A conceptual study into optimizing the delivery of trackbound twin ends through trackless mechanized development

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Abstract
The need to move towards faster and safer mine development is a key priority in mining houses globally. In addition to this, South Africa faces an array of challenges introduced by labour-intensive operations; hence a study was conducted to look into improving development rates and labour productivity, specifically in the areas where trackbound flat-end development is required. The aim of the study was to propose a method to deliver fit-for-purpose tracked tunnels that advanced at a rate of one blast per end every single working day. A major part of the study was to optimize the selection of an appropriate trackless fleet and mitigate any constraints introduced with the mechanization. This was done by creating scenarios, based on a typical case study, looking into the aspects around safety, mine design, mine activity cycling, men and machine requirements, service installations, and trackless-trackbound interfaces. The case study was based on a deep-level gold mine developing twin headings with connectings; however, with the move to extend and deepen platinum operations it is foreseen that twin end development will become more prevalent due to ventilation, logistical, and other requirements. With the introduction of the trackless mechanized system suggested, development rates of 56 m of system advance are expected (189 m total development), with an average of three headings and fixed blast times. Scenarios run with multi-blast conditions yield expectations of 75 m/month advance of the system, significantly higher than the conventional performance seen today.

Introduction
The need to increase development rates is not a new challenge, and the benefits from higher development rates are both financial (with a better NPV result) and operational (allowing more flexibility). Additionally, the single biggest barrier to achieving mine call is insufficient face availability; higher rates of development would mitigate this problem. Typically mining activities in conventional mines have been evolving for decades, and development rate and stoping rate were matched to optimize production. However, with more labour and safety constraints, performance has progressively deteriorated.
A step change is needed to achieve the results that the mining houses are now striving towards. It is perceived that this can be achieved through the introduction of a trackless system employing mechanized equipment and ways of working.

Blast rounds in conventional mining are limited by the ability of operators to accurately drill blastholes with hand-held rockdrills. Mechanized drill rigs enable mines to drill longer and more accurate rounds and thus achieve higher rates of advance per blast. More advance means more rock to clean and more support to install. All activities are increased but need to be completed in the available time.

The introduction of trackless mechanized machinery into South African mining operations has been slow and marred by many challenges and setbacks. The focus on safety is a top priority, and mines are looking for ways to remove men from the face and other dangerous working areas.

Additionally, the mine design and its supporting infrastructure is based on trackbound machinery and hand-held equipment. As a result, trackbound mines have been slow to adopt new technology available through trackless machinery. The challenge explored in this paper is how to integrate trackless mechanized mining at a higher rate than conventional mining with operational trackbound rock transport systems.

In small single-end development, trackless equipment has limited application, there is just no space for different pieces of equipment to pass each other, to be parked or maintained. Typically the deep-level gold mines employ the twin-end trackbound development designs. With the platinum mines progressing deeper, the need for twin-end flat development is foreseen to be more widely adopted due to ventilation requirements, man and material transport, safety aspects, and the need to mechanize.

To this end Sandvik has looked into a conceptual study of a mechanized fleet of trackless equipment for flat twin-end development supporting trackbound machinery for production. The study was based on an actual case study from a deep-level gold mine. This paper discusses the details and benefits of such a system, with the aim of applying the lessons learned to future platinum mines. Understandably, the challenge remains in implementing such a change both in an operating mine with an established way of working and to new operations resistant to change.
Objectives

The objective of the case study was to evaluate a new approach to ‘fit-for purpose’ level development of rail/trackbound mines to realize, amongst others, production and safety benefits.

- First and foremost, safety on mines is not only a strategic objective but impacts operations on a frequent basis. The study recognized an array of safety benefits with the introduction of the trackless machines on the case study site
- The system objective was set to achieve one blast per end per day. This entailed the two twin ends as a priority, the footwall (FWD) drive and return airway (RAW), and either the crosscut to the orebody or the connecting
- With further mechanization, the labour productivity is expected to increase, allowing mining houses to better utilize their resources. This aspect is becoming more of a concern with the availability of skilled personnel and more importantly the willingness of people to work in such environments.

Methodology

Based on site studies, information, and observations the following fundamentals were used as a basis for evaluating and selecting the optimal mining system:

- the mine design
- resources (machines, people, time)
- the mining process.

The purpose was understanding and estimating the impact of changes on the mine performance and costs. In order to establish the most optimal state a number of scenarios were tested, resulting in an iterative process shown in Figure 1.
Design details

*Mine design - case study specifications*

The introduction of a fleet of mechanized trackless machinery introduces an array of new challenges and, more importantly, a number of changes in the way the operations are managed, planned, and measured. Ultimately, the new fleet needs to deliver the same ‘fit–for-purpose’ drives with the same dimensions, hence this is established first. The following details relate to the fixed parameters for the study, namely drive dimensions and services. Layouts are addressed briefly but will be discussed in further detail in a following section.
Dimensions

- Haulage dimensions: 3.5 m wide x 3.5 m high
- Crosscut dimensions: 3 m wide x 3 m high

Installed services

- Rails and concrete
- Vent pipe, compressed air, water column, pump column, electrical cables
- Specifications as per mine standards, layout as per Figure 2.

Figure 2-Drive cross-section with dimension and fittings

Twin-end development layout (shown in Figure 3):

- RAW drives and FWD (the priority ends)
- Crosscuts to stoping areas – typically dependent on the orebody and designed stope dimensions, the case used spacing of 160 m apart and the development drive needs to be extended 120 m into the stoping areas
- Connectings - at 90 degrees as the hoppers no longer need to transfer between drives.
Distances between crosscuts have been optimized to 53 m based on a trade-off between:

- loading times within the cycle to ensure the blast
- extra development metres as a result of increased frequency
- ventilation requirements in the drives
- most importantly, considering practical considerations such as machine cycling, logistic storage, and track installation whilst still carrying out operations.

![Figure 3-Development drive case study layout](image)

The constraints in the layout considered when introducing the trackless system are:

1. Distance to LHD-hopper tipping points and the interface between the LHD and hoppers (discussed later)
2. The trackless-to-trackbound interface, especially for the travelling machines. The aim was to reduce, if not completely eliminate, machines travelling on the tracks. The benefit of this is twofold: the loaders are not interfering with the permanent rail construction and are not exposed to the rail infrastructure at speed, fully loaded. For major services the machines will need to travel to the main workshop over the rail infrastructure
3. Blast constraints of faces in close proximity. The standard used was that the faces must be more than 20 m apart, and this has been taken into account when scheduling the connecting blasts and crosscuts.
Mining activities

Each activity is considered separately initially in order to address the mining requirements (planned dimensions and development meters). However when considering mechanized operations no activity occurs without influence of another activity, hence a holistic approach is considered when creating the ‘mining system’.

Drilling

An electro-hydraulic drilling rig provides many benefits from an operational perspective (for the operators) as well as productivity. With the move towards more stringent safety regulations and more influence from the workforce, operating a drilling rig is highly advantageous over the jacklegs. In order to ensure a workforce of the future, these aspects need to be seriously considered.

Figure 4-Drill rig for face drilling and support

The advantage of the conventional drilling crew with jacklegs is the flexibility of the crew to move to different locations and scale up or down in line with specific drilling requirements through merely adding more men with equipment. Additionally, the reliability of the method is very high, and many of the problems encountered can be solved by adding more equipment or people. When applying mechanized machinery, maintenance is of paramount importance. The unavailability of a machine means the activity is completely halted, and this in turn impacts the entire mining cycle. Effective maintenance is essential to reduce breakdowns and unexpected delays. Additionally, the planning of production needs to take maintenance into account, as the machine will be removed from activity for planned maintenance.

A single boom trackless drilling rig with 6/10 foot split feed can be used for both face drilling and for bolting. The machine it is capable of drilling and bolting three ends per day. However, in order to increase flexibility, reduce risk, and allow planned and unplanned maintenance time, two drilling rigs are recommended.
Ideally one rig should be dedicated to bolting and one to face drilling, even though essentially the rig can perform both functions.

The 10 foot feed for face drilling allows an increased advance per blast of 2.8 m. Based on the current drilling data and mine parameters, the total drilling cycle time has been estimated at 3.3 hours (details shown in Table I).

Table I-Drilling cycle time details

<table>
<thead>
<tr>
<th>Face drilling</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of holes</td>
<td>46 holes</td>
</tr>
<tr>
<td>Penetration rate</td>
<td>1 m/min</td>
</tr>
<tr>
<td>Hole length</td>
<td>3.1 m</td>
</tr>
<tr>
<td><strong>Drilling time</strong></td>
<td><strong>142.6 min</strong></td>
</tr>
<tr>
<td><strong>Drilling time</strong></td>
<td><strong>2.38 hrs</strong></td>
</tr>
<tr>
<td>Setup time (per hole)</td>
<td>0.5 min/hole</td>
</tr>
<tr>
<td>Rig up and down time</td>
<td>30 min</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3.3 hrs</strong></td>
</tr>
</tbody>
</table>

**Charging**

Charging-up of the face is expected to take 2 hours. Due to the drive dimensions and charge-up requirements, the following trackless scissor lift options are applicable.

**Fermel Liberator scissor lift**
- Height: 2 000 mm
- Length: 7 400 mm
- Width: 1 900 mm
- Lifting height: 3 900 mm
- Lifting capacity: 6 t

**Normet Utilift 6330X scissor lift**
- Height: 2 300 mm
- Length: 7 800 mm
- Width: 1 800 mm
- Lifting height: 3 500 mm
- Lifting capacity: 3 t

With utility vehicles the charging up process is much safer and easier to carry out. In a 3.5 m high heading the means of charging the holes without proper equipment is a safety hazard. In addition to the discomfort experienced by the operator and safety risk introduced, the charging-up time is expected to be reduced.
Support

The same model of machine used for face drilling will be used for support. Removing the operator from unsupported ground, and providing him with better lift, visibility, and the ability to drill the correct angle of holes are intangible benefits of the drilling rig. Again, the introduction of the mechanized fleet required a change in the way the cycles need to be planned and measured. With two rigs that can bolt or face drill this allows the shift boss flexibility to move machines as desired. The way the mining cycles need to be arranged (discussed in further detail below) ensures that the rig drills the bolt holes and the bolts are installed once the face is cleaned. This eliminates the potential of support not installed to standard, which is possible with the current set-up.

Based on similar operational assumptions to the drilling rig, the bolting rig uses the 6 foot feed length to drill all bolt holes. The total drilling time is assumed to be 1.5 hours (details shown in Table II). In line with current practices, the drill rig only drills the bolt holes; the bolts are installed manually, which is assumed to take a further 1.5 hours. Further potential for improvement exists with the introduction of a mechanized bolter which has recently been introduced into the deep-level gold mines in South Africa. This bolter eliminates the need for any person to work outside the operator’s cabin, since bolts are installed by the machine. However, the challenge is to minimize the fleet composition while maximizing production. If dedicated bolters are used, then the fleet is increased to provide for equipment maintenance and other downtime.

Table II-Bolting cycle time details

<table>
<thead>
<tr>
<th>Bolting</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration rate</td>
<td>1 m/min</td>
</tr>
<tr>
<td>Number of bolt holes</td>
<td>18 holes</td>
</tr>
<tr>
<td>Hole length</td>
<td>2.4 m</td>
</tr>
<tr>
<td>Drilling time</td>
<td>43.2 min</td>
</tr>
<tr>
<td>Drilling time</td>
<td>0.72 hrs</td>
</tr>
<tr>
<td>Setup time (per hole)</td>
<td>1 min/hole</td>
</tr>
<tr>
<td>Setup time</td>
<td>30 min</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1.5 hrs</strong></td>
</tr>
</tbody>
</table>
Loading

The cleaning cycle proposed is one of the biggest changes for the conventional miner to adapt to. The current process with boesman loaders loading onto hoppers, which in turn need to be shunted backward and forward, is hugely inefficient and has a number of associated safety concerns. In addition to this, the numbers of people still willing to work in such conditions are expected to become a problem. Careful consideration was given to the current infrastructure, mining layout, and operational requirements in order to determine a feasible and practical loading alternative.

The constraints introduced with a trackless loader are:

a) Interface between trackless loading and trackbound hauling, additionally allowance for stockpiling to eliminate any waiting time from the loader or hoppers
b) Extra ventilation requirements
c) Interference of the loading cycle with other operations
d) Man-machine interface (width of the loader is larger than the boesman)
e) Distances between loading bays and transfer points need to be managed
f) Dependence on loader availability.

The following review addresses these points and provides an indication of expected productivity based on the trade-offs conducted.

a. Loader-hopper interface

- A transition point arrangement has been devised that eliminates the loader travelling on rails to load the hoppers, removes the need for shunting the hoppers backward and forward, and allows for a small buffer capacity
- The transition point includes a feeder receiving rock from the loader and feeding the hoppers at a constant rate. The feeder provides the height and constant flow rate for the hoppers to ensure that the hoppers are filled correctly and efficiently. The feeder has a capacity of two buckets, which allows a small buffer for the loader. An area for stockpiling is necessary near the transition point when the train of hoppers are being exchanged or to act as a buffer for other process delays. The stockpiling area should be located close to the face being cleaned, in an area out of the flow of any traffic and in an area large enough for all the rock from a blast (Figure 5)
The transition point is located three connecting back from the face to allow space for the train of hoppers to move, to allow the machines space to move freely between drives, and to provide sufficient space for any machines to be maintained or materials to be stored.

Matching to loader, feeder, and hoppers – the feeder acts as a buffer between the loaders and hoppers, hence matching is not necessary. However, if the feeder is unavailable, the loader bucket size should be in line with feeder capacity and hopper dimensions. The hoppers in use at the moment are 2.8 m³. Based on fill factors and heaping factors the LH306E (6 t loader) and LH307 (7 t loader) are most appropriate.

b. Ventilation

Ventilation is challenging and expensive in all operations, especially at the depths the platinum mines are moving towards and given that the thermal gradient in platinum mines is approximately twice that in gold mines. Diesel-powered LHDs generate approximately three times more heat for a rated power output than similar-size electric loaders. Consequently, the efficiencies of using electric LHDs and lack of noxious gases allow far less ventilation for electric loaders.
• Simulation scenarios were carried out with the LH306E (6 t loader) and the LH409E (9 t loader) based on a range of anchor points for the cable and tipping configurations.

• The LH410 (10 t loader) diesel loader has 46 per cent more power output than the LH307 (7 t loader) with their 220 kW and 150 kW engines respectively. This requires a significant amount of extra ventilation, hence power output played a large part in loader selection. The cycle time of the LH410 is expected to be 1.5 hours, whereas the cycle time of the LH307 is expected to be 2.5 hours (for a maximum traveling distance of 200 m one way).

c. Interference of the loading cycle with other operations

• With the introduction of new machinery, new constraints can be expected. The nature of the loading process sterilizes a portion of the working areas due to travel routes. These have been considered in the light of the mining cycle with supporting machines. A notable concern has been raised when evaluating the electric loader, that of the cable management.

• The cable lengths are 200-240 m long (for 525 V supply), which is sufficient for loading and tipping in the layout. However, the location of the tether points posed a problem. A situation arose where the other mining activities would be in operation in the FWD and the loader cleaning the RAW would block access and pose a safety risk for personnel moving around that area. It is for this reason that the electric loading options are not practical at this point. A recommendation for further studies to be done with new technology or new layouts should be considered.

d. Man-machine interface

• Due to the nature and flexibility of trackless machinery, several benefits are realized (better operator comfort, safer working conditions, etc.). However, further considerations need to be addressed. Here we discuss the man-machine interface when considering the loader model.

• The drive dimensions constrain the size of machine capable of operating safely in the mining environment. The LH409E and LH410 are 2.5 m and 2.6 m wide respectively (Table III). This increase in machine width requires more consideration be given to the turning radius, especially in the connectings. Additionally, the machines in general are wider and more mobile than the tracked boesman, and hence could pose an additional safety hazard. To address this, in industry the general rule is to allow 40-50 cm width allowance on each side of the machine, but this is not possible in the connecting drives with the LH409E and LH410.
e. Loader tramming distances

- In the recommended shift setup, a 22 hour working day is available (discussed below), where on average three faces need to be blasted in this time frame. Assuming one blasting time per day, at the start of a shift three faces are waiting to be cleaned, so the longest complete mining cycle occurs on face 3 owing to waiting for face 1 and face 2 to be cleaned. This mining cycle is considered below based on increasing tramming distances to evaluate the maximum distance allowable in order to achieve the development aims (one blast per face per day) with the LH307. At the extremities the loader will be cleaning at the end of a crosscut, so the maximum distance is expected to be 280 m. Figure 6 shows that even with a one-way distance of 300 m the mining cycle is still easily able to be completed in the available time.

![Figure 6-Mining cycle times for varying loading distances for the LH307](image)

- Based on the average loading cycle times, the mining layout, the interference with other mining activities, and especially considering the distance into the crosscuts, simulation scenarios were run for varying connecting dimensions and transition point locations. It was decided that the most optimal connecting spacing was 53 m apart and the transfer point location should be three connectings from the furthest development face (discussed previously). This results in an average one-way tramming distance of 150 m.
f. Loader availability

- In all aspects of mechanized mining operations maintenance plays a significant role in ensuring the machines are cost-effective and more importantly available to perform the required work. This translates to operational planning for planned maintenance where the machine is not available for a whole shift each week and effectively managing machine breakdowns through good communication systems, maintenance skills, and correct tools at the very least. As can be seen from the cycle times in Figure 6, delays in any part of the process are exacerbated due to the limited number of faces and limited effective face time. It is recommended that two loaders are required in order to ensure that one blast per face per day is achieved. This means that an LHD is always available and that the longer cycle times in the crosscut do not pose any additional risks.

<table>
<thead>
<tr>
<th>Table III-Summary of loading details and trade-off parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Loader</strong></td>
</tr>
<tr>
<td>Performance - Total Cycletime for 150m one way</td>
</tr>
<tr>
<td>Loader Capacity</td>
</tr>
<tr>
<td>Bucket Capacity</td>
</tr>
<tr>
<td>Tons per bucket</td>
</tr>
<tr>
<td>Travelling speed</td>
</tr>
<tr>
<td>Fixed time (load, turn, tip)</td>
</tr>
<tr>
<td>Trips per end buckets</td>
</tr>
<tr>
<td>Cycle time</td>
</tr>
<tr>
<td>Machine Dimensions:</td>
</tr>
<tr>
<td>Length</td>
</tr>
<tr>
<td>Width</td>
</tr>
<tr>
<td>Turning Radius</td>
</tr>
<tr>
<td>Constraints introduced:</td>
</tr>
<tr>
<td>KW power</td>
</tr>
<tr>
<td>525 V Cable Length</td>
</tr>
</tbody>
</table>

Based on the considerations discussed and trade-offs conducted the LH307 (diesel 7 t loader) was selected. The ejector bucket is recommended to ensure clean unloading at 3 m height, this bucket has a volume of 3 m³. At a one-way tramming distance of 150 m, the cycle time is 2.1 hours.
This is acceptable, since the drill rig drilling time is expected to be 3.3 hours so the drill rig will dictate the speed of the mining cycle. With at least 50 minutes of slack time, this reduces any risks of not cleaning out the face in the allowable time. However, extra opportunity exists with an additional loader, allowing all the faces to be completed sooner and if an extra face is available (crosscut and connecting) the system has the potential to achieve four blasts.

Service installation

It is essential that the ventilation, meshing and lacing, and service piping closely follow drive development. The assumption is that these activities do not interfere with the primary development cycle, but need to be installed nonetheless. A scissor lift should be purchased to aid in completing these activities safely and effectively. Acquiring a similar scissor lift to that specified for charging allows these two machines to be interchangeable and hence reduces risk if the machine is unavailable, increased flexibility, requires less parts-holding space and skills for maintenance etc. These activities typically occur behind the drill rigs or when the face is waiting to be blasted. An activity cycling diagram has been completed for each activity based on different shift breakdowns, including the extension of services (Figure 10).

Mining sequence

In order to complete the mining cycle in the proposed manner, the following process and practicalities have been proposed:

- During development of the section, only one rail should be installed, the rails must be constructed in the RAW giving easy access to the crosscuts by trackless equipment
- The rails must be extended only as far as two connectings are still available. This gives access to the machines between drives and allows space for stockpiling of the broken rock (shown in Figure 7)
- The tip should be placed in the next closest connecting, which is the transition area for loading the hoppers. The rail can extend beyond the tip to avoid shunting
- Trackbound waste is hauled by the hoppers in the RAW
- To control ventilation, vent walls must be installed in the connectings behind the tip.
Figure 7-Drive layout with initial set-up

After one month of development (estimated to be 56 m system advance) the rails can be extended up until just before the next connecting and then the tipping point can be moved forward. This ensures that there are sufficient routes for the trackless loaders to access the tip without crossing the rails and the tramming distance for the loaders remains in range (see Figure 8).

Figure 8-Drive layout with advancing parameters
After the tipping point has been moved forward, the rails can now be installed in the footwall drive. This allows access for equipping the connectings and the trackbound equipment to the stoping areas, where stoping can begin (see Figure 9).

![Drive layout with rails in the footwall drive](image)

**Figure 9-Drive layout with rails in the footwall drive**

**Resources and logistics**

The following section looks into the resources required to achieve the mining objectives, taking the layout and mining cycles into account.

**Machines**

Mechanized machines:

- 2 x LHDs - LH307 (7 n loader with 3 m³ ejector bucket), to be serviced on day shift
- 2 x single boom telescopic feed DD210s for support and face drilling. Services on afternoon shift
- 2 x utility vehicles used for installing services and charging up
- Feeder for the transfer point to the hoppers.

Existing machines:

- Electric locomotives and at least two sets of hoppers. (Hopper sizes used are the standard: 2.8 m³, 2.5 m wide, and 1.650 m high)
- Flat cars for logistics.
**Maintenance**

The cornerstone of effective mechanized machine utilization is to ensure that machines are serviced on schedule, inspections are conducted daily, and that there is a suitable service facility. The service bay for the mechanized machinery will move with development. These should be equipped approximately three connectings back from the working faces (after the free connecting for access and the connecting for the tipping point). After this connecting becomes available the vent doors should be installed.

**Re-fuelling**

Refuelling of the loaders is to be done from a 1000/2000 litre drum on a flat top on rails. This reduces the lost time due to tramming long distances to refuel points.

Services and rail are extended with development and advance of the RAW and FWDs (to be discussed later)

**Labour**

Labour is a crucial aspect in the mining process and comes with higher and higher risks. The labour component will be discussed next. An important factor in activity cycling is the amount of available working time at the face. The activity cycling has been done on three different shift structures.

The options available are:

**Two-shift set-up:**

- 2 x 8.5 hour shifts and 1 half shift for loading. This allows 22 actual working hours out of 28 shift hours worked in a 24 hour day. The shift times are shown in Table IV below for illustrative purposes. The objective in overlapping shift times is to reduce idle time at the face. This is essential in such deep and extensive mines where travelling time to the working end can take up to one hour.
Table IV - Working times of the two-shift set-up

<table>
<thead>
<tr>
<th>Shift</th>
<th>Shift Times</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Night Shift</td>
<td>10-00pm to 06-30am</td>
<td>8.5</td>
</tr>
<tr>
<td>Day Shift</td>
<td>06-30am to 03-00pm</td>
<td>8.5</td>
</tr>
<tr>
<td>Afternoon Shift</td>
<td>05-00pm to 10-00pm</td>
<td>5</td>
</tr>
</tbody>
</table>

Work face time: 22 hours

Three-shift set-up:

- 2 x 9 hour shifts and 1 x 10 hour shift resulting in 28 hours shift time and 22 hours actual work time.

Multiblast set-up:

- 3 x 10 hour shifts, these are overlapped to allow for changeovers and mining delays associated with SOS and EOS procedures. This results in 30 hours’ shift time and 24 hours actual work time. The major differentiator in multiblast operation is the assumption that blasts can be carried out at any time of the day (ventilation and regulation permitting).

Based on the shift options and mining cycles required, as well as current labour structures, the number of labour required for each shift setup has been estimated. An example is shown in Table V. The total number of people has been estimated to be:

- Two-shift set-up: 43 people
- Three-shift set-up: 53 people (increase due to full afternoon shift)
- Multiblasting: 57 people (4 extra to charge up on all shifts).
Table V: Labour structure for a two-shift set-up

<table>
<thead>
<tr>
<th></th>
<th>Day Shift</th>
<th>Afternoon Shift</th>
<th>Night Shift</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shift Structure - 2 Shifts</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>From below Mine Overseer</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Crew Numbers</strong></td>
<td>15</td>
<td>11</td>
<td>17</td>
</tr>
</tbody>
</table>

**Labour skill** requirement change with the introduction of the mechanized fleet. These higher skills need to be planned for upfront through training (for both mining personnel and maintenance personnel), outsourced, or recruited from outside. It is recommended that appropriate training facilities/programmes are considered to ensure the sustainability of the operations. Special attention should be paid to the supervisors. New skills are required for achieving successful mechanized operations, it is not just a change in the machinery.

**Mining cycles**

Activity cycling simulation scenarios look at the activity cycle times, number of faces, and shift set-up. This allows one to determine the amount of blasts that can be achieved on each face and hence determine the face utilization or potential for improved development performance. Figure 10 shows the activity cycling based on the two-shift setup and highlights the relationship between each activity and the utilization of the face. This has been done for all shift set-up alternatives and run over 6 months.
The focus of the activity cycling is to understand the constraints in the system and to determine the development metres achievable. In the additional columns the services have also been accounted for, these include meshing and lacing, extending ventilation, and extending other mine services (compressed air, power, and water). These are not considered part of the critical path but can occur behind the primary activities.
Typically these services are installed while drilling, bolting, or charging the end. This activity cycles diagram (Figure 10) excludes the connecting development due to the priorities set for the simulation month. Cycle diagrams are applied in line with faces available.

In the activity cycling a number of assumptions have been made, these include:

1. 30 minutes idle time at the start of shift (once already at the face)
2. 30 minutes idle time between activities
3. 2 hour blast and re-entry time
4. One machine is dedicated to drilling, one machine is dedicated to bolting, and one loader is used for loading.

**Development performance**

The mine performance can be determined based on the number of blasts achieved per month on each heading, averaged over 6 months of the simulation. The assumption is the advance per blast is 2.8 m.

![Figure 11-Average meters developed per heading per month](image)

As can be seen from Figure 11, the performance achieved with the two-shift set-up and three-shift set-up is equal. The reason is that the entire mining cycle is able to fit into the available shift time in both instances, but there are no more faces available to work on. Therefore in the three-shift set-up the machines are less utilized (based on working time).
System advance achieved for two- and three-shift set-up is equivalent to 56.7 m system advance per month. In multiblast conditions, this system advance is expected to reach 75 m per month. These performance numbers can be compared to that seen in industry in trackbound operations: numbers in the range of 30-40 m/month are typical (Figure 12).

Figure 12-Development performance per month

As mentioned throughout, not only are there performance benefits but with the increased metres there are labour efficiencies to be gained. Based on the data in Table VII it is evident that labour effectiveness increases by 25% - 54%.

Table VII-Summary of development performance and labour productivity

<table>
<thead>
<tr>
<th></th>
<th>*Conventional</th>
<th>3 shifts</th>
<th>2 shifts</th>
<th>Multiblasting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average metres per month</td>
<td>189</td>
<td>189</td>
<td>251</td>
<td></td>
</tr>
<tr>
<td>Number of people per crew</td>
<td>53</td>
<td>43</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>Metres per man</td>
<td>2.9</td>
<td>3.6</td>
<td>4.4</td>
<td>4.4</td>
</tr>
</tbody>
</table>
Conclusions

With current technology and operating practices, the application of trackless mechanized machines in trackbound infrastructure is possible and practical, offering not only production benefits but also reducing safety hazards and employing labour more effectively and sustainably.

A mind-set expresses concerns that mechanization is perceived to be costly, inflexible, and not reliable in delivering performance. However, with the proposed system these concerns have been sufficiently addressed through the fleet selection and shift set-up where the machines are semi-redundant (for the loading) or dedicated to activities (bolting and face drilling) to allow for effective maintenance and ensuring all processes are completed as scheduled. The proposed fleet would consist of 2 x LHDs, 2 x drilling rigs, and 2 x utility vehicles working in conjunction with the current trains and hoppers.

In the given environment, with two development ends, cross-cuts, and connecting drives, on average three faces are available for the fleet, and the planned system advance is significantly higher than that currently being achieved. According to the simulations, 56 m per month can be expected, and up to 75 m/month in multiblast conditions.

Labour productivity increases by 25-54 per cent, depending on the shift set-up. This has far-reaching implications; not only can the mine generate more development metres with the same workforce, but the workforce is now operating in safer working environment; has a better working environment; and applies higher skills to the task at hand. The job is less taxing and allows the workforce to work longer before becoming fatigued, and remain in a better state (physically and mentally), which in turn has further knock-on benefits.

The major challenge is to allow the machines to perform to their potential, far surpassing production numbers currently seen in conventional development with the same workforce, which necessitates a shift in the mind-set from shift supervisors and above.
The Author

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After graduating from Wits in 2006 I started work as a junior engineer at Sandvik. As an Industrial engineer in the mining industry my role has been to optimise mining productivity through a structured and quantitative. This typically entails the development and application of specific tools and approaches on mining sites globally. I started out applying the tools on strategic customer sites, both locally and globally, as I gained more experience I moved into developing new tools and took on a bigger role within the team and gained more mining exposure. Currently as a project manager I am also involved in customer liaison and feedback, and ensuring the team delivers what the customer expects.