Optimisation of Waste Dump Limits

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Tamer completed his Mining Engineering degree at Middle East Technical University (METU) Ankara, Turkey in 1986. He worked as a Research Assistant in METU for three years with involvement in major coal mining research projects with government enterprises and then worked as a Lecturer in mining engineering after completing his Master's Degree.

He started his research on Pit Limit Optimisation while studying for his Ph. D. Degree at the WA School of Mines in 1993 sponsored by a postgraduate scholarship. He further advanced his strong interest in computer applications and provided training for the undergraduate students.

In 1994, Tamer joined WMC's new Mount Keith Operation, initially responsible for the development of the computer systems, later working as a Strategic Planning Engineer for 2 years.

After joining SNOWDEN in early 1996 he has undertaken a number open pit planning projects as a consultant mining engineer. He is still continuing his Ph. D. research part-time, which is leading to the development of a new pit optimisation and parameterisation program.

Introduction

The expenditure for loading and hauling unit operations may account for up to 65 percent of the mine operating costs in open pit mining. For large open pit mines, the haulage costs may constitute almost half of the mining costs as shown in Figure 1.

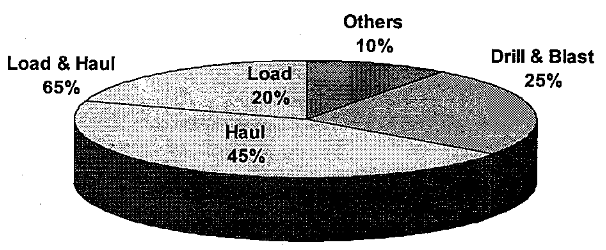

Figure 1. Surface Mining Operating Cost Allocation

There are numerous controllable and uncontrollable factors affecting the design of a mine. The most important of these factors affecting the haulage operation and its cost at the final count are:

- Pit design and ramp system
- Topography and drainage system
- Processing plant site location
- Waste dump location and design.

With reduced mining costs, lower grades and the added cost benefits of bulk mining, high stripping ratios ranging from 5:1 to 10:1 are common in surface mining today. This means that waste haulage can make as much as up to 40% of the total mining costs. With the environmental issues and the associated additional cost, waste dump design becomes an important task in today's open pit mining.

Various computer methods are available for the main mine planning tasks of pit limit optimisation, pit and ramp design, production scheduling and financial analysis.

It is common practice that the CAD programs used for open pit designs are also employed to generate waste dump contours. No other computer tool or method is known today to help, or most importantly, to improve the waste dump design process.

As established by Bohnet and Kunze (1990), important factors in the design of the waste dumps are:

- Pit location and size through time
- Waste rock volumes by time and source
- Topography
- Property boundaries
- Existing drainage routes
- Reclamation requirements
- Foundation conditions
- Material handling equipment.

The ultimate objective of a dump design is to minimise the total dumping cost, including haulage and other dump area related costs. Most of the design factors mentioned above can be quantified by assigning a cost factor which varies by surface topography location.

This paper introduces a method developed for the optimisation of waste dump limits. The similarity in both pit and dump optimisation problems is illustrated. The procedure of setting up a dump cost model and the use of a pit limit optimisation program, in this case Whittle 4D, in the optimisation of waste dumps is explained. The application of the method is discussed with respect to a case study optimisation.

Dump v Pit Optimisation

The dump optimisation problem can be described as a mirror image of the pit optimisation problem. The dump section illustrated in Figure 2 is obtained by rotating the pit section given in the same figure about the horizontal axis.

The slope constraints in dump optimisation are defined by using a set of structural arcs as in the case of pit optimisation. In Figure 2, the slope constraints defined by the structural arcs are simplified in the form of cones: an inverted mining cone for a pit and a dumping cone for a waste dump. In order to mine an ore block, the associated blocks within the removal cone should be mined first in an open pit. In the case of a dump, the blocks within the dumping cone should be dumped first.

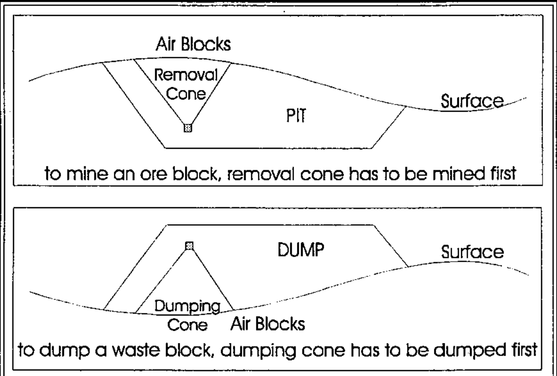

Figure 2. Pit vs. Dump Optimisation

The general procedure used for the optimisation of dump outlines is given in Figure 3. The procedure is similar to pit optimisation except that the dump optimisation model is created outside the modelling package by a custom program.

The block model input to the optimisation is inverted around the horizontal plane by renumbering the block model levels so that the air blocks transform into solid blocks. Conversely, the solid blocks become the air blocks as they do not have any effect in the dump optimisation process.

After model inversion, the slope angle constraints are defined by the creation of structural arcs in exactly the same way as for pit optimisation. Additional arcs can also be used to define the surface structures, such as roads, rivers or buildings that will affect the optimum dump limits.

The area codes generated in the planning package are used to divide the topographic surface into different cost areas. By using the area codes as the equivalent of ore codes during a pit optimisation, the volumes and costs can be tracked down in the optimisation runs by defined areas. The optimisation results for different dump areas can be processed and reported separately in the analysis stage.

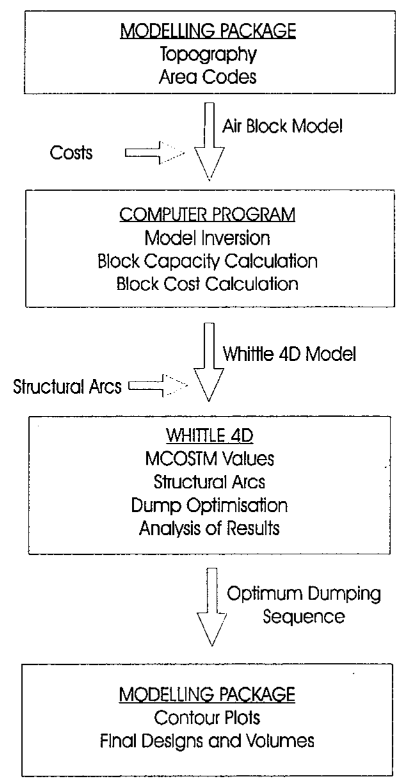

Figure 3. Flowchart for Dump Optimisation

The Cost Model

The two main categories of costs that can be used to construct the dump optimisation model are haulage and area costs.

The haulage cost is calculated for each block in the model depending on the block's location with respect to dump access or pit ramp exit locations. Since the haulage cost depends on the vertical displacement as well as the total distance travelled, it is divided into both horizontal and vertical components.

The following input data is required for the calculation of vertical and horizontal haulage costs for each block:

- Location of pit ramp exit(s)
- Volume of waste through each pit exit
- Haulage equipment type
- Operating cost of equipment.

In the case of multiple pit ramp exits, the pit exit providing the lowest haulage cost can be selected for the estimation of each block's haulage cost. It is also possible to define which exit will be used for each block by employing a ramp code as well as an area code in the modelling stage.

The area costs apply only to the blocks on the topographic surface. They can be assigned in two ways:

- as direct area cost which is allocated on the basis of unit area. It can be used for such items as land acquisition, clearing and rehabilitation costs.
- as lump sum cost where the cost is assigned to a single block, with the other blocks in the same area connected to this block by additional structural arcs. In order to access any of the blocks in the area for dumping, the lump sum cost has to be paid first. This method can be used to allocate the cost of diverting a drainage route or shifting a surface structure such as a road.

Building a cost model is a relatively difficult phase of the dump optimisation procedure. Depending on the details and the objectives of a dump optimisation study, development of complex cost models can be required with the inclusion of all the relevant factors.

Although a geological modelling or planning package can be used to generate a cost model, a custom computer program is much more flexible for a complex cost situation. The flowchart of a FORTRAN program, DUMP4D, used for cost model generation is given in Figure 4. The number of pit exits and cost areas input to the program are unlimited. The program can be customised easily for site specific requirements.

Whittle 4D Optimisation

After the calculation of the dumping cost and the available dump volume for each model block, it is necessary to transform those variables into a form that can be used by the Whittle Four-D pit optimisation program. The application of Whittle Four-D pit optimisation parameters is slightly different for dump optimisation.

Compared with pit optimisation, the use of Four-D input model fields differs as follows:

- The ROCK field normally used for the total tonnes of the block is used to store the calculated dumping cost.
- The METAL field normally storing the metal quantity in an ore parcel line is replaced by the calculated dumping volume of the block.
- The TYPE field defining the ore type is used for storing dump area codes.
- The variable costs are already calculated in the cost model so the mining and processing cost adjustment factors are always set to 1.

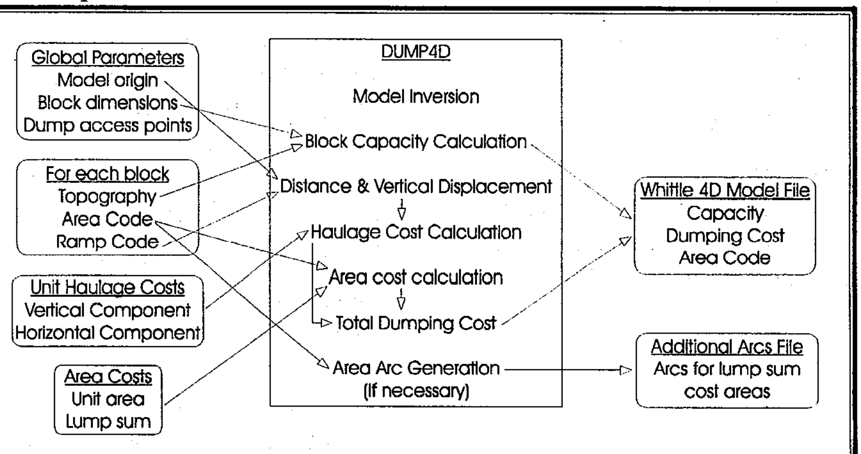

Figure 4. Operation of Program for Dump Optimisation Model Creation

In essence, the ROCK and the METAL fields define the two primary economic variables in pit optimisation, mining cost (ROCK) and revenue (METAL). In dump optimisation, the dumping cost and the available dump volume replaces these two pit optimisation variables respectively.

Setting-up the Four-D parameters file for dump optimisation is relatively simple:

- The reference block mining cost is always 1 since the costs are already stored in the input model file.
- The dumped waste volume is the product itself so there is no need to account for a processing cost. The reference block processing cost ratio (CRATIO) becomes redundant in dump optimisation.
- The metal cost of mining (MCOSTM) parameter, which equivalent to the ratio of mining cost to price, is calculated as the ratio of dumping cost (ROCK) to dump volume (METAL) in dump optimisation. The MCOSTM range in dump optimisation can be determined by finding the minimum and maximum dumping cost per unit dump volume.

Analysis of the dump optimisation results can be performed with the standard analysis program FDAN. The only two quantities that can be analysed in FDAN are the dump volumes and the dumping costs by area.

As in pit optimisation, the resultant dump increments are ordered from best, having the lowest dumping cost, to worst, having the highest cost. The sequence maximises the net present value of the dumping cost. By defining a dumping capacity, it is also possible to generate a dumping schedule reporting the dump volume, the slice, the cost and the NPV for each period.

Case Study

To demonstrate the application of dump optimisation, a block model was built by modelling a topographic surface and coding the different dump areas into each block. The plan view of this example model set-up is shown in Figure 5.

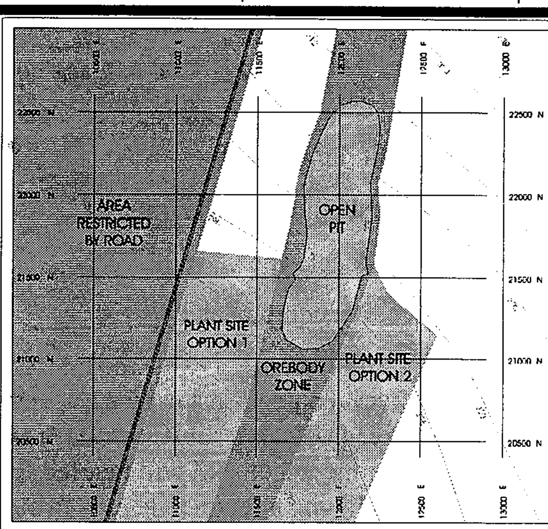

Figure 5. Dump Optimisation Case Study Topography and Cost Areas

In this example it is assumed that a total dump capacity of 150 million cubic meters (Mm^3) is required for waste disposal from the pit. The areas for which dumping options will be evaluated are:

- South-west plant site option (1)
- South-east plant site option (2)
- Western area separated by the road.

Three objectives of the study are:

- To determine the optimum ultimate dump limits for given topography, haulage and area costs
- To compare the two plant site options in terms of dumping costs
- To investigate if the western road diversion is justified to open up space for the dumps.

For the purpose of this study, a constant area cost for land clearing is assigned to all areas, except the orebody contact zone. A very high cost is assigned to this area in order to prevent any dump development here. The single pit ramp exit is assumed to be located at the centroid of the pit. The only optimisation variables are the haulage cost changing by location and the topography sloping down from the north-east to the south-west corner with less than 1 degree (1 in 100) gradient on average (Figure 5).

The optimisation results are given in Table 1. The costs and the volumes are reported against the dump slice and the area. The average cost applying to the cumulative dump volume and the marginal cost for the last dump increment are also calculated. The dumping cost is plotted against the increasing dump volume in Figure 6.

Dump Slice No	Cost \$M	Dump Area Cost \$M	Dump Area Vol Mm3	Plant Site 1 Cost \$M	Plant Site 1 Vol Mm3	Plant Site 2 Cost \$M	Plant Site 2 Vol Mm3	Road Area Cost \$M	Road Area Vol Mm3	Total Cost \$M	Total Vol Mm3	Unit Costs Avg. \$/bcm	Unit Costs Marg. \$/bcm
1	0.0	0.0	0.0							0.0	0.0	0.06	0.06
21	0.0	0.0	0.5							0.0	0.5	0.07	0.07
25	0.1	0.1	1.0	0.0	0.6					0.1	1.5	0.08	0.08
26	0.1	0.1	1.1	0.1	0.7					0.1	1.8	0.08	0.08
29	0.2	0.1	1.6	0.1	1.3					0.2	2.9	0.08	0.08
31	0.3	0.2	2.1	0.1	1.6					0.3	3.7	0.08	0.09
32	0.3	0.2	2.4	0.1	1.7					0.3	4.2	0.08	0.09
33	0.4	0.2	2.7	0.2	1.9					0.4	4.6	0.08	0.09
34	0.4	0.3	3.1	0.2	2.1					0.4	5.2	0.08	0.09
35	0.5	0.3	3.5	0.2	2.2					0.5	5.7	0.09	0.09
36	0.5	0.3	3.9	0.2	2.4					0.5	6.3	0.09	0.09
37	0.7	0.4	4.7	0.2	2.6	0.1	0.6			0.7	7.9	0.09	0.09
38	0.8	0.5	5.5	0.2	2.8	0.1	0.8			0.8	9.1	0.09	0.10
39	0.9	0.5	6.1	0.3	3.0	0.1	1.0			0.9	10.1	0.09	0.10
40	1.0	0.6	6.8	0.3	3.2	0.1	1.2			1.0	11.2	0.09	0.10
41	1.1	0.7	7.6	0.3	3.4	0.1	1.5	0.0	0.0	1.1	12.4	0.09	0.10
42	1.2	0.8	8.3	0.3	3.6	0.2	1.7	0.0	0.0	1.2	13.6	0.09	0.10
43	1.4	0.9	9.2	0.3	3.8	0.2	2.1	0.0	0.0	1.4	15.0	0.09	0.10
44	1.5	1.0	10.2	0.4	3.9	0.2	2.3	0.0	0.0	1.5	16.5	0.09	0.10
45	1.7	1.1	11.2	0.4	4.1	0.3	2.7	0.0	0.0	1.7	18.0	0.09	0.11
46	1.9	1.2	12.2	0.4	4.3	0.3	3.1	0.0	0.1	1.9	19.7	0.10	0.11
47	2.1	1.3	13.4	0.4	4.5	0.3	3.5	0.0	0.1	2.1	21.5	0.10	0.11
48	2.3	1.5	14.7	0.4	4.8	0.4	3.9	0.0	0.2	2.3	23.7	0.10	0.11
49	2.6	1.6	16.0	0.5	5.1	0.5	4.4	0.0	0.4	2.6	25.8	0.10	0.11
50	2.9	1.8	17.6	0.6	5.7	0.5	4.9	0.1	0.5	2.9	28.7	0.10	0.11
51	3.2	1.9	19.0	0.6	6.4	0.6	5.5	0.1	0.7	3.2	31.6	0.10	0.12
52	3.6	2.1	20.6	0.7	7.1	0.6	6.0	0.1	0.9	3.6	34.6	0.10	0.12
53	4.0	2.3	22.4	0.8	8.2	0.7	6.6	0.1	1.2	4.0	38.4	0.11	0.12
54	4.6	2.6	24.4	1.0	9.4	0.8	7.3	0.2	1.6	4.6	42.8	0.11	0.12
55	5.1	2.8	26.4	1.1	10.6	0.9	8.0	0.2	2.1	5.1	47.2	0.11	0.12
56	5.8	3.1	28.8	1.3	12.0	1.0	8.9	0.3	2.7	5.8	52.3	0.11	0.13
57	6.5	3.4	31.1	1.5	13.5	1.1	9.7	0.4	3.5	6.5	57.9	0.11	0.13
58	7.2	3.8	33.7	1.7	15.0	1.2	10.6	0.6	4.6	7.2	63.8	0.11	0.13
59	8.2	4.2	36.7	1.9	16.5	1.3	11.5	0.8	6.1	8.2	70.7	0.12	0.13
60	9.3	4.7	40.9	2.1	18.0	1.5	12.4	1.0	7.9	9.3	79.2	0.12	0.14
61	10.6	5.3	44.9	2.4	19.8	1.6	13.4	1.3	10.3	10.6	88.4	0.12	0.14
62	11.8	5.8	48.8	2.6	21.2	1.7	14.4	1.7	12.6	11.8	97.1	0.12	0.14
63	13.2	6.5	53.1	2.8	22.7	1.9	15.6	2.1	15.4	13.2	106.9	0.12	0.14
64	14.8	7.2	58.0	3.0	24.1	2.1	16.9	2.5	18.5	14.8	117.6	0.13	0.15
65	16.5	8.0	63.5	3.2	25.7	2.3	18.3	3.0	22.0	16.5	129.5	0.13	0.15
66	18.5	8.9	69.7	3.4	27.2	2.5	19.8	3.6	25.7	18.5	142.4	0.13	0.15
67	20.6	9.9	75.9	3.7	28.7	2.8	21.4	4.3	29.9	20.6	155.9	0.13	0.16
68	23.1	11.1	83.3	3.9	30.3	3.1	23.2	5.1	34.8	23.1	171.7	0.13	0.16
69	26.0	12.4	91.4	4.2	32.3	3.4	25.2	6.0	40.3	26.0	189.2	0.14	0.16
70	29.3	13.9	100.7	4.7	34.7	3.7	27.1	7.0	46.7	29.3	209.2	0.14	0.17
71	33.4	15.6	110.6	5.2	37.9	4.1	29.3	8.5	55.2	33.4	233.0	0.14	0.17
72	38.0	17.6	121.5	5.7	40.9	4.5	31.7	10.1	64.7	38.0	258.9	0.15	0.18
73	43.5	20.1	135.3	6.3	44.1	5.0	34.3	12.1	75.8	43.5	289.6	0.15	0.18
74	49.4	22.7	149.6	6.9	47.4	5.3	36.3	14.5	88.7	49.4	322.0	0.15	0.18
75	56.1	25.5	164.8	7.6	51.1	5.7	38.4	17.2	102.8	56.1	357.1	0.16	0.19
76	63.5	28.8	181.6	8.2	54.3	6.2	40.5	20.3	118.9	63.5	395.2	0.16	0.19

Table 1 Dump Optimisation Results

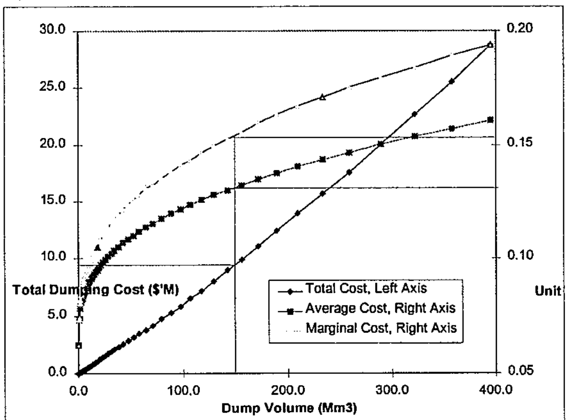

Figure 6. Optimum Dumping Cost Curves

The optimum outlines for a 150Mm^3 dump volume are plotted in Figure 7. As expected, the dump outlines are circular with the centre at the pit's centroid. In general, the centroids of both the western and the eastern dumps are shifted towards the south-west following the topographic surface sloping down in the same direction.

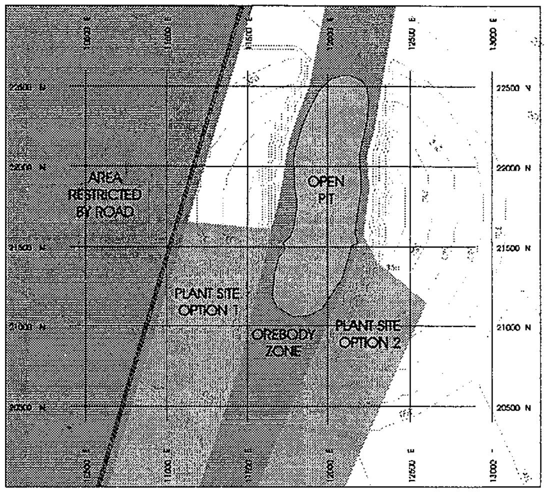

Figure 7. Dump Optimisation Case Study
150 Mm3 Optimum Dump Outlines

Two plant site options are compared in Figure 8. It is estimated from Table 1 that 20-30Mm^3 of the total waste will be dumped on either of the plant sites. The cost versus volume curve shows that the plant site option 1 is approximately \$250,000 better than the plant site option 2. This result is significant considering the small variation in topography between the two plant sites, 5m average vertical offset. The results can be used to decide on the best plant site after the inclusion of ore haulage and other plant site related costs into the analysis.

Similar cost curves are established in Figure 9 for the western road diversion option. According to the figure, the total cost for a 150Mm^3 dump would be reduced by \$750,000 if the area restricted by road is used for waste disposal. As a result, the diversion of the road will be justified if the cost of diversion is less than \$750,000.

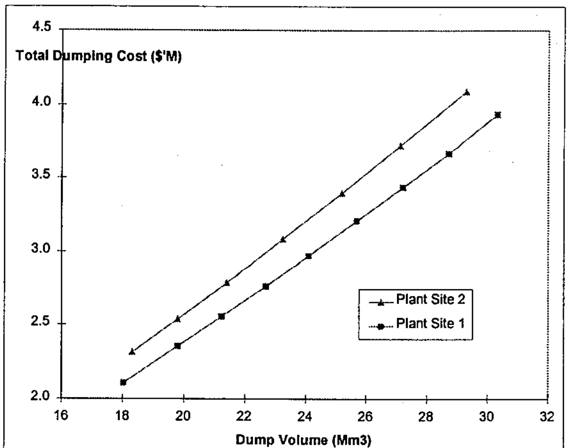

Figure 8. Comparison of Plant Site Options

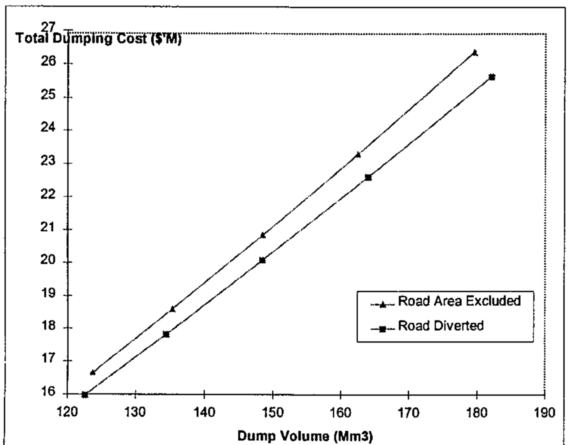

Figure 9. Road Diversion Options

In this case study, the dump optimisation problem is simplified to analyse only the effect of the variable topography on the optimum dump limits. With the inclusion of other cost factors, the results obtained from a dump optimisation study can be even more significant.

After the inclusion of pit ramp exit locations, further optimisation runs can be performed for a more detailed analysis of the available dumping options. The pit ramp exits can be designed to spread the waste evenly throughout the available dump area, which will result in savings in the haulage costs.

In the analysis of the results, various dumping schedules can be generated and net present values can be compared rather than undiscounted values. More constraints can be included into the dump optimisation. For example, if required by environmental regulations, height restrictions varying by area can be imposed on to the dump limits.

Conclusion

Dump optimisation is a useful tool in the design of the waste dumps, especially where:

- The topographic surface is variable
- The operation size is large with a high stripping ratio
- There are multiple dump site options controlled by other surface structures
- The costs are variable for land clearing, drainage, reclamation and purchasing.

In addition to the direct benefits from optimising the shape and the location of the dumps through minimising the costs, dump optimisation can also be used effectively for:

- Providing an optimum dumping schedule
- Evaluation of site options for surface structures
- Comparison of different pit ramp options
- Evaluation of mining contracts.

References

Bohnet, E. L. and Kunze, L. 1990, "Waste Disposal - Planning and Environmental Protection Aspects", Surface Mining Second Edition, SMME, Littleton, Colorado, pp.485-492.