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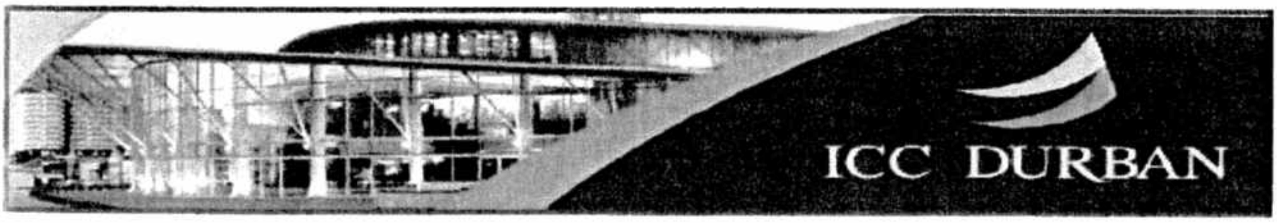

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A review of the application of ergonomics design of trackless mining equipment (TME) – lessons and challenges

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Abstract

Despite increasing levels of trackless mining automation in South African mines, there is a distinct lack of design focus specific to the human operator tasked with driving machines for prolonged periods of the working shift. In many instances the design of trackless mining equipment (TME) is poor, with improvised seating, poor cabin layouts and sub-standard display instrumentation.

This paper will present the key findings of two studies assessing ergonomics risk factors associated with automated mining equipment currently in use in the South African platinum mining industry. The purpose of this review is to quantify the current levels of vehicle safety and ergonomics application specific to cabin-driven mining machinery used in narrow reef platinum mining operations.

A summarised report on the detailed work observations and findings which have been conducted to determine the different types of TME currently in use in platinum mines will be provided. The specific problems focused on in this paper will include the design of machines with a view to providing basic guidelines to the manufacturers of units used extensively in platinum mines. Key lessons and future challenges will be addressed with a view to assessing the potential long-term viability of trackless mining in the platinum sector.

Keywords: Mining, trackless machines, ergonomics, design

1. Introduction

Trackless mining machinery may be subdivided into two principal categories, according to the mining stope height and/or method, namely low profile trackless machinery (LP) and extra low profile machinery (XLP). Extra low profile machines are predominantly remote-controlled and provide unique design and operator positioning challenges when an ergonomics risk assessment is conducted in an underground environment. For example, the optimal position for the operator using remote-controlled equipment has been an issue for debate. The most important factors that should be considered in influencing the position of the operator include their ability to see, geological conditions, ventilation, positions of other mine workers, and moving machinery (Steiner et al., 1998). Poor positioning of the operator increases risk, and effective design of remote-controlled systems is critical for ensuring that workplace injuries are minimised within platinum mines.

The use of LP and XLP mining machinery in narrow reef platinum mining operations is favoured by mining houses in many instances for providing higher productivity. As with many industries, the mining industry implements new technologies as they are developed in an attempt to increase productivity and reduce costs (Steiner et al., 1998). LPs and XLPs are seen as a more productive alternative to traditional mining methods employed within platinum mines. However, these machines are not without potential risks to the operator and many ergonomics hazards have to be taken into consideration when the design of XLPs, either operator driven (in the instance of the long haul dump (LHD)) or more recently fully Radio-remote-controlled (drill rig, roofbolter and dozer) is being evaluated. The design requirement for such machinery limits the height of LP machines to approximately 1,2 m, but many of the current XLPs have a working height of less than 0,9 m. Menasce and Thorley (2004) state that extra low stopes are currently defined as operating areas of between 1,1 and 1,2 m in South African platinum mines. Stoping height restrictions frequently obstruct the operators' vision and result in limited working space.

The use of trackless equipment has been faced with a number of challenges in the hard rock mining environment. Early attempts at using low profile equipment showed that machine damage was a frequent occurrence because of the nature of the Bushveld Complex (Menasce and Thorley, 2004). Design changes have therefore been common in the case of trackless equipment as stoping heights have been decreased in an attempt to operate more productively. The current XLP suite consists, in principle, of a face drill rig, a roofbolter, a dozer (currently not used in all XLP areas) and a cabin-driven long haul dump (LHD). Radio-remote-controlled units are commonplace for the drilling rigs and roofbolters, but have only more recently been applied to the XLP dozer. The LHD will shortly be available as a fully radio-remote-controlled unit and will be used in selected platinum mines. The wider application of remote-controlled units has arisen from the need to reduce the physical work demands, to remove the operator from a confined workspace and to increase the safety of operation in the stope. For example, in the case of the drill rig, the operators are now able to operate the rig from a safe working distance and also work more rapidly during the completion of face drilling. When compared to traditional rock drilling operators (RDOs) there is a significant reduction in physical exposure (most notable hand-arm vibration) and enhancement of the safety of the drill rig operator.

2. Findings of investigations and learning related to TME design

2.1 Preliminary Investigation

The original investigation into platinum mine TME operation aimed to assess the current task demands and shortcomings of trackless machines with the focus being placed on the human operator. Consequently, dimensional measurements and perceptual responses were taken during hazard identification risk assessment (HIRAs) conducted in the underground mining environment (James et al., 2005). The field sample consisted of 7 workers (2 workers in each of the four focus areas, with the exception of the remote-controlled dozing operation). Table 1 summarises the key findings of this investigation into the human-machine interaction specific to trackless mining.

Table 1. Summary of key findings – TME (from James et al., 2005).

No.	Checklist Question Area	Yes	No
1	**Operator:** Does the operator work in a confined space? (Stope Height of < 1,5 m)	X	
2	Does the operator work in an awkward posture? (Kneeling, bending or crouching)	X	
3	Are there other miners working in this area that could move into the path of the machine?	X	
4	Do manual tasks require frequent, repetitive motions	X	
5	Is the worker unable to change body position often?		X
6	Does job posture involve sustained muscle contraction of any limb for periods of more than 30 min?		X
7	**Visual Range:** Is the view of the operation obstructed (e.g., by the actual XLP, cab guards, pipes/hoses, etc.)?	X	
8	Is there sufficient upward visibility?	X	
9	Does the operator have to move closer to the machine to see the cut or roof bolt because of visual obstructions?		X
10	**Controls:** Are controls well labelled and sequenced?	X	
11	Can the operator easily depress the controls?	X	
12	Are emergency controls clearly marked?	X	
13	**Working Environment:** Are the XLP and environment excessively noisy?	X	
14	Is the working environment very hot?		X
15	Is the ventilation adequate for operation?	X	
16	Is the level of illumination adequate for operation of the XLP? (Can the operator see the work operation without undue strain?)	X	
17	Is there excessive dust in the working area?	X	
18	**Extra Low Profile (XLP) Machines:** Does the machine have guards to prevent accidental operation?	X	
19	Are controls and displays clearly marked?		X
20	Are safety hazards clearly marked on the XLP?		X

In addition body part discomfort ratings were assessed in an attempt to evaluate the operation of TME in relation to the human operator. Table 2 summarises the key findings from the body discomfort assessment.

The preliminary TME study (James et al., 2005) identified a number of task-related and design-related features that may well benefit from ergonomics intervention, including:

XLP tasks:

- Illumination of XLP equipment to minimise poor vision of the working environment;
- Higher levels of personal hearing protection to protect the operator(s); and
- Simple seating for the operator to be piloted.

Equipment design:

- Standardisation of control coding and labelling to aid understanding of remote-controlled units; and
- Radio-remote-controlled unit to be used on the LHD (in progress).

Additional areas that require ergonomics intervention include:

- Maintenance of control consoles to ensure that all levers and buttons are in good working order;
- Alternate power sources to minimise (or eliminate) movement of the power cables; and
- Improved design of the XLP equipment to allow for easier maintenance.

Table 2. Summarised discomfort ratings for XLP operators (from James et al., 2005).

Operation	Primary area of body discomfort	Other areas of discomfort	General Comments from operators
Drill Rig	Shoulder regions (Regions 2 and 3) due to pulling the power cable of the XLP. No major discomfort associated with XLP remote operations. The remote has removed the need for manual rock drilling and is viewed as a major improvement by the operators.	Lower back region (Region 8) due to the crouched seated posture. The operators improvise a seat out of a tyre inner to avoid having to sit on the damp ground surface. Prolonged work is seen as being uncomfortable in the crouched posture.	Operators generally feel that the cable pulling during tramming is the most demanding of all the sub-tasks. This results in some discomfort in the shoulders, and back and neck regions.
Roofbolter	Some minor knee discomfort reported by operators working in the kneeling posture (Regions 20 and 21). Most operators change postures on a regular basis and do not feel the demands of the low stope height are excessive.	No additional areas reported by roofbolter operators.	Similarly to the drill rig operations, operators generally feel the cable pulling during tramming is the most demanding of all the sub-tasks. This results in some discomfort in the shoulders, and back and neck regions.
Dozer	The primary area of discomfort reported by the operator was in the lower back (Region 8). The dozer operation takes place at stoping height of 1,1 m.	Minor discomfort due to the remote operations is also experienced in both knees (Regions 20 and 21).	The operator generally finds the working conditions acceptable for the task. The only concerns raised related to the lack of a seating alternative to sitting on the ground.
LHD (Cab Driven)	Neck region due to driving operation and looking side to side. (Region 0).	Minor discomfort in the shoulder region due to LHD driving operation. (Regions 2 and 3).	Operator cabin was not standard to specifications and will provide the operator with a swivel headrest.

2.2 Follow-up Investigation

In an attempt to apply key findings from the preliminary investigation in the design process a follow-up study was planned and conducted in South African platinum mines. The follow-up study included three mining operations currently utilizing TME in narrow reef mining.

The findings from the preliminary investigation were used in the development of a second phase methodology which aimed to assist in the design process specifically related to TME currently in use in South African platinum mines.

The subsequent TME research applied Jack CAD software to facilitate a detailed review of current design deficiencies specifically focusing on mining equipment. Future research papers will quantify the benefits of the optimised design and procurement guidelines provided to the relevant project mines.

3. Conclusions and Recommendations

3.1 Priority areas

The role of vision should not be underestimated in the completion of an underground task (James et al., 2005), as much as 80% of all sensory information coming to the operator is via visual sensory input. Illumination of the XLP unit and the operating area should always be given due consideration and allow the operator to work as efficiently and safely as possible. This is particularly relevant to the dozer operator who is required to work a rapidly moving dozing machine. The current levels of illumination of the unit remain inadequate and actually hinder the operation. The redesign of the lighting placement should be considered as a matter of priority for the XLP dozer, with further CAD work required on the positioning and balance of the systems.

Low stope mining poses a number of challenges to the worker with respect to the working posture adopted. The underground platinum mining environment is by nature not comfortable and the low stope height necessitates a crouched or kneeling posture. It is strongly recommended that further investigation be conducted to assess the feasibility of a basic *"extra low" seat* for drill rig and dozer operators. Both operations allow the operator to control the unit for extended periods of time from the same position. Clearly marked labels and controls will assist the operator in everyday operation and minimise the ergonomics hazards associated with inappropriate or incorrect use of controls.

3.2 Summary of proposed ergonomics interventions

The findings of these preliminary studies suggest that the aspects of XLP machine design and operation highlighted in Table 3 should be addressed (following basic intervention guidelines established by James et al., 2005):

It is finally recommended that all future design projects specific to XLP mining equipment incorporate consultation between the user (mine and operators) and manufacturer (equipment suppliers) in order that design, usability and safety of equipment can be improved. The ergonomics interventions suggested above should be used as a basic guideline for ensuring that there is due compliance in terms of Section 21 (1) (c) of the Mine Health and Safety Act (Act 29 of 1996).

Table 3. Summarised recommendations and learning from previous XLP research studies (adapted from James et al., 2005).

Ergonomics intervention	Improved health and safety	Key inputs required
Labelling of controls and displays	Reduce the number of errors and improve speed of activation	Maintenance, design and placement
Forward visual access and illumination of XLP vehicles	Improve visual input and perceptual capabilities of operators	Design of lighting configuration and visual access points
Communication and warning systems	Reduce margin for errors and warn miners of approaching XLPs	Design and advanced warning methods
Seating	Reduce muscular fatigue and improve body support in the stope	Maintenance and basic seat design
General working posture	Reduce static muscular fatigue	Maintenance and basic design for comfortable seating
Demarcation of hazard areas on the XLP machines	Reduce margin for errors and restrict operator from entering hazardous areas	Mine compliance and housekeeping related to signage in underground operations

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