The Use of Optimisation Sensitivity Analysis at Australia's Premier Gold Mine - Fimiston Open Pit
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Abstract

Situated on the famous "Golden Mile", Kalgoorlie Consolidated Gold Mines Pty Ltd (KCGM) manages Australia's largest gold mine. For over 100 years the area has been extensively mined by open pit and underground methods producing in excess of 1200 tonnes of gold, nearly 40 million ounces.

The current resource, in excess of 21 million ounces, is contained within a structurally complex orebody of some 847 lodes covering an area 4.5 kilometres in length, 1.6 kilometres in breadth and at least 1.2 kilometres deep. The resulting orebody model is enormous, consisting of some 2 million blocks derived from over 60,000 drill holes.

Even with such a large database, 78% of the resource is categorised as either Indicated or Inferred. As a result of this lower confidence material, some 100,000 metres a year of surface and underground drilling is undertaken to better define mineralisation both internal and external to the current optimised pit design.

With such a large scope for drilling, sensitivity analysis using Whittle Four D forms a key part of the optimisation process. It identifies areas of susceptibility to gold price by virtue of the pit shell and, together with the life of mine schedule, prioritises the areas requiring more information. This is then fed-back to the resource definition team who schedule their drilling accordingly.

KCGM is already committing to final walls in some areas of the pit. The validation of these designs through the drilling of unknown and inferred areas within the model is therefore of a very high priority. By being able to target the priority areas identified by sensitivity analyses using Whittle Four D, KCGM can jointly pursue its cutback strategy whilst continuing to better define its orebody.

Introduction

KCGM's Fimiston Operations lie immediately to the east of the city of Kalgoorlie - Boulder and completely cover the area known as the Golden Mile.

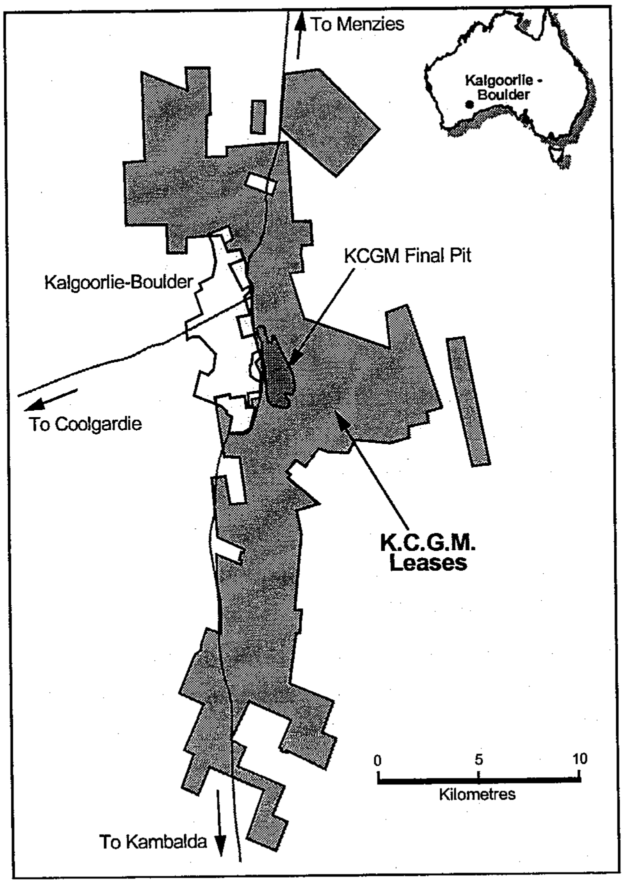

Figure 1: Showing KCGM's Final Pit's proximity to Kalgoorlie - Boulder

Today the Fimiston Open Pit has a mining rate of approximately 68 million tonnes of total material moved per annum, producing 8.5 million tonnes of ore that yields in excess of 700,000 ounces of gold per year (22 tonnes).

Mining has continued by both open pit and underground on the Golden Mile since gold was discovered in 1893. The current Fimiston leases contain in excess of 60 underground shafts from which some 2,500 kilometres of underground working emanate. The deepest shaft, Chaffers shaft, extends 4,100 feet below the surface and still operates today as an exploration platform.

Open pit optimisation work using Whittle Four D is based on the diluted geological block model. This model combines some 1,840,000 metres of drilling with extensive historical mining data.

Even with such a large database 78% of the total reserve within the optimum final pit relies on combined indicated and inferred resources. This low confidence material represents a significant risk to the operation in terms of optimising mine schedules and cash flows.

With such a reliance on indicated and inferred resources it is clear the solution is to upgrade this material by intensive drilling within the next few years. The main question was where to begin.

This paper discusses how KCGM approached the task of prioritising the drilling programme through sensitivity analysis using Whittle Four D.

Background

Whittle Four D is used by the KCGM Strategic Planning Department to define optimum pit shells and cash-flows for various geological resources that exist within their leases. Recently however Whittle Four D has been used to ascertain not only the optimum pit shell but also its sensitivity (and the operation's risk) to factors such as gold price and resource classification.

With regard to the Fimiston orebody, the shell's sensitivity to these factors was essentially controlled by the quality of information within the resource block model.

Fimiston Geological Resource Block Model

The geological resource block model used by KCGM in the pit optimisation process was the culmination of four years work by a team of some 44 people including geologists, data entry personnel and database managers. Completed in May 1993, it provided for the first time a composite model that involved the entire Fimiston orebody.

Some interesting facts:

- It incorporates diamond core information from as early as 1897.
- Incorporated 14 survey grids.
- Required the re-assaying of some 50,000 metres of selectively sampled drill core.
- Incorporates 12,500 historical surface diamond drill holes.
- Incorporates 19,500 historical underground diamond drill holes.
- Some 11,700 AO plots required interpretation.
- The stope modelling alone required 6.5 man years to complete.
- The model size is in the order of 250 Megabytes.
- The current resource model covers 5 kilometres in length, 2 kilometres in breath and extends nearly 1 kilometre below the original land surface.
- The current resource model holds some 252 Million tonnes of ore at 2.46 grams per tonne, in effect containing some 20 Million ounces of gold.

The model has been revised every year since to incorporate further drilling information in an effort to provide the best quality data for resource estimation. In 1995 100,000 metres of core and RC drilling was completed, mainly aimed at reducing inferred material in the model.

Even with extensive ongoing drilling programmes accurate resource estimation is difficult due to poor quality historical data. Problems include:

- A dependence on selectively sampled, small diameter core (EXT - 23mm). This data comprises two thirds of the existing data.
- Incomplete sampling and need to use default assays.
- local data clustering
- Inadequate assay methods
- The inability to drill through large underground stopes.

Selective Mining Unit Model

For optimisation purposes, the geological resource block model was diluted using the Selective Mining Unit (SMU) process. A Datamine macro re-blocked the model to create a minimum block size of four (4) metres east and ten (10) metres north and elevation. This reflects the minimum block size that can be delineated and mined using the present grade control, blast pattern, bench height and mining equipment configuration.

The SMU model was also restricted to 675 mBD from 975 mBD to reduce model size and hence processing time.

Rock Type Code

A rock type code was created that targeted the resource classification in conjunction with the pit regions. This was inserted into the SMU model via Gentra in Datamine. An example of the rock type code called Matclass is shown below:

	Eastern Lodes	Western Lodes	Northern Basalt	Golden Pike	Drysdale
Measured	OR11	OR21	OR31	OR41	OR51
Indicated	OR12	OR22	OR32	OR42	OR52
Inferred	OR13	OR23	OR33	OR43	OR53

Table 1: Rock type codes inserted into the SMU model

This Matclass rock type code meant that through the parameter file used in the FDOP process specific combinations of zone and resource classification could be manipulated by altering their recoveries.

For example, by setting the Inferred codes to zero recovery in the parameter file, the effect of removing the inferred's influence on the pit shell could be analysed. The results of this work are discussed in more detail under the heading Sensitivity Analysis.

Pit Optimisation

Base Case Selection

The first optimisation's aim was to create and then identify the best Net Present Value (NPV) optimum pit shell from the base case information. This shell's shape and cash-flows would then set the standard from which all other runs would be compared. To begin with the Matclass code's were given the average 90 percent sulphide recovery in the parameter file.

The oxide component of this model was found to be less than 1 percent of the total and so was included within the sulphide material.

The initial optimisation's output indicated that the Pit 10 shell at the $525oz gold price produced the best Net Value pit. In terms of NPV, Pit 9 and Pit 10 were very similar. As a result the smaller Pit 9, $500 shell was chosen as the basecase to be used in the final pit design because it produced the most robust pit with a comparable NPV.

Sensitivity Analysis

Once the optimum shell was selected, its sensitivity to a number of parameters was examined. These factors included changes in slope angle, gold grade, mining and processing cost, mining area and Measured/Indicated/Inferred recoveries. By varying these factors within the parameter file, the sensitivity of the pit was gauged.

The sensitivity analysis conducted as part of the 1996 Fimiston Open Pit Resource Optimisation identified that of the open pit reserve reported, Inferred ore represented the greatest risk to the operation. It was found that it constituted 6 years of the mine's 15 year scheduled life by making 56 Million tonnes of ore and 318 Million tonnes of waste economic to mine. KCGM was confident that the ore tonnes exist because the orebody model had, since its creation in 1993, consistently undercalled tonnes in areas where previous underground mining occurred. Of greater importance to KCGM was the verification of the Inferred ores' actual grade before final wall positions were committed to.

Commitment to Final Walls

Scheduling waste and ore from the cutbacks indicated that KCGM would have to commit to final walls in two regions in the next five years. It was important that the model be confident to the level of the Measured or Indicated category in these areas to enable the correct final wall profile to be designed and excavated.

An investigation of the basecase Whittle shell and the model seemed to indicate that the shell was influenced by either one of two factors.

1. A smooth wall extending to the base of pit clearly showed the influence of the main lode base of pit ore. Ore within the walls had little effect in determining this area's shell. To commit on a too optimistic final outline here would result in the mining of many millions of tonnes of waste to access base of pit ore that might not exist. On the contrary, too conservative a line might well sterilise ore by leaving these base of pit main lodes in the wall. Figure 2 shows a Whittle shell driven principally by base of pit ore.
2. A final wall characterised by glitches or deviations in what would have been a smooth wall to the base of the pit indicated the presence of influential in-wall lode structures. Here the Whittle shell was chasing economic ore into the wall and deviating the shell as a result. Further investigation found that these glitches contributed significant tonnages of ore, particularly in the next five years. The investigation also found that a significant proportion of these tonnes were Inferred.

The ramifications of committing to a final wall in these areas did not involve the large costs associated with mining millions of tonnes of waste to access base of pit ore. Instead its effect was on short term revenue and in the mine's monthly scheduling. Figure 3 shows a Whittle shell influenced by significant in-wall lodes.

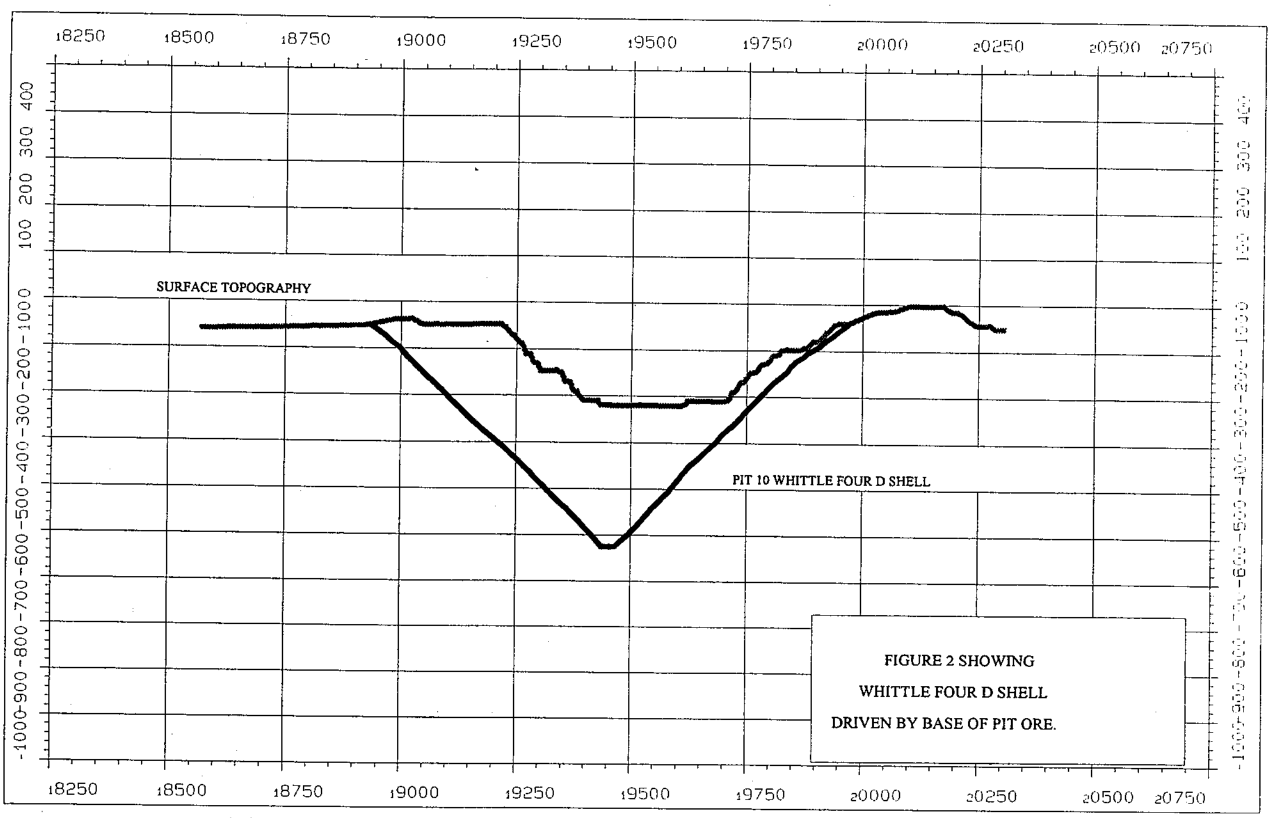

Figure 2: Showing a Whittle Four D shell driven by base of pit ore.

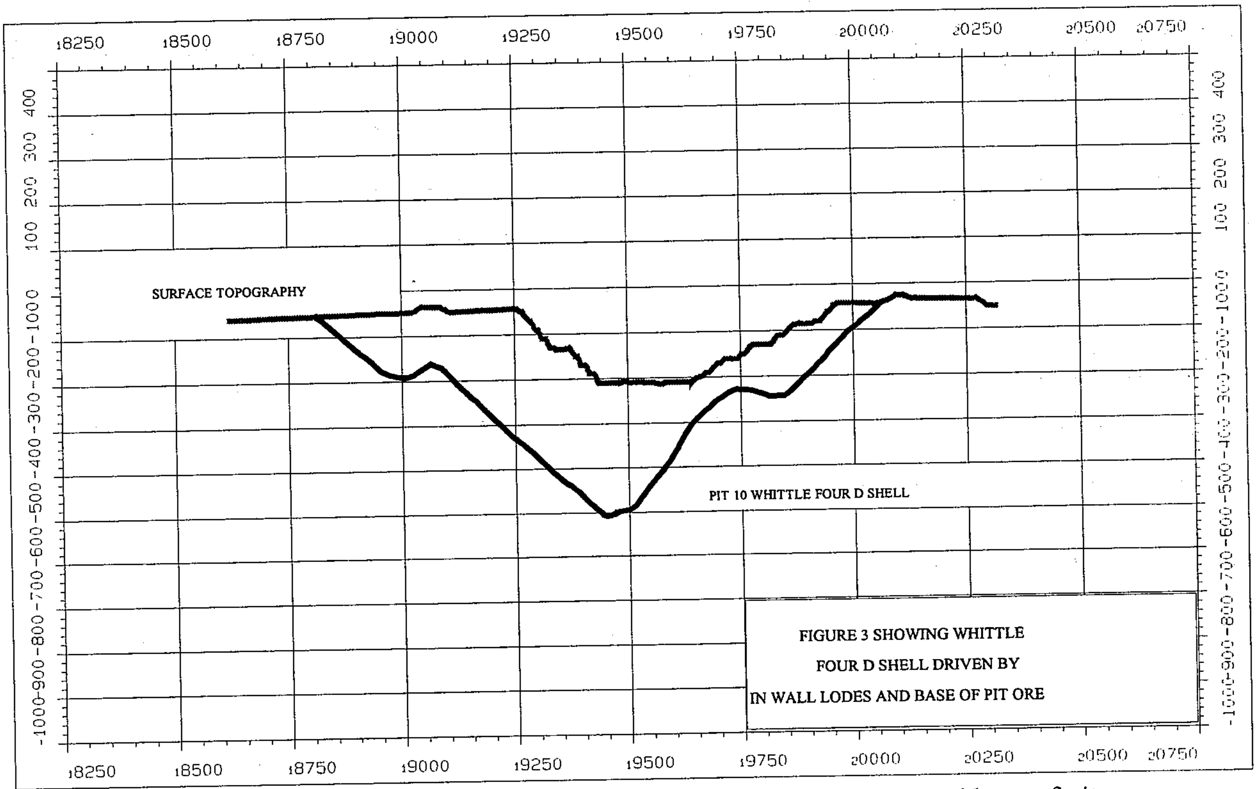

Figure 3: Showing a Whittle Four D Shell driven by inwall lodes and base of pit ore

Sensitivity to Inferred

The task in the short term was to accurately gauge the basecase shell's sensitivity to inferred. Being able to see the shell's response to the lower confidence ore would enable area priorities to be assigned to target some infill and final wall drilling.

The best means of gauging the sensitivity to the inferred ore was in using Whittle Four D to vary the recovery and rock tonnes of the lower confidence material in these areas.

After discussions with the Resource Definition Department, possible best case and worse case scenarios were agreed upon. They are expressed below as a percentage variance from the existing model.

- Best Case:

  Indicated: + 20% tonnes and + 0% grade

  Inferred: + 50% tonnes and + 0% grade

- Worst Case:

  Indicated: - 20% tonnes and - 10% grade

  Inferred: - 50% tonnes and - 20% grade

- Base case:

  Recovery 90% for all resource categories.

It is important to note that the grade assigned to the Inferred categories was higher than that assigned to the Measured. This was because the past practise of incompletely sampled holes had meant that only the higher grade material in the drill core was assayed and the remaining lower grade halo left. It was therefore unlikely that the actual grade of the ore block would be higher than the portion of the core already sampled. Hence the zero percent increase in the best case grade.

The parameter files were adjusted to incorporate these grade and tonnes ranges by altering the recovery and the Rock Cost Adjustment Factor (RCAF) respectively.

For example, calculating the inferred ore's recovery and RCAF for the Worst Case run described above:

> If the actual recovery = 100 percent, the worst case recovery would simply be 100 - 20
> However actual recovery is around 90 percent, therefore the worst case recovery would be as follows:
>
> $$\frac{90}{X} = \frac{100}{80}$$
>
> The revised recovery (X) equals 72 percent.

> The calculation of the RCAF to allow for 50 percent more tonnes was simply 100 percent plus 50 percent or 1.5. This would increase the mining cost of the blocks by 50 percent.

The results of these optimisations are shown by a section view through the pit.
This can be seen below in figure 4.

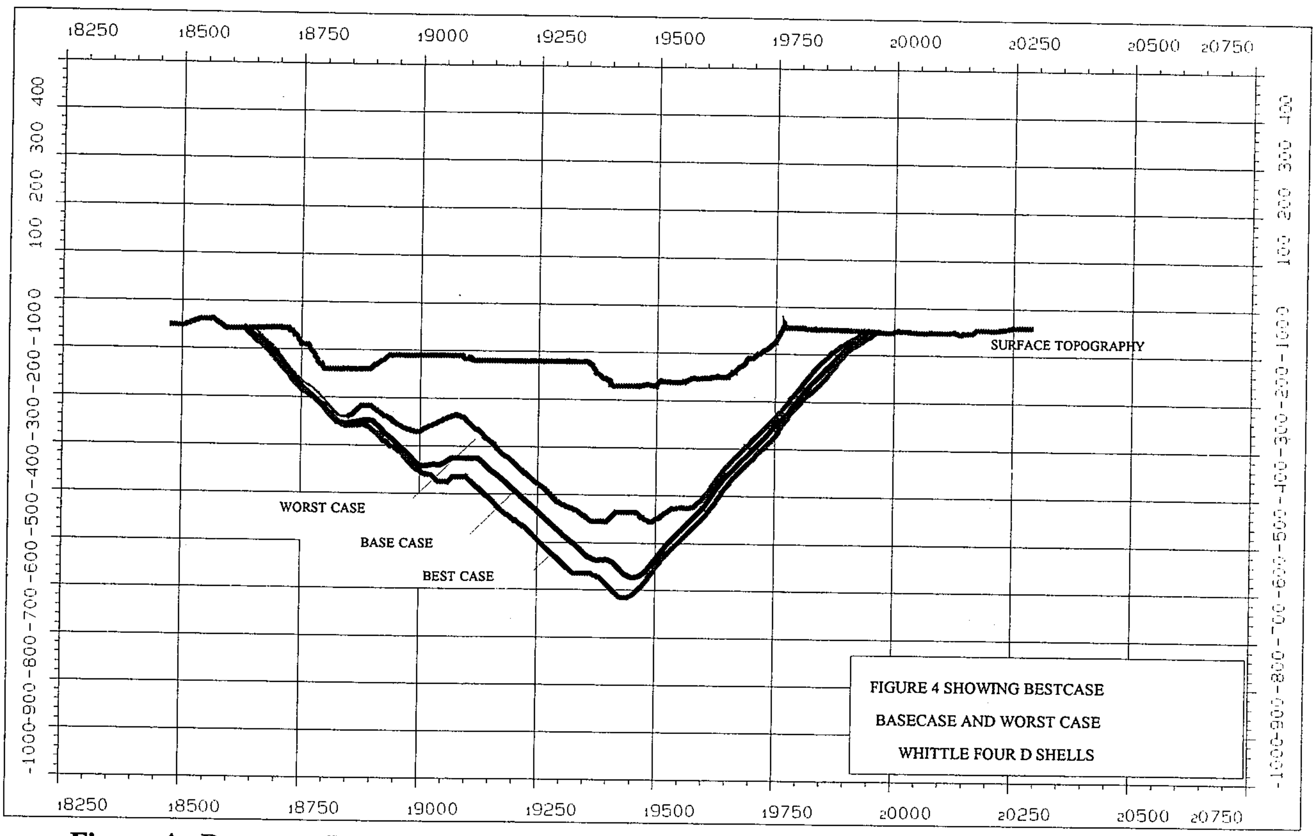

Figure 4: Best case, Base case and Worst case Whittle Four D shells showing inferred sensitivity.

The section (shown in Figure 4) clearly shows that this area in particular is very sensitive to possible changes in tonnes and grade of the measured and inferred categories. Table 2 subtracts the Best and Worst case runs from the Base case run to gauge their overall effects on cashflow and tonnage.

	Waste Tonnes	Ore Tonnes	Opvalue (NPV) Best Case
Base case - Plus	- 13,951,000	- 1,211,000	- $22,035,000
Base case - Minus	426,602,000	51,818,000	$40,889,000

Table 2: Base case minus Best and Worst Case

Assigning Drilling Priorities

The allocation of drilling priorities to these sensitive areas was not a simple exercise. This is supported by the magnitude of the tonnage shown in Table 2. In all, almost 500 Million tonnes of material required drilling to significantly reduce the impact of inferred ore. The question was often asked of where to begin.

The life of mine schedule was used together with the three Whittle Four D shells to prioritise drilling areas in the short to medium term. Mining in the next three to five years was scheduled principally on the eastern and southern regions of the final designed pit. These regions were cut out and removed and the shells analysed. Areas to the north and east fell outside of the $350 shell and as a consequence were mined as future cutbacks to the current pit.

It was found after an investigation of the sections that the shells were being driven largely by base of pit ore to the south and in-wall lodes to the north. The most sensitive of these areas showing the difference in position between shells were assigned the highest priority for drilling.

KCGM enjoys a unique advantage in that extensive underground workings enable drilling to be carried out directly beneath the pit via the Chaffers Shaft. This provides underground access for drilling the base of pit ore. Once drilling in these deeper areas to the south was prioritised, work began establishing access for diamond drilling.

Areas to the north driven in the short term by in-wall lodes were drilled by surface RC rigs working both within the pit and on its periphery. Surface drilling in the first zone is expected to be completed by March 1997. Recent drilling in these northern zones indicates more tonnes at a higher than modelled grade.

Conclusion

KCGM's objective in the next three years is to complete approximately 90,000 metres a year of surface RC drilling and 16,000 metres of underground diamond drilling principally targeting the Inferred resource. Sensitivity analysis using Whittle Four D allows the drilling to be assigned to the most important areas first enabling both confident final wall positions to be excavated and realistic scheduling to be achieved.

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