PROJECT GEN10
94/02/0
1994 PROJEC
PROPOSA
Page 1 of

PROJECT GEN109

PROJECT LEADER
G S Harper

PRIMARY OUTPUT
Recommendations for a detailed programme of development for remote control systems for underground mining equipment.

HOW USED?
As the basis for preparing a programme of work to develop a suite of remotely controlled equipment for underground mines in South Africa.

BY WHOM?
Mine management, equipment developers and manufacturers.

CRITERIA FOR USE
The recommendations must be based on an indepth review of current technology world wide and should propose the use of appropriate, existing technology, where possible, matched to the SA mining environment and personnel.

POTENTIAL IMPACT
Remotely controlled equipment will remove, or drastically reduce, the need for workers to enter potentially dangerous areas thereby reducing the number of accidents in these areas.

OTHER OUTPUTS
Nil.

ENABLING OUTPUT
ENABLING OUTPUT AND METHODOLOGY

MILESTONE

DATES

1 A comprehensive survey of existing remote control technologies for free steered vehicles and mining equipment.
1.1 A world wide literature search of existing remote control systems for free steered vehicles and mining equipment.
1.2 Review of mining operations to identify where remote control of vehicles and mining equipment should be applied.

Apr 94

2 A report outlining a future work programme.
2.1 Analysis of information from 1.1 and 1.2 above to identify potentially suitable techniques.
2.2 Prepare a report outlining a future work programme.

May 94
There are many situations in mining where it would be preferable to have the operator divorced from the equipment that he is to use because of the potentially hazardous mining situation. This requirement pertains particularly to mining situations where the preferred mining method is block caving or wide reef mining. In these mining layouts there is need for a suite of remotely controlled equipment to:

- drill the blastholes,
- charge up the blastholes,
- clear the ore from the stope,
- remove the fines from the stope, and, possibly
- provide a view of the face to be drilled or surveyed.

There are currently many systems available for the remote control for vehicles and equipment, both World Wide (USA and Europe may be the primary applicants of this technology) and in South Africa. It is proposed, therefore, that an indepth survey of available technology be carried out using the various information systems available to Miningtek. In parallel to this search, existing and potential mining layouts for large ore bodies will be reviewed and evaluated to identify the type of vehicles and equipment that would be required in a "remotely controlled mining system".

Based on the information derived from the above exercises, appropriate technologies will be identified that could provide the degree and range of control required for the situations where such control is essential; should no suitable technology be found then proposals for developing it would be prepared. The technology that is identified must take due note of the personnel required to operate and maintain it, the environment in which it must be used and the equipment that it will control.

The output of this, the first phase of the project, will be a report that recommends a programme of work to:

- design,
- manufacture/purchase, and
- evaluate

a remote control system for an L.H.D.; this technology will then form the basis of remote control systems for other equipment as necessary.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Project staff costs</td>
<td>45 500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating costs</td>
<td>5 000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital costs</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collaborators</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value Added Tax</td>
<td>7 100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Project Cost</td>
<td>57 600</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>COLLABORATORS</th>
<th>ACTIVITY</th>
<th>1994</th>
<th>1995</th>
<th>1996</th>
</tr>
</thead>
</table>
SAFETY IN MINES RESEARCH ADVISORY COMMITTEE

SIMRAC

Final Project Report

Title: DEVELOP REMOTE CONTROL SYSTEM FOR MINING EQUIPMENT

Author: Dr V A KONONOVA

Research Agency: Division of Mining Technology of CSIR

Project No: GEN 109
Date: May 1994
SUMMARY

It is widely recognized that remote control of mining equipment can provide safe mining operations and, in some cases, increased productivity. The objective of this report is to clarify various issues pertaining to remote control of mining machines, demonstrate some specific aspects of its various forms of application and recommend a detailed programme of future development for South African mining industry.

The term "telecontrol" has been introduced into this report as a broader classification for any kind of "non-on-board control", of which remote control is one form.

A review of mining industry applications of telecontrol from around the world is presented. Different views and aspects of telecontrol are discussed and a method of evaluating the safety and efficiency of telecontrol is proposed.

It is shown that the effectiveness of telecontrol applications depends very much on the associated mining, technological and human factors which, if not accommodated appropriately, can completely negate any safety and productivity benefits. Different ways of preventing these factors from arising with telecontrol application in South Africa are given and ways of developing telecontrol for the mining industry are proposed. A new method of remote control for continuous miners and recommendations for the further customization are also presented.
CONTENTS

SUMMARY

1. INTRODUCTION AND DEFINITION OF TERMS
   1.1 Telecontrol as a Factor in Increasing Safety. 1
   1.2 Terminology
       1.2.1 Stand-off control 2
       1.2.2 Advanced stand-off control 2
       1.2.3 Limited remote control 3
       1.2.4 Remote control 3

2. COMMUNICATION CHANNELS FOR TELECONTROL 4
   2.1. Physical Line Systems 4
       2.1.1 Hoses and electrical cable. 4
       2.1.2 Machine trailing power cable. 5
       2.1.3 Fibre optic communication link 7
       2.1.4 Safety and physical links 8
   2.2. Wireless Systems 8
       2.2.1 Radio. 8
       2.2.2 Infrared 10
       2.2.3. Safety of wireless systems 12
   2.3. Combined Systems 12

3. MINING OPERATION AND TELECONTROL 12
   3.1 Hazardous Zone and Safety Efficiency of Telecontrol 12
   3.2 Longwalling 14
   3.3 Continuous Miners and Roadheaders 15
   3.4 Gathering Arm Loaders 16
   3.5 Load Haul Dump Machines 16
   3.6 Drilling and Charging 20
   3.7 Other Operations 21

4. AVAILABLE TECHNOLOGY. 21
   4.1 Stand-off Control 21
   4.2 Remote Control 22

5. FACTORS INVOLVED IN UNDERGROUND TELECONTROL
   APPLICATIONS IN THE SOUTH AFRICAN MINING INDUSTRY 23
   5.1 Present Situation 23
   5.2 Mining and Technological Factors 23
   5.3 Human Factors 24
   5.4 Installation Costs 25

6. TELECONTROL DESIGN CONSIDERATIONS 25
6.1. Safety. 25
   6.1.1 Intrinsic safety 25
   6.1.2 Flame proofing 26
6.2 Environment 26
6.3 System Design Concept 26
   6.3.1 Generic consideration 26
   6.3.2 Ergonomics 28

7 RECOMMENDATION FOR DEVELOPMENT OF TELECONTROL FOR
   THE SOUTH AFRICAN MINING INDUSTRY 28
   7.1 Generic Requirements 28
   7.2 Coal Mining. 29
   7.3 Gold Mining. 32

8 CONCLUSIONS 32
1. INTRODUCTION AND DEFINITION OF TERMS

1.1 Telecontrol as a Factor in Increasing Safety.

In order to remain competitive and profitable, mining industries around the world have expended considerable effort on increasing safety and productivity. In the last twenty years meeting these objectives has involved, inter alia, mechanization and electronic control of the many mining activities. Levels of technological sophistication differ significantly from country to country and depend on the economic situation, mining methods and labour forces.

British research has shown that mining is the most dangerous occupation, with an estimated risk index of 8.3 on a scale of 10. Apart from the very hostile environmental hazards such as dust, high temperatures, rockfall and other natural phenomena, developments aimed at increasing productivity continually alter the nature and extent of hazards.

A significant trend towards an increased incidence of accidents in high technology mines was noted in the 1980's [1,2]. Even if the frequency of some types of accident was reduced, their severity often increased [3]. Increased levels of mechanization have frequently introduced additional restrictions to human mobility at the working place, an area which has always been notoriously confined. At the same time, the relocation of the operator from on board a machine to a location under a supported roof and away from dust, noise and vibration in some cases can increase safety.

Despite more than 70 years of commercial use of mining machinery underground, most of equipment still involves local control whereby the operator manually controls a machine from on-board or from an adjacent ground position using the on-board controls. Remote control of equipment has been under consideration for some 30 years and the main purpose remains the same, namely the increased safety and productivity of labour. Implementation of remote control in world coal mines provided a 95% reduction in accidents involving mining machines and a 50% decrease in the total number of fatal accidents. In addition to the increased safety, average increases of productivity of about 18% have been achieved [1].

Any further improvements to be obtained through better machine control will involve the application of high technology that already exists in other industries. This will require extensive cooperation in R&D between the mining machinery and equipment manufacturers, mining companies, mining houses and associated areas of industry. An example of such development is the "Intelligent Mine Technology Programme" that has been under way in Finland since 1992 and is due for completion in 1996. The main purpose of the
Programme is to improve safety, productivity and profitability of mines. The Programme consists of twenty-eight R&D projects with a total cost of $12 million and includes remote control and electronically programmed modes of operation for drilling and LHD machines [4]. Two different departments of the U.S. Bureau of Mines have also been involved in R&D in the field of mining machine telecontrol and computerized control for at least the last two decades.

1.2 Terminology

Although the term "remote control" has been acceptable nomenclature for any non-on-board method of control in the past, at present, "telecontrol" is becoming accepted as a far more appropriate and descriptive term for the diverse array of systems that have been developed over the last two decades for non-on-board control in mining industry. Accordingly, this is the predominant generic term used throughout this report.

The principal methods of telecontrol for underground mining applications referred to in this report are defined as follows:

1.2.1 Stand-off control

This refers to the use of a portable controller, whereby an operator can control a mining machine only within a line-of-sight range and relies solely on his own visual and auditory senses to monitor operational activities directly. The operator is usually within a range of 4-6 m. Safety and productivity are strongly dependent on the ability and common sense of the operator. The costs of installation and operation are low [1,5,6,7].

Only minor changes to the machine are required.

1.2.2 Advanced stand-off control

An operator controls the machine from within his range of visibility using information about crucial machine conditions, such as position of cutting boom, depth of sump, etc., which is supplied via a display on-board the machine which is sufficiently bright and large enough to be seen by the operator up to 10 m away, or from a display built in to the portable controller. It should be noted, however, that adding the display and a second channel, to accommodate two way communication, to the basic stand-off control system will lead to an increase in the size and weight of the portable controller and may result in the operator being distracted from potentially hazardous conditions.
From an engineering point of view, this method incorporates two practically independent systems: the same telecontrol system as for the stand-off control and a monitoring system which will include transducers, a monitoring unit and a display. Information from the monitoring unit could also be used for some on-board closed-loop machine control functions [1].

Significant changes to the machine will be required.

1.2.3 Limited remote control

Limited remote control provides for the relocation of the operator out of the hazardous area without requiring the introduction of significantly different technology for example in the continuous miner (CM) situation. One of the results of this report has been confirmation of the viability of this method for South African collieries and it is, therefore, described in more detail in 7.2.

1.2.4 Remote control

This method of telecontrol enables mining operations to take place without the permanent presence of miners in a section. This concept involves control from beyond the range of visibility and, as such, can place the operator at any distance from the machine that will ensure his safety, including on the surface where maximum safety and ideal working conditions can be established.

Lack of sensory information for the operator can be overcome by using video, audio and other relevant systems obtaining information from sensors on the machine which is transmitted via communication channels to the remotely positioned operator's site. If necessary, this information may be processed before being presented to the operator. The same or separate communication channels can be used to transmit control instructions back to the machine. Some instructions can initiate on-board pre-programmed control functions.

Significant changes to the machine, and additional equipment and technology will be required.
2. COMMUNICATION CHANNELS FOR TELECONTROL

Telecontrol systems can incorporate various types of communication channels between the control station and the controlled machine or equipment. Appropriate examples are as follows:

- physical line (hydraulic hose, hard wires, electrical or fibre optic cable, machine trailing power cable)
- wireless (radio, infrared, ultrasonic)
- combined, (using physical line and wireless channel)

The main factors which have to be taken into consideration when selecting a particular channel are as follows:

- method of telecontrol
- type of machine to be controlled
- mining conditions and associated constraints upon technology that can be utilized
- presence of other locally or telecontrolled machines in the same area
- level of mobility of the machine
- electromagnetic compatibility of telecontrol with other systems used in the vicinity

2.1. Physical Line Systems

2.1.1 Hoses and electrical cable.

The first remote control system for mining machines using hydraulic drives used a pilot line from a portable controller incorporating manual pilot valves. Such umbilical control systems are still in commercial production [6].

When an electro-hydraulic interface (set of solenoid valves), is installed on the machine hard wires or cables can be used between the machine and a controller which uses buttons and toggle switches [5].

The practical limit on the length of a control cord for a stand-off control is 5-10 m.

Advantages

* low cost and simplicity
Disadvantages

* restriction of operator's movement
* safety limitations (2.1.4)

2.1.2 Machine trailing power cable.

This concept involves the use of the trailing machine power cable as communication medium for telecontrol. Three different methods of using a trailing power cable are available:

i) Direct galvanic connection through the pilot cores of a power cable.
   This is the oldest method of electrical communication used and is based on the use of pilot cores for controlling remotely positioned switch gear from a mining machine. Later, pilot cores were used for the transmission of encoded control and monitoring signals for mining machines.

   At present time, not all countries intrinsic safety standards permit the use of pilot cores as intrinsically safe circuits, in which case special protective units, at both ends of the cable, have to be used to protect pilot core circuits against high voltages which are induced under normal conditions and could be applied directly following a cable fault or mechanical breakdown. This method requires modifications or redesign to include flameproof enclosures. Hence, this method is not recognized as being widely acceptable.

ii) High frequency carriers injected into the main or pilot cores of power cables

   A high frequency carrier is applied through a capacitor to the main or pilot cores of the power cable. This method was used by the former Mining Research and Development Establishment (British Coal) for their system 7000 prototype [8] and Balmoral Technology (Australia) developed a colliery information system using a power cable as a 2-way communication channel [9]. The blocking capacitor, however, has to comply with an intrinsically safe standard. The incorporation of the capacitor also requires the modification of the flame proof enclosure.

iii) High frequency carrier induced in the power cable or a steel rope
Clip-on inductive antennas which can be clamped around both sides of the trailing power cable or steel rope at the machine and the switchgear. The main difference from a conventional radio system is the antenna and propagation medium.

Test were carried out where a signal was induced into the trailing cable of a continuous miner and retrieved at the switchgear end. The results demonstrated that communication was possible over a distance of 200 m. The system was based on a non-intrusive method of coupling that was developed by COMRO. The same method was used by CERCHAR (France) in remote control and shearer automation systems developed in 1982 [10] and has been used in the Russian LIRA radio control system since 1974 [1]. In the UK a communication distance of 2.5 km was achieved [11].

This is a highly attractive method as it provides quick in-mine installation of a communication channel and offers the following features.

**Advantages**

* Depending on the choice of the operating frequency, the electrical noise is low. In some cases the signal to noise ratio was better than 100 dB.

* As an existing power line is used, there is no need for any extra cabling for the communication system. The influence of atmospheric moisture and dust has therefore no effect on the propagation path.

* The installation of the system is fast and easy, it only involves the clipping of the antennae around the trailing power cable. It needs no modification of flameproof enclosures.

**Disadvantages**

* The antenna used to couple into the power cable is more complex than for normal radio systems. This would increase the cost of a system.
2.1.3 Fibre optic communication link

With the establishment of affordable maintenance systems and expertise, the price of optical fibre systems is starting to compete with conventional signal transmission systems. With the advantages offered by optical fibres, it is foreseen that they will eventually replace most copper wire systems. There are two options for the successful utilization of optical fibres as a communication medium:
- a separate optical fibre cable;
- including the optical fibre in the power cable of the equipment. These type of cables are becoming more readily available.

Advantages

The advantages are discussed with respect to the relatively severe conditions experienced in mines.

* Optical fibres are fabricated from glass or plastic and are therefore electrical insulators. This makes them ideal for communication use in an electrically hazardous environment as they create no arcing or spark hazard.

* As an optical fibre forms a wave guide, signals are free from electromagnetic interference, radio interference or electromagnetic pulses from switching transients. This characteristic allows the use of optical fibres in electrically noisy environments.

* Cross-talk between fibres is negligible, even if many fibres are cabled together. It is thus possible to combine the power cable and the communication link.

* Cable structures have been developed that are flexible, compact and extremely robust. By installing the optical fibre in the power cable, an extremely rugged communication link can be achieved.

* Modulation of several gigahertz over a few kilometres, without the intervention of electronic repeaters, is possible. The information carrying capacity of optical fibre systems is far superior to the best copper cable systems or wide band radio systems.

* At present, optical fibre cable is reasonably competitive with coaxial cable, although not yet with simple copper wires (eg.
twisted pairs).

**Disadvantages**

* The electrical to optical and optical to electrical interface units are more expensive than the driver and receiver units used in copper cable systems. The use of an optical fibre channel would require alterations to existing flame proof enclosures.

* The maintenance and installation equipment will be costlier by far if compared with the soldering iron and crimping tools necessary for installation of copper and/or coaxial cables.

2.1.4 Safety and physical links

A physical link between a portable controller and a mobile machine was used in the first commercial application of stand-off control for mining machinery. This method of stand-off control can comply with machine control requirements but at the same time the umbilical control limits the freedom of the operator and physical damage to the cable is a frequent problem [6]. A few cases have been registered where a control cable has been caught by caterpillar tracks or armed conveyer pads and an operator has been dragged under or into a machine when the portable controller was fastened to the operator's body [1]. This method of stand-off control, therefore, can not be recommended for permanent control of a mobile machine unless some special measures were implemented. For installations which are immovable during the production cycle, such as a drilling rig, umbilical control is applicable.

Application of fibre optic communication links with the trailing power cable as a communication medium would be recommended for remote control.

2.2. Wireless Systems

2.2.1 Radio.

The first attempt to use a radio waves in mines took place in the 1920's. Today, radio stand-off control systems have several underground mining applications, notably for longwall, thin seam continuous miners and LHD machines. Without some form of
"waveguide" such as cables, rails, steel ropes or pipes, a radio system cannot provide for long distance out-of-sight control. In most cases a "leaky feeder" installed throughout a mine can provide reliable remote control links between a control suite and a mining machine.

Radio control system production is limited. In the USA, only approximately 15 shearers and continuous miners per year have been manufactured with radio control. An annual world production figure for radio control systems for mining application is unlikely to exceed 50-60 units. In the former USSR during the period 1970-1990 only 240 radio control units were produced [1].

Advantages

* It is easy to install, and only minor modification of machinery is required.

* Maintenance costs are moderate.

* It provides reasonable ruggedness and does not restrict day-to-day mining operations.

Disadvantages

* Propagation of radio waves is unstable. Propagation depends on:
  - wavelength
  - cross-section of mining development or face
  - kind of rock and coal and moisture contents
  - rock/coal stress
  - conductive structures along propagation path.

* The electromagnetic field in a gate cross-section or near a machine chassis is unstable. Even a loose bolt on a machine in the immediate vicinity of the receiver antenna may be a source of interference and a cause of dropouts [6].

* Cross activation is possible. Cross activation is defined as the response of a radio controlled machine to a radio signal not directed to that machine [2,12,13].

* A stand-off control system may cost as much as 10% to 15%
of the total machine price [6]. Reliable long distance remote control needs a costly leaky feeder.

* Siting restrictions: In a coal mine a leaky feeder has to be installed in the intake side of the ventilation system otherwise performance of a feeder will be reduced due to coal dust deposited on the cable surface. This is not a problem in longwall panels as the feeder will be deployed along a main gate.

As room and pillar sections are very mobile, consisting normally of at least 7 roads of which some could be used for intake or return ventilation alternatively, using of leaky feeder do will come to interaction with normal coal mining operation. There are no restriction on the use of a leaky feeder in non coal mines.

2.2.2 Infrared

In the mining industry, infrared radiation as an open communication channel has been used since the late 1970's. In France it was used for automatic reversing of a mining plough, while in Germany infra-red communication was used for the telecontrol of monorail haulage systems. In the United Kingdom infra-red communication was used for coal face alignment and powered roof support initiation. In the former USSR the first research in propagation of infrared radiation in underground mines started in 1978 and commercial production of infra-red stand-off control systems for LHD machines, loaders, roadheaders and shearers began in 1982. About 350 infra-red control units for stand-off control have been manufactured in the former USSR [1].

Research and practical experience has shown that even without special optical devices, and despite the presence of coal dust up to a level of 100 mg/m³, a total LED radiation power of 200 mW can give reliable transmission distances of 30-40 m without a problem. A single lens at either the transmission or receiving side will increase the distance to 60-80 m. Due to the reflection of infrared radiation from road and pillar surfaces, as well as scattering at coal/rock dust particles, control is possible even without a direct propagation path between the infrared transmitter and receiver.

In stone dusted roadways or non-coal mines, the surface reflects 40% of incident 0.95μm radiation and an out-of-sight transmission distance of 10-15 m can be achieved. If a coal only surface is present which reflects only 6-8% of radiation, a distance of 2-4 m could be expected.
Both, line-of-sight and non-line-of-sight transmission distances are longer in non-coal mines.

The distance of non-line-of-sight control is dependant on parameters such as:
- transmitted optical power
- sensitivity of photo-receiver
- optical direction of transmitter and receiver
- mutual orientation of transmitter and receiver
- roadway cross section
- reflection coefficient of road/pillar surfaces.

**Advantages**

For stand-off control an infra-red channel has the following advantages:

* Fully independent of mining or technological conditions. If operator can see the machine it can be controlled at any condition within transmission range.

* High level of electromagnetic interference immunity and compatibility with other electronic and electrical equipment exists.

* Low cost.

* Harmless for human health.

* Deliberate delimitation of the control area is possible.

**Disadvantages**

* The non-line-of-sight communication distance is short and screening of direct infrared signals by moving equipment and personnel is possible. Using two or more spatially separated transmitters or receivers could prevent this problem.

* Cross activation is possible.

* Periodical cleaning of transmission and receiving windows is needed.
2.2.3. Safety of wireless systems

Special attention has to be paid to design of radio and infra-red control systems to avoid cross activation. An underground mine in Ontario, Canada, reported at least one fatality in 1989 due to a radio cross activation [12].

Using different separate frequency channels in the same work area is essential to prevent interference. A new concept of a smart wireless control to prevent cross activations has recently been proposed [12]: each component of a wireless control system is assigned its own ID code at the factory - these ID numbers will be never used again. This allows the user to interchange machine and operator units without compromising the security of the wireless channel. To exchange the codes an operator connects a short cable between a portable controller and a machine unit. After about a second, the exchange or learning is complete and the system can be used in wireless mode. This operation must be done when any part of a system is changed.

2.3. Combined Systems

In some special cases a combination of physical and wireless communication channels can bring new features to stand-off and remote control.

A physical communication link between a remotely positioned control console and the vicinity of a controlled machine is established. The machine's end of the line is then equipped with an appropriate adapter which provides wireless communication with the mobile mining machine. Such a combination caters for machine advances of 40-60 m without any need to extend the physical line [14].

3. MINING OPERATION AND TELECONTROL

3.1 Hazardous Zone and Safety Efficiency of Telecontrol

A potentially hazardous zone can be defined around all mining machines. For most machines, such as a continuous miner, loader, drill rig, roof-bolting and LHD machines, it extends to at least 1 m beyond the machine chassis and even further around the cutting boom. Therefore, the extent of this zone depends on the machine's dimensions. It occupies an area $S_H$ (see Fig.1) and moves with the machine.

Understanding of this zone is very important in evaluating an operator's
safety. In the case of an operator activating on-board controls from a local ground position, the operator is always within the hazard zone due to the machine design. In the case of an operator using a stand-off control, the operator will mainly work from beyond the zone although he may enter it for various reasons such as for better observation. It is, however, quite evident that a stand-off control significantly reduces the exposure of the operator to hazards in this case.

Theoretically, an operator can occupy any position in an area $S_c$ (see Fig. 1) determined by the available road width and the transmission distance of the portable controller. The ratio of $S_H$ to $S_c - S_H$ gives a priori probability $P_H$ of the operator's presence in the hazard zone. Given the different machine and road widths, this probability will be within the range of 0.1-0.25. This means that the likelihood of an accident occurring will be at least 4-10 times lower with a stand-off control than with a local ground position of the operator when he is always in the hazard zone.

![Machine](image.png)

**Figure 1**: Hazardous $S_H$ and Control $S_C$ zones

This is a conservative estimate of the reduction of the hazard and, in practice, operators occupy positions 3-6 m away from the machine for 80% of the time [1,15]. The results of five years monitoring of extensive use of stand-off controls on gathering arm loading machines indicated a reduction in
accidents associated with these machines of 95% which was 2.5 times the rate of reduction in total mine accidents in working areas [1].

3.2 Longwalling

Coal mines and particularly longwalling may be regarded as the most technically advanced method of coal extraction at the present time. A few fully electronic faces in Australia, Germany, UK, USA, France and CIS can run without any permanent presence of miners in the face or with only one miner in the face at a time. These faces can be operated in a remote control or an automatic mode. Control systems for such faces consist of at least two highly sophisticated systems: the first being the shearer control and the second being the roof supports control systems which are synchronized with the machine initiation. Although this represents the state of the art in terms of mining technology, it can only be used in coal seams which comply with stringent requirements.

Shearer operators working with local control arrangements are exposed to dust, noise and vibration and damage to the hands and face from flying coal or debris from the cutting drum. In thick strata falling loose coal from the roof or face can also cause accidents. In the USA 184 accidents involving shearer operators were reported during 1978-1980 [6]. About 35% of accidents in longwalling in Russia during the 1970's involved shearer operators and could have been eliminated through the use of telecontrol. Ordinary stand-off control is highly suitable in this case as it enables an operator to take a position away from the drum and within the protected area of the roof support legs. The freedom of movement provided to the operator by a stand-off control can also bring distinct operational advantages such as improved horizon control due to better observation.

For many years different kinds of umbilical control have been available from most USA shearer manufacturers. More than 50% of longwalling in that country is therefore now equipped with stand-off control features, 60% of which are radio control systems [6]. Umbilical control is not appropriate in thick seam operations where the operator has to travel between the front and rear roof support legs. In this instance radio or infra-red control provides a better alternative.

Full remote control of longwall was introduced in France by CERCHAR in the Lorraine Colliery in 1984. The TELSAFE-CA system provided remote control of the shearer from a surface control station.
3.3 Continuous Miners and Roadheaders

For continuous miners working in thin seams an operator normally assumes a local ground position as no cab is available on the machine. In the USA the level of accidents involving continuous miner operators working from local ground positions reached 1451 in 1979, 13 of them fatal [16]. Most accidents happened under an unsupported roof. Simple wireless or umbilical stand-off controls capable of reducing this problem in thin seams became available in the USA in the early 70's [5]. As an example of the problems, a CM's operator working in the local ground position mode would have to turn his head more than 180° to observe the coal cutting area in one direction and the process of shuttle car loading in the other. This would impede performance with respect to both processes. With the use of a stand-off control, an operator need only observe about 90-100° which provides improvements to both the cutting and loading processes [5]. Stand-off control has thus found successful application in USA thin strata operations.

For on-board operator positions, particularly with robust cabin designs, the level of accidents is much lower and the problems are limited to dust, noise and vibration. Relocation of an operator to the ground with a portable stand-off control unit cannot improve safety at all as the operator becomes exposed to the hazards of moving shuttle cars and, in fact, moves into the hazard zone. The main disadvantages of stand-off control, in this case, are the very reasons for considering telecontrol in the first place: safety is very often compromised because the operators often use their additional freedom to try to achieve better observation of the working zone than they would have with local or on-board control. As a result they often move into the hazard zone. Reported examples include roadheader operators straddling the cutter boom. They explained that this position enabled them to increase productivity and provided better accuracy of tunnel shape through better observation [1].

The introduction of stand-off control systems with infra-red communications can improve safety in this case [1]. Proper positioning and orientation of the photo-receivers on a machine can preclude the possibility of controlling the machine from dangerous places [17].

Since 1979 the U.S. Bureau of Mines has been working on different methods using remote control to enable the relocation of machine operators a few hundreds metres away from a face. Two departments investigated several methods. The so called THMS (Teleoperated Highwall Mining System) was developed in 1988 and successfully tested in Marion Country (West Virginia) in 1989 [7].

The THMS consisted of a remotely controlled thin-seam Jeffrey 102HP continuous miner, a Jeffrey continuous haulage system, a remote control and monitoring system and a remotely positioned operator's cabin. The 102HP
was chosen because the cutting auger is slumped into the face by hydraulic rams, while the whole body of the machine remains stationary - this increases the static coefficient of friction between the fixed crawlers and the floor by more than 50% [5]. Therefore, the precise depth of sump can be determined by measuring the hydraulic jack stroke. The CM was equipped with an electro-hydraulic interface, eleven transducers including a microphone, a flame-proof enclosure with an intrinsically safe power supply and a microprocessor control unit. The operator controlled the CM and major functions of the haulage equipment using two colour TV monitors, a control panel and stereo headphones or speakers to control the highwall system. Mining proceeded along two entries that were extracted to an average depth of 37 m.

3.4 Gathering Arm Loaders

Loading machines with gathering arms normally have no place for an operator's cabin and the operator works from a local ground position. The main causes of accidents on such loaders are the operator being trapped against a side wall or the tracks running over the operator's feet. Analyses of 96 reportable accidents which occurred during 1980-1984 in headings in Ukrainian collieries showed that 38 were associated with loading machines. Extensive introduction of infra-red stand-off control for loading machines reduced this figure to 2 accidents during 1986-1990 [1].

With a stand-off control an operator usually occupies a position behind the loader near the end of machine conveyer. Besides the safety improvement a 17% increase in productivity was achieved due to:

- better control of the loading process that led to the elimination of manual floor cleaning
- better trimming along side walls.

3.5 Load Haul Dump Machines

A noteworthy success has been achieved in LHD automatic control. It must, however, be noted that telecontrolled and autonomous LHDs are not expected to be faster than conventionally operated LHDs, but rather to have higher utilization rates [19,20].

Operation of LHDs can be divided into phases:

Load:

- LHD orientation for loading
- drop a bucket
- drive into pile
- machine and bucket shuffle to fill bucket
- pull back

Haul load:
- drive standard route to dump
- define tipping point and stop

Dump:
- lift bucket
- rotate bucket and dump load
- lower bucket

Haul empty:
- drive standard route to load
- define loading point and stop
- floor trimming if needed

When loading, an operator of an LHD machine is exposed to high levels of noise, vibration and dust. Using radio or infra-red stand-off controls for loading and dumping can improve the operator’s working conditions and safety. At the same time, increases in productivity of up to 20% can be obtained, because the stand-off control enables an operator to load a machine under unsupported or unstable roof. Such results were achieved with an infra-red stand-off control system on 7 t and 10 t LTF machines in potash mines in Germany. In Norilsk Nickel Mine (Russia) a 15% increase in productivity was achieved [1].

When LHD machines operate in big caves or rooms, dropout of the radio signal between the portable controller and the machine are noted. Reorientation of transmitter or receiver aerials may re-establish the radio link, but it is sometimes impossible to reposition receiver antenna because of the dangers of unsupported roof over the machine. In such situations another radio controlled LHD must be used to drag the first one out of the face. Such an operation is costly not only because two machines are unproductive during the exercise, but also due to tyre damage when a loaded machine has to be dragged out of the area while its brakes are applied through the fail-safe systems.

Loading can also be carried out using stand-off or remote control supported by TV monitoring. Another alternative is the use of pre-programmed activity cycles whereby, after positioning the LHD in front of the pile, the operator initiates a sequence of actions by a single instruction. Such a concept has been proved in USA and Russia [1,19].
Route guidance systems can provide LHD steering control without an on-board driver, and can enable a remote operator to control several LHDs simultaneously. The first research into automatic LHD steering took place in 1972. There are various ways of providing autonomous LHD steering using different types of navigation equipment and concepts.

**Direct Visual Steering**

TV cameras installed on-board LHD machines can provide a remote operator with a real-time picture of the driving route and the load/dump operations. INCO Ltd. of Canada has developed a mine-wide information system which includes LHD telecontrol. The system was tested in the Copper Cliff North Mine in 1990 [22]. The LHD was fitted with monitoring and remote control systems and two video cameras for teleoperation. Thirty-six different sensors were used in the monitoring system. Initial tests were successful. After about an hour the operator could efficiently operate the machine using only the TV picture. After three hours the operator was able to perform complicated operations such as turning corners in the drift.

**Route Guidance**

Most current autonomous LHD machine steering systems use buried wires, overhead trolley lines or paint stripes to navigate mine drift. In Sweden autonomous 7-ton LHDs in Zinkgruvan Mine follow a white 10 cm width line painted on the roof of a drift. On-board cameras are used to detect the line and enable an accuracy of +/- 10 mm. One concept involving the integration of automation and telecontrol on LHDs proposes that the full cycle can be performed by a remotely positioned operator with TV system assistance. The LHDs can orientate themselves using radio transponders placed along the route at points where the vehicle has to turn, accelerate, stop, etc. The transponders can be programmed remotely. The automatic LHDs in Zinkgruvan have operated successfully since December 1989 and were still in use in December 1990 [23].

In the Vieille Montagne Mine (Sweden) an optical guidance system provided correction every 10-20 cm of a route at LHD speed about 20 km/h [24].

The biggest advantages of the use of painted line guidance are:

- no advanced skills are required for painting a line or putting up a white cable;
- it is easy to change a route.
Cooperation between ARA Inc. (Finland) and LKAB Kiruna (Sweden) provided an automatic control system for a TORO 500E which was successfully tested over two years in Kirunavaar Iron Ore Mine. The main objectives of this System for Automated Loading and Transport (SALT) project were to improve safety and the working conditions for operators, to increase machine availability and reduce maintenance [20].

A TORO 500E was equipped with video cameras and radio communication equipment and buried wire was utilized for steering. Different types of sensors monitored the speed, gear, bucket position, etc. The reaction from LHD operators was generally positive, especially with regard to the improvement in working conditions. The average production speed of the automatic LHD was 80-90% of the average speed of a manually driven machine [20].

At the Norita Mine in Canada, a complete automated haulage cycle on a Wagner LHD was achieved using an optical line made up of retro-reflector ribbon 5 cm wide. The encoded milestone-points were made of narrow retro-reflector strips similar to a bar code. The System was developed by Noranda Technology Centre and Canadian Centre for Automation and Robotics [25,26].

Ultrasonic Guidance

Guidance systems using ultrasonic ranging sensors mounted along one or both sides of the machine and a wall-following algorithms have been developed. Ultrasonic rangers in conjunction with a wall-following algorithms provide steering of the machines along the drift [19,27]. When an LHD travels, the dead reckoning position is updated periodically to achieve absolute positioning along the drift and to enable corners to be determined. The typical top speed of the LHD is about 14.5 km/h [19].

The main advantages of ultrasonic guidance:
- a route guide such as buried cable or painted line does not have to be installed and maintained
- the LHD is fully free for steering and can be guided through multiple drifts without route guide installations
- ultrasonic rangers can provide route mapping of drift profiles.

Problems such as a multiple reflection of ultrasonic waves have to be taken into consideration [24].
3.6 Drilling and Charging

The main purpose of introducing telecontrol and computer control for long-hole production drilling is to increase real drilling time, and to provide accurate control of hole length and deviation. Running time for a drilling machine is normally only 60-70% of the time available for drilling given travelling times, lunch breaks, ventilation requirements, etc. Computerization of the drilling process enables rigs to work during these normally non-productive times, without the operator's participation.

At Outokumpu Finnmine's Enonkoski Mine at least one hole is drilled by a Data Solo during the lunch break and one more while the shifts change, increasing overall drilling metres per day by about one-third [13].

A rig can be left to drill the hole to the pre-programmed depth itself and after that to retract the drill string, dismantle it and put rods in a magazine. Average increases of productivity can exceed 25% [28]. In drill and blast technology accurate hole positions and orientations are the most critical factors affecting the tunnel dimensions or fragmentation of ore. Laser beams can be used to determine hole positions (drilling patterns) instead of manual marking-up of a face, and can reduce the amount of holes needed and the total drilling cycle time.

Computerized rigs are very complicated and expensive. The current difficulties with such drilling equipment are their limited reliability and the lack of skilled personnel to maintain and repair such equipment.

Telecontrol and computer control also provide better and safer working conditions for rig operators as they can be located away from the hazardous areas. In high grade uranium mines the application of computerized drilling equipment can improve safety and productivity significantly.

The Kurina Mine in Sweden has produced millions of tons of iron ore by sublevel caving. Their equipment includes a fully automatic SIMBA 269 (made by Atlas Copco) drill rig which can automatically extend, retract and store 54 drill tubes 1.875 m length. The operator is seated in a ventilated and heated cabin supervising the rig via closed circuit TV [30].

In spite of telecontrol and computerization, an operator's role will continue to be vital in order to control the quality of an excavation. He is also needed to adjust drilling parameters [29].

Telecontrol for charging blast holes improves safety and operator working conditions. Infra-red stand-off controlled pneumatic charging machines have been successfully used in Kombinat KALI in East Germany [1]. The ROCMEC 2000, developed by Nitro Nobel AB, enables the operator to charge a hole
and install the detonator from the machine cabin thereby reducing the risk of injury and eliminating manual labour [13].

A Miniature Blasting Method (MBM) was proposed in the late 1970's in the USA to reduce drill and blast cycle times. The method eliminates equipment "shuffling" in the face, drills small short holes, charges them with a small amount of explosive and blasts one hole at a time. It needs no fuse to detonate the charge. These Drill-Charge-Shoot Modules (DCS) can be installed on suitable vehicles or LHD machines and could be controlled in telecontrol or automatic mode. Field tests were conducted at a quarry near Seattle. The basalt was drilled at a rate of 10 cm per minute. Thirty shots were made with the DCS and the performance of the explosive was reportedly excellent, using just 0.6 kg/m³. The MBM has great potential for improvements through extended application of telecontrol and automation, particularly, for small drifts [31].

3.7 Other Operations

In the mid 1980's a radio control system for an impact ripper machine was developed by COMRO and tested in gold mines [32].

Telecontrol of an underground locomotive during loading and unloading can improve safety and provide a 15% increase in transport system productivity [33].

4. AVAILABLE TECHNOLOGY.

4.1 Stand-off Control

Radio stand-off control systems are manufactured commercially by:

- MOOG Inc. (USA, UK): One way communication system. The biggest manufacturer of radio control systems for shearers and roadheaders. "Anderson Strathclyde PLC" and "Anderson Mavor" used this equipment for a long time.
- Blackbox Controls Ltd, IQ series (USA): One way communication system for LHD.
- Catron (USA). Two way communication system for Joy thin seams continuous miners.
- Catron 864: Radio control for mining locomotives.
- JNA (USA): One way communication Joy Network Architecture is developed by Joy Technologies.
- BJD (UK): One way communication system for BJD shearers.
- Nautilus (Canada).
- CERCHAR (France): One way communication system for shearsers.
- TORO-TELL (Finland): One way communication system for TORO LHD machines developed by ESTRON. Production level is about 20 units per year.
- Tegnoplan (SA): system very similar to ESTRON.
- Penn Pack (Australia): One way communication system for continuous miners.

A few different electronically operated drilling rigs are available:

- TAMROCK (Finland) developed a CAD (Computer Aid Drilling) system, which is used on a Datamatic HS205D, HS315U, Data Solo H1006RA and Data Duo, Data Jumbos. Around the world about 30 Data Solo & Duo and 10 Data Jumbos are in operation.

- ECS (Electrical Control System) developed by "Atlas Copco" (Sweden) is used on a Simba 269 drilling rig.

- Ingersoll-Rand manufactures a 200DHD drilling rig.

Most of these rigs can work in a gate/drift with cross sections more than 8 m².

4.2 Remote Control

Many countries in the world have achieved successful results using remote control in longwall and highwall sections but these can be regarded as experiments.

Commercially available electronic longwalling systems which can provide permanent operation with the presence of 1 or 2 miners in the face, is produced by Longwall International U.K. (formerly MECO and Gullick International).

No system for autonomous steering of LHDs is currently in operation on a permanent basis in an underground mine or in commercial production [25].
5. FACTORS INVOLVED IN UNDERGROUND TELECONTROL APPLICATIONS IN THE SOUTH AFRICAN MINING INDUSTRY

Various technical, technological and human factors, and their influence on telecontrol applications must be considered to facilitate development of telecontrol in this country.

5.1 Present Situation

If the local situation is considered then the low level of telecontrol application leads to the conclusion that although the production from mechanised mining operations in South Africa compares favourably with that of the rest of the world, the actual state of the art of technology associated with mining machinery is well behind overseas developments. Any development of electro/electronic control systems, including telecontrol, in South Africa has, therefore, some way to go to reach the same point as other countries.

From time to time, various trials to use telecontrol in South African mines take place. Radio control systems for continuous miners have been tested at several local coal mines but have not been well received as the simple stand-off controls offered for use in thick seam operations have not produced the envisaged safety benefits.

Some representatives from South African mining companies stated that for South African mines the simple, reliable, cost-effective, non-computerized drill rigs will continue to satisfy local requirements in the near future. Hand held jack-leg rigs are still regarded as the main-stay of production. A few manually controlled jumbo rigs have shown high performances with low maintenance costs. More sophisticated units are not considered suitable for South African operations in the foreseeable future [28].

5.2 Mining and Technological Factors

Very often, available telecontrol technology from overseas is not well suited to local underground conditions as was the case with radio stand-off controls for continuous miners manufactured in the USA. Being, in most cases, developed for thin seam conditions, many control units were designed for local ground position use and equipped with skids so as to be moved along the ground rather than carried by the operator. Usually, such control units are bulky and heavy (up to 6-7 kg) and only suitable for thin seam applications.

As mentioned above, some local CM operators using radio stand-off controls in close proximity to the CM may be exposed to higher safety risks than they
would be if they were in the operator’s cab. The argument of a reduction in the operator’s exposure to dust is also unproven at this stage. There is a high likelihood of operators moving to positions closer to the cutter head and consequently being exposed to greater danger from moving machinery and higher dust levels.

Restricted roadway widths and heights also limit the opportunities for using many of the available automated drilling rigs.

The introduction of telecontrol in South African mines will, therefore, require modifications to most existing control system equipment or development of new methods of telecontrol to provide compatibility with local mining conditions.

5.3 Human Factors

Introduction of new technology changes the tasks, attitudes, working conditions and safety of human resources. The US Bureau of Mines has conducted extensive research in this area. Apart from concern over the influence of high technology on the accident rates in mines, it has been shown that about 60% of new technology introduction failures can be attributed primarily to human and organizational factors rather than technological faults [2].

Some different human aspects of telecontrol safety have been considered previously in this report, but it is worth emphasising the importance of human factors in the adoption of new technology in the mining industry as well as the even more serious problems due to the notorious resistance to change prevalent in the industry.

Overseas experience has shown that almost every technological innovation in the mining industry is greeted with fierce opposition at all levels from the mine worker up to senior mine management. That is understandable. The mine manager believes he can optimize performance using proven methods he is familiar with. Technical staff see increased demands in terms of skills, costs and infrastructure. In the case of telecontrol systems, machine operators are forced to switch from reliance upon their own skills and senses to dependence upon unfamiliar technology.

The introduction of telecontrol has, therefore, to be made step by step and to incorporate the creation of a new culture not only for workers but for all levels of management as well.
5.4 Installation Costs

There are currently two ways by which telecontrol technology could be introduced at a mine:

- The manufacturer delivers machines with the telecontrol facility built-in as an option
- The mine buys and installs telecontrol equipment on existing machines

Prior to 1994 all mining machines manufactured in South Africa could not be readily modified to accept even a simple stand-off control due to the lack of electro-hydraulic interfaces, which would have increased initial machine prices by 8-10%. These machines could still be modified by the mine but the final cost would be significantly higher. The price of telecontrol hardware alone, would be in the range R4,000 - R10,000 depending on the machine.

As will be shown later, the introduction of full remote control for a continuous miner section would require an increase in capital outlay of as much as twice. Remote control involves modification of the continuous miner, the use of a continuous haulage system, and special ventilation.

6. TELECONTROL DESIGN CONSIDERATIONS

When designing any electrical or electronic equipment for use in underground mines, two important conditions have to be considered at all times. These conditions are safety and the harsh environment in which the equipment has to function. To manufacture equipment for all market sectors it is necessary to allow for both requirements in all equipment.


The equipment has to work in an atmosphere which can contain explosive gases, in particular, methane. Any system must therefore incorporate protection against the ignition of the gases. The two forms of protection are intrinsic safety and flame-proofing.

6.1.1 Intrinsic safety

In an intrinsically safe system the amount of energy available in the circuitry, is insufficient to ignite a flammable mixture of gas and air. The ignition mechanisms considered are the generation of electrical sparks, and thermal heating. The system must be designed in such a way that it provides safety under normal and probable fault conditions.
6.1.2 Flame proofing

A system is classified as flame-proof if the equipment that could ignite the gas-air mixture and cause an explosion, is placed in an enclosure which can withstand the pressure developed during an internal explosion. The enclosure will prevent the transmission of the explosion to the surrounding atmosphere.

6.2 Environment

Telecontrol systems for use in mining applications have to provide reliable operation under the severe conditions found underground. In order to fulfil this requirement, telecontrol equipment has to satisfy the following conditions:

* Mine-proof: All parts of a system have to be protected against coal/rock dust, water and moisture penetration into electric/electronic enclosures and cables. All parts have to be robust enough to withstand mechanical impacts caused by falling material or movable parts of equipment. All units installed on machines have to be protected against vibration.

* Maintenance and repair: All parts of the system should be light and capable of being exchanged underground without interfering with other parts of the control system. These factors have to be borne in mind when choosing an appropriate method of protection against gas ignition and proper electro-hydraulic interface designs have to be established accordingly.

* Restriction of mining operation: Any kind of installation, maintenance and repair of telecontrol systems should introduce no restrictions to the ability to control the machine manually.

6.3 System Design Concept

6.3.1 Generic consideration

* The controlled machine has to be equipped with an electro-hydraulic interface.
The design of the electro-hydraulic interface must provide for quick changing of operational mode from local manual to local electrical and back.

The telecontrol system has to be intrinsically safe.

Machine control system should provide for quick changing of operational mode from local to telecontrol and vice-versa.

To make the telecontrolled machine acceptable to the workforce and to encourage operators to use the telecontrol facilities, the machine has to provide different modes or levels of control.

For machines with stand-off control:

- local manual control for maintenance and repair
- local electrical control for operation during a breakdown of the stand-off control or other difficulties which the operator can experience with stand-off control
- stand-off control: umbilical or wireless for normal operation

For remotely controlled machines:

- local manual control for maintenance and repair only
- remote control for normal operation

Wireless telecontrol should not influence or be influenced by other wireless controlled machines or equipment in the same or adjacent faces/stops/roadways, to avoid cross activation.

Telecontrol systems have to be electromagnetically compatible with other electrical and electronic equipment.

The systems should provide audio or visual warnings in the event of telecontrol channel breaks or corruption.

Umbilical control is recommended only for semi-fixed positioned machines. In the case of fully mobile machines a portable controller has to comply with special requirements.

Autonomous power sources (batteries) for portable or mobile controllers should be quick and easy to change.

The process of recharging batteries should put no extra burden on mine personnel.

Any portable/mobile controller must operate in a fail-safe/"deadman" mode.

In the case of remote control, a set of on-board transducers, TV cameras and electronic algorithms must enable the operator to effect all the machine actions just as if he was positioned on the machine.

It must be possible to exchange damaged parts of a telecontrol system in the underground environment.
6.3.2 Ergonomics

* It is difficult to overstate the importance of proper ergonomic design of a portable controller given that the operator has to carry the unit throughout the full shift. The controller dimensions, weight, and ergonomic design depend on:
  - the method of control
  - the kind of machine to be controlled
  - the physical dimensions of the roadway or the coal seam thickness
  - the mobility of the machine

* A portable/mobile controller has to provide "blind" operation with tactile feedback to ensure that the operator is not distracted from the working area or monitor.

* Remote control usually incorporates a mobile or base control panel and is very often positioned in a control room, but "blind" operation is still important.

* It should be noted that making the portable controller for a stand-off control system as small as possible will make "blind" operation difficult or impossible as the operator will be distracted by having to glance at the controller continually. Optical and audio feed-back on the portable controller is, therefore, not recommended.

* It should not be possible to accidentally send incorrect instructions in the case of the controller or the operator falling down.

7 RECOMMENDATION FOR DEVELOPMENT OF TELECONTROL FOR THE SOUTH AFRICAN MINING INDUSTRY

7.1 Generic Requirements

* The overall aim of telecontrol is to make the job easier and safer for miners.

The very first step in telecontrol application has to be the supply of mining machines with electro-hydraulic interfaces or kits to enable mines to convert their machines. Since 1994 all Joy continuous miners have been equipped with electro-hydraulic interfaces. The electro-hydraulic interface itself can improve an operator's working conditions as it will enable electrical control via push buttons, toggle switches, and/or joysticks instead of heavy insensitive levers. Ordinary "Local/Telecontrol" switches and plugs can provide connections for
any umbilical or wireless control system which could be installed at the factory or mine.

* For successful development and application of remote control a national mining industry strategy is required.

7.2 Coal Mining.

The primary coal winning machine in S.A. that could benefit from remote control is the continuous miner. The thickness of local coal seams enables CMs to incorporate a cab that protects the operator against falling rock or coal, but present cabin designs do nothing to protect against dust and vibration. The main objective of the introduction of telecontrol for CMs is the removal of the operator from the CM to a place of lower health and safety risk. As was noted before (3.3), using a stand-off control in close proximity to a CM may, however, place the operator in a more dangerous situation than in a cabin. Therefore, the use of stand-off controls for CM's cannot be recommended. The introduction of telecontrol must not, however, reduce the production rate of the CM - if anything, it should rather impact positively.

The introduction of full remote control will necessitate significant redesigning of the CM to provide for automatic handling of the trailing power cable and water hose, machine orientation in a face, horizon and advance control, etc. Maneuverable methods of coal transportation will have to be considered as well as automated roof-bolting. Effectively, full remote control will require the introduction of new generations of CMs, roof-bolters, coal transportation equipment, ventilation systems and coal extraction technology [7]. The whole mine culture will change dramatically and human and education factors must be considered.

Telecontrol could increase the CM maximum advance per cut up to the distance determined by the position of the shuttle car drivers and cable-handlers who must remain under supported roof.

* The introduction of electronic control technology must proceed on a step by step basis to avoid frustration and the various obstacles. The following procedure is recommended:

- installation of electro-hydraulic interfaces on machines, incorporating mode selectors and connection plugs for umbilical or wireless stand-off control equipment
- day to day use of local electrical control and periodic use of stand-off control for training purposes or continuous control if operational conditions allow
- introduction of limited remote control with relocation of the CM operator away from dust, vibration and the hazardous atmosphere to whatever distance required (including the surface).

* Limited remote control is a proposed compromise form of telecontrol for coal mines which provides comprehensively improved safety and health for the CM operator without the significant financial and technical demands of full remote control, that would currently be unacceptable to the South African mining industry.

In a CM coal section at least two miners, the CM operator and the cable handler are in constant danger. During a shift each shuttle car operator also spends about 40-60 min in the coal face area. Existing CMs in S.A. have no facility to automatically handle and store the trailing cable and water hose, and can therefore not operate without a cable handler. It is evident that the presence of a cable handler is unavoidable given current machine designs. From the safety point of view relocation of the CM operator to a safe remotely positioned control station would improve overall safety by at least 2.5 times.

It is interesting to note that the ratio between the number of accidents involving CM operators and the number involving cable handlers is 2:1 [16]. Therefore, even the elimination of the cable handler alone could reduce the number of accidents in working area by 1.4 times [16]. Some collieries have already modified some of their CMs and installed automatic cable handlers and reels.

The main purpose of limited remote control is the ability to operate the CM from a station that is situated remotely from the machine, in response to instructions that have been sent to operator by the cable handler who monitors and advises on the situation at the face. The limited remote control involves a control panel installed in a control room or in a safe place free of dust and the other face hazards (see Fig.2). The operator sends instructions to control the CM via a cable or radio link to the machine switch box and then to the control unit on the CM through a clip-on antennae on the trailing power cable. The cable handler uses a hands-free radio transmitter and sends verbal commands such as "Sump", "Shear", "Lift the boom", "Switch-on conveyer", "Stop," etc. to the CM operator. The cable handler also has an "Emergency Stop" button which can override any CM operator instructions [21].
It would be desirable to equip CM with Horizon Control System such as has been developed by COMRO/MININGTEK. The operator would then have a
display which could provide him with information about the vertical position of the boom and the depth of sump that would in turn significantly reduce the number of instructions required from the cable handler. The limited remote control will involve standard communications technology and will require no modifications to a CM equipped with an electro-hydraulic interface.

The wide scale application of CMs with electro-hydraulic interfaces, stand-off control and limited remote control will create the necessary new culture to enable further development towards full remote control which will include the following steps:

- redesign and manufacture of CMs with automatic cable handling and other features needed for telecontrol
- introduction of continuous haulage systems
- redesign of ventilation systems
- development and manufacture of full remote control systems for colliery sections.

Other mining equipment in coal mining sections that could be operated more safely via a stand-off remote control would be roof-bolters and drilling rigs, where any type of wireless or umbilical stand-off control would be fully acceptable.
7.3 Gold Mining.

* Present levels of mechanization of stoping operations offer no real opportunities for the application of telecontrol to improve safety.

* In conditions where the cross-section of the drift permits the use of electronically controlled drilling rigs, any of the commercially available (3.6, 4.1) units could be used successfully.

* Apply commercial wireless equipment for stand-off controls for loading and dumping by LHD machines. The TORO-TELL radio control system would be recommended for this application. The problems related to losing radio control links between the controller and the LHD machine while operating under unsupported roof have to be investigated in local underground condition and an acceptable solution has to be found.

* Identify a suitable remote steering system for S.A. application as local mining and technological factors have a great influence on the selection of the method for steering. The systems have to be adopted, modified or developed to the specific requirements of each mine. Therefore, a wide research of local underground conditions has to be done to define and develop the proper method of LHD steering.

* Stand-off control for locomotives during loading and changing tracks at junctions will improve safety and productivity. Detailed analyses of existing transport systems to determine where the method could be applied.

8 CONCLUSIONS

Any kind of non-on-board control is classified as "telecontrol."

Telecontrol can be implemented in a variety of different ways on machines that are equipped with electro-hydraulic interfaces.

Stand-off control, limited remote control and remote control are some options of telecontrol.

With stand-off control an operator can control a mining machine only within a line-of-sight range and relies on his own visual and auditory senses to monitor operational cues directly. This method of control is the cheapest.
Full remote control provides mining operations without the permanent presence of miners in the section. This is applicable beyond the line-of-sight range and the control station can be at any safe distance, including the mine surface, and brings maximum safety and the best working conditions for miners. Introduction of full remote control involves a substantial capital expenditure.

Telecontrol of mining equipment and machines will increase safety and improve working conditions. However, some technical, cultural and human problems have to be overcome. In the foreseeable future, the South African mining industry will continue to involve an operator directly in the mining process either on-board the machine or at a safe distance away from the machine. The positioning of the operator, using stand-off control, in close proximity to mobile machines is not to be recommended and could be acceptable only for machines which remain stationary during the production cycle.

A range of commercial stand-off control systems for shearers, roof-bolters, drilling rigs and LHD machines is available. Remote Control systems are not commercially available accept systems for longwalling which can provide operation without presence of miners in a face.

The proposed method of limited remote control provides for relocation of the continuous miner operator to a site outside the hazardous area, in a safe remotely positioned control station, without requiring any changing of the technology in the coal section. Improving overall colliery section safety by as much as in 2.5 times could be achieved by this method.

Wide research of gold and other non-coal mines underground conditions has to precede introduction of telecontrol for LHD machine.

The future development of telecontrol for the South African mining industry has to pass through several distinct stages.

1. Mining machinery manufacturers must be convinced of the need to modify machines to enable them to be telecontrolled, ie: to install electro-hydraulic interfaces.
2. Apply existing commercial stand-off control systems to a LHD for loading and dumping operations.
3. Develop/adapt and introduce local electrical or stand-off controls on those mining machines where safety could thereby be improved.
4. Develop and introduce limited remote control for continuous miners.
5. Provide technical, technological and financial analyses of full
remote control introduction.

6. Develop/modify production mining machines, transport systems, ventilation systems and other equipment amenable to full remote control operation.

7. Develop full remote control system.

As telecontrol is not a total requirement, detailed analyses of operational processes, safety and mining conditions, as well as the costs involved, have to precede any conclusions as to the expediency of introducing telecontrol, in each particular case.
REFERENCES


11. E.S.Entwistle. Technology "away from the sharp end". Mining Technology, October 1993.


September 1993.


17. V.A. Kononov. Patent USSR, No 778386 Device for mobile unit remote control.


