Pre-requisites for safe and effective underground railbound transport
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Synopsis
For all the vagaries of geological facies, structural variety, and mineral content variability, mining remains essentially a transportation industry; mineral-rich rock is removed from its place of occurrence to a place where it can be induced to release its valuable content. Of the methods by which underground transport is conducted, railbound systems are fairly widespread. In the South African gold mining industry, very few mines do not rely at least partially on railbound vehicles. Tramming load in tonne-kilometre terms grows as the mine expands, and problems of interference and congestion develop slowly and perhaps imperceptibly. Sub-optimal performances become accepted by default. This paper reminds readers of the drawbacks which arise from poorly installed infrastructure and describes the improvements in railtrack construction which were developed over several years at the mines where the author held responsibility. Associated improvements in rolling stock design, maintenance practices and locomotive motor design are also described. Having made improvements, the question of how to maintain the installations at the new and improved level of effectiveness is also covered. In conclusion, the effect of the work on personal safety, equipment life and costs is demonstrated through statistical analysis.

1. Introduction
The highest source of injuries arising from accidents underground in mines after falls of ground used to be the tramming activity. About 30% of the fatalities and about 50% of injuries were attributable to this source. They arose mainly from derailments, runaways, unstable trackwork and mechanical failures. Improved performance in this area has been achieved by the combined effect of a number of interventions. The particular situation and the work done at Kopanang mine serves as a case study for other operators on how investment in infrastructure has a pay-off in improved safety and reduced costs. These are both ongoing areas of concern, and while safety can be maintained by adherence to standards, it is the inverse relationship between the life of a mine and its tramming cost that makes cost-reduction particularly important. The relationship is a direct result of the increasing distance over which men, rock and material have to be transported as the workings move away from the point of access. The paper’s relevance is increased by the trend in legal compliance requirements which is pushing users towards improved construction standards.

2. Tshepong work – the “prequel” to the Kopanang initiative
Having first encountered the problem at Tshepong mine during the late 1990s, one of the authors took steps to address it. This background is useful insofar as it provided the basis for the interventions which would later be undertaken at Kopanang. The problem areas identified at that time included:

- unacceptable accident statistics
- excessive repair costs
- insufficient training
- inadequate standards
- absence of control
- sub-standard track conditions
- unclear responsibilities

It should be remembered that Tshepong mine was then still in a build-up phase, and therefore the quality of the railbound transport infrastructure would be an important factor in its ability to meet expectations of output and profitability. The innovations which were made included the creation of a dedicated Mine Overseer’s section to address the work of railtrack rehabilitation and construction, and the introduction of a bonus scheme for specific tramming activities. Hitherto, railtrack installation and maintenance, boxfront construction and tramming had been part of the responsibilities of the production Mine Overseer within whose section the activities took place. The separate responsibilities, coupled with inadequacies in standards, and the priorities associated with production had contributed to the deterioration of the transport infrastructure. Also, tramming crews had merely shared in the production crew bonus at a discounted rate, and construction crews did not participate in any bonus scheme. The influence of the quality of their work on the ability of the production crews to achieve their targets was thereby not being recognised.

The full scope of the dedicated Mine Overseer’s section’s responsibility eventually grew to include;

- boxfront construction
- railtrack construction (to a repeatably high standard)
- suspension of piped service columns
- water control
- electrical substation cubby, refuge bay and ventilation wall construction

Most of the workload consisted of rehabilitation of trackwork. The situation that presented itself was usually the result of work performed by the development crews, with little or no maintenance having been undertaken afterwards.

The installation consisted of permanent rails supported on timber sleepers, which lay on a bed of ballasted rock. Some areas were further constructed with a skin of concrete to assist in drainage and clean-up. Run-off water was collected in drains constructed from pre-formed semi-circular section concrete elements. Water draining out of boxfronts, from leaking pipes and dripping from hoppers added to any natural inflows to create a generally wet and muddy environment in the haulages and crosscuts. Rail geometry was often poor with excessive joint gaps, and variable compaction in the ballast. The rail installation became uneven over time, and the incidence of derailments and accidents rose.

Recognising that corrective action was only part of the task and that preventative maintenance also needed to be addressed; solutions were sought which would provide for low-cost maintenance of the rehabilitated installations. Control of the water received immediate attention through the creation of drains designed to cope with the volumes encountered. This was achieved by casting continuous drain sections of adequate depth. Track stability was addressed by replacing timber sleepers with concrete. By design, the required cant was provided, thereby achieving maximum contact between wheel and rail. Also, cast-in shoulders ensured exact gauge. Stability was enhanced by the mass of the concrete sleepers. Where possible, drain water was piped; elsewhere, drain segments were provided with an overlap to minimise leakage.
were used to replace the precast sections. Ballasting was addressed through training and closer supervision to ensure that the correct rock sizes and depth were installed.

Over a three-year period between 1996 and 1999 the following results were achieved.

<table>
<thead>
<tr>
<th></th>
<th>1996</th>
<th>1999</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accidents</td>
<td>34</td>
<td>15</td>
<td>56%</td>
</tr>
<tr>
<td>Construction productivity (m/crew member)</td>
<td>5</td>
<td>14</td>
<td>180%</td>
</tr>
<tr>
<td>Cost (R/m)</td>
<td>440</td>
<td>273</td>
<td>38%</td>
</tr>
<tr>
<td>Monthly cost of wheel repairs (R)</td>
<td>70 000</td>
<td>54 000</td>
<td>23%</td>
</tr>
<tr>
<td>No. of operating locomotives</td>
<td>71</td>
<td>64</td>
<td>10%</td>
</tr>
<tr>
<td>Tonnes hoisted per month</td>
<td>114 000</td>
<td>141 000</td>
<td>24%</td>
</tr>
<tr>
<td>m² broken per month</td>
<td>24 000</td>
<td>31 500</td>
<td>31%</td>
</tr>
</tbody>
</table>

A letter of commendation was received from the regional Principal Inspector of the DME is recognition of the work.

The main lessons learned from this experience were that:

- such a project required a long-term commitment
- significant improvements were possible in the areas of safety, cost and efficiency performance
- the importance of the work required ongoing reinforcement to ensure motivation

3. Kopanang’s situation in 2001

In common with most business entities, Kopanang conducts an annual strategic planning analysis and review. At the 2001 conference it was demonstrated that without some sort of intervention, the mine would reach a breakeven situation between costs and revenue in 2004, and thereafter would become a loss-making operation. Several initiatives received impetus from this revelation, the most significant of which was the self-directed work team project. That and the so-called “Big Mamma” project have been separately reported on. Another element in the Kopanang rejuvenation which arose from that event was the railtrack upgrade for the rest of the mine, that is other than the upgrade associated with the “Big Mamma” on 70 level. The situation as regards tramming and transport underground at the mine at that time was described by someone who knows about such things as being “in chaos”. Haulages and crosscuts were muddy, derailments were frequent, and the number of operational locomotives was inadequate due to mechanical and electrical breakdowns. Overtime working was a necessity. The voice communications system between drivers and guards was inoperative, either for lack of maintenance or possibly due to sabotage. Morale among tramming crews was low due to the long hours of work and perceived inadequacy of compensation. The production operation was severely hampered by the shortcomings of the tramming and transport facilities, and people were being hurt in accidents. Also, the mine’s return air capacity was constrained, and environmental conditions were unpleasantly hot.

A comprehensive programme was developed to address all of the strategic issues and thereby to extend the mine’s life. For ventilation, ore handling and drainage, it
involved the drilling of thirty interlevel raisebored holes, ranging in diameter from 1.8m to 3.0m, and seventeen interlevel NX holes. This paper covers the work done to overcome the tramping and transport problems and to enhance the effectiveness of that operation.

4. The context of the work
Kopanang mine as it is known today produced its first gold in 1984, shaft sinking having begun six years earlier. The workings extend to a depth of 2200m below surface and principally exploit the Vaal Reef; a secondary reef, known as the “C” reef, is also mined. Stoping is scattered in nature due to the complexity of the geological units and inconsistencies in both their development and their gold-bearing characteristics. It takes place over ten levels. Rock transport has been optimised through the creation of so-called “centre-of-gravity” orepasses. This concept allows the tramping distances from loading boxes to tipping to be reduced by the provision of a tip system nearer to the workings. The strategic plan for the mine involved consolidation of stoping to four mining levels on the southwest of the shaft, and two mining levels on the west side of the shaft. This concentration of production meant that the railtrack quality serving the areas had to be brought up to an acceptable standard if the expectations were to become reality.

5. Elements in the upgrade programme
5.1 Drying the mine
The mine was hot and wet. If any progress was to be made in improving the condition of trackwork, then the worst enemy of footwall construction, namely water, had to be defeated. As part of the centre-of-gravity orepass system, and the work required to improve the return airway capacity, a series of raisebored holes was drilled. Associated with these developments was an improved drain water control system. It comprised a network of NX holes between levels with drain water being lifted into pipe columns at strategic points in haulages and crosscuts on the levels, and dams. The drainholes were drilled close to the mining areas and water is accumulated on two levels, namely 53 level for the upper areas and 70 for the lower areas. From there it is piped to the settlers on 73 level. By not carrying drain water all the way back to the shaft stations, fewer vertical spindle pumps are required and pipe column maintenance is also reduced. Haulages are therefore dryer. The vertical spindle pump installation was improved through the inclusion of a non-return valve and use of a lateral for the inflow into the main column. It incorporated a properly constructed sump excavation which was deep enough to provide positive suction for the pump and which was separated from the drain by a weir behind which mud was trapped. Drains themselves were improved through the addition of bund walls to provide adequate capacity.

5.2 Specialist skills
For the upgraded track on 70 level, where the high-speed high-volume “Big Mamma” was to operate, qualified plate-layers were recruited from South African Transport Services (SATS) to construct the Class 1 rail installation which was required there. Kopanang mine was the first, and perhaps the only gold mine to employ plate-layers.

5.3 Introduction of contractors
At Kopanang mine, the haulages between the shaft station and point at which they turn to a direction approximately parallel to the strike of the reef are referred to as “main” haulages. From that point onwards, they are referred to as “sub” haulages, and
it is from the “sub” haulages that crosscuts to reef are developed. For the work on the “main” haulages, outside contractors were employed to perform the upgrade. It was felt that their experience would ensure a speedy completion of the work in the more important areas of the tramming network. The mine itself undertook the rehabilitation of the “sub” haulages and the crosscuts as well as all new construction through the dedicated section.

5.4 Construction standards
For lack of any existing documents, the standards for construction adopted initially were those which had been developed at Tshepong. Kopanang’s standards at that time only covered the construction performed as part of the primary development activity. However, the passage of time and the influence of local conditions and experience resulted in progressive modifications. This process continues to the present day, adopting suitable technological and design improvements as they arise or are created. The modified standards were assembled into a manual, and this process revealed a number of gaps in existing documentation; for example, no sketch existed of a side-tipper. Subsequently, the manual has been converted into electronic form for simpler updating. The full set of applicable standards contains the following items:

- permanent equipping of a haulage
- permanent equipping of a sub-haulage (the principal difference between the two lies in the concrete support for the rails in the latter)
- permanent equipping of a crosscut (fewer and smaller diameter pipes than in a haulage, and concrete thrown across entire width of the excavation, not just below rails)
- permanent equipping of a crosscut top entrance (ie no rock tramming takes place here, ballasted foundation for rails without concrete)
- compressed air and water reticulation standards (includes pipe and valve sizes)
- drain hole equipping
- vertical spindle pump installations
- arresting devices
- tools and personal protective equipment (PPE)
- equipment and material (as used by construction crews)
- precautions to be taken when working in haulage ways
- track installation
- locomotive safety checklist
- hopper safety checklist
- rolling stock couplings
- development, equipping and use of tramming spurs

The creation of specific standards for construction over and above those being taught to the development crews meant that a purpose-built training facility was also necessary. This has been created, and crew members pass through it on return from leave, thereby learning any changes and updates that have been introduced during their absence. Railtrack maintenance remains the responsibility of the Mine Overseer within the boundaries of his section. Should a problem develop which exceeds the ability of the maintenance crew, then the dedicated section provides assistance in the form of a so-called “uplift crew”. Specific details of the key standards are provided below.

5.4.1 Excavation and construction
To reduce the amount of work required for construction a modification was made to the development drilling round. Previously, underbreak at the footwall meant that sliping was often necessary to create sufficient space for proper ballasting. By increasing the vertical dimension of a development end below the gradeline by 0.3m, a significant improvement in construction labour efficiency was achieved, and thereby the rate of completion was increased. It also overcame the need to load mud prior to the track installation phase of the construction. As shown in the sketch below, each of the four stages of the work are completed at a progressively reduced dimension between rail height and gradeline.

Figure 1: Stages in track installation

Temporary track is installed 2.1m below the gradeline; jumpsets are placed 2.0m below it; temporary track is lifted a further 0.2 metres and the permanent installation is 1.5m below it or 300mm above the temporary track. To put this into context, a fully equipped haulage is also illustrated.
5.4.2 Sleepers, trackwork and ballasting
As has been mentioned, the condition of trackwork is a reflection of the environment in which it has been constructed, and of the quality of the workmanship that went into it. The main factors are:

- uncontrolled water
- inaccurate geometry
- excessive joint gaps
- poorly compacted ballast
- quality of maintenance

Figure 2: Permanent equipping of a haulage
Most of these factors can be controlled by good supervision, correct design and adherence to standard procedures. However, none of them can compensate for inadequacies in the materials used, and so it is the components themselves which should be correctly specified and matched to each other. If careful selection of the components can also achieve the aim of low maintenance, then in terms of overall cost per tonne transported, some sort of premium can be justified when evaluating the prices of competing alternatives.

5.4.2.1 Sleepers
Aside from the environmental aspects of consuming hardwood at an unsustainable rate, wooden sleepers have been superseded by concrete for a number of reasons. Chief among these is the ability to design characteristics into the concrete sleeper to meet the requirements for an efficient and low maintenance installation. The so-called 10-tonne pre-stressed concrete sleeper possesses the following advantages:

- its mass provides stability
- pre-stressing provides it with durability
- the moulded construction ensures that sleepers are identically shaped
- casting provides built-in cant for better wheel contact and less flange wear, therefore enhanced traction and extended wheel life
- casting ensures exact gauge
- gauge widening can easily be catered for through the use of gauge plate inserts
- connectors can be installed more efficiently than dogspikes; a resilient pad provides a damping effect to reduce vibration

The enhanced accuracy of installation around bends through the use of gauge plate inserts also results in fewer derailments. To address the requirement for stability at switches, the spacing of sleepers near the fishplate joints was reduced from 25cm to 20cm with good effect. 13 sleepers are installed per 9m length of track. Figure 4 below illustrates this.

5.4.2.2 Rail attachments and rails
Pandrol clips were used to attach the rails to the sleepers, but in their original design, a derailment could have the effect of tearing many of them loose. A design modification has reduced this possibility. The Mineclip has replaced the Pandrol. It is shown in the photograph below.

![Illustration of a Mineclip](image-url)
Fishplate bolts are now installed with spring washers and not locknuts. Not only is this a cost-saving, but the problem of them becoming loose over time is also reduced. The construction standard covering this aspect is included below.

30kg/m rail is the smallest size that can effectively be applied in a main tramming environment. It will work with the 10-tonne sleeper, fishplates fit the web well and joints can be properly supported.

5.4.2.3 Trackwork
The turn radius for crosscut breakaway rail switches was changed after it was
determined that excessive wear on hopper wheel flanges was attributable to the short (4,8m) switches which were being installed. A decision to replace them with 6m switches was made, but initially without taking the excavation dimensions into account. To achieve the necessary clearances, several crosscuts needed sidewall slipping. The modification to the standard was effective in reducing the wheel flange wear rates, but it shows that all aspects of a change need to be considered before the final determination is made, if it is to be implemented without any unexpected outcomes. Where sharp radius curves are unavoidable, rail flange lubrication provides a reduction in wear, and thereby enhanced safety.

Figure 5: Rail turnout installation

### 5.4.2.4 Ballast
Ballast provides for stability of the railtrack installation, distribution of the load, some
elasticity and drainage. The size range of the material should be small enough to guarantee that point loading cannot occur. The material chosen should be easy to maintain. Rather than utilise the randomly sized product from development, long-term benefits have been enjoyed using 25x50mm washed ballast.

5.5 Equipment improvements
Close attention to the construction activity inevitably brought the rolling stock into sharper focus. Changes and improvements were made to buffers, couplings, lubrication seals for hopper wheels, and the lubricating grease itself, as well as to the locomotive motors.

5.5.1 Hopper axles
Axle failures were found to be the result of water and mud ingress into the wheel bearings. Over a trammimg distance of the order of 6km bearings became hot. If they were then plunged into cold water due to uneven trackwork and poor drainage, and the water became mixed with mud, a very effective grinding paste was then created with severe wear resulting. A more effective seal, used with a more tacky grease produced a measurable reduction in the number of axle failures. In addition, protective platework has been added as shown in figure 6. The wheel bearing is enclosed by a strap; splash plates and a bottom plate serve to reduce the accessibility of water to the wheel bearings.

![Figure 6: Additional protective platework for the hopper wheel bearings](image)

5.5.2 Hopper buffers, shackles and pins
Until 2003, hoppers were fitted with “Kudu” type buffers. These have a relatively large number of components, and require more maintenance than simpler designs. A semi-automatic coupler, known as the “Bison” is being introduced as a replacement. It consists of a solid casting and the latch is an integral part of it. Manual operation is required to release the pin, but connection takes place when the shackle is pushed into the body, thereby removing the latch which then drops the pin into place under
gravity. A reduction has been noted in hand and finger injuries, and less maintenance is required than on the “Kudu” type. To date, 800 of the 1100-strong hopper fleet have been converted.

![Modified buffer showing components](image)

**Figure 7: Modified buffer showing components**

In the illustration below, the carrying handle of the shackle and the sling suspension for the pin are shown. These provide protection from hand injuries during the coupling operation

![Shackle being coupled to buffer](image)

**Figure 8: Shackle being coupled to buffer**

### 5.5.3 Trunnion plate

Prevention of finger injuries was also the driving force behind a modification to the trunnion. The addition of a plate effectively prevented fingers being inadvertently caught in it during hand-shunting activities
5.5.4 Bucket stoppers
Overtipping of the bucket is prevented by the addition of brackets.
5.5.5 Hopper repair process
Minor hopper repair had been undertaken underground, but breakdown repair was
dealt with as on off-site activity performed by contractors. The length of time that
hoppers remained out of use in this arrangement resulted in a reluctance to send them
for repair. Thus leakage of mud and ineffective rock transport was widespread.
Following the establishment of a hopper repair facility on surface, the off-site
contractors were replaced with the labour force already in service and a scheduled
service-exchange system was introduced. Initially, it was provided for the stoping
sections, but it has since been extended to include the development sections as well.
Apart from the expected improvement in rock transport effectiveness, that is from
trains running with a full complement of hoppers, there is less spillage and haulages
are cleaner as a result. Measurable financial benefits have also accrued as shown in
the tabulation below.

<table>
<thead>
<tr>
<th>Cost elements</th>
<th>On-site</th>
<th>Off-site contract</th>
<th>On-site advantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour</td>
<td>R1483</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material</td>
<td>R9867</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>R11350</td>
<td>R22000</td>
<td>48%</td>
</tr>
<tr>
<td>Turn round time</td>
<td>1 day</td>
<td>3 days</td>
<td>66%</td>
</tr>
</tbody>
</table>

5.5.6 Surface mock-up
Included in the surface repair facility is a mock-up of an underground tip. It serves
two purposes. Refurbished hoppers are tested on it before being passed by the quality
control process for deployment underground. It is also used for training purposes.

![Surface mock-up of a tip](image)

Figure 11: Surface mock-up of a tip

5.5.7 Locomotive motor improvements
Kopanang ran a fleet of about 120 locomotives in 2002. Arising from water ingress,
bearing and armature failures meant that about twenty motors per month were having
to be replaced. In addition to the changes already described which were improving the
environment, some modifications were also made to the 75D locomotive motor.
These were a conversion to a 12-ball bearing on the drive side; a breather to draw off
carbon dust from the brushes which had an additional effect of cooling the motor;
changing the brush gear from spring-feed to constant-feed which provided better
contact on the commutator and longer brush life; a field coil conversion utilising a
more water-resistant resin and longer service interval. The effect of these changes has
been to reduce the number of motors requiring replacement to six per month, and it has been possible to reduce the fleet size to 109 due to greater efficiency.

5.5.8  Locomotive wheels
No modifications were made to locomotive wheels; however longer life has resulted from the improvements to the railtrack installation and to the changes in the standards, for example, the longer switches.

5.6  Piping
Steel pipes previously used for chilled water, drain water and compressed air in main haulages have been replaced by UPVC. Not only is the internal friction lower, but the lack of corrosion means that they need to be replaced less frequently, and having less mass they are easier to change.

5.7  Safety practices
A chain placed across the entire width of the haulage, from which a “stop” sign is suspended has been introduced as a replacement for the portable sign which was erected between the rails. This was the response to the realisation that the portable sign was not easily seen by locomotive drivers, and a number of injuries had resulted from collisions. As a further precaution, track maintenance crew members retire to cubbies before a train is allowed to pass them, rather than merely standing beside the track. Haulage maintenance also includes making safe the sidewalls and hanging by barring and this work is performed by the construction crews.

6  Results
Monthly hoisting at Kopanang is of the order of 200 000 tonnes, although up to 265 000 tonnes has been achieved. Only about 40 000 tonnes per month of this total is waste rock. Simple arithmetic provides the result that each underground locomotive moves on average about 1800 tonnes per month, or about 80 tonnes per day. Over the course of the changes and improvements, the number of derailments has reduced by about 30% and a dramatic reduction in the number of accidents has been achieved. To indicate the scope of the work within which these achievements have occurred, the table below shows what has been done.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main haulage metres upgraded</td>
<td>30 870</td>
</tr>
<tr>
<td>Sub-haulage metres upgraded</td>
<td>22 990</td>
</tr>
<tr>
<td>RAW metres upgraded</td>
<td>690</td>
</tr>
<tr>
<td>Crosscut metres upgraded</td>
<td>19 240</td>
</tr>
<tr>
<td>Total</td>
<td>73 790</td>
</tr>
</tbody>
</table>

The reduction in accidents is shown below.
Figure 12: Safety performance

Loco and hopper wheels and motor repairs are described in the following graphs.

Figure 13: Locomotive wheel repair history
In average cost terms, these achievements are represented in the following summary.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hopper wheels</td>
<td>120</td>
<td>100</td>
<td>90</td>
</tr>
<tr>
<td>Rate per unit</td>
<td>R 2 800</td>
<td>R 2 800</td>
<td>R 2 800</td>
</tr>
<tr>
<td>Average cost per</td>
<td>R 336 000</td>
<td>R 280 000</td>
<td>R 252 000</td>
</tr>
<tr>
<td>------------------</td>
<td>-------------</td>
<td>-------------</td>
<td>-------------</td>
</tr>
<tr>
<td></td>
<td>month</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Locomotive wheels</td>
<td>Average number per month</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Rate per unit</td>
<td>R 6 000</td>
<td>R 6 200</td>
</tr>
<tr>
<td></td>
<td>Average cost per month</td>
<td>R 84 000</td>
<td>R 62 000</td>
</tr>
<tr>
<td>Locomotive motors</td>
<td>Average number per month</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Rate per unit</td>
<td>R 22,143</td>
<td>R 28,000</td>
</tr>
<tr>
<td></td>
<td>Average cost per month</td>
<td>R 310,000</td>
<td>R 280,000</td>
</tr>
<tr>
<td></td>
<td>Average total cost per month</td>
<td>R 730 000</td>
<td>R 622 000</td>
</tr>
<tr>
<td>Improvement year-on-year in Rand terms</td>
<td>15%</td>
<td>15%</td>
<td></td>
</tr>
</tbody>
</table>

The savings have been achieved as a result of investment in improved trackwork, but for a full financial analysis to be performed, the savings attributable to the improved safety performance would also have to be included. Suffice to say that this work, together with the other initiatives has enabled Kopanang to extend its profitable life for at least another nine years.

7. Conclusion
The completed work in comparison to the conditions encountered before the exercise began is shown in the following illustrations. Through the description of their experiences, the authors have attempted to demonstrate the beneficial effects of.

![Figure 16: “Before”](image-url)
installing and maintaining good trackwork. At Kopanang, it has improved the safety performance and has contributed to the extension of the mine’s profitable life. It has been achieved through the creation and development of site-specific, simple and effective standard procedures, designed to meet the local challenges. As many of these are not unique to this location, it should be possible for other operations to utilise this experience for their own benefit. The single most important lesson learned is that it is necessary to predetermine requirements and to design to meet them in a consistent way. Mismatched selections will not just fail, they can also be hazardous. The benefits arising from safe and effective railbound operations outstrip the costs.

Figure 17: “Before”
Figure 18: “After”

Figure 19: “After”
Reference
Fourie FJ and Gibbs GR: Developments in the successful implementation of concrete sleepers. AMM (SA) 1999.
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