departments is not possible without the availability of personnel vehicles (land cruisers). These vehicles are extremely versatile in that they carry personnel, explosives, spare parts and other mining material anywhere in the workings and are relatively inexpensive to purchase and operate.

**Equipment Performance**

Basic planning parameters for the major units for this operation are as follows (assuming two shift operation only):
(a) Monthly production from L.H.D. units can be expected to be for a 2.7 m³ unit and a 3.8 m³ unit 8 000 tons and 11 000 tons respectively.
(b) Assume 12 000 tons/rig/month (face drill rig).
(c) The 18 ton dump trucks can be expected to tram 8 000 tons per month; 32 ton dump trucks 12 000 tons per month. These tonnages assume a one-way tramming distance of 1 000 metres with a decline.

In determining the above parameters, a mechanical availability of 85% and a utilisation of 80% have been assumed; for definitions of these terms refer to Appendix 1.

**Legal Permissions**

In terms of the Mines and Works Regulations it has been necessary to acquire certain legal permissions regarding the use of trackless equipment; some permissions being detailed below:
(a) Mines and Works Regulation 16.104

Use of a telescopic basket boom of the roofbolter and the utility vehicle as a lifting machine for raising and lowering persons.
(b) Mines and Works Regulation 9.20.1

Conveyance of explosives in the underground workings in a land cruiser truck.
(c) Mines and Works Regulation 18.4.2

Regular conveyance of persons underground in a land cruiser truck.
(d) Mines and Works Regulation 9.20.1 and 9.20.3

Conveyance of explosives in the basket of the utility vehicle required for charging up operations.

**Workshops and Maintenance of Equipment**

Effective maintenance of equipment is a prerequisite for a successful mechanised operation and in this respect mining managers have the key role; if managers do not provide for the necessary workshops before the operation commences and do not provide back-up to the responsible engineers' maintenance programmes, the project is certain to fail. It is the responsibility of mining managers to enforce discipline and supervision throughout the operation.

Mining and engineering personnel must work as a team and it is imperative that the senior manager in charge of operations is committed to this goal.
Underground Workshops

For the successful introduction of mechanised equipment for stoping operations there are certain definitive phases which link development and stoping operations with workshop construction and these phases are as follows:

**Phase 1**

Where machines are stripped on surface and re-assembled underground as in a South African gold mine, it is essential that an assembly bay be constructed at the entrance to the mechanised section (or at the end of the track system); this bay will also provide for maintenance facilities for the initial equipment necessary to develop the first workshop.

**Phase 2**

Development of the workshop facilities is carried out with minimum equipment; this workshop will be adequate for Phase 3.

**Phase 3**

During this phase the necessary development to enable stoping operations to commence and the extensions to workshops (for additional stoping equipment) will be completed.

**Phase 4**

The additional vehicles for the stoping operation to build up to full production will be transported underground.

**Phase 5**

Full stoping operations commence with full workshop facilities available for the total fleet of equipment.

**90 Level workshops**

Workshops have been designed for the full fleet of equipment and because it is underground captive equipment (as is almost certain to be the case in other South African gold mines) adequate facilities for major overhauls and replacement of sub-assemblies have been provided for. Figure 11 shows the general layout of workshops; Figures 12 and 13 show details of No. 1 Workshop and No. 2 Workshop respectively.

**Diesel fuel supply**

Situated in immediate proximity to the workshops are two 9 m³ service fuel tanks. Diesel fuel is pumped from a surface storage tank (23 m³) down the Auxiliary Shaft to 90 Level (660 metres depth) into an intermediate storage tank (9 m³) or batching tank from which tank the diesel fuel is transferred in a 3200 metre pipeline to the service tanks at the workshops; all pipelines in the system are 25 mm diameter. The purpose of the batching tank is to obviate the necessity for high pressure piping for the 3200 metre pipeline; to enable the 660 metres pipeline (in the shaft) and the 3200 metre pipeline to be drained by acting as a sump following the completion of the transfer of a batch of fuel.

The system is automatic in that the desired quantity is pre-set on
a meter at the surface storage tank. Figure 14 details schematic arrangements.

**Maintenance**

Maintenance of all the equipment is carried out strictly in accordance with planned schedules and in this respect it cannot be over-emphasised that strong discipline must be exercised over the operators and mining supervisors to ensure that machines are made available when required.

Notwithstanding the above, supervision of the maintenance programme by the appointed foreman in charge and the responsible engineer must be of a high standard.

Reference is now made to matters where specific attention is necessary.

(a) Drifter Maintenance

All maintenance of equipment takes place in the underground workshops, with the exception of the drifter overhauls; this work is carried out in a dust-free atmosphere in a surface workshop designed for the purpose. Spare drifters should be kept to a minimum, but at Cooke 2 it is necessary to provide for additional spare drifters because of the logistics of the operation; spare drifters must be kept available in the underground workshop in order to avoid delays as the time taken to obtain a drifter from surface is prohibitive.

(b) Artisan Training

Certain types of trackless equipment have been in operation in South African mines for many years (even on gold mines L.H.D. units have become common). However, the introduction of specialised equipment, such as the electro-hydraulic drill rig, in recent years, demands a complement of rig fitters who have acquired specialist training with this equipment.

Experience at Cooke 2 has proved that this specialised training with the necessary experience can be obtained and the electro-hydraulic drill rig can be maintained to achieve mechanical availabilities (Appendix 1 for definition) in excess of 85%.

However, the present problem is to retain the services of such specialist fitters for stoping operations when higher rewards (bonuses) can be obtained at other mines where development bonus incentive schemes are in operation and where trackless operations have just been introduced. It is, therefore, considered vital that bonus incentive schemes for artisans working in production operations be approved in the immediate future; such a scheme being linked to performance.

(c) Spares

In order to maintain high mechanical availabilities with specialised trackless equipment, it is imperative that adequate spare parts are immediately available on the mine. If it is considered that an electro-hydraulic drill rig is responsible for a production call of 12 000 tons per month it is axiomatic that downtime waiting for spare parts to be located is totally unacceptable and, therefore, a stores system must be introduced for mechanised mining which is streamlined when compared
to the present system for conventional mining.

In addition to changes to the mine store infrastructure, it is necessary that the responsible engineer be aware of any limitations on the part of the supplier of the equipment or his agent and in this respect regular contact is essential; in the early stages of a mechanised operation frequent meetings between the supplier and the responsible engineer are vital.

TRAINING (OPERATOR AND SUPERVISORY)

Training of operators to an acceptable level of competence and establishing driver (operator) discipline is a further prerequisite for the success of any mechanised operation; without this factor being satisfactorily resolved costs will be allowed to escalate out of control because of the abuse of, and damage to, vehicles.

In recognition of this problem at Cooke 2 Shaft, an early appointment (before any equipment went underground) was that of a Mechanical Equipment Supervisor (M.E.S.); the person appointed as M.E.S. had previous experience with mechanised equipment and, in addition, he completed several training courses (including hydraulic courses for artisans) presented by the suppliers of the equipment.

The M.E.S. has a legal appointment in terms of Mines and Works Regulation 18.2.2.(c) in that he is delegated by the responsible engineer to test the competence of any driver before issuing such a person with a licence.

In terms of an instruction from the senior manager, the M.E.S. has the authority to select and train all operators; to promote or demote any operator if he should deem it to be necessary.

The authority wielded by the M.E.S. therefore provides for a strong basis for establishing driver discipline.

Selection of Operators

Before qualifying for training, any potential operator (novices preferred) must satisfy the M.E.S. of the following requirements:

(a) Have an educational standard of a least Standard 6, with a Dudec rating of 1 - 5.
(b) Pass the mechanical ability test and the Putco (aggression) test at the R.E.G.M. Training Centre.
(c) Prove he does not suffer from defective sight or hearing.
(d) Prove that he can read and write an official language to an acceptable standard.

Training of Operators

Under normal circumstances training will commence on the most simple vehicles and progress through to the most complex equipment; the stepped programme would be firstly a dump truck, then to L.H.D. units and, finally, the electro-hydraulic drill rig. At the outset of any project this programme is not relevant for obvious practical reasons.
Again, in order to promote driver discipline, before training actually commences, the trainee is unequivocally informed that any incompetence or lack of consideration for the condition of any vehicle could lead to immediate removal from the training programme.

In general the basic stages of the training programme are as follows:

Stage 1

Using a checklist each component of the machine is shown to the trainee and the various functions of the components are explained to him.

Stage 2

The trainee is instructed how to start the machine after carrying out the pre-check list; all gauges being indicated and explained.

Stage 3

The trainee is instructed how to drive the machine. When the M.E.S. is satisfied as to the competence of the trainee, he will test and pass the trainee under operating conditions. During the training programme the trainee will satisfy the M.E.S. that he understands the contents of all the modules which form a sequence in the training programme; the various modules being signed off during the training period by the trainee.

Supervisory Training

It is an unacceptable situation to provide for operator training without similar training for immediate supervisors. It is not a requirement for a supervisor to be able to operate a machine to the level of competence of the appointed drivers, but they must know how to operate the machine and understand the basic functions and, in addition, be aware of abuse to the machine by the operator; if these skills are not acquired then the supervisor cannot supervise efficiently.

Management Responsibility

It is the responsibility of mining managers to control, manage and direct operations and, therefore, the onus is on such managers to gain the necessary engineering technical knowledge to enable them to manage effectively.

In addition to the basic training programmes outlined above, it is essential for management to document and enforce standards for mechanised mining; special instructions for trackless equipment have been introduced at Cooke 2 Shaft.

LABOUR EFFICIENCIES

Non Common Wage Scale (N.C.W.S.)

Current labour planning in conventional wide reef stopes is of the order of 9 tons/N.C.W.S./shift (stope labour only), and generally this efficiency is being achieved. In comparison, the planned efficiency for the trackless operation is 23 tons/N.C.W.S./shift at the planned production of 40 000
tons per month; the objective being 29 tons/N.C.W.S./shift at the objective tonnage of 50,000 tons per month with no increase in labour and equipment. The efficiency of N.C.W.S. labour for the operation through the build-up period has been monitored and is shown in Figure 15.

Overall planned and objective efficiencies for total N.C.W.S. labour (mining and engineering) are 16 tons per shift and 20 tons per shift respectively; Figure 16 shows a graph of performance to date.

**Common Wage Scale (C.W.S.)**

The C.W.S. labour efficiencies (mining and engineering operating labour and supervisory to mine overseer level) are 83 tons per shift (planned) and 104 tons per shift (objective); Figure 17 shows a graph of performance to date.

**EQUIPMENT COSTS AND OTHER EFFICIENCIES**

In a mechanised operation it is vital to establish from the outset a system of records for costs and efficiencies, including individual machine costs.

A planning officer (responsible directly to the senior manager) compiles a monthly report on all equipment costs and efficiencies for the mechanised operation and certain aspects are discussed as follows:

**Overall Equipment Costs**

Monthly and progressive costs are prepared (by a manual system) for all individual vehicles and groups of vehicles. The progressive costs to date compared to the costs submitted in the project motivation report are as follows:

<table>
<thead>
<tr>
<th></th>
<th>Rand/Tons</th>
<th>Progressive to December, 1985</th>
</tr>
</thead>
<tbody>
<tr>
<td>L.H.D.</td>
<td>1,00</td>
<td>0,95</td>
</tr>
<tr>
<td>Rig (Engineering)</td>
<td>0,95</td>
<td>0,87</td>
</tr>
<tr>
<td>Drill String</td>
<td>1,10</td>
<td>0,94</td>
</tr>
<tr>
<td>Drifters (1)</td>
<td>–</td>
<td>0,30</td>
</tr>
<tr>
<td>Trucks (3)</td>
<td>(0,60)</td>
<td>–</td>
</tr>
<tr>
<td>Utility Vehicles</td>
<td>–</td>
<td>0,03</td>
</tr>
<tr>
<td>Land Cruisers</td>
<td>0,18</td>
<td>0,02</td>
</tr>
<tr>
<td>Tyres (2)</td>
<td>–</td>
<td>1,01</td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td><strong>3,23</strong></td>
<td><strong>4,12</strong></td>
</tr>
</tbody>
</table>

N.B.: (1) Included in rig costs.
(2) Included in equipment costs.
(3) Not included in total costs of R3,23
Current costs may appear high, but cognisance should be taken of the following:

(a) Motivation report costs were estimated in late 1984 money terms and since then spares costs have increased significantly, primarily due to the continued deterioration in the exchange rate of the rand.

(b) The motivation report costs were estimated at the planned production rate of 40 000 tons per month but the current production from the operation is only 22 000 tons per month due to the constraints of the ore clearance system (construction of the main tip for truck tipping is not yet complete).

(c) The introduction of trucks to the operation will reduce the overall costs for the reason that trucks are less expensive to operate than L.H.D. units and the present tramming distances of the L.H.D. units are excessive (L.H.D. units are tramming the reef from the face to the train).

(d) Tyre costs are excessive at present mainly due to the present necessity for ramp development. Tyre costs will be reduced in 1986, with the introduction of a roadbed grader; the commencement of stoping operations; less ramp development.

It can, therefore, be confidently predicted that the commencement of stoping operations will cause a reduction in total actual equipment costs.

**Individual Machine Costs (Spares)**

Monthly and progressive spares costs are plotted in graph form for each individual unit, including drifters, the objective being to determine at what point in time costs for an individual unit start to escalate; this information is essential for scheduling of future equipment overhauls.

**Monthly Costs (General)**

Detailed monthly and progressive costs are monitored for individual machines for diesel and lubrication; tyres for groups of vehicles; drilling equipment, bits (new and re-sharpened), drill steel, couplings and shanks being recorded separately.

**Tyre Records**

All new tyres are branded with a number and a record is kept of the history of each individual tyre (a separate record card for every tyre) until the tyre is scrapped; scrapped tyre record cards are retained for statistical use.

The tyre record card provides for the branded number, make, size and manufacturer's serial number of the tyre; date fitted to a machine, machine number, wheel position and machine hourmeter; date removed, machine hourmeter reading when removed and reason for removal (re-tread, damage, puncture etc.)

A tyre survey is carried out monthly by the tyre contract company and a detailed report is submitted to the mine; this service is considered to be an important management tool.
**Future Records**

A policy of monitoring costs (and life) of major sub-assemblies has been introduced; during the life of any machine, major sub-assemblies are changed on the unit and it therefore becomes necessary to capture this information for control purposes. Each bucket has now been given an individual number and costs and life are now being recorded in the same manner as for tyres. The system will be extended to engines, torque converters, transmissions and all other sub-assemblies.

It is considered that, with the introduction of a computerised planned maintenance system (soon to be introduced at Cooke 2 Shaft), detailed information on all sub-assemblies can be made available.

**WORKING COSTS**

A comparison of calculated working costs for a conventional wide reef operation and the mechanised (trackless) operation is given below; these costs are for a 40 000 tons per month operation and do not only represent stoping costs, but include certain ancillary operations (tramming and other haulage work) in addition to stoping.

<table>
<thead>
<tr>
<th>Operation</th>
<th>Rand/Ton Conventional</th>
<th>Rand/Ton Trackless</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development</td>
<td>1,28</td>
<td>0,16</td>
</tr>
<tr>
<td>Stoping</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drilling</td>
<td>3,46</td>
<td>3,10</td>
</tr>
<tr>
<td>Breaking</td>
<td>2,20</td>
<td>1,67</td>
</tr>
<tr>
<td>Cleaning</td>
<td>4,16</td>
<td>3,06</td>
</tr>
<tr>
<td>Support</td>
<td>1,50</td>
<td>0,58</td>
</tr>
<tr>
<td><strong>TOTALS:</strong></td>
<td><strong>12,60</strong></td>
<td><strong>8,57</strong></td>
</tr>
</tbody>
</table>

Difference in favour of a trackless operation is, therefore, R4,03 per ton, (say) R4 per ton.

*Argument for financial justification*

The mechanised (trackless operation) on the E8 Reef at Cooke 2 Shaft is considered economically viable for the reason that working costs will be less than for a conventional operation; because the Cooke 2 Shaft system is working at its hoisting capacity the significant reduction in waste development rock broken will allow for an increase in hoisting capacity of reef and, therefore, provide for additional revenue.

In terms of the above monetary benefits D.C.F./N.P.V. calculations have shown the mechanised operation to be economically viable.
SAFETY

It is axiomatic that in wide orebody mining operations where conventional labour-intensive methods of mining are employed, it becomes more difficult to maintain safe working conditions as the mining height increases. However, where mechanised mining is practised in such circumstances, the safety of persons at the face is improved with the use of equipment designed for the conditions.

Further, there is evidence to show that accidents from falls of ground are reduced significantly in highly mechanised operations compared to conventional mining due to the reduced labour complement working in the mechanised operation.

During the 1983/1984 period, when conventional wide reef mining was first introduced at Cooke 2 Shaft, many serious accidents occurred from falls of ground, drilling and roof bolting operations and when persons fell from ladders and drilling platforms in wide reef stopes.

During the twenty month period from April, 1984, to November, 1985, (the trackless operation commenced in April 1984), thirty-three accidents were recorded in conventional wide reef stopes (for 1 378 000 tons production) and in the wide reef trackless operations (250 000 tons production) four accidents occurred during the same period. In terms of the estimated costs of accidents (R17 000 for a reportable accident and R2 000 for a lost time accident) it can be calculated that the cost of accidents in the trackless operation was R0,09 per ton compared to a cost of R0,19 per ton in the conventional stopes for this period.

Notwithstanding the above, the use of large, highly mobile mechanised equipment, with poor driver discipline and operators not working in accordance with laid-down standards and procedures, can cause very serious and often fatal accidents. Many of the working instructions issued to operating personnel and the various modules in the training programmes are directed towards safe driving techniques.

CONCLUSIONS

The wide reef mechanised (trackless) operation at Cooke 2 Shaft is considered to be technically successful.

Productivity has shown consistent improvements during the build-up to full production, which is expected to be achieved in early 1986, and when full scale stoping operations commence at that time it can be confidently predicted that a very high output per manshift will be achieved.

Notwithstanding the sharp increase in spares costs, working costs for the operation can be expected to be considerably less than for the conventional wide reef stopes and this difference can only be expected to increase as the cost of N.C.W.S. labour escalates with time.

The trackless operation has proved to be a safe method of mining for wide reef conditions, with a notable improvement in the accident rate.

However, the above benefits can be negated if management control is
not effective and dynamic; mechanised mining demands that a 'hands-on' management style is adopted. Some factors contributing to improved management control are offered as follows:

(a) The continuous influence of the M.E.S. on operating standards and driver discipline and support of the function of the M.E.S. by the senior manager in charge.
(b) The necessity for high standards of engineering maintenance work and the provision of adequate workshop facilities for engineering artisans at all stages of the operation.
(c) The commitment by mining managers to the engineering function.
(d) The realisation by mining managers, who are now responsible for a mechanised (trackless) operation for the first time, that they are still on the learning curve; highly mechanised well-managed operations appear to be straightforward but, if the operating controls have not been understood, any attempt to introduce mechanisation at a rapid rate will cause costs to spiral upwards and out of control.
(e) 'Hands-on' management necessitates the daily control of all aspects of the operation by the senior manager in charge.

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REFERENCES

APPENDIX I
DEFINITIONS OF AVAILABILITIES

L.H.D.'s and Trucks
Available Hours = 23 hours per day (three shifts working with one hour for daily maintenance allowance)
Availability = (Available Hours — Engineering Downtime) + Available
Utilisation = Meter Hours worked + (Available Hours — Engineering Downtime)

Drill Rigs
Available Hours = 15 hours per day (two shifts working with one hour for daily maintenance allowance)
Availability = (Available Hours — Engineering Downtime) + Available Hours
Utilisation = Percussive Hours worked + (Available Hours — Engineering Downtime)
FIGURE 2
Cooke 2 Shaft — Section 'A' — 'A1' through N1 line
FIGURE 3
Trackless room and pillar mining method (general stope configuration)