A systems approach in implementing Minerals Resource Management at a base metal mine (Rosh Pinah Zinc Corporation, Namibia)

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Synopsis

Rosh Pinah Zinc Corporation (RPZC) identified implementing a Mineral Resource Management (MRM) programme at the mine as a strategic incentive. The purpose of the programme is to optimize the economic value of the RPZC mineral resource, over the total value chain of the mine, taking expected macro economic conditions into consideration as well.

With Mineral Resource Management still being a relatively young drive in the mining industry, information on the concept is relatively scarce. RPZC had several successes and problems with implementing such a concept and also still has a way to go before a complete Minerals Resource Management approach is implemented at the mine and entrenched as a working culture.

The purpose of this paper is to:

- define a systems approach to implementing a Mineral Resource Management programme at a base metal mine
- indicate the specific MRM approaches taken at RPZC
- indicate the expected advantages of implementing a MRM approach
- measure the actions already taken against the systematic MRM approach, and indicate the advantages already captured
- indicate the way forward taking lessons learned into consideration
- indicate proposals to implement the MRM approach in the macro mining environment in South Africa.

Introduction

Rosh Pinah mine is situated in the Namib desert in south-western Namibia. The mine started production in 1970. The beneficiation plant throughput is in the order of 650 000 tons ROM ore per annum. The mine currently produces about 75 000 ton zinc concentrate and 25 000 ton lead concentrate respectively per annum. The zinc concentrate is sold to Zincor, in Springs, South Africa. The lead concentrate is exported through Walvis Bay harbour and sold on the spot market.

The Rosh Pinah mine is an underground operation, using a sub-surface jaw crusher. Ore is transported via conveyor to the surface where it is further crushed to less than 9 mm with a cone crusher and gyradisc crusher and then stockpiled. The ore is then milled down to typically 80% minus 100 microns in a ball mill and a three-stage cyclone system. The lead and zinc concentrates are produced by differential flotation as shown in Figure 1 and Figure 2.

Characterization of a system

Kerzner (1998:61) indicates that 'general systems theory can be described as a management approach that attempts to

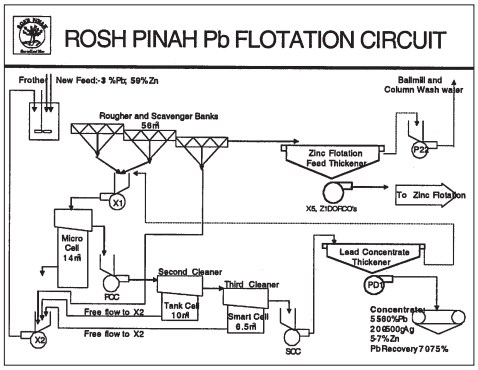

Figure 1

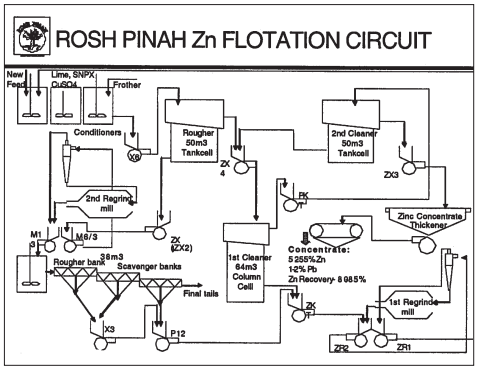

Figure 2

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integrate and unify scientific information across many fields of knowledge'. He continues, giving the following definition of a system:

'A group of elements, either human or non-human, that is organized and arranged in such a way that the elements can act as a whole toward achieving some common goal, objective or end'.

Bowersox (1996:457) stresses that the systems concept is a 'total integrated effort toward the accomplishment of predetermined objectives'.

From these views the following on systems theory should thus be highlighted:

- systems analysis is a methodology
- to optimize
- the integration
- of a system's components in such a way
- the whole is greater than the sum of the individual components
- in reaching a common goal.

Mineral Resource Management (MRM) is a methodology to optimize the integration of a system's components in such a way that the whole is greater than the sum of the individual components in reaching a common goal.

Although the major intent of this paper is to indicate the MRM paradigms, an indication at this stage is given of the systematic steps in implementing a MRM programme at a mine.

Total and absolute acceptance by management that the mineral resource management principles have financial advantage for the mine

Absolute commitment by managers towards the concept is absolutely vital, as the concept largely depends on cross-functional understanding and relationships in the workplace. Certain traditional work procedures and responsibilities of traditional functional departments and their heads will definitely change. The broad purpose of the changes will primarily be to optimize the total value chain under consideration.

This would include the following:

- functional department heads would have to manage their departments, taking the influence of their section's performance and work procedures on the previous and following functional departments in the value chain into consideration
- they will have to change the way they measured and understood their performance and contribution to the value chain
- a lot of work procedures will have to change and people would have to accept new responsibilities and lose old responsibilities
- a third party, namely the Resource Manager, will have a large input into the management of the production functional departments in so far it concerns the optimization of the total value chain.

Determine conceptual and broad responsibilities and outputs of the Resource Manager (RM)

Firstly the outputs and responsibilities of the Resource Manager on the mine should be spelled out. This is generally an iterative process taking the proposed positioning of the Resource Manager in the organizational structure and the paradigms as indicated in this presentation into consideration.

The outputs and responsibilities determined at this stage should be fundamental of nature and not detailed. This will help prevent prolonged debate but help start with the co-operation process between the typical functional managers and the resource manager.

Determine broad organizational structure that will lead to the appointment of the Resource Manager

There are several configurations of an organizational structure that can be implemented and there is probably no absolute answer. The structure would probably depend on:

- the size of the organization
- the type of mining business involved
- the amount of production systems across the total value chain
- the level of maturity of the organization in terms of cross-functional support and interaction
- the length of the value chain under consideration as regards different major value adding processes involved.

It is important though to ensure that the organization chosen would comply with the following:

- independence across the total value chain
- acceptance across the total value chain
- responsibility of optimizing the economic resource utilization across the total value chain.

A proposed organizational structure is a hybrid between the traditional functional organizational structure and a matrix organizational structure. At Rosh Pinah the Resource Manager is a departmental head in his own right as indicated in Figure 3.

Following are identified advantages and disadvantages of the proposed organizational structure.

Advantages:

- principles of resource management is driven by a management team member, being his explicit responsibility
- resource utilization is optimized with inputs from an independent department over the total value chain
- inputs from production heads across the value chain
- conflict between traditional department heads is minimized.

Disadvantages

- an extra department head is required on the management team
- control over production is subject to production system's department heads co-operation and acceptance of MRM principles.

The RM draughts the first action plan to implement the Mineral Resource Management principles on the mine so that the responsibilities and outputs of the RM as determined by the management team is realized

When an implementation plan to implement MRM principles is set up, the following should be taken into consideration:

- at present the principles of MRM are not documented concisely
- the principles of resource management are in actual fact not new rocket science but pure logic
- the process will on average take between 2 to 3 years to implement
- the implementation process will be more an evolution process than precise action sheet actions being followed
- the implementation process is more the institutionalizing of a different thinking process
- a large amount of training will be involved
- change management will be crucial.

The critical success factors for implementing a successful MRM programme should also be taken into consideration when compiling an implementation plan. These factors will include the following:

- total management support
- articulation of the principles in such a manner that it is understood across the total workforce of the value chain
- an effective change management process
- an effective institutionalizing programme that would include
  - training in MRM principles as applicable to each post involved
  - changes to performance measurement programme
  - changes to job descriptions
  - changes to task descriptions
- effective measurement system for managing success of the MRM programme
- an effective organizational learning culture that will embed new lessons learned as regards MRM.

Implement the Resource Management principles across the total value chain

The implementation process would include the following steps:

- Describe the total value chain under consideration using a systems approach and taking all the characteristics of the value chain into consideration
  - horizontal system description
  - vertical system description
  - supporting systems
  - environment
- Describe optimization possibilities
- Describe the information and information flow required
- Describe the necessary sampling, analysis and evaluation campaign necessary
- Describe the measurement and reconciliation procedures necessary to implement the Resource Management actions
- Describe the necessary work procedures and detailed organizational structure to implement the Resource Management strategies
- Describe the IT requirements to support the Resource Management actions.

Institutionalize the MRM principles across the total value chain

Institutionalizing of the MRM principles across the total value chain is critical, ensuring the success of the principles is not a function of individuals championing the approach but a total commitment by all involved.

Characterization of Mineral Resource Management (MRM) principles

An individual/department is tasked with optimization of the total value chain

The traditional mine would have the typical functional production departments e.g. geology, mining and plant. Mostly they optimize in their own departments and more often than not sub-optimize as regards the total value chain. The measurement of their performance is also largely not correlated to the optimization of the total value chain.

The new paradigm is to have a Resource Manager that is specifically tasked to ensure the optimization of the total value chain and that the production performance measurement in place to support this now and in future.

The Resource Manager should endeavour to ensure that the utilization of a particular mineral resource is economically optimized over the total value chain employed to create value by considering:

- physical and mineralogical characteristics of the resource
- limitations and properties of the involved value adding processes
- market requirements
- the economic environment predicted and of the day
- social and political requirements
- environmental obligations.

Proposed responsibilities of the Resource Manager would include:

- Optimum ore utilization (resource recovery)
- Maximum mine life
- The defining of fit for purpose, resource optimization, measurement systems to measure the total value chain's performance and the contribution of the individual functions in the value chain
- Optimum valuable mineral and metal utilization of the resource
- Designing production plans (not just a mine plan) that takes the variables of the total value chain into consideration
- Optimizing the NPV of a production plan vs. the risk profile of the production plan.

Model the resource according to the lithological characteristics of the resource as well and not only elemental and waste/ore descriptions

The traditional method of modelling an orebody is to identify an ore zone, put it in a grade envelope and only model the grade variation across the orebody. On some external platform, early in the mine's history a so-called economic cut-off grade is calculated and any material above this grade is considered as ore and any material below this value is considered waste.

The new paradigm is to model the orebody according to the different lithological characteristics identified in the targeted mineral resource.

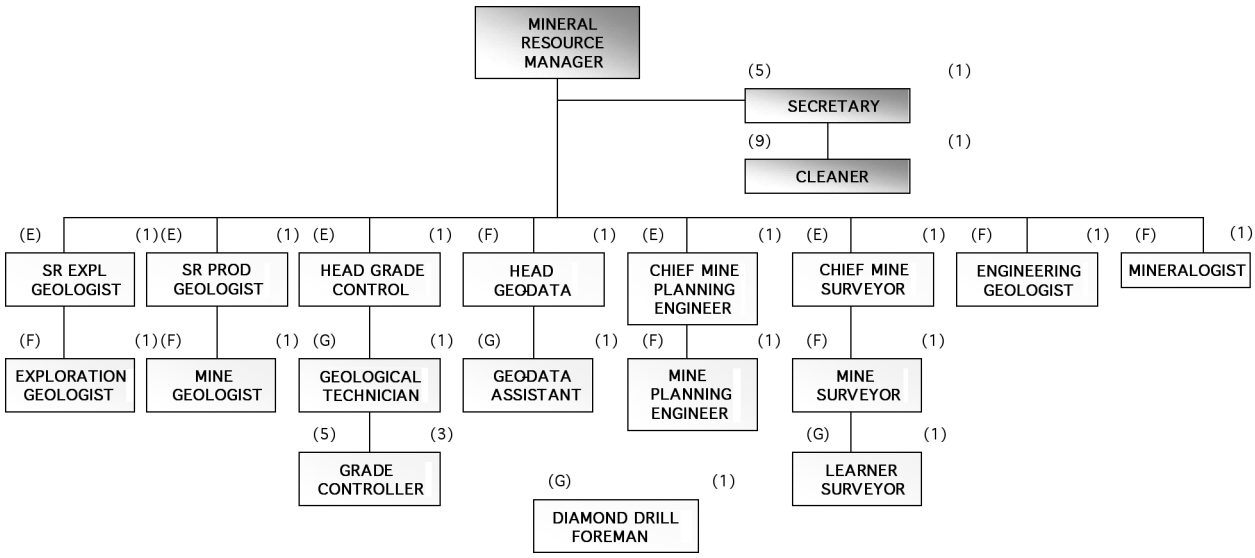

Figure 3

To address this paradigm the various ore, waste and orebody characteristics have to be identified and described geologically. At Rosh Pinah the litho types as indicated in Table I were identified and described.

Table II indicates the information now entered into the geological model compared to the previous level of information (white background). At this stage it is only necessary to take note of the ore class, now also described in the geological model.

Figure 4 and Figure 5 indicate the differences in the geological model of an orebody.

At the moment Rosh Pinah is working on the problem to Krig the Zn values within the lithological units and not across them.

Schedule the mining of the resource according to the compatibility of the different lithological units, with regard to the beneficiation process involved, as well and not only according to grade

When the long-term mine layout and short- and long-term mine scheduling is done, the typical mine plan would at best take the plant into consideration and only design and schedule in an effort to minimize the variation in plant feed with regard to feed grade. The different lithological units on the other hand have completely different performance characteristics in the plant and will thus also have different required optimal plant conditions; e.g. the micro-quartzite ore is much harder to grind than the carbonate ore. The optimal grind for both of the lithological units cannot be maintained at the same time with resulting losses in grade and recovery performance of the plant. Even a simple piece of equipment like an in stream x-ray analyser is sensitive to the different ore types and will not give accurate readings if the correct regression curves are not set up for the different ore types.

The new paradigm is to firstly schedule according to compatible ore types and then to equalize the feed grade.

This paradigm is addressed by trying to take the different lithological units involved and draw up a compatibility matrix as indicated in Table III. The highest value indicates perfect compatibility.

The mixing factor can be incorporated into a mixing curve, which is typically a second order function as depicted in Figure 6.

The recovery when mixing two ores can be calculated via the following equation:

Recovery = $(H–L)(1–E)x^2 + (H–L)Ex + L$

where

H = the highest recovery of the two orebodies
L = the lowest recovery of the two orebodies
E = the mixing factor as given in Table III
x = the mix fraction.

Figure 6 indicates how the blend with the better compatibility factor will have a mixing curve closer to the weighted average. A similar correction will be made towards the grade predictions.

The compatibility matrix is thus used:

- firstly to indicate to the scheduler in what order it should blend the different lithological units
- secondly with what weight the weighted average grade and recovery forecast should be adjusted with to cater for the level of incompatibility.

At present at Rosh Pinah the figures are gutfeel/experience based. An active flotation programme is under way, whereby the different lithological units are mixed at different ratios and floated to try and get an improved indication of their compatibility. The ideal would be to develop some relationship between the compatibility matrix and the fundamental mineralogical and physical properties of the different lithological units. Empirical data from the plant can also be used to determine the values for the compatibility matrix. Figure 7 indicates a typical mixing curve derived from actual plant data for a period of past 6 months, where

Table I

Class	Lithological unit	Ore types	Rock type characteristics		Discontinuities	Mineralogy (main components)
			Colour	Texture		
A	Non-siliceous carbonate ore	1. Baritic carbonate ore	Light gray to yellowish	Fine to coarse grained	Massive, banded	Bi-carbonates, dolomite, calcite, sphalerite (red-brown) galena, minor chalcopyrite, bornite, tennantite-tetrahedrite
		2. Carbonaceous carbonate ore	Light to dark gray mottled	Fine to coarse grained, bladed and acicular	Massive, banded, fragmentary	Dolomite, calcite, ± carbonaceous material, sphalerite (red-brown), pyrite, galena, minor chalcopyrite, bornite
		3. Massive carbonate ore	Light gray with a metallic shine	Fine to coarse	Massive, fragmentary	Sphalerite (Fe/Mn-rich), pyrite, galena, minor chalcopyrite, bornite
		4. Leached carbonate ore	Light gray, yellowish	Fine to medium, 'box work'	Massive	Dolomite, calcite, sphalerite (Fe-poor), pyrite, galena, minor chalcopyrite
B	Siliceous carbonate ore	1. Siliceous carbonate ore	Light gray to gray	Fine to medium	Massive	Dolomite, quartz, sphalerite (Fe-rich), galena, minor chalcopyrite
		2. Sugary quartzite ore	Light to dark gray	Fine to medium, sugary texture (glittering)	Massive banded	Quartz, dolomite, sphalerite (Fe-poor). pyrite, galena, minor chalcopyrite, stromeyerite
C	Ore zone arkose/ breccia	1. Arkose ore	Light to dark gray	Fine to coarse	Massive	Quartz, potassium feldspar, ± carbonaceous material, pyrite, sphalorite, galena, minor chalcopyrite
		2. Arkose breccia	Light to dark gray	Fine to coarse	Massive brecciated	Quartz, potassium feldspar, pyrite, sphalerite, galena, minor chalcopyrite
D	Micro-quartzite ore	1. Micro-quartzite ore	Mainly dark gray to black, sometimes light gray; depends on the content of carbonaceous matter	Very fine grained, aphanitic	Massive, banded, slumping structures, micro folding, interbedded with arkosic quartzite, graded bedding	Quartz, (+silicified), potassium feldspar, carbon, mica, pyrite, sphalerite, galena, minor chalcopyrite
E	Argillite ore	1. Argillite ore	Dark gray to black	Very fine	Banded	Quartz, potassium feldspar, carbon, mica, pyrite, minor sphalerite, subordinate galena
F	Arkose (waste)	1. Arkose	Light gray to dark grey	Fine to very coarse	Massive, graded	Quartz, potassium feldspar, ± carbonaceous matter, pyrite
		2. Arkose breccia	Light gray to dark gray	Fine to very coarse	Massive, brecciated	Quartz (+silicified), potassium feldspar, ±carbonaceous matter, pyrite, sphalerite, galena, minor, chalcopyrite

Table II

General	Sphalerite	Galena
Volume	Grain size	Grain size
Rd	Intergrowth	Intergrowth
Tonnage	Purity	Purity
Zinc	Max recovery	Max recovery
Lead	Detrimental mineral recovery factor	Detrimental mineral recovery factor
Iron	Detrimental mineral grade factor	Detrimental mineral grade factor
Copper	%Ag in sphalerite	%Ag in galena
Silver		
Silica		
ore class		

predominantly eastern ore field and western ore field material were mined. Both these ores were classified as carbonate ores.

A couple of important lessons were learned from this particular exercise:

- the compatibility differs per major mineral type e.g. for sphalerite and galena at Rosh Pinah
- the compatibility differs for grade and recovery for a specific mineral type
- even the same lithological ore type in different ore fields, may have different compatibilities
- do not underestimate the influence of incompatibility on the performance of the value chain and the value to be gained by taking it into consideration during mine planning
- try to understand the underlying mineralogical and metallurgical principles on why the incompatibilities and the extent thereof exist.

Use mineralogical as well as the flotation kinetic characteristics of the lithological units together with their respective compatibilities to predict the future plant performance in short- as well as long-term planning

Also with regard to plant performance prediction, the typical prediction is done according to some flotation tests done before the mine was opened as base and then using history to forecast the future recoveries and grades, and somehow sometimes indicate some correlation to the expected variation in feed grade. This process can be improved drastically with regard to accuracy.

The paradigm under consideration here is that it is important to predict the future plant performance taking the following into consideration of the ore still to be mined:

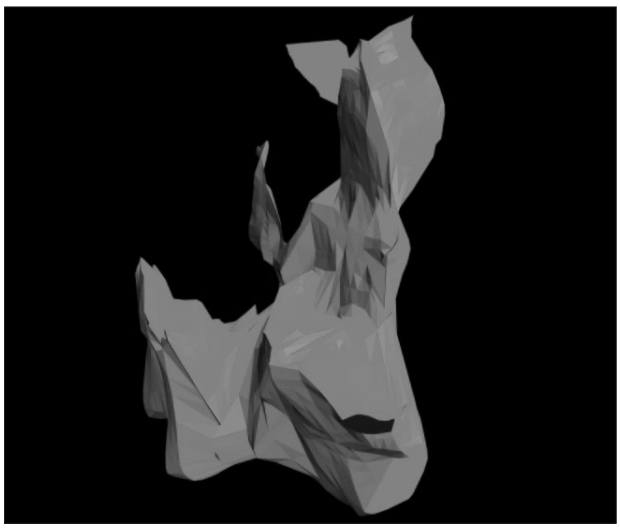

Figure 4

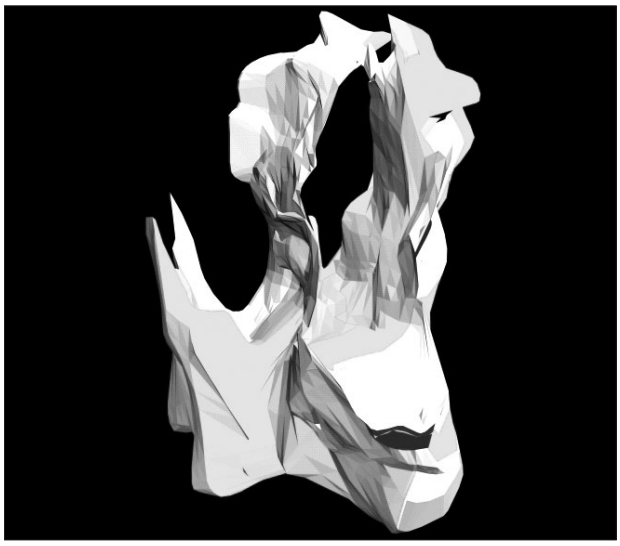

Figure 5

Table III						
Ore class	**A**	**B**	**C**	**D**	**E**	**F**
A	1	0.91	0.89	0.89	0.9	0.87
B		1	0.95	0.95	0.89	0.89
C			1	0.95	0.87	0.95
D				1	0.9	0.95
E					1	0.85
F						1

- basic mineralogical characteristics of the ore types such as grain size, liberation and purity of the sought-after mineral, maximum mineral recovery
- the deleterious effects of other minerals in the ore type on the mining and especially beneficiation process
- the plant efficiency at that particular stage
- physical properties of the host rock.

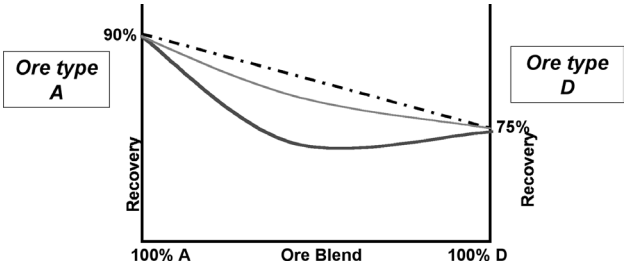

Figure 6

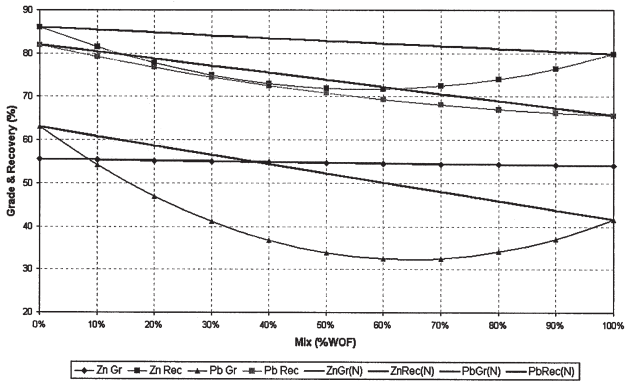

Figure 7

Rosh Pinah started on a mineral model that would predict more accurately the expected grades and recoveries as a function of the lithological type's mineralogical properties that would be mined in future. This model is based on the following features:

Liberation characteristics (LF)

Liberation of a mineral is dependent on two main parameters namely grain size and intergrowth. Figure 8 and Figure 9 typically indicate the grain size differences and Figure 10 and Figure 11 the intergrowth differences in Rosh Pinah's ore.

To differentiate between the degrees of grain size and intergrowth, the grain size and intergrowth parameters are divided into five categories, as indicated in Table IV and Table V respectively.

To determine the liberation factor (LF) the following equation is used.

$$\text{Liberation\_factor (LF)} = \frac{\text{Grain\_size factor} + \text{Intergrowth\_factor}}{2}$$

Mineral crystal purity (PF)

The Zn content of pure sphalerite is 67%, and thus indicates the maximum possible grade of a Zn sulphide concentrate. During the crystallization process of the sphalerite some of the zinc is displaced by other cations. This will dilute the sphalerite grade. A higher purity concentrate can thus be made from a lower feed grade sphalerite than from a higher feed grade as indicated in Table VI.

The value of this parameter is thus the amount of zinc in the sphalerite crystal lattice.

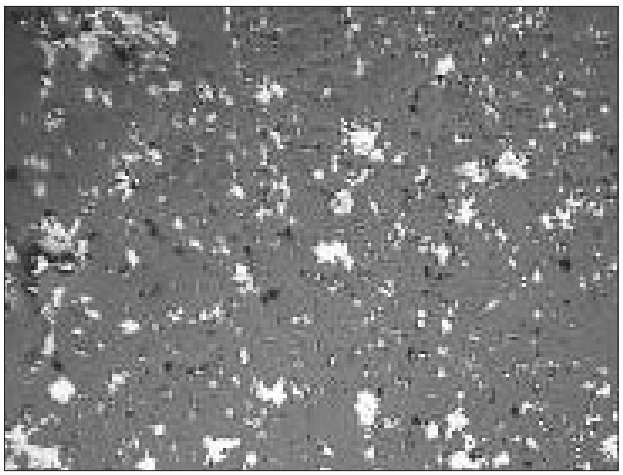

Figure 8—Fine (8X)

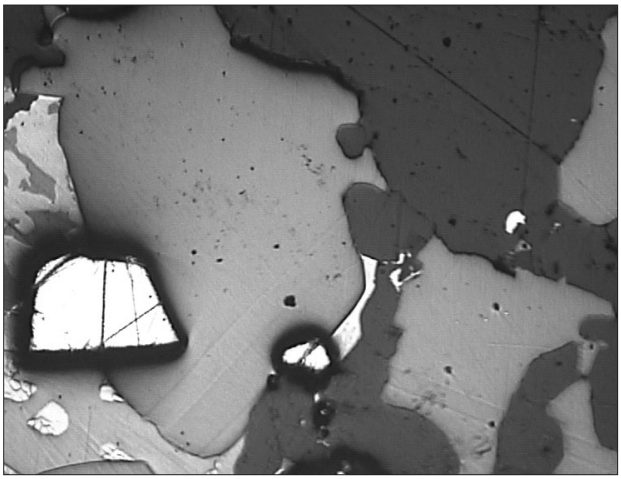

Figure 9—Coarse (8X)

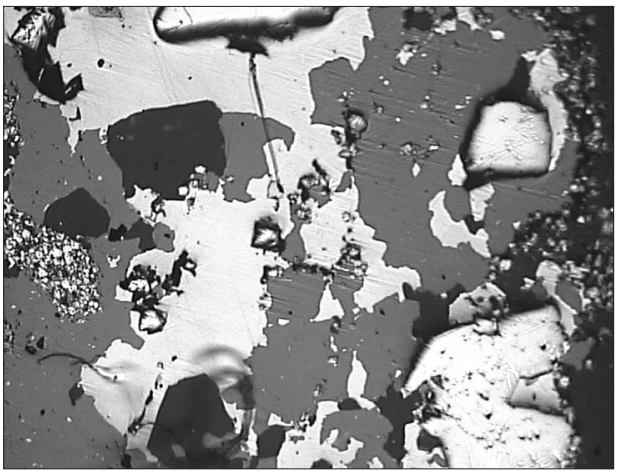

Figure 10—High (16X)

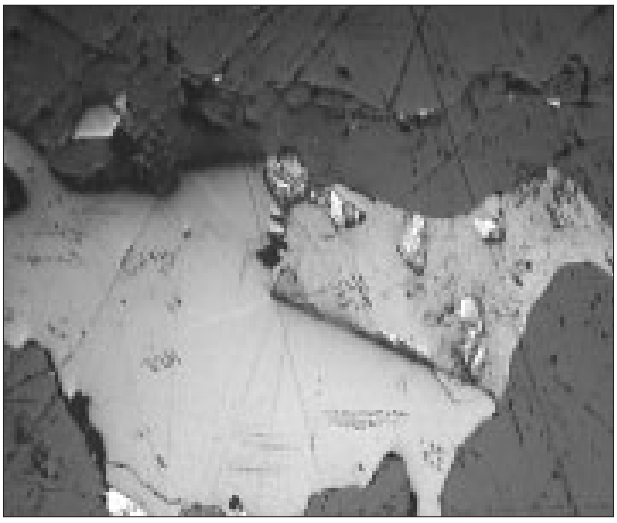

Figure 11—Low (8X)

Maximum recovery potential (RF)

The flotation plant is designed to only float Zn sulphide. Zn metal value may, however, occur in other minerals, such as dolomite, and thus not be able to be recovered. The value of this parameter is calculated taking the Zn value in other minerals than Zn sulphide into consideration.

Detrimental mineral influences (DMFR)

A so-called detrimental mineral factor is also introduced into the model to cater for minerals such as pyrite, talc, graphite etc. that have a negative influence on both grade and recovery. Their occurrence in the mineral resource varies considerably.

Recovery model

The plant recovery efficiency model was derived from the liberation factor and taken as a linear relationship. The equation used for the model was the following:

$$REF = 0.03LF + 0.77$$

where,

REF = the recovery efficiency factor

Table IV

Factor	Classification	Amount	Grain size
1	Very fine	80%	< 50 μm
2	Fine	80%	50 μm – 75 μm
3	Medium	80%	75 μm – 100 μm
4	Coarse	80%	100 μm – 125 μm
5	Very Coarse	80%	> 125 μm

Table V

Factor	Classification
1	Very High/complex
2	High/complex
3	Medium
4	Little/simple
5	Very little/simple

Table VI

	Feed grade	Crystal purity	Conc. grade
Ore type 1 Ore type 2	7% Zn 8% Zn	63% Zn 59% Zn	54% 52%

LF = the liberation factor.

The recovery is then calculated from the following equation:

Recovery = *REF* × *RF* × *DMFR*

where,

RF = the recovery factor

DMFR = the detrimental mineral factor for recovery.

Grade model

The plant grade efficiency model was derived from the liberation factor and taken as a linear relationship. The equation used for the model was the following:

$GEF = 0.03LF + 0.77$

where,

GEF = the grade efficiency factor

LF = the liberation factor.

The grade is then calculated from the following equation:

Grade = *GEF* × *PF* × *DMFG*

where,

PF = the purity factor

DMFG = the detrimental mineral factor for grade.

Scheduling the mining of the resource taking into consideration the plant's physical capability involved as a function of the lithological and mineral characteristics

The typical mine schedule would use an average capacity of the plant to schedule the capacity/ROM for a certain period. A plant on the other hand has several sub-systems as processes, each with their own capacity.

The paradigm proposed here is to schedule the mining activities with regard to rate, taking the mineralogical and physical properties of the feed's influence on the major sections of the plant into consideration.

The Rosh Pinah plant consists of four basic sections:

- crushing and screening
- milling
- Pb-flotation
- Zn-flotation.

Table VII indicates the variation in grade for the eastern ore field at Rosh Pinah.

With these characteristics of the ore under consideration it is obvious that:

- at high Zn feed grade, the Zn flotation circuit might dictate the throughput of the value chain
- at high Pb feed grade, the Pb flotation circuit might dictate the throughput of the value chain
- at low Pb and Zn feed grade and hard ore, the milling circuit might dictate the throughput of the value chain
- at low Pb and Zn feed grade and soft ore, the mining process might determine the throughput of the value chain.

The crushing circuit is oversized compared to the milling circuit and is not considered in the scheduling. For the milling section, the milling rate is scheduled according to the SiO_2 content of the feed, with the higher content indicating harder ore, as indicated in Figure 9.

This mechanism still has the following flaws,that will be evaluated and re-proposed:

- it assumes the SiO_2 content indicates quartz, but minerals such as muscovite are also present in some cases, which is softer and not so abrasive material

Table VII

	U1480 88.00-88.30	U1487 138.50-138.80	U1493 110.60-110.90	U1493 132.60-132.85	U1504 77.50-77.80	U1512 145.40 145.70	U1513 126.50-126.83	U1515 114.64-114.94	U1515 132.58-132.90	U1518 82.40-82.70	U1518 85.40-85.70	U1520 114.20-114.50	U1526 96.60-96.90	U1538 133.63-133.99
Graphitic C (%)	0.13	0.11	0.09	0.19	0.09	0.06	0.09	0.05	0.05	0.07	0.13	0.06	0.04	0.07
Total C (%)	8.07	6.27	7.62	6.56	0.66	8.19	8.64	0.96	8.72	6.38	3.78	9.15	10.4	0.69
CO_3 (%)	39.1	30.1	37.3	30.2	0.71	39.1	41.6	4.39	43.0	31.7	16.1	44.2	51.1	<0.05
Total S (%)	8.16	15.4	7.14	13.4	6.94	10.6	8.03	0.73	6.64	8.85	11.3	7.52	2.14	6.67
SO_4 (%)	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40
Cu (%)	0.49	0.08	0.07	0.13	0.30	0.07	<0.05	<0.05	0.08	<0.05	<0.05	0.07	0.26	0.29
Pb (%)	5.05	2.82	3.69	15.4	6.88	3.01	1.01	0.30	4.08	2.81	1.52	0.83	0.90	1.59
Zn (%)	11.7	20.3	8.23	15.8	9.22	7.37	8.11	0.50	10.7	10.1	6.15	7.52	2.38	5.94
Mn (%)	2.40	3.04	2.77	1.56	0.17	3.96	4.00	0.21	3.45	1.59	11.6	5.45	3.25	0.04
Fe (%)	2.71	4.89	2.33	4.12	1.93	6.11	4.41	0.48	1.55	2.60	4.53	3.77	1.45	3.47
Cr (ppm)	<10	<10	<10	<10	48	<10	<10	<10	<10	<10	23	<10	<10	58
Ag (g/t)	51	<5.0	35	45	50	<5.0	<5.0	<5.0	<5.0	24	<5.0	<5.0	<5.0	<5.0
Al (%)	0.11	0.21	0.06	0.28	1.20	0.12	0.56	2.77	0.03	0.03	3.24	0.02	0.28	1.93
Ca (%)	14.8	11.2	11.5	9.61	0.54	14.1	14.7	1.47	16.3	8.16	4.51	16.1	18.3	0.11
K (%)	0.02	0.08	<0.01	0.16	0.88	0.07	0.52	1.65	0.01	<0.01	0.25	<0.01	0.20	1.67
Mg (%)	7.77	5.53	5.99	5.24	0.33	7.09	7.13	0.80	7.69	3.38	1.24	6.98	9.82	0.15
Na (ppm)	25	38	<20	62	580	33	120	750	<20	<20	160	23	97	850
P (ppm)	850	540	200	660	330	240	200	350	220	330	280	110	1190	260
Si (%)	0.29	0.43	0.20	0.72	30.4	0.69	1.44	37.9	0.25	0.15	8.11	0.47	1.01	34.2
Ti (ppm)	77	230	82	580	590	36	190	1410	55	10	1540	10	19	1020

- it does not take the hardness variation into consideration between the ore types that do not have a SiO_2 differentiation. Thus the physical hardness will have to be determined.
- it does not take the grain size and intergrowth of the minerals in the host rock into consideration.

For the two flotation systems, the processing rate used is 3.8 t/h and 12.5 t/h concentrate production for the Pb and Zn circuit respectively.

The reason for using a t/h, concentrate production value is as follows:

- the concentrate floated, is the bottleneck of the flotation plant, when high feed grades are experienced
- a t/h figure would then also be able to take availability, utilization, feed grade, recovery and concentrate grade, as values in the scheduling system, into consideration.

For purposes of short- to long-term planning build the prediction of the plant performance into the scheduling models

Typically mine layout design and scheduling, leading to short- and long-term planning would only indicate ROM and feed grade predictions. The plant predictions will be worked out at the plant, mostly using history as a base, and supplied to the planners drafting the short- and long-term plans of the mine.

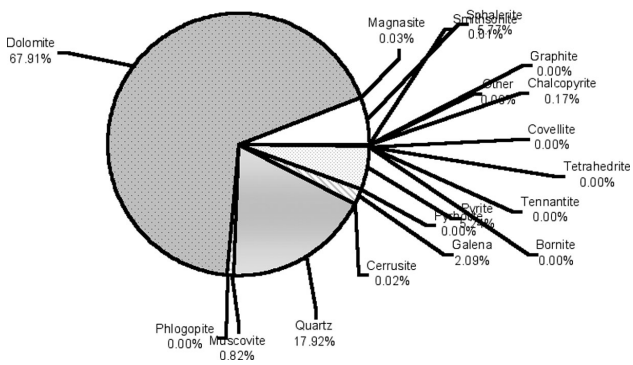

Figure 12—Calculated mineral distribution in feed

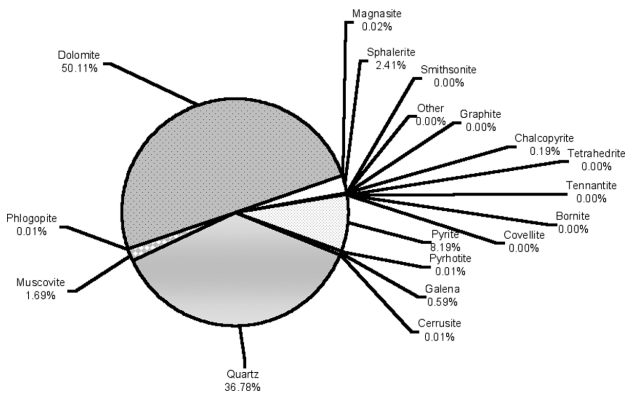

Figure 13—Calculated mineral distribution in lead concentrate

The new paradigm is to include the plant performance prediction in the scheduling capability of the short- and long-term mine planning.

Thus, the bottom line with regard to this paradigm and the previous paradigms is that a mine plan, is a plan for the total value chain under consideration and not just a plan to mine material to be delivered to a processing unit.

Short- and long-term planning should be done on an in time economic base and not a once off / long-term periodically determined cut of grade

It is commonly found that the determinant of material as ore or not, is done according to some cut-off grade determined some time before the actual mining process. This cut-off grade is then used for years into the mining process and evaluated only periodically.

The paradigm proposed is that each unit of material in the blocked mine layout, should be evaluated on a financial basis as it is mined, taking the macro and micro economic conditions of the day into consideration. This should then be the ultimate determinant if material should be considered as ore or waste.

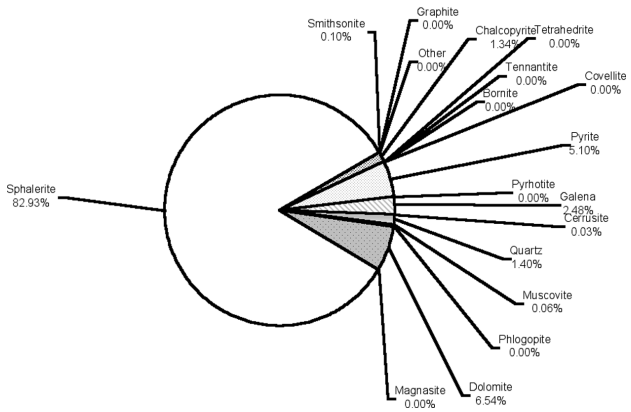

Figure 14—Calculated mineral distribution in tailings

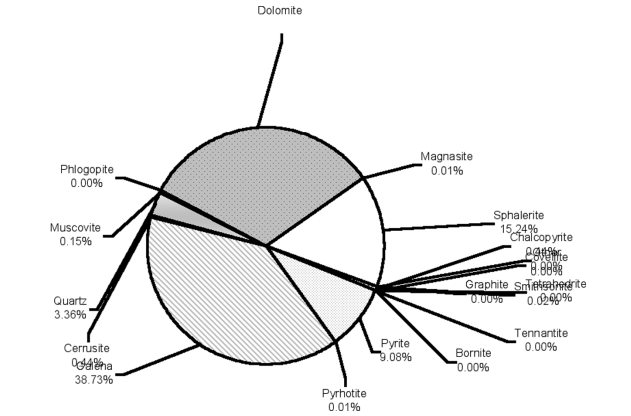

Figure 15—Calculated mineral distribution in lead concentrate

The principle to be held is that there should be an economic cut-off value in the scheduling process already and not just a cut-off grade. Although this does not pose such a big problem with the daily decision and scheduling between ore and waste it may pose a problem with the long-term mine layout. This will definitely entail an iterative process between mine layouts for different long-term macro economic conditions. The complexity of the problem will then depend on the variation in mine layout per set of economic conditions.

Condition based and activity based costing should be a central part of the economic modulation of the economic viability of each part of ore

The traditional method in a mine, beneficiation environment is to use average costs.

Typically in a mine/beneficiation value chain the costing would be averaged, e.g., tyre costs per ton moved for the mine as a whole, or reagents costs per ton processed. To calculate the profitability of a unit of material to be mined and processed, it is important to realize the specific cost attributed to that material unit; e.g., ball mill liner costs will be a function of the abrasive properties of a certain material. The latter also being a function of the quartz content.

The paradigm to be considered is that costs allocated to a material unit should be conditions and material based and not averaged

At Rosh Pinah the conditions and material based costing is programmed into the scheduler. For example, different costs are associated with different material types for certain reagents sensitive to material types. This is also applied to wear costs such as mill liners. The physical determination of these costs still need to be done.

Plant performance is primarily measured at a mineralogical level and secondary at an elemental level

Most beneficiation plants that produce a concentrate, measure their performance at an element/metal value level. Thus, the measurement in the total value chain is done on an elemental/metal base which is contradictory to the fact that it is mineral types that are mined and beneficiated. A particular mineral is thus the ultimate component for a mine and beneficiation system producing a concentrate.

The paradigm presented here is that a mine/plant producing concentrate's, value chain performance should primarily be measured at a mineralogical level and secondary at an elemental level.

The purpose of this paradigm is to indicate in the value chain what is in actual fact happening on a mineral base, as this is ultimately what is being handled and treated in a mine and beneficiation plant value chain producing concentrate. For example, in Rosh Pinah, Zn value is found as sulphides or oxide minerals or in some of the host rock matrix (dolomite). The plant's design on the other hand is to recover Zn sulphide. If these relationships were absolutely constant measuring at an elemental level would indicate what is happening on a mineralogical level. This is, however, mostly not the case. Secondary measurement of Zn at an elemental level is still necessary to indicate the long-term value to be extracted. Thus, processes need to be found in the long-term to extract value from the Zn in oxide and host rock matrix in the case of Rosh Pinah.

At Rosh Pinah this process has been started by implementing what is called a misplaced minerals model. The following definition is used for misplaced minerals:

- all the minerals that have no income value in the concentrates produced, e.g. dolomite, pyrite, quartz
- the minerals that have income value reporting in the wrong product, e.g. sphalerite in lead concentrate, chalcopyrite and galena in the zinc concentrate and galena and sphalerite in the tailings.

The principle is to indicate what was delivered from the mine and what happened in the plant on a mineralogical base. Because it is difficult to do physical mineralogical evaluation on a shift base:

- a chemical analysis, as indicated in Table VI
- certain assumptions on the identified minerals involved
- a mass balance is utilized to indicate the mineral placement throughout the value chain, as indicated in Table VII.

Figures 12 to 15 graphically indicate the mineral distribution throughout the value chain.

Rosh Pinah unluckily at the moment does not have the capacity to analyse a wide variety of elements, at an acceptable rate. The model is thus still based on to many assumptions and only done twice a week. Rosh Pinah is in the process of improving its analysing capability by obtaining a LECO and ICP to enable the evaluation to be done on a shift basis and give more accurate depiction of the mineral spread in the value chain.

The advantage of this analysis is that it also is a valuable tool in helping to focus the CI (Continuous Improvement) initiatives of the value chain. Using the misplaced minerals model, a breakdown of the income loss was determined as indicated in Figure 16. The present CI programme at the plant is driven to a great extent by this model.

A risk matrix should be used to indicate the risk profile of a specific mine plan

Many a mine plan, short- and long-term, had different scenarios compared to each other without having a feel toward the risk profile of each mine plan. Huge advances have been made to at least compare different mine plans according to a NPV value. Mostly the mine plan with the highest NPV value is chosen, without taking an informed risk profile of each scenario into consideration.

A new paradigm with regard to choosing a specific mine plan is to have a risk profile for each mine plan and thus compare different mine plans, taking an informed risk profile per mine plan into consideration as well.

The risk factors to be taken into consideration can be divided into the following groups, for example :

- Information risk
  - accuracy level of information used
  - geostatistic expertise
  - applicability of models used

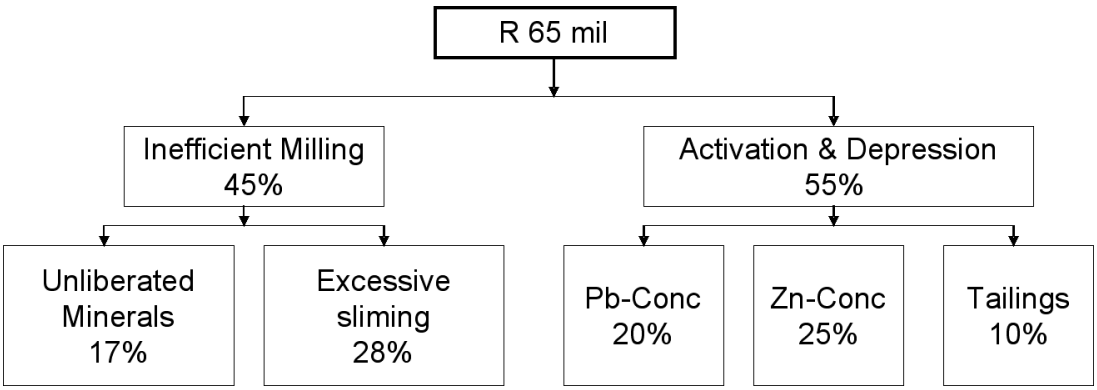

Figure 16

- Physical risk
  - geotechnical conditions
  - mining methods used
  - beneficiation methods used
  - mine layout risk
  - geohydrological conditions
  - plant design
- Production risk
  - production rate
  - equipment availability
  - equipment utilization
  - infrastructure
  - material properties, e.g. moisture content, fineness
- Quality and recovery risk
  - risk of contamination
  - degree of homogeneity of the ore
  - degree of control
  - measuring capability with regard to time and total value chain tracing of the material.

Rosh Pinah still has to compile such a risk matrix and incorporate it in its mine planning system.

The exploration description of a resource will have to change drastically

Typically when doing an exploration exercise on an orebody, it would consist mainly, of a geological description and chemical analysis of the material. The bulk sample collected for the beneficiation tests would normally be further evaluated in terms of mineralogical and physical description

The paradigm to be considered in this scenario, is that the exploration description of an orebody should be finalized taking the proposed beneficiation process into consideration.

This process is bit of an iterative process but it is important that the total orebody be described mineralogically and physically as required by the different value adding processes (mining and beneficiation). It is also a more expensive exercise and will thus be an iterative exercise with the feasibility of the project.

Create fit for purpose measuring criteria that will support the optimization of the total value chain and not functional sub-optimization

The following are examples of such measuring criteria.

- Measure and reconciliate the plant's performance primarily to actual material received and not against budgeted and planned targets.
- Measure the mining activities primarily to deviation from the given mining plan and not against ROM targets.
- Measure the mining activities primarily to waste/ore relationships and not feed grade.

Way forward

It should be remembered throughout the MRM model to try and consider only the 20% actions that have 80% of the influence. Do not complicate the model beyond the measuring and control limits at the different production stages. On the other hand do not let these limits prevent the CI exercise on the MRM model.

The following are still major actions to be completed in the process to implement MRM principles at Rosh Pinah:

- Develop a table for the relationship between mineralogical and physical properties of lithological units and the compatibility matrix
- Develop a total business model for implementing a mineral resource management programme at a mine
- Implementation of grade control personnel on shift
- Complete mineral model for all major minerals
- Complete mineralogical data for all ore fields and the lithological types within them
- Do the flotation/kinetic test work on the different ore field/lithological ore types
- Acquire a flotation test rig simulating the plant more accurately
- Improve the model for the mill scheduling rate
- Create a mechanism to create a risk profile for every mine plan evaluated
- Create the budgeting/financial forecasting capability of the MRM model
- Start with the institutionalizing actions, to institutionalize MRM principles, across the total value chain's organization.
- Determine the conditions and material based costs for the total value chain.

Proposed national institutionalization actions

It is considered vital to institutionalize the MRM principles on a national level. The following tools are proposed as mechanisms to be utilized:

- training at universities, pre- and post-graduate
- part of GIT training programmes
- the appointment, training and utilization of Resource Management specialists
- training of traditional managers on the new concept
- developing an industry strategy, on government level, to optimize the utilization of South African minerals to create greater value for the country
- get primary and secondary industries to also optimize their value chains.

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Harmony embarks upon theatre skills transferral programme*

Internal communications, the Blue Moon way, involves a different methodology, an approach that sets them entirely apart. And when it comes to their client, Harmony, street theatre is an integral part of their communications strategy that aims to get into the bloodstream of the entire organization.

Harmony constantlly needs to communicate to their workforce issues that are imperative to the safety and health of the miners, to the successful day-to-day running of the mine, and ultimately, to ensure long-term profitability. Management realized that, to get their messages across successfully, they had to find a way to bridge the communication gaps that exist because of cultural, language and literacy differences. And to sustain it, they would need to pass on these communication skills to Harmony employees.

They turned to Blue Moon for the solution.

The result is Woza-Nazo—a group of performers recruited directly from the Harmony workforce who range from winch operators and drillers to HR assistants. They wear bright orange overalls and a star on their badges that signifies the spirit of the messages they bring. It is the star of communication.

Blue Moon facilitated the use of skilled practitioners in the art of street theatre to train the Woza Nazo recruits. Street theatre originated as activist or issue theatre. It was a means to take issues directly to people on the street with the aim of raising public awareness and creating debate.

In Harmony's case, the 'streets' are the crush, the lamp-room and other places where workers congregate before their shift begins. It is at these locations that the Woza Nazo teams perform in a style of communication that is probably unique to South African mining.

Their communications are aimed specifically at the underground mining teams and some of their support structures so, and they interact with the Harmony miners in the most gutsy, gritty and effective way possible—face-to-face, miner-to-miner.

'Many of these workers do not have high levels of literacy,' comments Michelle Caldeira, managing director of Blue Moon, 'and most are familiar with a culture that values the spoken word and face-to-face contact as a means of communication. So we identified street theatre as an effective channel.'

'And', she adds, 'Because they are insiders, it is easier for the miners to relate to them and understand the messages they convey'.

Cost Focus, for example, is a key component of the Harmony Way of mining. But what does this mean to a worker at the face if he's never been put into the picture? He might assume that it's just a matter of scrimping and that it makes his job more difficult. The first Woza Nazo communication tackled this head-on by looking at Harmony's history and locating it in the broader context of the global business environment of lower gold prices and rising costs. The communication made it clear that Cost Focus is what keeps people in their jobs.

Follow-up communications have included the concept of understanding the possibilities for success of your personal goals in relation to your contribution to the success of team and company goals.

Part of the training that the Woza Nazo teams have received has been in the art of listening and responding to the input of their audience—and each Woza Nazo performance raises a multitude of questions and requests. As a result, informal 'debating societies' often emerge after the performances—generating further discussion.

The debate is not wasted, nor does it fall on deaf ears. Pressing issues are reported back to HR structures and those that frequently occur are in the process of being addressed. For some of the issues, the Woza Nazo teams themselves are part of the feedback process.

'Communication itself is an important component of the Harmony Way,' comments Bernard Swanepoel, chief executive operator of Harmony, 'and it is no surprise that the way that Woza Nazo is evolving demonstrates the Harmony concept of 'communication in action', which entrials responding to the communication needs that arise, on the ground and in the process of production.' ◆

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