The re-engineering of the ground handling system at Cullinan Diamond Mine

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Synopsis

Cullinan Diamond Mine currently handles 3.2 million tons of run of ore per annum. This is done by means of an underground train system, which is located at 763 metre level. Four trains, one in each quarter of the pipe, collect ore from passes and transport it to centrally located tips in the north and south of the pipe. The ore is then split into coarse and fine fractions. The coarse fraction proceeds to the primary crushers in the north and south. Historically, mining has been performed in such a manner that an equal amount of ore has reported to each quarter of the pipe. However, the tonnage profile of the mine will change such that the ore will no longer be split equally. For approximately five years the majority of ore will report to the east and thereafter most of the ore will report to the western portion of the mine. This will continue for the remainder of the current infrastructure level's operational life. Coupled with this is the fact that the mine is aiming to increase its annual production to 5.8 million tons. The result is that the current ground handling system cannot accommodate the additional tons and therefore alternative ground handling options have been investigated. The continued existence of Cullinan Diamond Mine relies on finding a system that can economically handle the additional tonnage.

Three options were investigated. Firstly, a train option, which would be an upgrade of the current system, was investigated. Two truck options were also investigated, the first of which was a conventional truck option. The second truck option was more interesting and involved an unfamiliar Combi truck system. The truck options were investigated primarily due to the fact that the block height of the BA West (a new production block) can be increased by 15 meters if a truck option is decided upon. This would create a significant increase in revenue for the BA West project. Each of the options was assessed in terms of its physical and financial feasibility. In terms of the physical constraints, it was found that all three systems could work. Detailed financial analysis indicated that either of the two truck options would be a suitable solution. However, due to the limited information regarding the Combi truck option, it should be further investigated. This applies particularly to the actual running and maintenance costs for the equipment.

Introduction

Mine background

Cullinan Diamond Mine is a division of De Beers Consolidated Mines. It is situated 30 kilometres east of Pretoria in the town of Cullinan and is currently celebrating its centenary year of mining. The Cullinan pipe has an elongated oval shape, with the east-west axis approximately 900 m long and the north-south axis 450 m on surface. It has a surface area of 32 ha, decreasing progressively with depth. Figure 1 shows a section through the pit, which indicates the exact geology of the pipe.

There are three main types of kimberlite present in the Cullinan pipe, namely brown, grey and black (hyperbyssal) kimberlite, the latter being the most competent of the different kimberlite types.

The current mining method is known as mechanized panel retreat block caving. In this method, a drilling level is developed to allow the orebody to be undercut by drilling and blasting. When a sufficiently large area has been undercut, continuous caving initiates. Mining operations on the undercut level also include long hole drilling and charging, blasting and tramming of limited amounts of ore.

A production level is situated 15 metres below the undercut level, and tunnels into the orebody are developed on this level. Out of these tunnels, drawpoints are developed. These drawpoints are then raise-bored, and a drawbell developed so that the caved ore falls into the drawbell and flows into the drawpoint. The ore is then loaded by LHDs and trammed to passes outside of the orebody. On the extraction level, 43% of the rock is extracted to create the drawbells, production tunnels, and cross-cuts needed for mining.

Two blocks are currently being mined, the BA5 and BB1 East. Block BA5’s undercut level is 615 m below surface, with its production level at 650 m below surface. Block BB1 East’s undercut is 717 m below surface and the...
The re-engineering of the ground handling system at Cullinan Diamond Mine

production level is 732 m below surface. Because of severe stresses on some of the production tunnels on 732 level, tunnels have collapsed. In order to mine these areas, another recovery production level, 747 Level, was introduced.

Figure 2 shows a side view of the pit. It can be seen that the mining operations have been divided into a number of segments or blocks. The mine is currently mining the BA5 as well as the BB1 East. The BB1 East advanced undercut is currently in the implementation phase and is due to start production in 2005. The AUC will have its production level at 732 metres below surface. Studies are taking place to determine the feasibility of the BAW (BA West). Planned mining of the BAW is scheduled to commence in 2011 and will continue until the end of the current life of mine. Further investigations are evaluating extensions at depth.

**Project background**

The ground handling system is designed to ensure the removal of broken ground at the same rate as it is produced; this is vital in terms of achieving production requirements. At Cullinan Diamond Mine the ground handling system includes ore passes, box fronts, a train system, a crushing system, a conveyor system and the hoisting infrastructure.

Currently four locomotives operate on the 763 level at an individual rate 260 tph (tons per hour). These locomotives collect ore from ore passes located in the four quadrants of the mine. There are two trains operating in the north haulage and two in the south haulage. Once the hoppers have been filled at the box front, the train proceeds to dump into a central tip (520 tph); thereafter the ore is split into coarse and fine fractions. The coarse fraction is passed through the
primary crusher and rejoins the fine material at the next stage. Ore moving through the crusher is handled at a rate of approximately 450 tph, and 70 tph moves through the fines pass. Once the crushed coarse fraction and the fine fraction have rejoined, the ore is transported to 500 m level via a series of winzes. Thereafter, the ore is hoisted to surface and proceeds to the plant. Figure 3 shows a plan view of the haulages and tunnels that are of importance in the ground handling process.

Most of the ore on the western side of the pipe has been depleted (BA5) and operations are now moving to the eastern side of the pipe (BB1 East and the advanced undercut). There is still one block that will be mined on the western side of the pipe (BA West). The BAW is of critical importance to the mine because of the fact that the C-cut project has been delayed and final approval for the C-cut has not yet been given. Due to the new advanced undercut mining method in the AUC and the ramp-up in production of the BB1 East block, approximately 80% of the ore supply will report to the eastern side of the pipe for the next five years. After this period and for the remainder of the life of mine, 100% of the ore supplied will come from the western side of the pipe (BA West).

How is Cullinan Diamond Mine going to handle its ore in the future when the split of ore is not uniform on both sides of the pipe? Providing an answer to this is the main reason for this investigation. The investigation, however, encompasses only a small yet critical part of the entire feasibility study for the BA West.

Current ground handling operations involve a 2-shift working arrangement, which allows the handling of 3.2 million tons per annum. The current ground handling configuration and infrastructure does not allow for the handling of 3.8 million tons per annum, which is the target. Figures 4 and 5 show the planned tonnage profile for the next 10 years for the eastern and western sections of the pipe.
The re-engineering of the ground handling system at Cullinan Diamond Mine

Note that the lines in Figures 4 and 5 indicate the limiting tonnage for two locomotives and not four locomotives. This means that any additional tonnage that lies above the line will not be able to be handled using the current ground handling system. Due to the change in the distribution of ore, two locomotives will need to achieve roughly the equivalent tonnage of the four current locomotives. If the production is pushed up to 3.8 million tons then each train would need to achieve double its current call. In terms of tonnages, a quadrant would be required to process 520 tph rather than 260 tph. As can be seen, this is double what the train is currently tramming. The graphs indicate that from about 2005 the tonnage will exceed the hauling capabilities of two locos. It can be seen in Figure 4 that the majority of the additional tons will originate from the BB1 East advanced undercut from 2005 until 2010. Figure 5, in turn, indicates that there will be additional tons reporting from the BA West from 2011 until 2016. It is imperative that Cullinan Diamond Mine finds a ground handling system that allows it to handle 3.8 million tons per annum.

The underground storage capacity at Cullinan Diamond Mine is fairly limited and this plays an important role in the ground handling configuration. In order to ensure that the required tonnages can be achieved, it will be necessary to investigate various options that will suit the requirements of the mine. Thereafter the best option will need to be identified. If the required tonnages can be achieved, it will ensure that Cullinan Diamond Mine continues to operate effectively and efficiently and that the mine functions within the parameters stipulated by its business plan.

Problem statement
An investigation into the re-engineering of the ground handling system at Cullinan Diamond Mine.
The re-engineering of the ground handling system at Cullinan Diamond Mine

Scope of the study

The BA West is currently in a planning and design phase. This phase will be evaluated later in order to determine whether the BAW will be feasible. This present investigation forms a sub-project of the BAW feasibility investigation. Should approval be given for the BAW to proceed, there will be four main sections that will be established. There will be development and support, production, and ground handling sections, as well as an extraction section. This project focuses specifically on the ground handling section.

The ground handling section will consist of sub-sections and only some of these sections have been investigated. Note that the upstream and downstream effects of each individual item within the process will be taken into account because they directly affect the ground handling system. The LHDs, for example, are constraints because the design of the ground handling system will be configured in such a way that the LHDs will ideally never stand. In other words, there will always be tipping capacity for the LHDs to utilize. On the other end of the scale are the crushers, conveyors and hoisting mechanisms. The main constraint in this case will be the crushers because they can only process material at a rate of 450 tons per hour. These are typical aspects that will be investigated.

Methodology

In order to satisfy the objectives of the project, the student undertook a number of associated tasks that facilitated the collection of relevant project data. The aim was to systematically approach set objectives and focus on the specific outcomes of each particular objective. The following aspects were dealt with in detail:

➤ A literature search was undertaken so as to familiarize the student with the mine layout as well as the current operational details of the ground handling system. The literature study facilitated in highlighting operations that are or have been successful and also assisted in the identification of systems that have not worked well
➤ An underground site investigation was conducted in order to identify critical elements that affect the ground handling process
➤ Potential options that may be feasible solutions for the problem were identified and were compared in terms of time constraints, practicality, physical parameters and costs
➤ A detailed cost analysis was performed on the physically feasible options
➤ Conclusions were made based on all the acquired information as well as on the results of the investigation
➤ Recommendations were made based on final conclusions.

Results

Overview

The solution to the additional tonnages that the ground handling system will be required to handle was twofold. The first step that was taken was to redesign and reconfigure the work schedule. The mine currently operates on a 2-shift basis, morning and night shift. The afternoon shift is dedicated solely to maintenance during which time the hoppers and locomotives are serviced and maintained. The railway lines are also cleaned and serviced during the afternoon shift. The hopper fleet is large and, due to the age of the hopper, maintenance is time consuming. The hoppers do vary in respective ages but most seem to be in excess of 40 years old. The locomotives also require attention and are just as old as the hoppers. The locomotives have, however, been overhauled and upgraded in recent years. The change to the calendar can be seen in Table I.

The table shows that there are 3 shifts planned per day. It must, however, be noted that there will still be only 5 working days per week due to the old infrastructure that needs to be maintained. The tramming hours per day have been calculated directly from the shift utilization figure. The tramming hours per day have been calculated directly from the shift utilization figure. The utilization figure has been determined by taking into account time for workers to move to the work place, tea and lunch breaks, as well as time to return to the shaft before the end of the shift. From the figures in the calendar, the tonnage requirements to achieve 3.8 million tons per annum could be calculated. Table II shows an annual, monthly and hourly breakdown of the production figures under the revised schedule.

| Table I |
| Working schedule for the BAW |
| Weeks per annum | 52 |
| Public holidays | 12 |
| Shift utilization | 80% |
| Working days per annum | 248 |
| Shifts per day | 3 |
| Tramming hours per shift | 7.2 |
| Working days per week | 5 |
| Hours per shift | 9 |

| Table II |
| Required tons for revised calendar |
| Total (tons) | 3800000 |
| Per rim (tons) | 1900000 |
| Per annum | 316667 |
| Per month | 158333 |
| Per hour | 709 |
| Per rim (tons) | 355 |
The re-engineering of the ground handling system at Cullinan Diamond Mine

This table indicates that the change in schedule will have a major impact on the tonnage requirements in terms of increasing the capacity of the ground handling system. The scenario without the schedule change was that each train would be required to double its production from 260 tph to 520 tph. Remember that this is because of the unequal distribution of ore. It can now be seen that each train (there will be only 2 trains operating) in the BAW will be required to handle ore at a rate of 355 tph. This effectively means that the tonnage requirements per train will only increase by 37% with schedule changes versus a 100% increase without schedule changes.

The second part of the solution to the ground handling system requirements was to find a system that could accommodate the additional tons. This meant finding a system with increased capacity. The ground handling system of any mine usually has a unique layout and poses various challenges when being selected and designed. For this project, three particular options have been investigated. The first is an underground train system, which utilizes trains to transport ore on 763 level. This is the current system and any changes that take place would be an upgrade of the current system. Underground trucking systems that include a conventional truck option, as well as a Combi truck option, have also been investigated. Either of these systems will have its production on 747 level. The third option that was investigated was a conveyor belt system. The three options will now be discussed.

The options

New proposed train option

As previously mentioned, a train system is already in use at the mine and, therefore, in many regards keeping a train system would appear to be the easiest option. However, it was soon discovered that changes that would need to take place in the system to accommodate additional tons would be significant.

The layout for the train option

With reference to the proposed layout shown in Figure 6, if the train system continues to be used as the ground handling system, then the production level will be located on 732 elevation. The ore will be fed by LHDs on 732 level into passes, which will feed the train on 763 level. This system is identical to the current system employed in the BB1 East and the BA5. Major work that will take place is the installation of the ten tips. The significance of these tips will become apparent upon investigation of the capital expenditure for the train option.

A description of the train option

When considering a new train system, various suppliers of parts and equipment were consulted. Well-known manufacturers such as Trident SA, Galison Equipment and Battery Electric were consulted in order to determine the requirements of a new train that will be able to handle 355 tph. A train is a difficult item to research in that a different company manufactures each of the large components. Trident SA, NDA Mining Supplies and Daelian Engineering specialize in the manufacturing of locomotives, while Galison Equipment and Octa Engineering provide hoppers. Battery Electric is a company that can provide assistance in terms of the control systems for a train fleet.

When investigating the train option, one of the first assignments undertaken was to identify and determine typical cycle times for the current trains. The existing arrangement is a train that pulls 10 hoppers with a payload of 6.5 ton per hopper. The train handles ore at a rate of 260 tons per hour. This would indicate a cycle time of 15 minutes, on average. Underground time studies confirmed that cycle times on average were indeed approximately 15 minutes, but spillage during loading of hoppers caused major time delays. If spillage occurs while the hoppers are being loaded, the operator of the box front that loads the hoppers must first move any objects that are preventing the train from moving. The time to move rocks and debris off the railway line causes a significant increase in cycle time. Based on the time studies performed, a delay due to spillage could cause an increase of up to 4 minutes on a cycle of around 10 minutes, which equates to a 40% increase in the cycle time. Note that the 10 minute cycle times were due to very short distances being trammed when the actual times were being recorded.

Once the cycle times were determined, the effect of these times on the new system could be identified. This meant that the new train system would be required to perform the same task in a similar cycle time. It would not be practical to have a train that can deliver 355 tph but only tip once per hour. The idea was to strike a balance between an increase in capacity of the hoppers and by increasing the power of the locomotives to achieve a larger payload capacity per hour. This would result in the passes in the haulage being serviced regularly enough to ensure that they would always be available for the LHDs to tip into, i.e. there will always be sufficient storage capacity.

The new train system will include the following items:

- 4 new locomotives and 2 upgraded locomotives
- 24 10-ton hoppers
- Upgraded control systems
- Rehabilitated railway lines
- Tips and associated equipment.

Figure 6—The layout for the train option
The re-engineering of the ground handling system at Cullinan Diamond Mine

A cost breakdown for the train option

A breakdown of costs associated with the train option is recorded in Table III below. The table contains details on the capital expenditure and includes an operating expenditure component for the life of the project. The majority of the costs has been determined or obtained from industry but some had to be estimated. **Note that for all the different options cost calculations were performed on the premise that equipment will be maintained for the life of the project rather than being replaced.**

From Table III it can be seen that the major capital cost component for the train option is the 10 tips. The train option will require the tips to be installed almost immediately, which results in a large capital expenditure early in the life of the project. This cost will amount to approximately R80 million. These costs include costs to develop and equip each tip. The items that contribute to the high cost of the tips are rock breakers, grizzleys, and materials for lining the inside of the passes, as well as the cost of raise-boring the passes.

Operating expenditure accounts for a greater proportion of the overall costs than the capital expenditure. As can be seen from Table III, the OPEX amounts to R110.2 million. Operating expenditure was calculated by breaking down the OPEX into 3 components, namely: maintenance, electricity and sundry operating costs. Maintenance costs were calculated from a rand-per-ton figure that was obtained from the financial model used by the C-cut project team. Maintenance costs include costs to service and maintain the locomotives, Granbys and railway lines. Electricity costs also play an important role, but these costs were slightly more difficult to calculate due to the fluctuating hourly rates as well as the different rates for summer and winter months. The peak cost in summer is R0.1545 per kWh, whereas the same kWh will cost R0.5044 in the winter months. Winter rates are charged for the months June, July and August. Sundry OPEX includes items such as rock breakers, grizzleys and chutes (box fronts). The cost components for each item include an annual labour and spare parts cost.

**The advantages and disadvantages of the train option**

**Advantages**

➤ A train-based system is currently in use at Cullinan Diamond mine. It is a well-known system with which employees at the mine are comfortable. All the ground handling expertise is geared towards a train system.

➤ There are lower operating and maintenance costs when compared with a trucking option. The operating costs for the train would be lower due to that it employs the use of electricity to power equipment, which is cheap in comparison to diesel, which is used to fuel trucks.

➤ The trains fit in with the existing infrastructure and will provide a solution for the eastern rim trammimg. This means that the information gained for the BAW project will be suitable for application in the other two blocks in the east, namely the BB1 East and the AUC. The set-up in the east will need to be similar to that for the west.

**Disadvantages**

➤ The train option will require 10 passes to be equipped, manned and maintained in order to ensure sufficient capacity. The costs involved in establishing the tips are very high and the operating cost per annum for each tip is also significant.

➤ There will be a large amount of capital invested early in the project’s life. This cost must be regarded as a sunk cost that cannot be regained should there be problems that cause the mining operation to discontinue. The tips and all the equipment associated with the tips will need to be installed in the first three years of the project, when waste development is being done.

➤ The BAW will be required to hole into some of the existing passes in the BA5 block (the block directly above the BAW). The reason for this is the lack of space to install new tips, because the existing tips are very close in some instances. A problem with holing into the existing passes is that the condition of these passes is unknown. This means that there could be serious scaling (wearing away of the inside of the pass due to impact and abrasion by falling rocks), which will provide a serious challenge in terms of trying to establish a new tip.

➤ The ability to ramp-up production to more than 3.8 million tons is limited because there will need to be major changes in terms of the infrastructure. To handle more than 4 million tons per annum, the primary crusher may also provide a constraint in that it can only handle 450 tph.

**The first truck option: 30-ton conventional diesel trucks**

A trucking option would provide a unique challenge to Cullinan Diamond Mine in that it is a very new concept for the De Beers group’s underground mines. The only other De Beers operation that aims to employ trucks for ground handling purposes is Finsch Mine. There were two trucking options that were investigated for this current project. The first is a conventional truck option, which will utilize 30- to 35-ton articulated diesel trucks. The second option involves a different and less well-known system known as a Combi truck system. This system will make use of 35-ton diesel trucks that have removable containers. Both truck options presented various challenges in terms of physical parameters and practicality that had to be investigated before any decision could be made.

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**Table III**

**Table of CAPEX and OPEX for the train option**

<table>
<thead>
<tr>
<th>Capital expenditure</th>
<th>Rands (million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost for 24 Granbys</td>
<td>2.4</td>
</tr>
<tr>
<td>Capital cost for 4 locomotives</td>
<td>5.0</td>
</tr>
<tr>
<td>Capital cost for refurbished locomotives</td>
<td>2.0</td>
</tr>
<tr>
<td>Capital cost for 10 tips</td>
<td>80.0</td>
</tr>
<tr>
<td>Capital cost for control systems</td>
<td>1.0</td>
</tr>
<tr>
<td>Cost for rehabilitation on 763 level</td>
<td>2.0</td>
</tr>
<tr>
<td>Total capital expenditure</td>
<td>92.4</td>
</tr>
<tr>
<td>Total project operating expenditure</td>
<td>110.2</td>
</tr>
</tbody>
</table>
The re-engineering of the ground handling system at Cullinan Diamond Mine

The layout for both trucking options

The layout shown in Figure 7 will be identical for both the truck options. From Figure 7 it can be seen that the layout for the truck option is significantly different from that of the train option. Notice in the case of the trucks that the production level will be located at an elevation of 747 metres, versus 732 metres for the train option. This entails an additional 15 metres of block height. The system will work as follows: a truck will report to a loading bay where it will be loaded by two LHDs, one from either side.

Once the truck is full it will proceed around the circular route to the tips, which will be located at the center of the pipe. The tips can be seen on the right-hand side in Figure 7. Figure 8 shows a side profile of the proposed layout for a truck-based system. It indicates the flow of ore from the tips located on 747 level.

Once the trucks have tipped the ore, it is cleared by a rock breaker. As with the train process, the rock breaker breaks down large rocks to a manageable size by forcing the ore through a sizing grizley. The ore then proceeds down the pass onto an apron feeder. The apron feeder will be situated in the position of the current camelback. The pass feeding the apron feeder will be holed through from 763 level to 747 level. Once the ore is fed onto the apron feeder, it will be tipped onto the existing grizzly that will separate the ground into coarse and fine fractions. Thereafter, the flow of ore is identical to the current arrangement.

A description of the conventional diesel truck option

The conventional truck option required an in-depth investigation into both the physical and financial viability of such an option. When considering the conventional trucking option, various suppliers such as Caterpillar/Elphinstone (Barloworld) and Bell Equipment were consulted in order to gain information about the performance parameters and specifications of their vehicles. Based on the information supplied by the manufacturers, a suitable vehicle could be selected for the application. Similarly, companies who could provide information regarding tips and apron feeders were also consulted. Osborn Engineered Products and Consolidated Rock Machinery personnel visited the mine to discuss challenges in terms of the practicality of the project. They also provided an indication of the costs involved for their respective equipment.

The conventional truck system will include the following items:

➤ A fleet of 9, 30-ton articulated diesel dump trucks
➤ 4 tips and associated equipment
➤ 4 apron feeders (one at each existing tip)
➤ A number of new and upgraded workshops.

A cost breakdown for the conventional truck option

A breakdown of the costs associated with the truck option is recorded in Table IV. The table contains details regarding capital and operating expenditure for the project.

Table IV indicates that the most significant investment in terms of CAPEX will be for the purchasing of trucks, as well the installation of tips. The capital costs in the case of the...
Advantages

- The main advantage and the reason for investigating the conventional trucks is that there will be an increased column height. Instead of the production level being on 732 level it will be on 747 level. The result is an additional 15 metres of block height, which increases the revenue-to-capital ratio by increasing the number of carats mined.

- In the case of the trucks, there will be only 4 passes that will need to be equipped, and manned and maintained. This is far fewer than for the train option.

- As mentioned previously, there will be a staggered flow of capital over the life of the project. This reduces the risk of the project, somewhat, because if the project should be discontinued for any reason, the full fleet of trucks may not necessarily have been purchased yet.

Disadvantages

- Trucks will be a new ground handling method for Cullinan Diamond Mine. Staff at the mine will require training, and personnel who can operate trucks will need to be employed. Specialist skills for servicing and maintaining the vehicles will also be required.

- The capital expenditure for the conventional truck option will be less than for the train option, whereas the operating and maintenance costs will be far greater than for the train system.

- There will be no surge capacity between trucks and LHDs. Should the crusher stand, there will be no capacity in the system except for that in the passes between the production level and the primary crusher.

The second truck option: 35-ton Combi diesel trucks

The next option that was investigated was the Kiruna Combi truck option. The Kiruna Combi truck makes use of an advanced hydraulic loading mechanism to load and dispose of a large rock container. The truck can handle several containers, depending on the application. The Combi truck has been employed in mining operations across Europe (primarily tunneling applications). It has been used predominantly for handling of softer ores such as salt, limestone and dolomite. The Kiruna Iron Ore Mine in Sweden was one of the first mines where the truck was employed and a great deal of the technological development and performance monitoring took place. The Combi trucks, however, are no longer in use at Kiruna. The idea of applying the Combi truck in the diamond-mining environment is a very recent one. The option has been investigated primarily due to the good results achieved with the truck elsewhere in the world.

The layout for the Combi truck option

As previously mentioned, the layout for the Combi trucks and the conventional truck option is identical. Figure 9 shows the loading layout. It can be seen that there will be two LHDs loading one container, which is similar to the set-up as for the first truck option.

A description of the Combi truck option

Figure 10 shows the various components of the Combi truck. As can be seen from Figure 10, the truck is very versatile. For the BAW application each truck will have two containers. Once the truck arrives at the loading bay it will deposit an empty container and collect a full container. It will haul and dump the full container while the empty container is being filled. The truck then proceeds back to the loading bay to deposit the empty container and collect the next full container. One cause for concern when investigating the Combi truck method was that it is no longer used at Kiruna.
The re-engineering of the ground handling system at Cullinan Diamond Mine

Figure 9—The loading configuration for the Combi truck option

Figure 10—General pictures of the Combi truck (Gia Industria Technical Specification Handbook)

mine. The decision to discontinue using the trucks could not be established. However, Figure 11 may provide some insight into the decision.

Figure 11 illustrates the difference between the Kiruna Combi truck and a conventional Kiruna truck. It can be seen on the graph that at a haul distance of 400 metres the Combi truck outperforms the conventional Kiruna truck, in terms of capacity per hour, by about 20%. This reading can be confirmed by looking at the line on the right-hand side of the graph. If one takes a reading at the 200-metre marker, it can be seen that the Kiruna truck far outperforms its counterpart. In fact, the Kiruna Combi seems to handle almost 50% more than the conventional truck. This effectively indicates a higher utilization for the Combi truck, which results in a smaller fleet being required to perform the same amount of work.
The question now remains: ‘Why does Kiruna no longer make use of the Combi truck?’ From the Figure 11 there can be only one explanation. The haul distances have increased to such an extent that the mine no longer gains an advantage from using the Combi trucks. The Combi trucks and the conventional trucks perform much the same at a haul distance exceeding 1 000 meters. Contrary to previous statement, the Combi truck is also a more expensive vehicle and, therefore, for the same size fleet, the conventional truck may prove a cheaper option.

In the case of Cullinan Diamond Mine, the haul distances will be typical of those indicated by the lines in the graph. Some of the distances may be even shorter than those indicated, which further highlights the advantages of the Combi truck.

The Combi truck option, like the conventional truck option, required an in-depth investigation into both the physical and financial viability of the option. When considering the Combi truck option, it was found that very little information was readily available. Because of the fact that the truck is only used in Europe, it was difficult to obtain information on the performance and specifications of the vehicle.

The Combi truck system will include the following items:

➤ A fleet of 5 35-ton Combi trucks, as well as 10 containers
➤ 4 tips and associated equipment
➤ 4 apron feeders (one at each existing tip)
➤ A number of new and upgraded workshops

A cost breakdown for the Combi truck option

A breakdown of the costs associated with the Combi truck option is recorded in Table V. The table contains details regarding capital and operating expenditure for the project. Note that due to the lack of technical information available, the Combi trucks’ financial figures were based largely on the costs for the conventional truck option. This was the case particularly when calculating the fuel, tyre and maintenance costs for the operating expenditure.

Table V indicates that the most significant investment in terms of CAPEX will be for the purchasing of trucks, as well as the installation of tips. The capital costs in the case of the Combi truck option will be staggered, as is the case for the conventional trucks. This means that capital will be invested as production increases. The staggered capital approach is particularly suited to the purchasing of the fleet of trucks. In the beginning a smaller number of vehicles will be required and additional vehicles are then purchased as additional tons are mined. It must be noted that there was no buy-back option taken into account for the truck options. In both truck options it was assumed that the mine would operate the trucks for the duration of the project. This approach is a worst-case scenario because a buy-back option would almost certainly work out cheaper than maintaining the trucks for such a long period. The overall CAPEX for the Combi truck option is R77.9 million, which is less than for the conventional truck option and the train option.

The operating expenditure for the Combi truck option was calculated in exactly the same manner as the conventional truck option. It can be seen that the OPEX for a Combi trucking option would be substantial, at a cost R175.1 million, that is, more than double the capital investment. Interestingly, the OPEX for the Combi truck option is higher than that for the conventional truck option, despite having only half the fleet size. One of the reasons for this is that the single truck with two containers will work much harder than

<table>
<thead>
<tr>
<th>Table V</th>
<th>Table of CAPEX and OPEX for the Combi truck option</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital expenditure</td>
<td>Rand</td>
</tr>
<tr>
<td>Capital cost for 5 trucks</td>
<td>19.9</td>
</tr>
<tr>
<td>Capital cost for 10 containers</td>
<td>2.8</td>
</tr>
<tr>
<td>Capital cost for 4 workshops</td>
<td>10.0</td>
</tr>
<tr>
<td>Capital cost for 4 apron feeders</td>
<td>5.0</td>
</tr>
<tr>
<td>Capital cost for 4 tips</td>
<td>40.0</td>
</tr>
<tr>
<td>Total capital expenditure</td>
<td>77.9</td>
</tr>
<tr>
<td>Total project operating expenditure</td>
<td>175.1</td>
</tr>
</tbody>
</table>
The re-engineering of the ground handling system at Cullinan Diamond Mine

two individual trucks. The result is that each Combi truck will require more maintenance, fuel and tyres in its lifetime.

The advantages and disadvantages of the Combi truck option

Advantages

- The main advantage of the Combi trucks, as with the conventional trucks, is the fact that there will be an increased column height. Instead of the production level being on 732 level it will be on 747 level. The result is an additional 15 metres of block height, which increases the revenue-to-capital ratio by increasing the number of carats mined.
- In the case of the trucks, there will be only 4 passes that will need to be equipped, manned and maintained.
- Since fewer trucks are required, a smaller capital investment is needed. One must, however, bear in mind that the operating costs for the Combi truck are very similar to the conventional truck option.
- This method will promote better utilization of the truck and LHD fleets.
- As mentioned previously, there will be a staggered flow of capital over the life of the project. This reduces the risk of the project, somewhat, because if the project should be discontinued for any reason the full fleet of trucks may not necessarily have been purchased yet.

Disadvantages

- Trucks will be a new ground handling method for Cullinan Diamond Mine. Staff at the mine will require training, and personnel who can operate trucks will need to be employed. Specialist skills for servicing and maintaining the vehicles will also be required.
- The capital expenditure for the Combi truck option will be less than both the train option and the conventional truck option, whereas the operating expenditure costs will be the highest of all three options.
- There will be no surge capacity between trucks and LHDs. Should the crusher stand, the only capacity in the system will be the capacity in the passes and the capacity in the empty bins that are available.
- There are some physical constraints that will play a role:
  - The Combi truck requires more space than a conventional truck, in order to change containers
  - Loading that is done from chutes will have no advantages in the Combi truck case. However, it must be noted that the planned layout will not make use of chutes
  - The Combi truck makes use of a front-wheel drive mechanism, which becomes problematic for steep ramps. Any ramp in excess of 10% will create a problem
  - Spillage when loading.

Analysis and evaluation of results

Table VI is a summary of the four options that were investigated.

Table VI is fairly self-explanatory and has been included to highlight the different capital and operating costs as well as the main advantages and disadvantages of the respective systems. The table shows clearly that the Combi truck option is the most effective in terms of capital investment. The table emphasizes that the main advantage of both the truck options is the increased block height that results in an increased number of carats produced.

Once all the financial details regarding the capital and operating expenditures had been collected, they were used to compile a cash flow. The results of the cash flow calculations have been summarized in two charts. The first graph (Figure 12) is a summary of the CAPEX over the BAW project life.

Note that the ‘Trucks A’ heading in the key refers to the conventional trucks, whereas the ‘Trucks B’ refers to the Combi truck option. The chart clearly indicates that all three options will require high capital investment in the first three years. Most of the capital costs have been spread over the first three years because there will be only waste development being performed in these years. This means that there will be sufficient time to rehabilitate railway lines and install new control systems in the case of the train option. This will also be enough time to establish the tips and ensure that they will be fully operational when the trains begin to operate. Notice that all the capital costs for the train will be invested in the first three years.

The truck options will spread the purchase of their equipment over a longer period. This is the staggered capital cash flow that was referred to in the discussions of the truck options. The first three years will see the installation of the tips and the development of the necessary infrastructure such as workshops. The additional costs for the truck options later in the project are due to additional trucks that will be purchased in those years to accommodate the increase in production.

<table>
<thead>
<tr>
<th>Option</th>
<th>Capital expenditure</th>
<th>Operating expenditure</th>
<th>Main advantage</th>
<th>Main disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Train</td>
<td>R92.4 million</td>
<td>R110.2 million</td>
<td>Provides a solution for eastern rim tramming</td>
<td>Large capital investment over a short period</td>
</tr>
<tr>
<td>2A Truck</td>
<td>R83.9 million</td>
<td>R171.2 million</td>
<td>Additional block height, therefore additional carats</td>
<td>No surge capacity between trucks and LHDs</td>
</tr>
<tr>
<td>2B Truck</td>
<td>R77.8 million</td>
<td>R175.1 million</td>
<td>Higher utilization than for conventional truck option, and additional carats</td>
<td>New technology</td>
</tr>
<tr>
<td>3 Conveyor</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Not enough height between production and ground handling level</td>
</tr>
</tbody>
</table>
The second graph (Figure 13) shows the OPEX over the life of the BAW project. The operating expenditure was found to be significantly different from what was initially expected, and there are a few very interesting trends that can be seen in the graph. It shows that all three models are extremely dependent on the production requirements for any particular year. As expected, the operating costs increase as the tonnage requirements increase. The operating expenditure for the trains seems to increase and decrease linearly, whereas the costs for the truck options are far more erratic. One will notice that there seem to be spikes in the cost figures, particularly in the case of the Combi truck option. This can be ascribed to the fact that the maintenance, tyre and fuel costs can vary considerably between years. For example, there may a particular year where the entire fleet of trucks replaces a set of tyres. In that same year a number of trucks may also fall into a bracket in the variable maintenance schedule, which is particularly costly because of major services that are planned for the allocated vehicles. Notice, in the last few years, that the operating costs for the trucks remain high despite the fact that the production requirements are less.

Table VII shows the inflated capital cost and the net present value, at a discount rate of 15%, for the life of the project.

<table>
<thead>
<tr>
<th>Option</th>
<th>Total capital cost</th>
<th>NPV @ 15%</th>
<th>NPV @ 15%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trains</td>
<td>R98.1 million</td>
<td>R -119.7 million</td>
<td></td>
</tr>
<tr>
<td>Conventional trucks</td>
<td>R97.5 million</td>
<td>R -157.9 million</td>
<td></td>
</tr>
<tr>
<td>Conventional trucks-</td>
<td>R97.5 million</td>
<td>R -39.2 million</td>
<td></td>
</tr>
<tr>
<td>Additional carats</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combi trucks</td>
<td>R85.5 million</td>
<td>R -156.0 million</td>
<td></td>
</tr>
<tr>
<td>Combi trucks—additional carats</td>
<td>R85.5 million</td>
<td>R -37.4 million</td>
<td></td>
</tr>
</tbody>
</table>

The re-engineering of the ground handling system at Cullinan Diamond Mine

Figure 12—A Summary of the CAPEX over the project life

Figure 13—A summary of the OPEX over the project life
The re-engineering of the ground handling system at Cullinan Diamond Mine

In the table it can be seen that the total project CAPEX figures show a similar trend to the CAPEX figures earlier in the report. The only difference is that the figures in this table have taken into account the net present value for each of the options was calculated at a rate of 15%. The values for the NPV are negative because no revenue values have been included except for the additional revenue generated in the two truck options. (These are the two named 'additional carats' in the table.)

Net present values were calculated based on two different scenarios for each of the truck options. The first scenario shows the NPV assuming no additional block height. The second calculation has included the additional revenue gained from the additional block height. It is interesting to notice that for the two conventional truck scenarios there is a R118.7 million (R157.9–R39.2) difference in the NPVs. In both cases where the truck options are assumed to have no additional block height, the train option is more feasible. Based on the results in Table VII it can be concluded that, overall, the Combi trucks appear to be the most economically feasible option. The conventional trucks are very close behind the Combi trucks, with a difference of only R1.8 million in the NPV figures.

Conclusions

➤ A literature study was performed, which provided meaningful information with regard to suppliers and manufacturers. Other mines in the company served as benchmarks to determine what methods and approaches had previously been used for ground handling systems. Current and future ground handling system requirements and constraints at Cullinan were established in order to solve the problem.

➤ Underground site investigations yielded important information on the layout and physical constraints of the current system. The investigations facilitated a better understanding of the problem and highlighted problem areas that needed to be addressed. Determination of cycle times provided a base for calculations around a new train system.

➤ Potential options were identified and compared in terms of physical constraints, practicability and costs. Three options were identified, namely trains, trucks and conveyors. There were two different truck options that were investigated. Options were broken down and evaluated on a number of different levels. These levels ranged from simple data collection to in-depth cost analysis:

- Firstly, it had to be established whether the proposed option would fit into the planned infrastructure. In all cases, this can be achieved with only minor changes taking place in terms of infrastructure.
- The next step was to gather all the costs for each of the proposed options. This cost information was then compiled to determine the most economically feasible option. This resulted in the Combi truck and conventional truck options being found to be the most suitable. It must, however, be taken into account that very little is known about the Combi truck, and because the NPV evaluation of the two options was so close, both have been selected as suitable solutions to the problem. In the same instance, the train would be the most suitable if there were no additional block height for the truck options.

Recommendations

➤ Based on the results, there is conclusive financial evidence to support the selection of a truck-based system. It must, however, be kept in mind that the Combi truck is a very new concept. It is therefore proposed that the Combi truck be researched in far greater detail so as to expose the various advantages and disadvantages of such a system. This would typically be best done by means of seeing the actual truck in action on a site. This will allow time for questions about a range of topics including manufacturing and maintenance contracts and costs. It will also allow for the collection of performance-based data that can be evaluated to determine whether the option is suitable.

➤ The optimum fleet size can be determined more accurately by using an advanced simulation program that can properly simulate the synchronization between trucks, trains and LHDs. This type of program may be able to indicate the most suitable configuration.

➤ The scheduling of the project must be investigated to ensure cohesion between different sections in the mine. This refers specifically to the integration of the ground handling systems of the different blocks. Because of the eastern portion of the mine will continue making use of trains, it is essential that overlapping and integration between the blocks takes place. The BAS will obviously influence the start up of the BAW, but thereafter no other blocks in the western portion of the mine will affect the BAW. The two blocks in the east, namely, the BB1 East and the Advanced Undercut will only affect the BAW for the first few years. The BAW will ramp-up production and simultaneously the other two blocks will reduce their production (as per the life of mine profile) as they remove the last of the B-cut reserves in the east. Coordination among the various parties is therefore essential.

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References


