A scenario-based comparison of underground coal mine proximity detection systems.

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ABSTRACT

One of the major hazards in an underground coal mine is the interaction between mining equipment and humans. This is the result of limited vision around underground equipment and the confined space within which the equipment operates. To address this hazard, various proximity detection systems have been developed.

This paper describes a project that evaluated different proximity detection systems available for use in hazardous areas. The scope of the project was to focus on interactions between the workforce with continuous miners, shuttle cars and LHDs. A testing programme was undertaken at an underground coal mine, which allowed testing without production interruptions.

During a two day workshop a suite of nine scenarios were developed. The scenarios represent the most common processes encountered in underground coal mines. The proximity detection systems were subjected to the appropriate scenarios and their performance was documented.

The detection zones of the different proximity detection systems were determined under normal operation, in the vicinity of an underground substation, tags at different heights, and multiple tags in zones.

The testing results provide a documented comparison of the different proximity detection systems when subjected to the same set of scenarios. This will assist the mines to make a selection of the proximity detection system most suitable for their conditions

INTRODUCTION

During the nineteen eighties and early nineteen nineties there was a drive to introduce remote controls for continuous miners (CM). The motivation for the introduction of this ‘new’ technology was the safety of the CM operator. It was felt the remote controls would reduce the operator’s exposure to dust and vibration. A further advantage would be that the CM operator would be able to move around and observe areas of the work site previously obscured when he was positioned on the CM. As the use of Radio Controlled Continuous Miners (RCCM) increased in underground coal mining, so did the number of incidents where CM operators or other personnel in the section were injured by mining machines. The injuries ranged from being run over, crushed or pinned by the mining equipment. This led to research into the causes of these accidents and possible solutions in South Africa [1], USA [2] and Australia [3]. In 2006 MSHA [4] published a comprehensive investigation into RCCM accidents and possible solutions. The publication presents a chart of No-Go zones for operating CMs. At the same time work was initiated into the design of proximity detection (PROX) systems to address the problem of mining machines injuring personnel in the section. The use of proximity detection systems in underground coal mines was legislated in South Africa and the USA in 2015. During the last ten years different Mining Companies in Australia have conducted their own tests on available proximity detection systems. The tests were mostly undertaken on surface and usually involved a single PROX system supplier.

In 2014 the major Australian Mining Companies approached Simtars to conduct an independent evaluation of the available proximity detection systems for use in underground coal mines. A project was established and funded as follows:

- Testing of proximity detection systems was funded by Australian Coal Association Research Program (ACARP).
- Mining machines used in the testing were supplied by the Mining Groups.
- A suitable test site was made available by the Mining Groups.
- Proximity detection systems used in the testing were supplied by the proximity detection suppliers.
- Labour to manage and conduct the testing was supplied by Simtars.

The objectives of the ACARP project were:

1. Provide an independent assessment on the effectiveness of existing proximity detection systems for use in underground coal mines against a range of relevant vehicle related interaction scenarios for:
   – vehicle to vehicle (V2V) interactions.
   – vehicle to person (V2P) interactions.
   – vehicle to infrastructure (V2I).

   This will provide mine management with objective information on available PROX systems to facilitate the selection of the most appropriate system for their operations, as well as helping PROX manufacturers to improve their systems.

2. The establishment of the most important collision accident scenarios. These accident scenarios will be used as ‘standard tests’ on available PROX systems. The ‘standard tests’ will also consider human factors including existing operational rules and challenge industry assumptions so that real comparisons can be drawn across the range of PROX systems. This will facilitate systems selection as it will be based on objective data and knowledge, and help to amend existing site rules and processes to suit human as well as technical performance.

3. Furthermore, the study will also list key rules and human factors that have a direct bearing on the effectiveness of a sound ‘interaction’ management system. Simple operational aspects of PROX system maintenance such as cleaning and adjustment will also be assessed. These considerations are also called up in *‘MDG2007 – Guideline for selection and implementation of collision management systems for mining*’

The final scope for the project agreed to by all participants is detailed below:

- The project had to focus on V2P interactions only, this was to reduce scope and thereby focus the investigation.
- The project was to address underground coal mines only and specifically address CMs, Shuttle Cars (SCs) and Load Haul Dump (LHD).
- The PROX systems had to be able to address the developed scenarios, the scenarios are described below.
- The PROX system expectations needs to be determined.
- The PROX systems submitted for evaluation had to be certified for use in hazardous areas or with certification well on the way.

METHOD

The scope of the project was addressed under the following headings.

V2P interactions

To confirm the decision to limit the scope of the project to V2P interactions a review of accidents, involving CMs, SCs and LHDs was undertaken. The source of the accident data was:

- Fatal grams, USA statistics on mining accidents
- Safety Alerts
- Safety Bulletins

All of the accidents from 2000 to June 2015 were evaluated. The accident data involving a CM, SC, LHD and humans was analysed and the statistics documented as part of the project.

Test location

The possibility of using the Mastermyne facility in Pinkenba was investigated. The site simulates an underground bord and pillar mine. Pillars are represented by shipping containers.

The investigation involved marking a grid at the Mastermyne facility, the grid and setup is presented in Figure 1. The grid consisted of 1 meter squares. A receiver was placed at two different locations, as indicated on Figure 1. At each location the orientation of the receiver was also changed to represent two perpendicular directions. A tag was moved to each of the grid points and the response from the receiver recorded.

A similar grid was marked out in a paddock at Simtars. All the testing conducted at the Mastermyne facility was repeated and results recorded.

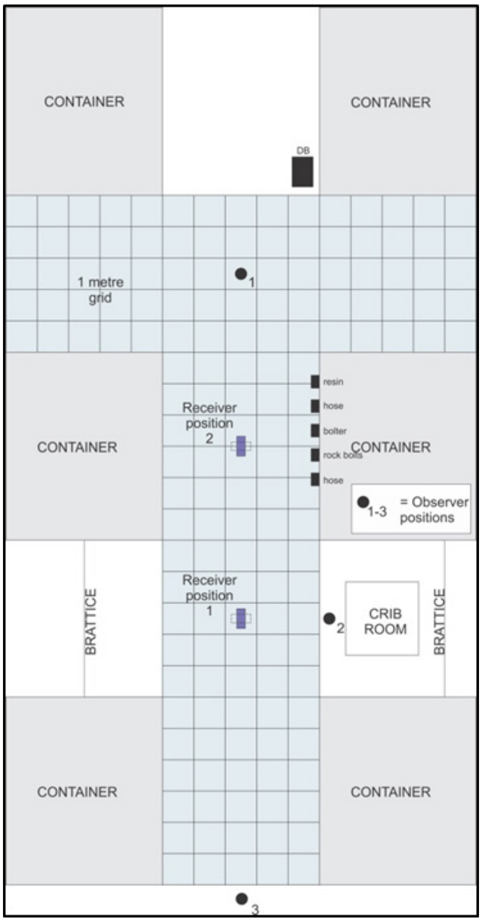

Figure 1 Test setup for Mastermyne evaluation

Scenarios

During a two day workshop, with representatives from Anglo, BHP, Centennial, Glencore and Peabody, a suite of nine scenarios were developed. The scenarios represent the most common actions undertaken in the normal operation of an underground coal mine and forms the basis of the PROX system evaluation. The scenarios were distributed to the PROX system suppliers, for them to ensure their systems would be able to address the requirements of the evaluation.

The scenarios included the determination of the detection zone of the PROX system, for the different mining machines, on surface as well as underground. The underground detection zones incorporate multiple tags in the zones, different heights of the tags and in close proximity to an 11 kV transformer. The detection zones are determined by placing the mining machine on a grid of one meter squares. A tag is then moved into the grid and the response from the PROX system recorded.

Interviews

To determine PROX system expectations a wide spectrum of users and regulators were interviewed.

RESULTS AND DISCUSSION

The results obtained from the different actions are presented below.

V2P interactions

In Table 1 the fatal gram results are presented. The Total column represents all the accidents for the particular year, it is then subdivided into Surface and Underground accidents. The accidents involving CMs, SCs, LHDs and humans were then extracted, a further sub-classification was made identifying the individual mining machine involved in the accident. Except for 2005, 2006, 2010 and 2013 CMs caused the most harm to humans in underground coal mines for the machine categories considered. During 2007 and 2009 none of the mining machines considered in this project were involved in interactions with humans.

The statistics from the Fatal Grams and Safety Bulletins are recorded in the ACARP project report C24010 "***Collision awareness - Capability of Underground Mine Vehicle Proximity Detection System***"

Test location

The testing at the Mastermyne facility, resulted in eight different patterns being recorded. One of the patterns recorded is presented in Figure 2. The arrows in the figure indicate the direction the tag was moved.

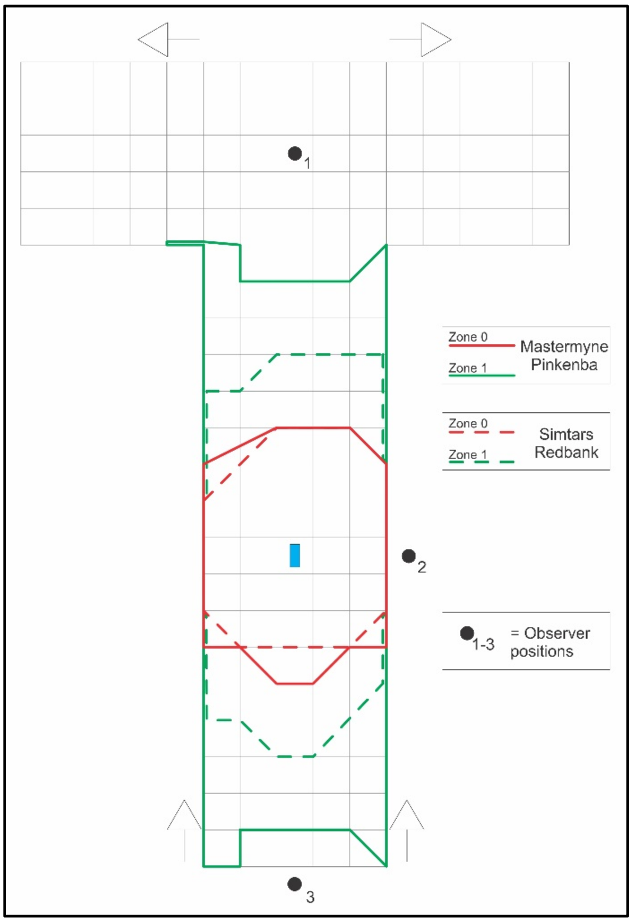

Figure 2

Table 1 Fatal Gram Statistics

Year	Total	Surface	Underground	CM, SC, LHD	CM	SC	LHD	%	%CM	%SC	%LHD
2000	38	19	19	5	3	2	0	26	60	40	0
2001	42	10	32	3	2	0	1	9	67	0	33
2002	27	12	15	2	2	0	0	13	100	0	0
2003	30	15	15	3	2	0	1	20	67	0	33
2004	29	14	14	2	2	0	0	14	100	0	0
2005	22	7	15	3	0	2	1	20	0	67	33
2006	46	11	35	1	0	1	0	3	0	100	0
2007	34	11	23	0	0	0	0	0			
2008	30	15	15	2	1	1	0	13	50	50	0
2009	18	11	7	0	0	0	0	0			
2010	48	6	42	6	2	4	0	14	33	67	0
2011	20	9	11	1	1	0	0	9	100	0	0
2012	20	6	14	3	2	0	1	21	67	0	33
2013	20	6	14	4	1	1	2	29	25	25	50
2014	16	6	10	3	2	0	1	30	67	0	33
Mar-15	4	0	4	1	1	0	0	25	100	0	0

The detection patterns at the Mastermyne facility are larger than the patterns recorded at the Redbank site. This was the case for both zone 0 and zone 1. Zone 1 displayed the biggest difference between the two sites. The increased zone 1 area is a result of the magnetic wave coupling into the steel structure at the Pinkenba site. The detection patterns are aligned with the direction of the long axis of the receiver.

Scenarios

Out of a potential six PROX suppliers only four were of the opinion their system could address the suite of scenarios and their system was certified or close to being certified. One supplier withdrew at a late stage in the project, just before testing commenced. The three remaining suppliers participating in the project are Strata WorldWide Australia, Becker Mining Australia and GE Mining. The developed scenarios are discussed below, with illustrations provided for some of the scenarios.

Scenario 1a: is to test if the PROX system prevents movement of SC when a person is located in a No-Go zone. A target is placed close to the SC and an attempt is made to drive the SC away.

Scenario 1b: tests whether PROX system detects an object as it approaches it and stops the SC before running over the target. The target is placed 15 m from the SC which is then driven towards the target.

Scenario 1c: is similar to scenario 1a with the target placed at the front of the SC, next to the cable reel, between the front and rear tyre and next to the front tyre. The setups for the tests are shown in Figure 3.

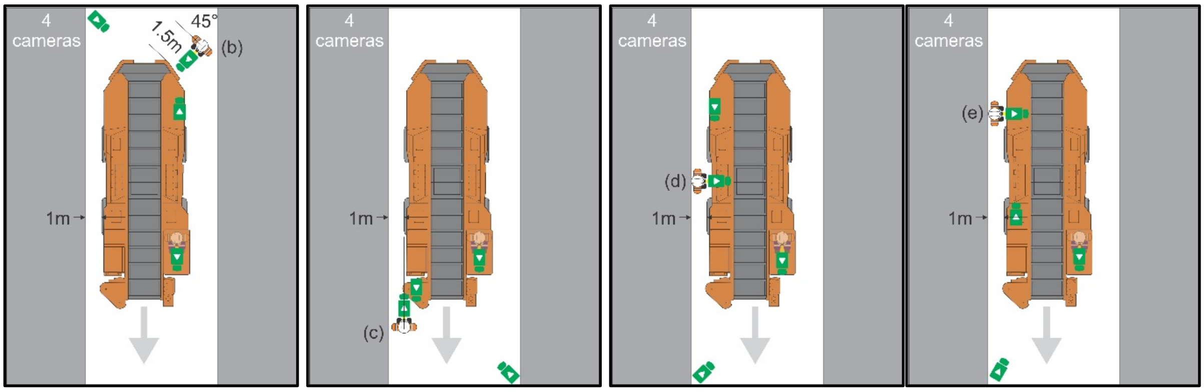

Figure 3 Scenario 1c

Scenario 1d: is to detect the response of the PROX system when the SC operator leaves the drivers cab with the SC energised.

Scenario 2a: tests if PROX system detects ‘personnel’ in the STOP and ALARM zones and brings the SC to a halt, before running over ‘personnel’ in the STOP zone, when turning into a cut through.

Scenario 2b: same as scenario 2a but turning in the opposite direction.

Scenario 3: determine if the PROX system detects targets, at different distances, as the SC travels past a cut through.

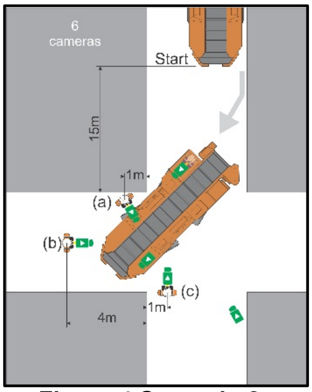

Figure 4 Scenario 2a

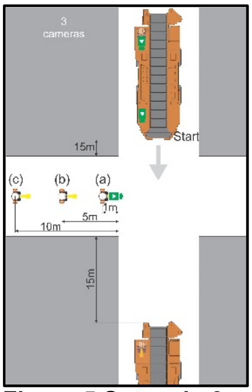

Figure 5 Scenario 3

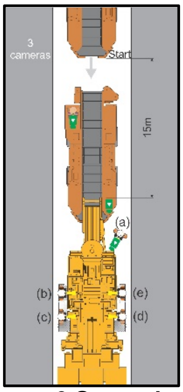

Figure 6 Scenario 4a

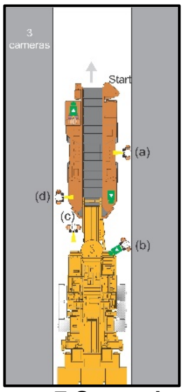

Figure 7 Scenario 4b

Scenario 4a: test if PROX system accommodates the loading of a SC during a cutting cycle, CM operator, SC operator and Bolter operators are in Silent Zones. The SC is moved from a distance to behind the CM.

Scenario 4b: evaluate how the PROX system copes with CM operator, SC operator and Bolter operators in No-Go Zones while the SC attempts to drive away from the CM after being loaded.

Scenario 5a: test if the PROX system accommodates 'personnel' in the Silent Zone when the CM is 'cutting' around a corner and the SC approaches to be loaded.

Scenario 5b: test if PROX system detects 'personnel' in the No-Go zones when the CM is 'cutting' around a corner and the SC approaches to be loaded.

Scenario 5c: determine if the PROX system accommodates 'personnel' in the Silent Zone when the CM is cutting around a corner and the SC approaches to be loaded (place change).

Scenario 6a: evaluate if the PROX system detects 'personnel' in No-Go zones and inhibits movement, while the CM is flitting.

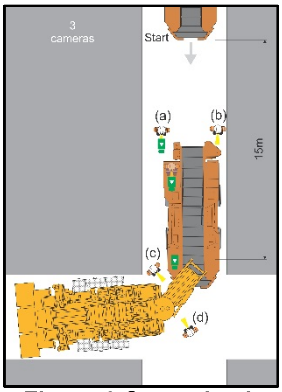

Figure 8 Scenario 5b

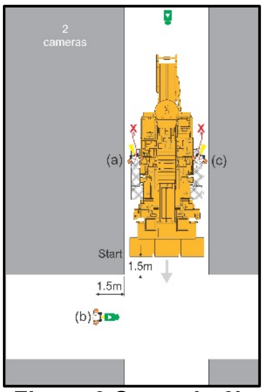

Figure 9 Scenario 6b

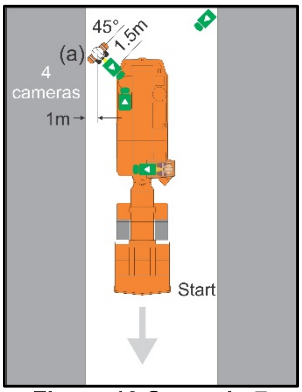

Figure 10 Scenario 7

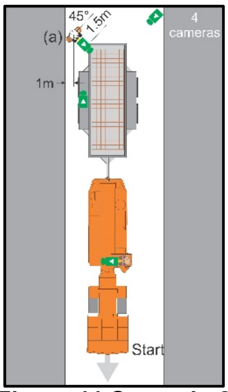

Figure 11 Scenario 8

Scenario 6b: determine if the PROX system prevents movement of CM when 'persons' move into No-Go zones. Targets are moved from the bolting platform, while the CM is flitting.

Scenario 7: is the same as scenarios 1a,1b,1c,1d, 2a, 2c and 3 with the SC replaced by a LHD. Figure 10 is the setup for Scenario 7a, which is the same as for Scenario 1a.

Scenario 8: is the same as scenarios 1a,1b,1c,1d, 2a, 2c and 3 with the SC replaced by a LHD and trailer. Figure 11 is the setup for Scenario 8a, which is the same as for Scenario 1a.

Scenario 9: test if PROX system can be overridden to allow a 'person', with a tag, trapped in the STOP zone, to be rescued.

Interviews

Interviews were conducted with seven regulators, six QLD and six NSW mining personnel. Interviews were undertaken using the set of questions below:

Question 1 PROX requirements.

- What is your expectation of a PROX systems?
- What do you need from PROX systems?
- Must the PROX system be able to 'see' around corners and why?
- How should the PROX systems handle ALARM, STOP and Silent zones?
- Do the PROX systems need to identify multiple targets?

Question 2 Operational information.

- What is the stopping distance of a CM, SC, and LHD?
- What are the existing controls associated with CMs, SCs, and LHDs e.g. No-Go zones?
- What are existing management procedures / rules, regarding No-Go zones?

Question 3: Position of personnel.

- Where should CM, SC and LHD operators, helpers and visitors be stationed?

Question 4: Infringements.

- How are infringements identified and recorded now?
- How are infringements handled now?
- When infringements are recorded by a PROX system, how should it be handled?

Question 5: Maintenance mode functions.

- What is it for CMs, SCs and LHDs?
- How is it handled for CMs, SCs and LHDs now?
- How should it be handled with the installation of PROX systems?

Question 6: Possible interference sources for prox systems.

- Does tag height influence zone dimensions?
- What should the tolerances be on the ALARM and STOP zones?
- Which environmental conditions could influence the performance of PROX systems?

Question 7: Competent people.

- How is the competency of mining machine operators determined now?
- How should the competency of operators be determined with the installation of PROX systems on mining machines?

Question 8: Operator complacency.

- Is this a concern?
- How should it be addressed?

Question 9: Nuisance alarms.

- What effect will nuisance alarms have on the acceptance of PROX systems?

Question 10: PROX system failure.

- How would you expect the PROX system to react when a tag fails?
- How would you expect the PROX system to react when a generator fails?

The testing of the different PROX systems will commence at the end of August 2016.

CONCLUSIONS

- As magnetic fields coupled into the steel structure at the Mastermyne facility an alternative test site was selected. The test site selected is the Baal Bone Colliery, where the tests will be conducted in actual underground coal mining conditions.
- At the completion of the project the mining industry will have an independent evaluation of the PROX systems available in the market. By comparing the performance of the different PROX systems in the scenario testing an objective selection can be made of the most suitable system to select for specific mining conditions.
- All interviewees agreed that a PROX system should be able to 'see' around a corner to allow detection of personnel in the path of turning machines. In addition it will warn operators of any personnel that could be harmed by the machine.
- There was agreement by interviewees for PROX systems to be capable of detecting multiple targets in the zones without degrading system performance.

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