0.3000
20	99	20	1	20	0.2857
21	101	6	1	6	0.0857
22	102	0	1	0	0.0000

Table VIII
Design and Layout functionality software utilization for PGMs as of April 2014

m	software_id	$f_{i,l}^{(m,t)}$	$w_{i,l}^{(m,t)}$	$u_{i,l}^{(m,t)}$	$r_{i,l}^{(m,t)}$
1	2	6	1	6	0.0706
2	5	2	1	2	0.0235
3	9	2	1	2	0.0235
4	10	6	1	6	0.0706
5	13	4	1	4	0.0471
6	31	0	1	0	0.0000
7	32	0	1	0	0.0000
8	46	0	1	0	0.0000
9	48	0	1	0	0.0000
10	49	0	1	0	0.0000
11	68	1	1	1	0.0118
12	70	2	1	2	0.0235
13	85	11	1	11	0.1294
14	86	0	1	0	0.0000
15	88	0	1	0	0.0000
16	89	1	1	1	0.0118
17	90	0	1	0	0.0000
18	96	3	1	3	0.0353
19	98	21	1	21	0.2471
20	99	20	1	20	0.2353
21	101	6	1	6	0.0706
22	102	0	1	0	0.0000

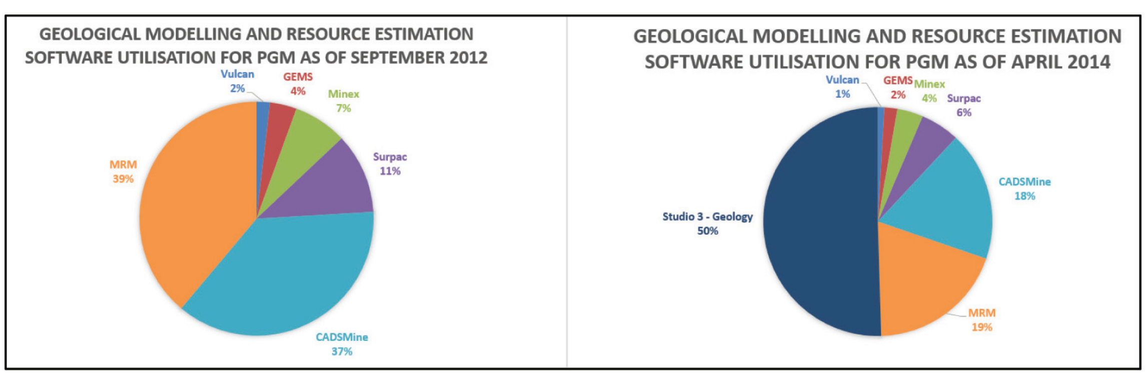

Figure 4. Geological Modelling and Resource Estimation functionality software utilization for PGMs

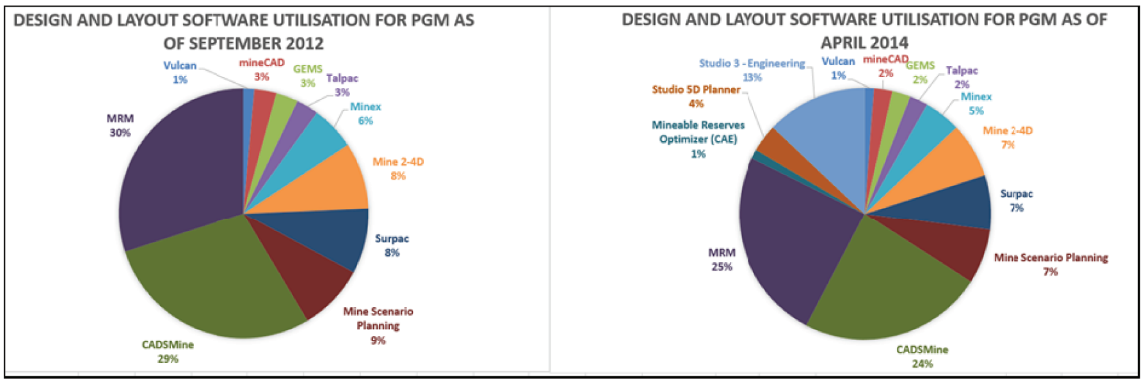

Figure 5. Design and Layout functionality software utilization for PGMs

Studio 3 – Engineering software is in the third place with a 13% market share in the PGM sector using the Design and Layout functionality.

Scheduling software results for PGMs

Table IX shows the market share of the individual software solutions for the commodity PGMs using the Scheduling functionality as at September 2012, while Table X shows the results using the second timestamp, April 2014. The data in Tables IX and X are illustrated graphically in Figure 6 and Figure 7 respectively.

A comparison of Figure 6 and Figure 7 does not reveal much difference; MRM and CADSMine software still have the biggest market shares in the Scheduling software field, with 17% and 16%, respectively.

Financial valuation software results for PGMs

When comparing the results for the Financial Valuation software between September 2012 and April 2014, it was noted that both timestamps were identical, indicating that there were no changes between the two different data-sets. Because of this, there is only one table, Table XI showing the market share of the individual software solutions for the commodity PGMs using the Financial Valuation functionality results for both timestamps. Similarly, Figure VIII represents both timestamps and is a graphical

Table IX
Scheduling functionality software utilization for PGMs as of September 2012

m	software_id	$f_{i,l}^{(m,t)}$	$w_{i,l}^{(m,t)}$	$u_{i,l}^{(m,t)}$	$r_{i,l}^{(m,t)}$
1	2	6	1	6	0.0508
2	4	7	1	7	0.0593
3	7	0	1	0	0.0000
4	12	4	1	4	0.0339
5	14	2	1	2	0.0169
6	20	1	1	1	0.0085
7	21	0	1	0	0.0000
8	33	1	1	1	0.0085
9	69	1	1	1	0.0085
10	71	4	1	4	0.0339
11	74	0	1	0	0.0000
12	75	1	1	1	0.0085
13	76	11	1	11	0.0932
14	80	1	1	1	0.0085
15	81	2	1	2	0.0169
16	86	0	1	0	0.0000
17	87	0	1	0	0.0000
18	88	0	1	0	0.0000
19	89	0	1	0	0.0000
20	91	0	1	0	0.0000
21	96	0	1	0	0.0000
22	98	21	1	21	0.1780
23	99	20	1	20	0.1695
24	101	6	1	6	0.0508
25	102	0	1	0	0.0000
26	108	15	1	15	0.1271
27	109	15	1	15	0.1271
28	111	0	1	0	0.0000
29	112	0	1	0	0.0000
30	113	0	1	0	0.0000
31	114	0	1	0	0.0000

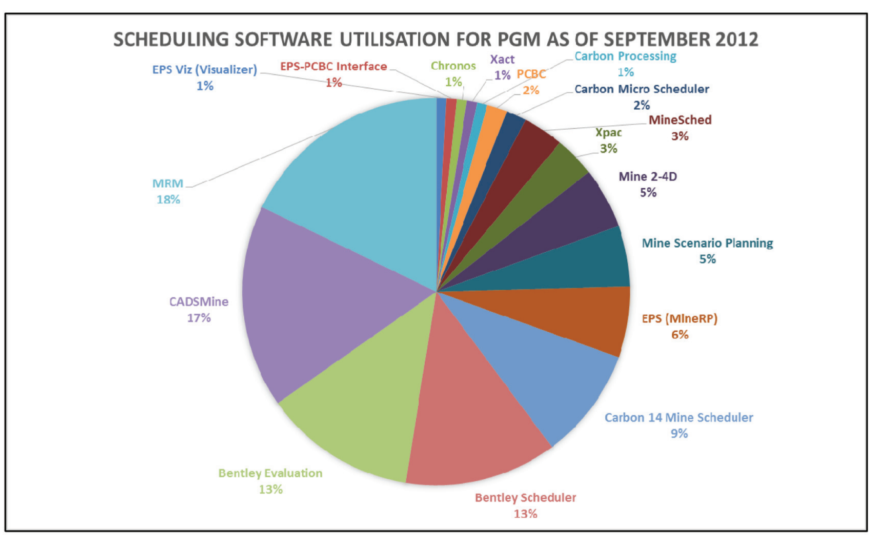

Figure 6. Scheduling functionality software utilization for PGMs as of September 2012

Table X
Scheduling functionality software utilization for PGMs as of April 2014

m	software_id	$f_{i,l}^{(m,t)}$	$w_{i,l}^{(m,t)}$	$u_{i,l}^{(m,t)}$	$r_{i,l}^{(m,t)}$
1	2	6	1	6	0.0480
2	4	7	1	7	0.0560
3	7	0	1	0	0.0000
4	12	4	1	4	0.0320
5	14	2	1	2	0.0160
6	20	1	1	1	0.0080
7	21	0	1	0	0.0000
8	33	1	1	1	0.0080
9	69	1	1	1	0.0080
10	71	4	1	4	0.0320
11	74	0	1	0	0.0000
12	75	1	1	1	0.0080
13	76	11	1	11	0.0880
14	80	1	1	1	0.0080
15	81	2	1	2	0.0160
16	86	0	1	0	0.0000
17	87	3	1	3	0.0240
18	88	0	1	0	0.0000
19	89	1	1	1	0.0080
20	91	0	1	0	0.0000
21	96	3	1	3	0.0240
22	98	21	1	21	0.1680
23	99	20	1	20	0.1600
24	101	6	1	6	0.0480
25	102	0	1	0	0.0000
26	108	15	1	15	0.1200
27	109	15	1	15	0.1200
28	111	0	1	0	0.0000
29	112	0	1	0	0.0000
30	113	0	1	0	0.0000
31	114	0	1	0	0.0000

representation of Table XI.

Figure 8 indicates that MRM is the leading software solution with a 30% market share in the PGM sector when it comes to Financial Valuation software. Bentley Evaluation and Carbon Economics both have a 21% market share in this section.

Optimization software results for PGMs

Table XII shows the market share of the individual software solutions for the commodity PGMs using the Optimization functionality as at September, 2012, while Table XIII shows the results using the second timestamp, April 2014.

Table XI
Financial Valuation functionality software utilization for PGMs

m	software_id	$f_{i,l}^{(m,t)}$	$w_{i,l}^{(m,t)}$	$u_{i,l}^{(m,t)}$	$r_{i,l}^{(m,t)}$
1	7	0	1	0	0.0000
2	15	0	1	0	0.0000
3	73	1	1	1	0.0143
4	77	15	1	15	0.2143
5	78	1	1	1	0.0143
6	79	0	1	0	0.0000
7	80	1	1	1	0.0143
8	91	0	1	0	0.0000
9	92	0	1	0	0.0000
10	98	21	1	21	0.3000
11	103	0	1	0	0.0000
12	104	0	1	0	0.0000
13	105	0	1	0	0.0000
14	106	12	1	12	0.1714
15	109	15	1	15	0.2143
16	110	4	1	4	0.0571

Figure 9 is the graphical representation of both tables, Table XII and Table XIII.

When comparing the diagrams in Figure 9, there is a noteworthy difference between the two pie charts; Studio 3 – Geology has emerged as a new leader with a 49% market share in April 2014, and is followed by MRM with an 18% market share in the Optimization software field.

Conclusion

In this paper, a methodology for the evaluation of mine planning software utilization in the South African PGM mining sector was developed. In this framework, three variables, namely commodity (i), functionality (l), and time factor (t) were used to calculate the results. The calculations can be done for any commodity in a similar manner. Six functionalities, namely Geological Data Management, Geological Modelling and Resource Estimation, Design and Layout, Scheduling, Financial Valuation, and Optimization, were applied using two different timestamps (September

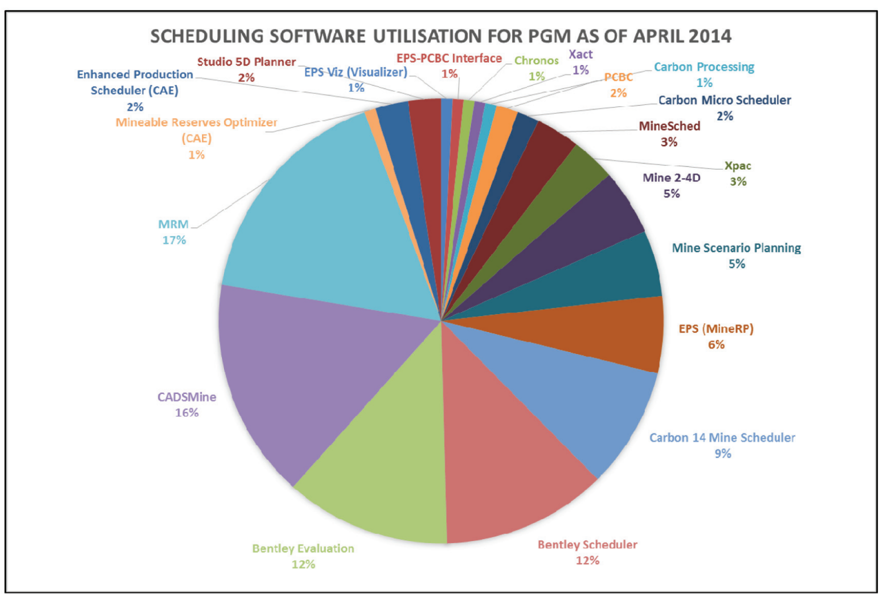

Figure 7. Scheduling functionality software utilization for PGMs as of April 2014

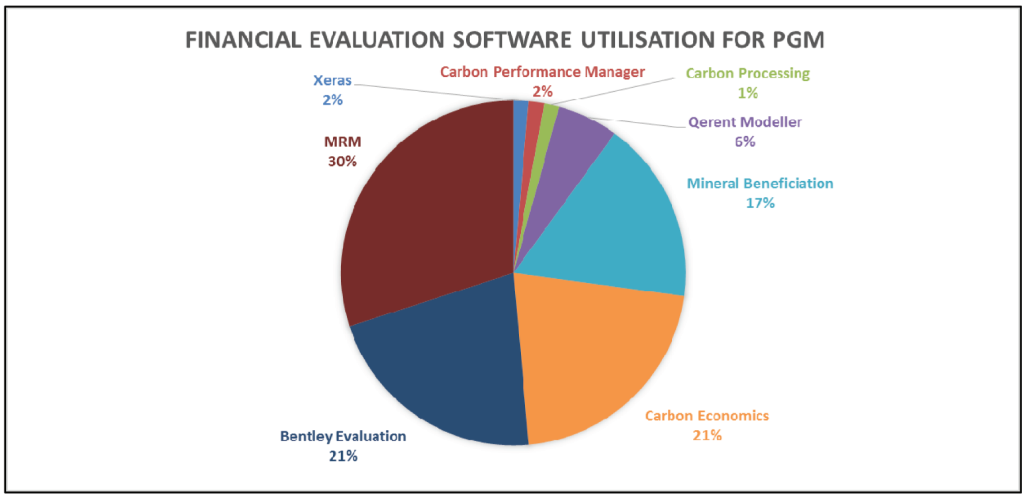

Figure 8. Financial Valuation functionality software utilization for PGMs

Table XII
Optimization functionality software utilization for PGMs as of September 2012

m	software_id	$f_{i,l}^{(m,t)}$	$w_{i,l}^{(m,t)}$	$u_{i,l}^{(m,t)}$	$r_{i,l}^{(m,t)}$
1	1	0	1	0	0.0000
2	15	0	1	0	0.0000
3	21	0	1	0	0.0000
4	73	1	1	1	0.0189
5	74	0	1	0	0.0000
6	77	15	1	15	0.2830
7	79	0	1	0	0.0000
8	82	0	1	0	0.0000
9	84	0	1	0	0.0000
10	87	0	1	0	0.0000
11	88	0	1	0	0.0000
12	91	0	1	0	0.0000
13	92	0	1	0	0.0000
14	98	21	1	21	0.3962
15	102	0	1	0	0.0000
16	103	0	1	0	0.0000
17	105	0	1	0	0.0000
18	106	12	1	12	0.2264
19	107	0	1	0	0.0000
20	110	4	1	4	0.0755

Table XIII
Optimization functionality software utilization for PGMs as of April 2014

m	software_id	$f_{i,l}^{(m,t)}$	$w_{i,l}^{(m,t)}$	$u_{i,l}^{(m,t)}$	$r_{i,l}^{(m,t)}$
1	1	2	1	2	0.0177
2	15	0	1	0	0.0000
3	21	0	1	0	0.0000
4	73	1	1	1	0.0088
5	74	0	1	0	0.0000
6	77	15	1	15	0.1327
7	79	0	1	0	0.0000
8	82	0	1	0	0.0000
9	84	55	1	55	0.4867
10	87	3	1	3	0.0265
11	88	0	1	0	0.0000
12	91	0	1	0	0.0000
13	92	0	1	0	0.0000
14	98	21	1	21	0.1858
15	102	0	1	0	0.0000
16	103	0	1	0	0.0000
17	105	0	1	0	0.0000
18	106	12	1	12	0.1062
19	107	0	1	0	0.0000
20	110	4	1	4	0.0354

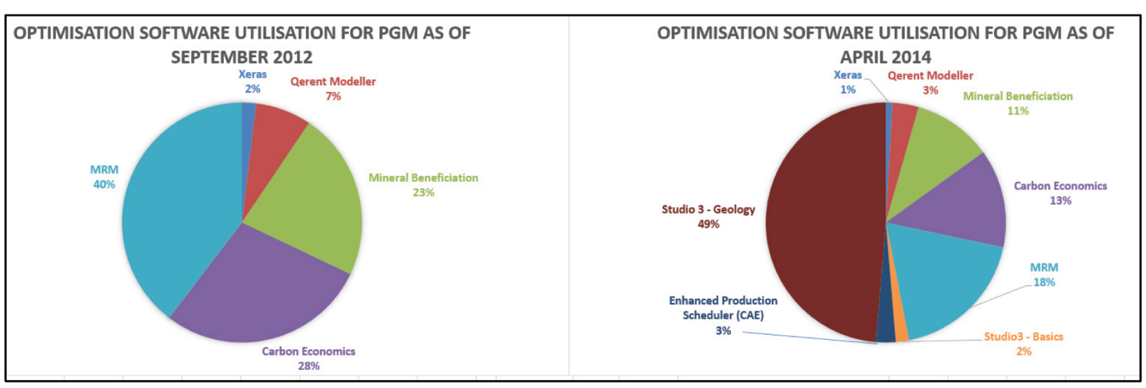

Figure 9. Optimization functionality software utilization for PGMs

2012 and April 2014). By using this newly developed framework, utilization of the various mine planning software solutions was measured. This information can be used to ultimately inform decision-making strategies on software utilization by software developers, mining companies, educational institutions, and consulting companies.

It is important to note that data on CAE Mining was made available only in the April 2014 data-set. When comparing the results, the CAE Mining market share is clearly visible in the PGM sector, especially in the field of Geological Data Management, Geological Modelling and Resource Estimation, Design and Layout, and Optimization.

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