Optimised Pit Scheduling Including In-Pit Dumps for Stratified Deposit

Ranajit Das[1(✉)], Erkan Topal[2], and Elham Mardenah[3]

[1] Curtin University and Senior Mining Consultant, Dassault Systemes, Brisbane, Australia
d.ranajit@gmail.com

[2] Faculty of Science and Engineering, Mining Engineering and Metallurgical Engineering, WA School of Mines, Curtin University, Perth, Australia
E.Topal@curtin.edu.au

[3] Faculty of Science and Engineering, Curtin University, Perth, Australia
Elham.Mardaneh@curtin.edu.au

Abstract. In stratified deposits such as coal, lignite, and phosphate, the ratio of waste to ore is often very high and one of the major concerns relates to waste placement to in-pit or external dumps. Unless it is known which waste dump will be used for the extracted material, depending on the availability of the waste dumps (in-pit or external), the haulage cost can largely vary at different times. Hence it is crucial to incorporate the waste placement decisions into the pit scheduling problem for better planning. Ignoring the waste placement and thereby the different waste haulage costs at different times could lead to flawed results. Traditionally, the pit scheduling problem and dump scheduling are studied in isolation with a few exceptions in the literature. Our aim is to fill the research gap in pit scheduling of stratified deposits with in-pit waste dumping and haulage road options. This paper focuses on the integration of pit and dump scheduling including in-pit dumping strategy. This strategy requires a factor of the lag to be considered with the working face. In this paper, we also demonstrate how to maintain a lag space with the dynamically changing mining face and consider waste rock placements in correct dumping (in-pit or external) locations.

1 Introduction

Stratified deposits are normally associated with large volume of waste removal, thereby a significant portion of the cost of mining is in removing the waste. Unless we know which dump the waste will be directed to, depending on the availability of space in the dump (external or in-pit), the cost of haulage will largely differ at different points of time (Li et al. 2013, 2014). The in-pit dump is a factor of the lag to be considered with the working face. While, the haulage cost depends on whether the optimal haul road option has been chosen (Hill et al. 2013). Thus ignoring the proper placement of waste into external and in-pit dumps in a schedule could lead to a flawed result.

The haulage distance for in-pit dumps are often much less compared to transportation to external dumps. Thereby the cost of mining is reduced with increased in-pit

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dumping. Hence, it is preferred to have internal dumping as early as possible in the mine life to be able to do early rehabilitation. Thereby reducing footprint of environmental impact.

Although production scheduling problem has the similar structure with stratified deposit as compared to massive or vein deposit, a few key differentiators can be listed as follow:

Pit Geometry and Layout: For moderately dipping stratified deposits, the base of the layer of ore/coal forms the base of the pit. Unlike, in a non-stratified deposit such as vein type deposit or a massive deposit we may have to mine the footwall to create a stable pit wall. Stratified deposits are large in lateral extent and normally shallow in vertical extent, hence mines like coal are known to extend several kilometres, as shown in Fig. 1 below. Because of this extent, almost all stratified mines try to do backfilling by in-pit dumping as a priority in order to decrease haulage cost and expedite reclamation. It is mostly not the case in vein type or massive deposits.

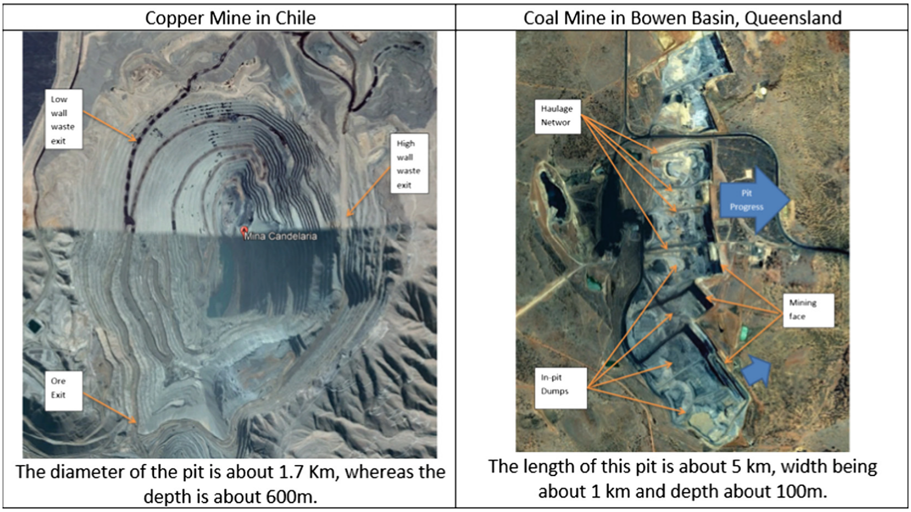

Fig. 1. Difference in pit geometry of stratified and non-stratified open pit mines using google earth images

Layered Blocks: Other than the pit geometry there is a difference in how blocks are treated in geological modelling and mine planning packages. For metalliferous deposits a block in a block model can be either waste or ore depending on its cut-off grade. Anything above the cut-off grade will be treated as ore and the destination would be a process plant. However, in case of coal deposits each block could consists of multiple coal and waste layers. Further, depending on the thickness of the coal layers and the quality, the layers could be combined with adjacent waste or coal layers while mining and such a model is often referred to as a ROM model with working sections.

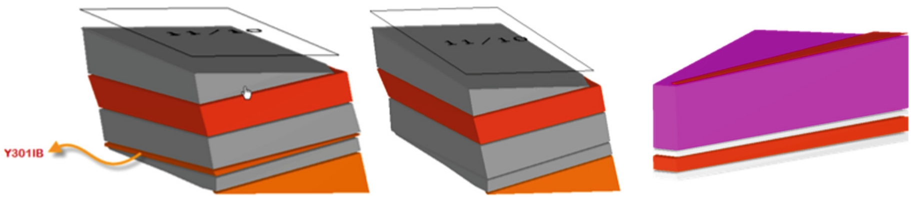

Fig. 2. Typical coal reserves individual block-containing both coal and waste layers

Figure 2 presents the typical blocks in a coal mine. The resource model could contain thin layers such as the Y301IB layer of Inter-burden. While converting the in-situ model to ROM model it is considered as coal and combined with the adjacent coal (Minex Reserves Database tutorial 2018). In order to mine the coal in a block the waste above it has to be removed.

Irregular Shape of the blocks: Another significant difference of a stratified deposit model is the shape of the blocks which are not perfect cubes or cuboids as in non-stratified. As seen in Fig. 2 blocks can have a definite slope angle which follow the ultimate wall or the strip wall angle. The blocks in plan view need not necessarily be a perfect rectangular shape, as commonly known. The block model referred here is only within the pit, where the pit can take any shape laterally. Hence, in order to fit in blocks at the edges or turns in a strip the blocks can be of any shape or size opposed to regular shaped block models in metalliferous deposits.

Pre-designed Pit: The design of these blocks are normally done after the pit optimisation process, hence all blocks in the design are within the optimised pit shell obtained through ultimate pit limit optimisation algorithm such as Lerchs Grossman or other optimisation method. The slope of the pit has already been considered during the design process. It may be observed that the sides of each block also has a slope as shown in Fig. 2. This slope follows the slope specified for the strip or final wall.

Pre-designed Dump: Similar to the pit, the dump is also pre-designed with slopes for each block. Dump blocks are designed and need to be considered as the lag distances are checked from each pit block to corresponding dump blocks. Dump slopes are more important as they are flatter and normally in the range of 35–38°. Hence in the same area the number of strips that can be fitted in the bottom bench may not be same as number of strips in top bench as shown in Fig. 6.

Predecessor Blocks for Mining: Typically 9 blocks above a pit block are considered to be mined in order to mine a block below. However, in a stratified deposit using strip mining method, the pit should be mined as strip by strip. Similarly we also want to proceed the dump strip by strip. Hence the mining or dumping precedence is slightly different. The same 9 blocks are located differently depending on the mining direction. The mining direction being the direction of increase in strip numbers. This is normally important in stratified deposits as they have a dip. The strip numbers normally increase along the dip direction. Mining normally proceeds from the shallower area to the deeper area (Fig. 3).

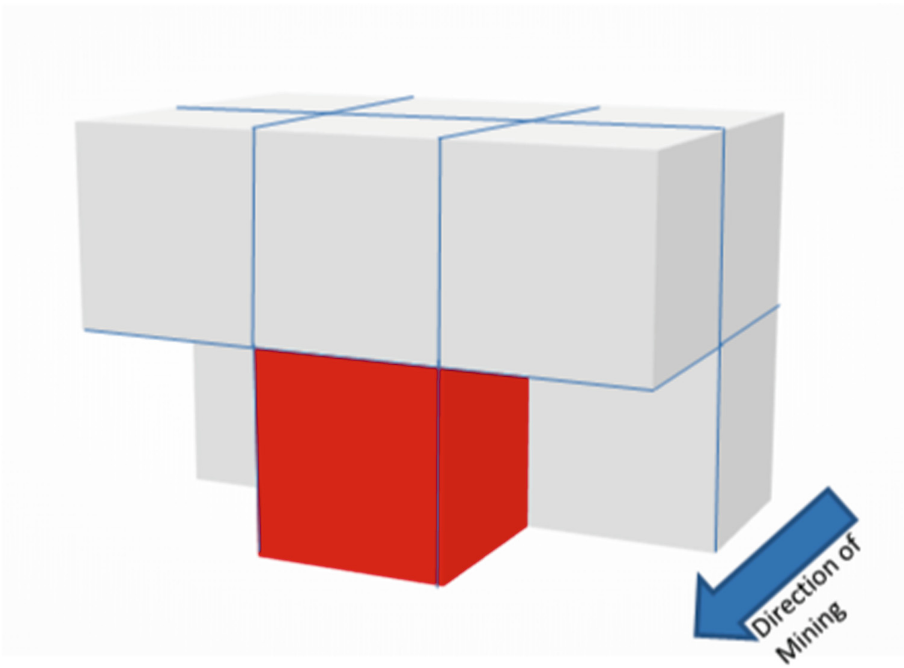

Fig. 3. 9 blocks with respect to block to be mined (red) and direction of mining

2 Methodology for Model

The design of the pit and the dump has been created using a 3D mine planning software. The volumes, tonnes, quality and block coordinates were reported out of the software and tabulated in an Excel workbook. A new mixed integer programming based model has been developed using CPLEX OPL in order to optimise the production schedule for each period and the corresponding dump locations to be used for each block. The mathematical equations considered in this model are similar to the one by (Fu et al. 2018), except certain modifications mentioned below to accommodate stratified nature of the deposit and in-pit dumping with lag distance.

A block here could contain both ore and waste. The dump has been deigned to contain individual blocks. Both pit and dump blocks have been considered to have a location with a coordinate for the centroid. One of the key differentiators of this model is the lag constraint which differentiates it from other models and makes it capable of scheduling for in-pit dumping.

A set of pit blocks have been calculated from each dumping block centroid, within a defined lag distance. The lag constraint checks whether these blocks have been already mined. The dump block can be filled only if the entire set of lagged pit blocks have been mined.

3 Implementation of the Model

The model developed has been tested for a dataset having the components as shown in Fig. 4. It has a single pit with 3 benches and 117 blocks of average size of 50 m 50 m. The coal is transported to either of the 3 stock piles – based on grade or can be directly fed to the coal wash plant. Coal is also fed to the wash plant from the stock pile by rehandling. The values used in the model are describes in Table 1 below.

Table 1. Input parameters for the optimisation model

	Maximum	Minimum	Unit
Wash plant capacity	150,000	120,000	Tonnes/Yr
Mining capacity	750,000	200,000	Cubic m/Yr
Specific energy		15	MJ/kg
		Australian $	
Coal sale price		100.00	per T
Coal mining cost		4.00	per T
Waste mining cost		3.00	per BCM
Waste haulage		0.0001	per BCM meters
Coal wash cost		7.50	per T ROM feed
Coal rehandling cost		0.50	per T ROM feed
Swell factor		1.25	
Discount rate		10%	
Recovery/yield		90%	

The waste is hauled and dumped into two dumps – one external and one in-pit. The in-pit dump maintains a lag distance of 50 m with the pit as both the pit and the in-pit dump progress. The dumps are selected based on the haulage distance and corresponding waste hauling cost. The objective here is to maximise the Net Present Value of the operations considering the above scenario.

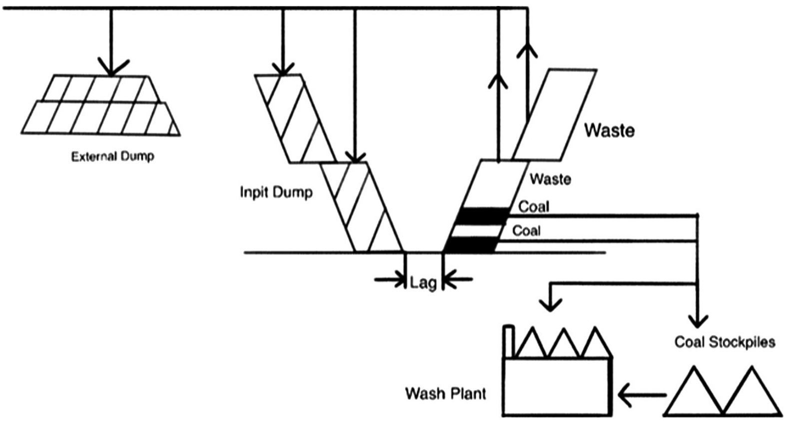

Fig. 4. Material flow schematic diagram

The model has been run on part of a pit for only the first 4 strips which have 117 blocks, in 3 benches as shown in Fig. 5 below. There is also an in-pit dump in the same footprint with 3 benches and 93 blocks as shown in Fig. 6. One ex-pit block has been considered which represents the external dump and has an equivalent capacity. Detailing of the external dump into benches, strips and blocks has been kept out of scope in this model. The pit blocks have multiple layers of coal and waste in them as evident from the colours of the layers in Fig. 5. The lowest bench, not visible in the image is mostly coal. The schedule has been run for 5 periods. The pit and dumps were designed in a 3D Mine planning software and the details including pit and dump block centroid coordinates were exported to excel, which formed an input to the model in CPLEX OPL.

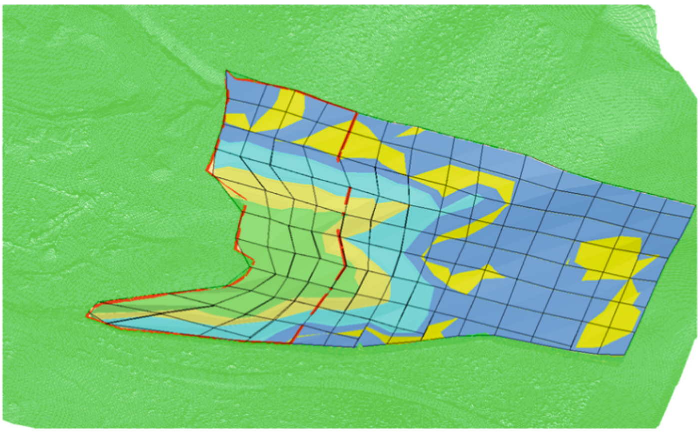

Fig. 5. Complete pit and topography surface (pit coloured by layers of coal and waste). Outline of 4 strips marked in red

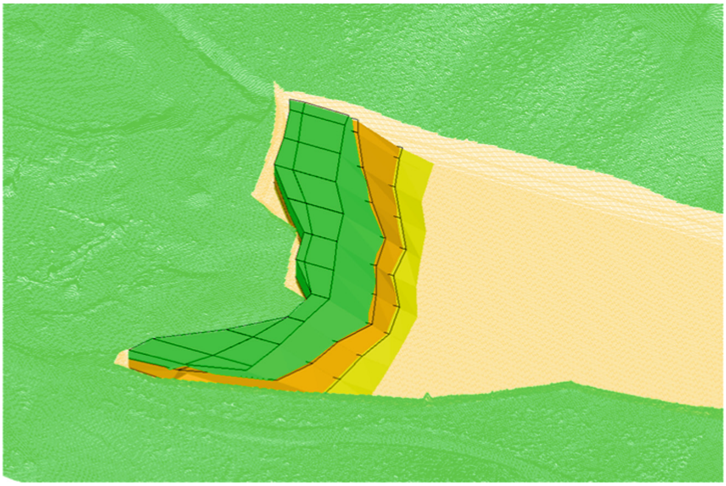

Fig. 6. In-pit dump blocks for the first 4 strips considered

The dump has been designed with blocks at 37° as seen in Fig. 6. Due to the slope in the design, although the bottom bench has 4 strips, there is not enough room for 4 strips on the top. The topmost dump bench as visible in Fig. 6 has only 2 strips. A swell factor of 1.2 has been considered for waste placed into dump blocks. Table 2 presents the pit data in excel which contain the block details. Some blocks contain both coal and waste where as some have only waste. There are other tables one of which have coordinates of each block, and one for the dump blocks and their coordinates.

Table 2. A sample format of the pit block details [The complete list has 117 blocks]

Block id	Bench	Strip	Block	CV (Quality)	Coal (Tons)	Coal density	Recovery	Waste vol	Total volume
1	1	1	2	23.76	4435	1.42	90%	39397	45694.7
2	1	1	3	23.91	4938	1.42	90%	31823	38834.96
3	1	1	4	25.39	3677	1.38	90%	18739	23813.26
4	1	1	5	27.04	4058	1.35	90%	20499	25977.3
5	1	1	6	27.88	1509	1.34	90%	36656	38678.06
6	1	1	7					21975	21975
7	1	1	8					17180	17180
8	1	1	9					16952	16952
9	1	1	10					26815	26815
10	1	1	11	27.65	1214	1.41	90%	48640	50351.74
11	1	1	12	27.52	3393	1.42	90%	21513	26331.06
12	1	2	2	24	3730	1.41	90%	38561	43820.3
13	1	2	3	24.04	5090	1.41	90%	34716	41892.9
14	1	2	4	25.49	3925	1.37	90%	19893	25270.25
15	1	2	5	27.04	4773	1.34	90%	22614	29009.82
16	1	2	6	27.88	1096	1.33	90%	23877	25334.68
17	1	2	7					16052	16052
18	1	2	8					11026	11026
19	1	2	9					14525	14525
20	1	2	10					26365	26365

4 Analysis of Results

The results from the run in CPLEX have been tabulated in the format in Table 2 in order to calculate the NPV outside the CPLEX model.

Table 3. Results obtained from model for waste placement from pit to dump blocks for each period

Year	Waste volume	Dump		Coal to plant	Coal to stock pile	Coal from stockpile
		External	In-pit			
1	620,545	615,033	5,512	0	129,455	129,455
2	338,440	193,434	145,006	–	135,349	135,349
3	565,689	536,594	29,095	–	120,000	120,000
4	195,525	–	195,525	0	120,000	120,000
5	236,763	–	236,763	–	120,000	120,000

As can be seen from Table 3, waste has been directed to both external and in-pit dumps. This has been decided based on the shortest distance (lowest cost) or based on blocks eligible for dumping in the in-pit dump in order to maintain the lag distance with the pit blocks being mined. In the early periods when mostly the upper waste is being mined there is not enough room for starting the in-pit dump. Hence the waste is mostly sent to the external dump block. The external dump has been assumed to contain a volume equivalent to a realistic dump outside the pit. From the 4th year onwards there is enough room in the in-pit dump hence all waste is sent there.

Coal could be sent to either wash plant or to stock pile from the pit, in this case all coal went to the stock pile for blending. All coal sent to the stock piles were drawn out by rehandling for feeding to the wash plant.

A sale price for the coal was assumed as $100 per tonne, and a 90% yield at the coal wash plant. For ease of calculation of NPV each period has been assumed to be an year. The NPV of the current schedule at 10% discount is $24.91 million, under the given assumptions, as shown in Table 4.

Table 4. Cash flow and NPV calculated from the schedule

Year	Waste mining cost	Waste haulage cost		Coal mining			Coal wash cost	Rehandling cost	Revenue	Margin
		Ext	In-pit	Mining	Haulage to plant	Haulage to stock				
1	1,861,635	3,427,326	2,361	517,820	0	936,014	970,913	64,728	11,650,954	4,806,171
2	1,015,320	643,051	324,154	541,396	–	1,059,358	1,015,117	67,674	12,181,406	8,574,694
3	1,697,068	2,221,300	50,211	480,000	–	667,071	900,000	60,000	10,800,000	5,391,421
4	586,575	–	1,225,708	480,000	0	609,126	900,000	60,000	10,800,000	7,547,716
5	710,289	–	1,806,868	480,000	–	454,355	900,000	60,000	10,800,000	6,842,843
									NPV	$24,910,484

5 Conclusions

The ability to decide the optimal destination of dump blocks into in-pit and external dumps along with the optimal mining sequence can add significant value to mining operations. This value has remained untapped in several operations globally. Not only does it give the opportunity to maximise value but also allows for quicker backfilling the in-pit dumps and making them available for rehabilitation. Thereby decreasing the footprint of the mine progressively. This research presents the integration of pit and dump scheduling which includes in-pit dumping strategy for stratified deposit. The paper also presents how to maintain a lag space for mining and in-pit filling with the dynamically changing mining face.

6 Future Research

Stratified deposits occur in a sequence, often referred to as the seam sequence. In the current research, the blocks has been considered to have 3 dimensions (i, j, k) which are bench, strip and block. In future research, it is proposed to work with i, j, k and layer name. Where the coal and waste layer in a block are treated separately. This will ensure that the coal and the waste layers are removed in the right sequence for blocks containing multiple layers of coal and waste. At the moment although the model forces all waste in the available block to be removed if the coal is removed. However, it would be more appropriate to have them removed in a particular sequence, giving the flexibility to have a few layers in a block mined in a particular period and remaining in another period.

It is also proposed to work on the development of different strategies and models to obtain faster solution for the larger datasets.

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