Final Report on SIM 14-07-01 "Develop Feasible Methodologies to Aid Escape in Poor Visibility in Underground Mining Environments"

Mine Health and Safety Council

DEVELOP FEASIBLE METHODOLOGIES TO AID ESCAPE IN POOR VISIBILITY IN UNDERGROUND MINING ENVIRONMENTS

Prof Jan du Plessis
Mr Pierre Bredell
Mr Eugene Preis

Research agency: Enterprises at the University of Pretoria
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<td>Centre for excellence in mining innovation</td>
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<td>FTA</td>
<td>Fault tree analysis</td>
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<tr>
<td>HPU</td>
<td>Holographic processing unit</td>
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<td>LLL</td>
<td>NIOSH’s Lake Lynn Laboratory</td>
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<td>MHSA</td>
<td>Mine Health and Safety Act</td>
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<td>MHSC</td>
<td>Mine Health and Safety Council</td>
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<td>MHSI</td>
<td>Mine Health and Safety Inspectorate regions</td>
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<td>MOSES</td>
<td>Mainsfail Operated Sound Evacuation System</td>
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<td>MRS</td>
<td>Mine Rescue Services of South Africa</td>
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<td>NIOSH</td>
<td>National Institute for Occupational Safety and Health, PB, USA</td>
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<td>OHS</td>
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<td>RF</td>
<td>Radio Frequency</td>
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<td>SANS</td>
<td>South African National Standards</td>
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<tr>
<td>SCSR</td>
<td>Self-Contained Self-Rescuer</td>
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<td>SIMRAC</td>
<td>Safety in Mines Research Advisory Committee</td>
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<td>WRAC</td>
<td>Workplace risk assessment and control</td>
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- Internal and industry workshop participants; and
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EXECUTIVE SUMMARY

Escape strategies for mine workers in the aftermath of explosions or fires underground are problematic. This research study aimed to find solutions for the problem in the context of South African underground mines. In order to find solutions a gap analysis was first conducted, comparing ideal escape strategies with current strategies and methodologies.

The escape process consists of the following sub-processes (based on current system constraints):

- Early warning;
- Donning the self-contained self-rescuer (SCSR);
- Protecting the eyes from fumes;
- Detecting the lifeline;
- Reaching the lifeline;
- Guidance to the waiting place;
- Changing over from short duration SCSR to long duration SCSR;
- Guidance to refuge bay; and
- Waiting in the refuge bay to be rescued.

The gap analysis performed revealed problems with:

- The use of SCSRs;
- The detection of lifelines in poor and zero visibility conditions; and
- Reaching lifelines.

The solutions devised were divided into two main categories:

- Short-term practical solutions based on current technology; and
- Longer-term concept solutions to be investigated further before finalising detailed product proposals.

The intent of defining the longer-term solutions was to evaluate how newer available technology or undiscovered innovations could transform the escape strategies if we were to completely disregard current constraints imposed by laws, costs or current technology.

The main short-term practical solutions can be summarised as follows:

- Implementation of centralised integrated early warning systems on all mines;
- Implementation of experiential SCSR training in donning and use (including eye protection);
- Implementation of an LED evacuation pulse system in conjunction with fire resistant lifelines, for easier detection of the lifeline, and
- Implementation of compulsory, regularly scheduled experiential emergency response training

The main longer-term innovation alternatives considered were as follows:
- Development of an integrated personal protective helmet incorporating:
  - Automatic toxic air detection system;
  - Automatic switching of source of breathing air from ambient air to a compressed air source;
  - Automatic warning of toxic environment via visible and audible warnings integrated into the headset;
  - Automatic visual navigation to refuge bay via an integrated on-board computer, and
  - Laser pointers to aid detection of walls, roof and floors.
- Development of an integrated umbilical lifeline incorporating:
  - Distributed fresh air supply;
  - LED lights (evacuation pulse and normal lights integrated into one);
  - LED lights integrated with early warning system;
  - Directional cones;
  - Radio frequency (RF) tags in lifeline detectible by RF readers in miners’ cap lamps, and
  - Secondary refuge bays or temporary inflatable tunnels extended from main refuge bay.
- Water assisted escape methodology

It was concluded by the project team that, although the integrated innovative solutions (IPPE and umbilical lifeline) could work, too many risks exist in terms of pursuing these solutions at this stage. The water spray assisted lifeline concept was also developed. The hypothesis was that, in a zero visibility and audibility environment, a water spray, when coming into contact with a person, would be able to guide the person to the origin of the spray. The hypothesis was tested and verified, and a conceptual methodology and system was proposed.
It is envisioned that the water spray assisted lifeline concept, if developed further, would be able to meet all the requirements of an effective escape system when used in conjunction with a proper early warning system, a traditional lifeline and self-breathing apparatus. A critical success factor lies with diligence in terms of detail design, installation and maintaining the system, as well as training workers on how the system works.

The project recommends the following:

- Further investigation of the self-breathing technologies
  It is recommended that the broad umbilical lifeline value proposition be further investigated. The primary drive of the investigation should be to investigate the feasibility of alternative self-breathing technologies, as opposed to the chemical SCSR.

- Further investigation of the water-assisted escape concept
  It is recommended that the water-assisted escape concept be further investigated. It is further recommended that this investigation should be in the form of a research and development project, where the main aim is to develop, test and implement a water-assisted escape system (refer to APPENDIX F: PROPOSED FUTURE PROJECT).

- Consideration of IPPE concept in other MHSC research projects
  It is recommended that the IPPE concept should be taken into consideration in other digital technology-based projects. The IPPE system could potentially be the solution in the "mine of the future", and should thus be considered in projects that are shaping the mine of the future.

- Testing of traditional lifeline at hard-rock mines
  Generally, no clear reason exists as to why the traditional lifeline is not used in hard-rock mines in South Africa. It is recommended that in-field, trial testing should be conducted on the effectiveness and practicability of lifelines in hard-rock mines. Ideally, the lifeline should be tested for the full spectrum of U/G mining layouts found in the SAMI (not currently using lifelines). Realistically, the test sample size should test as many layouts as practically possible.

- Issuance of air-tight goggles as part of PPE
  It is recommended that air-tight goggles should form part of standard PPE requirements, in environments where low visibility conditions could be experienced.

- Use of lighting-based systems
  Where practical and affordable, mines could consider implementing a lighting-based system. The lighting system should be able to deliver three-fold value: Act as an early warning system; act as static lighting under normal operating conditions; and provide visual guidance to refuge bays.
PROJECT INTRODUCTION

6.1 Introduction

Problems with escape from toxic irrespirable air and poor visibility conditions in underground mines are experienced globally and result in numerous injuries and fatalities every year. This study is particularly concerned with those incidents where people face the risk of injury or death due to a failure to escape which, in this case, means they do not reach a rescue chamber after an explosion or fire occurs despite the existence of an escape strategy. The following accidents are recent examples of this type of incident:

- Soma Mine, Turkey (May 2014), where 301 mine workers were killed following a fire caused by a methane explosion;
- Doornkop Shaft, South Africa (February 2014), where eight mineworkers died due to a lack of a fresh air supply in the refuge bay. Another root cause of the fatalities at the Doornkop incident can be attributed to a lack of adequate escape training, as well as a lack of knowledge of the mine layout (from a contractor point of view);
- Pike River Mine, New Zealand (November 2010), where 29 miners died following multiple methane explosions;
- Upper Big Branch Mine, USA (April 2010), where 29 mine workers died following a coal dust explosion; and
- Sago Mine, USA (January 2006), where 12 mine workers died following a methane explosion.

The best way to reduce the risk of fatalities within an underground mine is to prevent incidents from occurring in the first place. However, since we cannot completely eliminate the risk of explosions or fires underground, we must do our utmost to reduce the potential threat of any incident that does occur. One way to do that is to protect those who survive the explosion or fire while underground and get them safely out of the mine as quickly as possible. Current risk mitigation measures in underground mines in South Africa involve workers escaping to a refuge bay from which they are rescued (escape and rescue). The biggest risk these survivors face is death due to the inhalation of toxic fumes and a refuge bay provides them with, at minimum, a supply of fresh air.

Escape and rescue strategies currently in use involve a combination of factors. In South Africa, miners escape to refuge bays or fresh air bases with the assistance of self-contained self-
rescuers (SCSRs), which provide them with a limited supply of respirable air. The success of
this strategy depends on the miners’ ability to reach the designated refuge bays in a timeous
manner. This, in turn, is dependent upon the layout of the escape routes, the distance between
each working place and the nearest refuge bay, and the ability of the workers to reach the
refuge bay within their SCSR’s range or before the atmosphere becomes excessively
irrespirable. The ability of workers to see where they are going i.e. visibility, is an important
component of this strategy.

Guidance systems for helping workers escape in poor visibility conditions exist and have been
assessed in the past. The use of visual, acoustic and sensory escape systems, separately and
in combination, define the state-of-the art, although their effectiveness is not ideal. Many
workers still die due to ineffective escape strategies and technologies.

This research project aimed to redefine and review the “user” requirements in providing
underground mine workers with a safe escape in poor visibility conditions. With those
requirements at the forefront, the project will evaluate the shortcomings of current solutions in
the industry and recommend incremental improvements and conceptual solutions for
development.

6.2 Project Aims

The following questions were addressed in order to determine the root causes of the problem:

- What are the existing systems and methods available to mines to assist workers with
  escape in poor visibility underground environments?
- What are the shortcomings of the existing systems?
- How can these shortcomings be addressed?
- How can alternative solutions be prioritised?
- How well does the highest priority proposed solution address the problem?

In order to address the questions above, the following were achieved:

- Identification of all available systems that assist miners with escape in poor visibility
  underground environments;
- Determination of the shortcomings of the existing systems;
- Development of alternative solutions;
- Selection of better alternatives; and
Evaluation of alternative solutions.

The main objective of the research project was to reduce the risk of injuries and fatalities due to a failure to escape in poor visibility, underground environments. The project aims can be summarized as follows:

- Provide solutions to enable improved probability of escape in poor visibility and in underground environments;
- Reduce risk of loss of life due to failure to locate lifelines;
- Reduce risk of injury due to failure to locate lifelines;
- Reduce risk of loss of life due to failure to reach lifeline in time; and
- Reduce risk of injury due to failure to reach lifeline in time.

6.3 Project Hypothesis & Methodology

Current Hypotheses

- Current practices do not provide a fail-safe solution during emergency evacuation in poor visibility;
- Poor visibility results in disorientation; and
- Location of the lifelines make them difficult to find in poor visibility.

The above causes make it either impossible to locate lifelines or it can take too long to find the lifeline and reach a refuge chamber or a place of safety in the time afforded by the breathing apparatus provided. Before solutions to the problem can be solved, the root causes need to be properly understood. This entails:

1. Gaining a proper understanding of the current technologies in use together with an understanding of their shortcomings. These shortcomings need to be analysed and understood from the perspective of the mining companies, government and employees.
2. Understanding what technologies are currently being developed, if any, that could possibly address the shortcomings identified.
3. Reviewing and perhaps redefining the detailed user requirements for an ideal solution.
4. Doing a gap analysis between the ideal solution and existing systems.
5. Providing solutions that would address the gaps identified.
6. Identifying appropriate manufacturers to work with in manufacturing the proposed solution.
7. Developing solutions in co-operation with identified manufacturer/s.
8. Testing solutions.
9. Reporting.
10. Conducting workshops.

6.4 Project Milestones

The project milestones and progress reports can be seen in Table 1, and the schedule/Gantt chart seen in Figure 1. The project finances can be seen in APPENDIX A: FINANCIAL SUMMARY.

Table 1: Project Milestones Progress Report

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<td>✓</td>
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<td>Milestone 2 Determine all current technologies used for escape</td>
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<tr>
<td>Milestone 3 Gather and review reports and other available material on all current technologies in use</td>
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<td>N/A</td>
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<td>Milestone 4 Visit manufacturers and discuss current products and work on newer or improved products</td>
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<td>N/A</td>
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<tr>
<td>Milestone 5 Visit mines and discuss problems experienced and review accident reports</td>
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<td>N/A</td>
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<td>Milestone 6 Determine requirements for ideal technology or system</td>
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<td>N/A</td>
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<td>Milestone 7 Develop tool for assessment of current technologies</td>
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<td>Milestone 8 Gap Analysis – Define areas where current technologies fall short of requirements</td>
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<td>Milestone 9 Develop and analyse possible solutions</td>
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Figure 1: Project Schedule Gantt Chart

### 6.5 Champion Mines

The following mines/companies were consulted during the project:

- **Coal**
  - Sasol (Danie Schoeman)
  - AngloCoal (Andrew Thompson)
- **Platinum**
  - AngloAmerican Platinum Bathopele Mine (Site visit conducted)
- **Gold**
  - AngloGold Ashanti (Morne Beukes)
  - Sibanye Gold (Vijay Nundllal)
MILESTONE DELIVERABLES

The total project comprised of thirteen (13) milestones, with all thirteen (13) milestones completed.

7.1 MILESTONE 1: PROJECT INITIATION

The start-up presentation was done on 23 January 2015. See APPENDIX B: START-UP PRESENTATION for details of the presentation.
7.2 MILESTONES 2 & 3: DETERMINE ALL CURRENT TECHNOLOGIES USED FOR ESCAPE & GATHER AND REVIEW REPORTS AND OTHER AVAILABLE MATERIAL ON ALL CURRENT TECHNOLOGIES IN USE

In order to identify the existing technologies used for escape, the following approach was applied:

- Knowledge gained from recent underground visits.
- Internet searches.
- Review of documents retrieved.
- Discussions with Mine Rescue Services (Mr Christo de Klerk).
- Discussions with product suppliers (in progress).

In escape and rescue two distinctly different approaches were followed by mining operations, being:

- Self-escape; and
- Self-escape into place of safety, followed by rescue.

In South Africa self-escape into a place of safety or Refuge Bay, followed by rescue, is practiced. The effectiveness of escape to these places of safety depends on a number of factors including a well-trained workforce, proper escape routes etc., to assist workers reaching them. From previous research (Van Rensburg et al., 1995) the extreme difficulties caused by poor visibility were highlighted.

7.2.1 Results as per Milestones 2 & 3

In this section the main technologies supporting the means of self-escape have been identified.

7.2.1.1 Self-Breathing Apparatus

A self-rescuer is an emergency breathing apparatus which enables underground workers to protect themselves against the toxic emissions that may contaminate the ventilation system in the aftermath of a fire or explosion. Two types of self-rescuer are available: The filter self-rescuer and the self-contained self-rescuer (Walters 2014). In South Africa, only self-contained self-rescuers (SCSRs) are used.
There are two types of self-contained self-rescuer: The compressed oxygen and chemical types. The compressed oxygen type has a small pressurized cylinder of O₂ and a scrubbing unit. The chemical type contains a bed of potassium super-oxide (KO₂) and operates independently from the environment by using the carbon dioxide and moisture in the exhaled air from the user to generate oxygen from the KO₂. The principal advantage of this type of rescuer is that it can be used in a noxious or poisonous atmosphere or in an atmosphere where there is an oxygen deficiency.

These units are supplied in a variety of sizes affording various breathing durations which are normally calculated at a breathing rate of 35 l/min and are tested in accordance with SANS 1737 to guarantee their functionality. Obviously, the higher the breathing-rate, the shorter the duration of the set will be. When these units are used under adverse conditions such as in climbing or negotiating obstacles, a person's breathing rate will increase significantly. This must be kept in mind when determining the location and spacing of the refuge chambers or access to fresh air.

The smaller self-contained self-rescuers are worn on the belt and the larger, long duration units, are usually kept in caches or on vehicles. The strategy for deploying these units depends on the nature of the mine and they are normally stored in a cache. These units are not indestructible and require regular checking according to the manufacturer’s recommendations. It is recommended that self-rescuers be issued on an individual basis and not multi-shifted from a common pool (Schreiber et al., 2004). These units are also tested annually by the CSIR to confirm their functional performance.

Kowalski-Trakofler et al. (2008:4) highlight nine key concerns associated with the use of Self-Contained Self-Rescuers (SCSRs) in a research study completed after an explosion experienced at Sago Mine in West Virginia:

- Starting the unit.
- Heat.
- Induction of cough.
- Taste.
- Resistance to breathing.
- Quality of breathed air.
- Nose clips.
- The goggles.
- The bag.

According to Kowalski-Trakofler et al. (2008:6) there had been repeated calls for SCSR expectations training over the years, because a significant number of miners who had had to use the devices in an emergency maintained that the units did not work. We asked whether these concerns highlighted in their study had been addressed sufficiently by South African mines?

During an interview with Mr Christo de Klerk of Mine Rescue Services (MRS), he elaborated on the use of SCSRs in emergencies in South Africa and highlighted potential problems. Although SCSRs were mostly designed to last approximately 30 minutes, great deviations from this time have been observed. De Klerk was also of the opinion that improved practical training on an actual or simulated SCSR would go a long way to improving escape success, as many people were shocked when they used the SCSR for the first time. People who use the units for the first time become confused, due to the fact that the unit generates heat owing to an exothermic reaction. Demonstration on the effective use of the SCSR was not deemed an optimal training solution according to De Klerk. The option of using outdated SCSRs for training that some mining companies may be discarding, was mentioned.

7.2.1.2 Eye Protection (goggles)

During escape, particularly under poor visibility, smoke usually burns the eyes of the escapee, further adding to the problem of shock and disorientation. Some of the SCSRs include goggles, but none of those used in SA mines. This aspect needs further consideration and even providing workers with goggles as part of their standard personal protective equipment (PPE) was suggested. Goggles similar to those used by swimmers would be suitable.

7.2.1.3 Early Warning (communications)

In the discussions with Mr Christo de Klerk, the problem of early warning was discussed. It was felt that if all workers in a section could be effectively warned of emergencies as early as possible this would also improve the escape efficiency. The question was posed that perhaps
the solution lay with a section alarm or mine-wide emergency alarm that could be activated from the surface or within a section.

Use of a stench type system was developed and implemented some time ago. A system developed in South Africa was initially implemented but has not found widespread implementation. These systems are still available and the ZACON system (Zacon, 2015) is one of these. This safety system is designed to be a first line of defense for underground personnel. It relies on sense of smell and the ventilation or compressed air system to deliver the message to underground personnel. It is a completely automated system and simultaneously dispenses the stench at a metered rate to a multitude of sites even kilometers apart. This allows maximum mine penetration, correct worker exposure rates and an instantaneous response to an adverse situation in the mine. All systems continuously feed back information as to their readiness. The Zacon system can be seen in Figure 2.

![Zacon stench injection system](image)

Figure 2: Example of a Zacon stench injection system (Zacon, 2015)

7.2.1.4 Lifelines

Simple lifelines with cones, but without reflective properties were identified as being in use during recent (July 2014) visits to coal mines. Van Rensburg et al. (1995) reported on the effectiveness of the application of lifelines as part of research conducted for the MHSC.
An internet search identified lifelines, developed in the USA, that incorporate reflective cones and the line between cones, by spacing separate lengths of reflective tape. This reflective tape, hung on the line, also allows for direction indication by only applying the reflective material to one side of the tape being hung on the lifeline. This is a simple solution to aid in visual detection of the line. Different shaped cones or physical attachments are used to indicate various important locations, such as a branch in the line leading towards alternative SCSRs, Refuge Chamber doors, etc. None of these lifelines was seen in the coal mines visited. However, this does not mean that there are not mines in SA currently using the improved designs. It is nevertheless clear that part of the solution may prove to lie in simply applying existing technology in South African mines.

Figure 3: CAB lifeline with directional reflective cones and tape (Cabproducts, 2015)

Figure 4: CAB highly reflective tubes (Cabproducts, 2015)
Figure 5: CAB Lifeline Ball indicating door (left) & CAB Lifeline Coil indicating direction to refuge bay at branch (right) (Cabproducts, 2015)

Figure 6: CAB high visibility clip-on clipped onto roof bolts (Cabproducts, 2015)
7.2.1.5 Emergency response training

The importance of mine response readiness was not part of this investigation, but it is of great importance that management responsibilities include being ready and prepared to deal with emergency response situations. The importance of conducting emergency response drills is also of great importance. These should not only be done routinely as per the legal requirements but also need to be done during simulated, zero visibility training.

In Australia, all Queensland underground coal mines are required to test their emergency preparedness by running simulated emergency exercises annually. Each year, one mine is selected to be the focal point of the State's emergency preparedness and hosts the Level 1 emergency exercise. Assessors monitor the exercise and a report is produced that contains recommendations based on what was learned during the exercise. Cognizance of this best practice must be taken, as valuable lessons are learnt during these exercises.

In a chapter prepared by Walters and Lane (2014) they included an insightful section on emergency response training. In the paragraphs that follow some of the insights that they gained is detailed. An important aspect for ensuring successful escape and rescue during emergency situations is training. They state that lives have been lost in mine fires due to people not being adequately trained or not adhering to what they have been trained to do.

“There are four distinct sections of escape and rescue training:

1. How to recognise a warning to evacuate and ensure that other people in the area are also aware of the requirement to evacuate.
2. Procedures, such as when and how to don a self-rescuer.
3. Locating a place of safety and staying there until rescued or instructed to leave.
4. Procedures inside refuge chambers.

Training should cover the correct use of and reaction to any warning device. Self-rescuer training involves using proper training sets and training material provided by the original equipment supplier. People need to know exactly what to do when required to don a self-rescuer, as well as what breathing through a self-rescuer will be like so that they are less likely to panic when encountering breathing resistance and elevated breathing temperatures. It is vital that people underground should be aware of the location of the nearest refuge chamber or other place of safety and the route to be taken to reach it. Once they have reached a refuge chamber, they must know how to operate the air supply and how to inform those in charge of managing the incident of their location, the number of people in the chamber and the identities of all of them, and other necessary information.

With escape and rescue training there are the all-too-common problems of complacency and retention of knowledge. For these reasons supervisors should conduct fire drills and have on-the-job escape and rescue training sessions periodically, in addition to the formal induction and periodic (usually annual) retraining.”

7.2.1.6 Virtual Reality

The rapid development of virtual reality (VR) is believed to also provide potential solutions by providing VR goggles or screens to workers underground. This could feasibly navigate a worker to a Refuge Bay without the need for lifelines. This possibility was investigated further. The possibility was considered of developing a hard hat with incorporated screen including lamp, battery and SCSR.

An internet survey also revealed technology being developed in Canada and still under development, called integrated personal protective equipment (IPPE) (Miningexcellence, 2015). Although the details of this development project are not yet certain, it may prove valuable for the MHSC to explore participating in these new developments.
7.2.1.7 MOSES system

A research project completed by the MHSC in 1995 (Van Rensburg, et al., 1995) was reviewed where the lifeline concept was developed in conjunction with Haggie Rand. This project also highlighted and compared other technologies available at the time, including the MOSES system. The possible integration of the MOSES system with the lifeline concept was investigated.

7.2.1.8 New systems

The A-OSH EXPO 2015 was held at Gallagher Estate during May 2015. The Expo was attended by the team in order to gather information on potential newly developed products.
7.2.1.9 Milestone Conclusions

It is believed that many of the existing technologies available may, either on their own or in combination, provide dramatic improvements to systems currently used by many SA mines. The potential problems/opportunities identified to date are summarized as follows:

- **Lungs** - SCSR – improved experiential training, instead of demonstration only.
- **Eyes** - The use of goggles or some means of protecting eyes from smoke needs investigation.
- **Disorientation** - Great improvements in dealing with the disorientation problem were made through the introduction of lifelines. They assisted personnel to reach Refuge Bays, ONCE THE LIFELINE HAD BEEN REACHED. Reaching the lifeline still remained a challenge. Some improvements have been made to the original lifelines, by:
  - Adding reflective material.
  - Using steel cable instead of nylon rope.
  - Suspending lifelines at a convenient height.
  - Attaching the line to roof bolts with elastic material at roadway intersections.
- **Early warning** – Implementation of well-known and proven technologies can assist in the early warning of workers to shorten emergency response times.
• **Emergency response training** – This includes both the training of the workforce and additional simulation training to evaluate the emergency response fitness within individual operations.

• **Digital lifelines** – This technology will assist workers to escape as well as making further improvements to enable them to reach the currently used lifelines in time and in poor visibility. This needs further investigation.

• **Implementation of physical lifelines in mines other than coal mines**

**7.2.2 Conclusions from Milestone 2 & 3**

The A-OSH EXPO 2015 took place during 12-14 May in Midrand. The researchers attended this expo to gain further insights into current products available on the market.
7.3 **MILESTONE 4: VISIT MANUFACTURERS AND DISCUSS CURRENT PRODUCTS AND WORK ON NEWER OR IMPROVED PRODUCTS**

The original scope of this project provided for visits with manufacturers of technology; however, it quickly became clear that, in addition to the technology involved, emergency preparedness and emergency training were key to the success of escape in emergencies underground, as highlighted in the previous milestone report. Hence, the scope of the work required for the current milestone achievement was broadened to allow for this fact.

The following were consulted:

- Mine Rescue Services (MRS);
- Dubaco Safety Systems;
- Virtual Reality Centre – University of Pretoria; and
- Mine fire simulation software as an aid to escape

7.3.1 Results as per Milestone 4

7.3.1.1 **Mine rescue services**

The authors met with Mr Christo de Klerk of MRS in February 2015. The objectives of the meeting were:

- To gain insights into the equipment used by MRS during emergency rescue (Milestone 3);
- To gain insights into the methods used during rescue (Milestone 3); and
- To gain insights into problems as perceived by MRS in the events where escape failed by some people (Milestone 4).

The problems as perceived by De Klerk were categorized as technological and methodological.

7.3.1.1.1 **Technology**

According to De Klerk, there are several concerns related to the use of self-contained self-rescuers (SCSRs). These concerns were highlighted in the previous milestone report. A problem of particular note was burning eyes due to smoke present in underground emergency situations. Apparently, none of the SCSR units used on South African mines contain eye protection, something De Klerk noted as a serious flaw in the current escape “system”. There are many possible solutions to the problem of burning eyes, but the optimal solution will depend
on the overall solution proposed. A holistic approach will be required to determine the best solution to achieve the ultimate objective of effective escape in poor visibility.

The use of lifelines was also discussed. In De Klerk’s opinion, the fact that lifelines currently in use in South African mines were not specifically designed to be reached in conditions of poor visibility was also a serious concern. Attempts have been made to address this problem, such as by adding reflective properties to the lifeline (see Milestone 3 report for more on this), although a perfect solution is yet to be proposed or implemented. The authors believe the problems highlighted in terms of the SCSRs and the lifelines represent an opportunity to enhance the capability of the system.

7.3.1.1.2 Methodology

De Klerk was of the opinion that the effectiveness of early warning systems could also be improved. The absolutely critical time for escapees is the time between the moment they receiving the warning or instruction to retreat to refuge bays (RBs) and the moment they reach the lifeline. Plenty of evidence exists to demonstrate that once escapees reach lifelines, reaching a RB is not a problem, provided the lifelines had been installed and maintained correctly. It is therefore absolutely critical that escapees receive the early warning and instruction to retreat to RBs as early as possible. Definite options exist here and were addressed in this research.

With regard to the SCSRs, expectations training suggested would certainly add value, especially while we retain the concept of using chemical-type self-rescuers. If non-chemical type self-rescuers are used, less expectations training may be necessary.

Once escapees reach the RB, the decision of whether to stay or leave and attempt to self-escape from the mine remains a difficult decision in certain circumstances. Key to reducing the risk of injury or fatality due to incorrect decisions in these circumstances is a good communication system and procedure. Systems that use the rock for signal transmission exist and could provide a fail-safe means of communications in these circumstances. The escape from an RB to surface fell outside of the scope of this study, however any means of increasing confidence amongst escapees that they will reach safety would reduce the risk of failure.

7.3.1.2 Dubaco Safety Systems

Dubaco was also visited in February 2015. The objectives of this meeting were:
• To investigate the CAB products first-hand;
• To establish how widely the product was applied in South African mines; and
• To establish whether there were new products being developed and if so, what they were.

Dabaco Safety Systems are the re-sellers of the CAB lifelines (produced in the USA) referred to in the previous milestone reports (Milestones 2 & 3). As explained in the previous reports, CAB lifelines were developed with reflective properties to make them more visible in poor visibility conditions, and are made of steel wire and to prevent them from burning in case of a fire.

According to Dabaco, the South African mines have thus far not bought CAB products. The manager we met with, Mr. Vissard, stated that mines tend to do the minimum, i.e. spend the minimum amount of money, considered “necessary”. Thus most of them use the cheaper plain lifelines supplied by Rescue 1. These lifelines do not have reflective properties and are made of ski-rope. It should be mentioned that CAB lifeline is substantially more expensive than the plain lifeline. Mr. Vissard said no new developments were currently underway in terms of lifelines.

The potential to add lighting and audio properties to lifelines, effectively integrating the MOSES system with the lifeline concept, was considered.

7.3.1.3 Virtual Reality – University of Pretoria

The University of Pretoria is completing the construction of their new Mining Engineering offices which will include a virtual reality (VR) centre with immersive technologies. The VR Centre is intended primarily to enhance the education of mining engineers, but it will also be available to industry for various applications. The technology in the VR Centre will allow the user to feel as though they are actually in a mine and the authors believe it can also be applied to simulated emergency and escape planning.

Hololens, developed by Microsoft, is an example of the technology that could be used (https://www.youtube.com/watch?v=b6isL_5Wgvrg). It allows the overlaying of spatial data onto the real environment: augmented reality. Thus a person could, in theory, wear three-dimensional goggles underground, and even in situations of no visibility would be able to “see”. The augmented reality goggles could, for example, indicate the direction to travel from any
location in the mine to reach the refuge bay (navigation). As a second option, a hard hat with a built-in transparent screen could be envisaged, such as indicated in the previous milestone report (Milestones 2 & 3) or Microsoft’s Hololens. In the case of an emergency, the screen could indicate to the escapee the direction to travel to reach the refuge bay. It becomes a digital lifeline. The costs of a solution such as this may prove prohibitive at this stage, but it should be considered.

7.3.1.4 Mine fire simulation software
Mine fire simulation software has existed for some time, but to-date it has not been widely applied in rescue training. The concept of mine fire simulation software is that it demonstrates, in a dynamic fashion, the impact of fires on ventilation systems and the spreading of gases and smoke. The potential for applying the software in training of workers, rescue teams and rescue management teams is being investigated by Slaughter (2015). He argues that fire simulation software could be used in worker expectation training, rescue team training and rescue management training.

7.3.1.4.1 Worker Expectations Training
If mines could demonstrate to underground workers the way fires interact with the air flow in their specific sections, based on actual ventilation characteristics, the workers would better understand the importance of reacting swiftly when fire alarms are activated. They would see that even though they may not observe the effects of a fire not yet in their section, they are at risk of being overcome with smoke before reaching the RB if they do not respond immediately. If this was incorporated into regular safety training, workers would be better equipped to respond in an emergency. It is similar in concept to the expectations training suggested for SCSRs.

7.3.1.4.2 Rescue Team Training
Having the ability to model and test different fire and rescue scenarios would allow rescue teams the opportunity to test different strategies and even to practice best courses of action prior to any actual emergency. This would further enhance the probability of the successful escape of underground workers.

7.3.1.4.3 Rescue Management Training
Fire simulation software can be used in a similar fashion to assist management with planning and preparing for emergency response. It usually takes some time for MRS to reach a mine site after an incident, and in this critical time, good emergency response procedures are essential.

### 7.3.2 Conclusions from Milestone 4

Substantial information regarding existing systems in the market and new technologies under development have now been accumulated. The information acquired regarding existing systems should set the scene for fruitful discussions with mines.
7.4 MILESTONE 5: VISIT MINES AND DISCUSS PROBLEMS EXPERIENCED AND REVIEW ACCIDENT REPORTS

The objectives achieved in Milestones 1 - 4 were aimed at the following:

- **Identifying** current technologies and methodologies in use internationally to assist in escape, based on information in literature.
- **Understanding** the current technologies and methodologies, as highlighted by literature.
- **Improving understanding** of current technologies and methodologies from the perspective of manufacturers, and learning about possible newer technologies that may be in the development stages (i.e. not implemented in industry yet).

The objective of Milestone 5 was to improve our understanding of the problems associated with existing escape technologies and methodologies as perceived by the mines.

7.4.1 Results as per Milestone 5

7.4.1.1 Coal Mines

7.4.1.1.1 Early warning systems

The most common means of early warning systems include:

1. Alarm systems
2. Stench Gas systems
3. Communication systems

In coal mines handheld systems have been implemented and these are often supported by solid line telephone systems to fixed points such as the waiting places, refuge bays and along the conveyor belt systems

7.4.1.1.2 Lifelines

The mine did not perceive any real problem with the lifelines currently in use (hardware). However, it is recognized that in dense smoke, visibility becomes severely restricted and the mine’s solution to this problem is to alter the layout of the lifelines, to ensure that if a person were to walk in any direction from any location in a section, they would reach a lifeline without difficulty.
At Exarro a system of using plastic poles connected to the lifeline and covered in reflective tape installed at every second pillar is used to assist in the seek and find of the lifeline. In another mine steel cables are used, connected to the lifeline and also marked using reflective tape. This assists when needing to find the lifelines in poor visibility as well as when the escapee is not in a section and needs to find the lifelines. As previously explained the lifelines lead to the refuge chambers.

The use of lifelines is also limited to our collieries and not used in the hard rock mines. The personnel interviewed identified the problem with lifelines as more as a problem of implementation. During the research an alternative type of fixed lifeline was discovered. This uses directional LED’s to guide workers to the refuge chambers. This does seem to have merit and meetings with the suppliers and additional supporting documentation is being obtained.

7.4.1.3 SCSR

During the interviews it was the opinion of the interviewees that no problems were perceived with the current SCSRs. Reports from the functional testing of the body worn self-rescuers showed that in some units breathing time is significantly reduced over time. This can have a material impact on the positioning of refuge chambers and especially the distance between them.

The use of long duration SCSRs or long duration compressed oxygen units stored in a cache system is also limited to collieries and not used in hard rock mines.

7.4.1.4 Refuge bays

In fixed installations, the reliable supply, of either fresh air to collieries together with the continuous maintenance problem due to malicious damage, remains a problem. In collieries fresh air is supplied via drilled holes connected to the surface and it is the responsibility of the first entrant to start the fresh air supply fan. Two practices are used, being a small fan in the refuge chamber or a small surface fan. The bottom fan suffers severely from corrosion problems due to water ingress finding its way down the ventilation hole but it is protected against vandalism and theft. Surface fan protection against copper theft remains a real risk.

7.4.1.2 Hard rock mines

7.4.1.2.1 Early warning systems
In hard rock mines the use of fixed line communication systems to the working places and communication to refuge chambers are most often the only means of communication and early warning. The use of leaky feeders support the communication in some of the mines but is not common practice. In the past limited use was made of stench gas but this also is not common practice.

7.4.1.2.2 Lifelines

Currently, lifelines are not used in most hard rock mines. People being successfully guided to refuge bays in hard rock mines in poor visibility is acknowledged as a problem. One feature that most hard rock mines have introduced is to reduce the distances between refuge chambers and the distance from the working place to refuge chambers. This is commonly 750 m, compared to a 1000m in collieries. Furthermore, they must provide a second, alternative escape route and as such every workplace is covered by two refuge chambers.

7.4.1.2.3 SCSR

No problems were perceived with SCSRs.

7.4.1.2.4 Refuge bays

As previously highlighted, reliable fresh air supply and its maintenance to meet the life sustaining standard remains a challenge. An incident occurred where a fire severed the intake air compressed air line resulting in the refuge chambers heating up with smoke ingress. This sadly led to a large loss of life. The protection of the compressed air lines in areas where intake fire hazards are present remains a significant risk. This risk is even further increased where the use of “plastic” type pipes for compressed air is condoned.

7.4.1.3 Lessons learned from incidents

The recent incident at Doornkop shaft highlighted the importance of secure fresh air supply into refuge bays, especially in hard rock mines, where independent access from surface is usually much more difficult or costly, due to the depth below surface of most of South Africa’s underground, hard rock mines.

As mentioned in previous milestone reports, the investigation into the Sago mine disaster in the USA highlighted the problems associated with the use of SCSRs. The investigation report made recommendations for experiential training in addition to, or instead of, training by demonstration.
7.4.1.4 A-OSH Expo

The A-OSH Expo was attended on 14 May 2015. The objective was to determine whether there was technology available to the mines that had not yet been identified. The only new discovery was that, according to Robbie Taitz of MSA, a “TR” SCSR unit exists, specially developed for experiential training purposes.

Another MSA product of great interest is the “S-Cap-Air” unit, which has a full-face mask that provides 15 minutes of breathing time and eye protection.
7.4.2 Conclusions from Milestone 5

It was clear from discussions with mines and suppliers that there is consensus regarding the shortcomings of current systems and methodologies. However, there seem to be slightly different views on the best solutions to these issues.

- Early warning

It is clear that much can and should be done to improve early warning systems.

- Breathing apparatus
SCSRs work, but improved training methods must be implemented. Training units are available on the market, but improved training technologies can still be developed.

- Guidance to refuge bays

It seems logical that there is a critical time between the occurrence of a smoke-causing event and the stage where smoke becomes so thick that visibility becomes zero. If people reach a lifeline within this time i.e. before visibility reduces to zero, their chances of reaching a refuge bay improves dramatically. Emphasis should therefore be paid to available and developing technology and actions during this phase, including specific attention to:

  - Effective early warning of all underground personnel of smoke inducing incidents;
  - Available breathing apparatus that can be donned quickly;
  - Breathing apparatus with long enough life for users to reach a refuge bay;
  - Eye protection;
  - Employees being fully comfortable and experienced in the use of the breathing apparatus;
  - Lifelines AS CLOSE AS POSSIBLE to all locations in section;
  - Lifelines AS ACCESSIBLE AS POSSIBLE;
  - Lifelines AS VISIBLE AS POSSIBLE in dense smoke; and
  - All employees ALWAYS knowing where lifelines are located in their sections.

In terms of the different views on the solution to reaching the lifeline in time, the authors believe a combination of the following two approaches offers a good improvement in the probability of escape in poor visibility:

  - Increased density of lifeline installation in each section; and
  - Improved detection of lifelines (audio visual).

- Refuge bays

In deep mines, the availability of fresh air in refuge bays remains a challenge. Options for the provision of a secondary air supply, independent from main line compressed air systems, should be investigated.
7.5 MILESTONE 6: DETERMINE REQUIREMENTS FOR IDEAL TECHNOLOGY OR SYSTEM

Before possible solutions for an improved escape strategy or system can be provided, it is necessary to do a gap analysis to determine where the existing systems are lacking. In order to do this, the ideal system needs first to be fully understood. This was the objective of this milestone i.e. to specify the characteristics or functionality of the ideal system. The specification of the ideal system was approached in two parts: Specifying the system within current product constraints, and Specifying the system without current constraints.

7.5.1 Results per Milestone 6

In an emergency, all people in any location within a mine must be able to reach the refuge bay under poor or zero visibility conditions. Before an existing system is analysed for effectiveness, the high-level design of an escape system that would effectively assist escapees in reaching the refuge chamber must be considered.

7.5.1.1 Within current constraints

The system illustrated in Figure 11 has been designed based on the following assumptions:

- SCSRs are worn by all individuals, at all times; and
- A tactical guidance system is implemented to direct workers from all areas in the working sections to refuge bays. Although not current practice in hard rock mines, a system of this type should be seriously considered.

![Figure 11: Ideal escape system design](image)

Each element of the system is considered in more detail in the headings that follow.
7.5.1.1.1 Early warning

The ideal early warning system would activate as soon as possible after a fire, explosion or similar event occurred, and would immediately signal every worker who was underground that an incident requiring them to move to the refuge bay had occurred.

In order to achieve this, the system should provide for:

- Gas detection systems to detect fires or explosions that would activate the system; and
- The ability of every worker in the mine to activate the early response system from anywhere in the mine.

Workers could be alerted in any/all of the following ways:

- An audible alarm;
- A visible alarm for those workers who are working in noisy conditions;
- Consideration could be given to systems that would shut down all equipment when the early warning system is activated; and
- Smell (stench gas).

7.5.1.1.2 Respirable air

The ideal breathing apparatus would supply oxygen to each person from the time the early warning system is activated until the individual reaches the refuge bay. The apparatus should be:

- Easy to use;
- Quick to initiate;
- Comfortable;
- As light as possible; and
- Last as long as possible.

7.5.1.1.3 Eye protection

When the eyes come into contact with smoke, they burn and it becomes very difficult to keep them open, effectively rendering sight useless even in conditions where visibility through the
smoke may not be zero. Protecting the eyes is therefore a key to enabling some vision in smoky conditions. Eye protection should ideally be:

- Lightweight;
- Compact;
- Easy to put on;
- Airtight (not allowing smoke between glass or plastic visor and eyes);
- Always available; and
- Fit the wearer.

### 7.5.1.1.4 Detection of lifeline and reaching the lifeline

The lifeline should be easy to detect, or if there is no lifeline, it should be easy for each individual to detect the escape route to the refuge bay. Ideally, the detection of the lifeline or escape route should be visible or detectible even in very low or zero visibility conditions. Once the lifeline is detected, it needs to be easy for the individual to reach the lifeline. The lifeline should:

- Not be too far from any individual (i.e. any location in the section);
- Be suspended within reach of the ordinary person (i.e. not too high); and
- Be easy to distinguish by hand from other wires or lines (especially important in low or zero visibility).

### 7.5.1.1.5 Guidance to refuge bay

After reaching the lifeline, it should be easy to use the line to reach the refuge bay as quickly as possible. In order to achieve this, the line should be:

- Laid out in a way that minimises the distance to walk to the refuge bay;
- Robust and fire retardant; and
- Attached to the refuge bay in a way that makes it easy to enter the refuge bay.
7.5.1.1.6 Refuge bay

The refuge bay should comply with the stated requirements for refuge bays as described in the MHSA regulations.

7.5.1.1.7 Training

A vital component of effective escape is the individual worker’s confident knowledge of exactly how to respond in emergency situations. This includes knowing:

- How to don the SCSR;
- How to apply eye protection;
- How to search for the nearest lifeline;
- How to get hold of the lifeline;
- How to use the lifeline to get to the refuge bay; and
- What to do once in the refuge bay.

7.5.1.2 Without current constraints

It was important to consider the ideal system without constraints imposed by current systems and thinking as well as the ideal system within the current constraints. The following systems could be feasible:

- Replacing the current SCSR with longer lasting or compressed air or oxygen type systems.
- Using an IPPE helmet as referred to in Milestones 2 and 3 reports that incorporates:
  - An automatic switch from ambient air to SCSR when toxic gas levels are detected;
  - Integrated navigation system removing the need for lifelines;
  - Integrated cap-lamp and battery, removing the need for separate battery and lamp;
  - Integrated early warning via flashing cap-lamp when toxic gas levels are detected, and
  - Integrated air-filter for normal use
- Developing an integrated umbilical lifeline including:
Fresh air supply via a surface borehole, via fire retardant tube integrated into lifeline, potentially reducing the distance and duration requirement of SCSR;

- Integrated LED evacuation pulse system, replacing the MOSES type of system referred to in Milestone 2 report and increasing visibility of the lifeline itself; and

- Communications could also be integrated into the lifeline.

7.5.2 Conclusions from Milestone 6

It is recommended that the functional requirements of the ideal escape system stated here be used as a basis for identifying the shortcomings of the currently employed systems.
7.6 MILESTONE 7: DEVELOP TOOL FOR ASSESSMENT OF CURRENT TECHNOLOGIES

In order to assess the current technologies, it was necessary to identify the assessment criteria. The criteria used for the assessment originated from the constraints identified in Milestone 6. Not all constraints identified in Milestone 6 were amenable for assessment purposes, thus selected criteria were used. The assessment “point-of-view” is one where each technology was considered in isolation, and where it was assumed that each technology was installed and properly maintained. Although some of the technologies are not stand-alone solutions, this approach allows for an objective comparison. The cost of each of the technologies was not considered in the assessment. The costs will be incorporated into Milestone 10.

7.6.1 Results per Milestone 7

7.6.1.1 Assessment Criteria

The criteria used were as follows:

7.6.1.1.1 Does it act as an early warning system?
Yes / No. If Yes, through which sense?

7.6.1.1.2 Does it provide a respirable air supply?
Yes / No.

7.6.1.1.3 Does it provide eye protection?
Yes / No.

7.6.1.1.4 Does it allow for the detection of the lifeline?
Yes / No. If Yes, under which conditions and through which sense?

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Perfect visibility</td>
<td>Impaired Visibility &lt;20m object recognition</td>
<td>Poor Visibility &lt;5m object recognition</td>
<td>Extremely Poor Visibility &lt;2m object recognition</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
7.6.1.1.5 Does it allow for the lifeline to be reached?

Yes / No. If Yes, under which conditions and through which sense?

<table>
<thead>
<tr>
<th>1</th>
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<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perfect visibility</td>
<td>Impaired Visibility &lt;20m object recognition</td>
<td>Poor Visibility &lt;5m object recognition</td>
<td>Extremely Poor Visibility &lt;2m object recognition</td>
<td>Zero Visibility</td>
</tr>
</tbody>
</table>

7.6.1.1.6 Does it provide guidance to the refuge bay?

Yes / No. If Yes, under which conditions and through which sense?

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perfect visibility</td>
<td>Impaired Visibility &lt;20m object recognition</td>
<td>Poor Visibility &lt;5m object recognition</td>
<td>Extremely Poor Visibility &lt;2m object recognition</td>
<td>Zero Visibility</td>
</tr>
</tbody>
</table>

7.6.1.1.7 Does it require prior training to understand/use?

Yes / No. If Yes, how much over the lifetime of installation?

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Once</td>
<td>Yearly</td>
<td>Monthly</td>
<td>Weekly</td>
<td>Daily</td>
</tr>
</tbody>
</table>

7.6.1.2 Technologies/Strategies assessed

The technologies/strategies amenable to assessment were as follows:

- Self-breathing Apparatus
- MOSES system
- Tactile Lifeline
- Reflective Lifeline
- Lighted Lifeline
- Strobe Lights
- Laser Pointers
- Wireless Low Frequency Communications
- Stench Gas
7.6.1.2.1 **Assessment**

Table 2 displays the outcomes of the assessment performed, using the assessment criteria previously stated.

**Table 2: Strategies Assessment**

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-Breathing Apparatus</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>2</td>
<td>2</td>
<td>No</td>
<td>4</td>
</tr>
<tr>
<td>MOSES System</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>5 (Lifeline in this case is not tactile)</td>
<td>5 (Lifeline in this case is not tactile)</td>
<td>5 (Visual &amp; Audial)</td>
<td>3</td>
</tr>
<tr>
<td>Tactile Lifeline</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>1 – 2</td>
<td>1 – 2</td>
<td>5 (Tactile)</td>
<td>4</td>
</tr>
<tr>
<td>Reflective Lifelines</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>3</td>
<td>3</td>
<td>5 (Tactile &amp; Visual)</td>
<td>4</td>
</tr>
<tr>
<td>Lighted Lifelines (Visual)</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>4</td>
<td>4</td>
<td>5 (Tactile &amp; Visual)</td>
<td>3</td>
</tr>
<tr>
<td>Strobe Lights (Visual)</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>4</td>
<td>4</td>
<td>4 (Visual)</td>
<td>4</td>
</tr>
<tr>
<td>Laser Pointers</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>3</td>
<td>5</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Wireless Low Frequency Communications (Audial)</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>1 – 2</td>
<td>1 – 2</td>
<td>1 – 2</td>
<td>4</td>
</tr>
<tr>
<td>Stench Gas (Olfactory)</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>1 – 2</td>
<td>1 – 2</td>
<td>1 – 2</td>
<td>4</td>
</tr>
</tbody>
</table>
7.6.1.2.2 Assessment Outcomes

The outcomes of the assessment were interpreted by making use of radar charts for each technology/strategy. The red line depicts the performance of the individual technology/strategy, and the green outline depicts the ideal performance.

![Self-breathing apparatus radar chart](image1)

**Figure 12: Self-breathing apparatus radar chart**

![Moses radar chart](image2)

**Figure 13: Moses radar chart**
Figure 14: Lifeline radar chart

Figure 15: Reflective lifeline radar chart
Figure 16: Lighted lifeline radar chart

Figure 17: Strobe light radar chart
Figure 18: Laser pointers radar chart

Figure 19: Wireless communications radar chart
From Figure 12 through Figure 20, the following observations were made:

- Each strategy, apart from the self-breathing apparatus, scored zero in terms of air supply. This however does not eliminate these strategies, as the self-breathing apparatus can be used in combination with the other strategies.

- Each strategy scored zero in terms of eye protection. Once again, this can be increased to 100% performance within each strategy by using airtight goggles along with the specific strategy.

With these observations in mind, the following were concluded from the results:

- The MOSES system performance would be close to ideal, if used along with a self-breathing apparatus and goggles. However, the MOSES system does not serve as an early warning system.

- The lighted lifeline, as well as the strobe lights, if combined with a self-breathing apparatus and goggles, would yield the best performance based on the assessment method used.

The top 5 performing strategies, based on the assessment, were found to be:

1. Lighted Lifeline;
2. Strobe Lights;
3. MOSES
4. Reflective Lifeline; and
5. Tactile lifeline.
7.6.2 Conclusions from Milestone 7

It was recommended that the outcomes of the assessment of the current technologies be used to assist in defining the areas where the current technologies fall short (Gap Analysis, Milestone 8).
7.7 MILESTONE 8: GAP ANALYSIS – DEFINE AREAS WHERE CURRENT TECHNOLOGIES FALL SHORT OF REQUIREMENTS

Before potential solutions to serious problems were devised, it was vital that all possible causes of the problems were explored.

7.7.1 Results per Milestone 8

Some of the causes were highlighted by past incidents and accident investigations and others determined through a gap analysis where the ideal system was compared to the current practice. The direct causes of failure to escape in the aftermath of fires or explosions discovered during accident investigations were:

- Individuals not wearing SCSRs at the time of the incident;
- Not enough SCSRs available at the time of the incident;
- Individuals removing SCSRs during escape in toxic atmosphere even when they were still working;
- Individuals not able to find the lifeline, and
- Refuge bays not supplied with fresh air or oxygen.

Indirect causes that may exist, but would be very difficult to prove were the following:

- Early warning systems not activated timeously, and
- Eyes burning due to smoke, making it impossible to see even when smoke density was not so thick as to render zero visibility.

A cause and effect diagram is very similar to a “fault tree” and illustrates the relationship between the various categorised causes and failures to escape. The results from the fault tree analysis were used to construct a cause and effect diagram (Figure 21). Also, refer to the results of the gap analysis in Table 3.
Table 3: Gap analysis summary

<table>
<thead>
<tr>
<th>Safe escape system components</th>
<th>Ideal system: functional requirements</th>
<th>Current system capability</th>
<th>Cause of failure: gap analysis</th>
</tr>
</thead>
</table>
| Early warning                 | 1. Quick  
2. Automated & manual activation  
3. Activation from anywhere  
4. Warning by smell, vision, audio, equipment cut  
5. Warning everywhere  
6. Fire/heat proof communication system | 1. Varied effectiveness  
2. Each mine different | 1. Inconsistent effectiveness |
| Respirable air                | 1. Ease of use  
2. Quick to initiate  
3. Comfortable  
4. Lightweight  
5. Long duration | 1. Chemical-type self-worn SCSRs primarily in use | 1. Does not comply with ideal system requirement |
| Eye protection                | 1. Lightweight  
2. Compact  
3. Ease of use  
4. Airtight  
5. Available  
6. Well-fitting (all sizes) | 1. None | 1. Non existent |
| Detect lifeline               | 1. Possible in low visibility  
2. Possible in zero visibility | 1. Plain-coloured rope lifeline with directional cones | 1. Does not comply with ideal system requirement |
| Reach lifeline                | 1. Not too far (horizontal distance)  
2. Within reach (not too high)  
3. Ease of tactical detection | 1. Lifelines attached to sidewalls (coal pillars) and hanging walls in roadways | 1. Not easily reached in zero visibility |
| Guidance to refuge bay        | 1. Minimum distance to refuge bay  
2. Robust  
3. Fire proof  
4. Allow for easy entrance to refuge bay | 1. Refuge bays generally located within 1 000 metres of working places  
2. Lines constructed of fire retardant ropes  
3. Attached to refuge bay doors | 1. Not fireproof |
| Refuge bay                    | 1. Large enough  
2. Sufficient fresh air supply  
3. Other legal requirements | 1. Refuge bays conform generally to legal requirements | 1. Generally no problems here |
| Training                      | 1. Donning a SCSR  
2. Eye protection  
3. Detecting lifeline  
4. Reaching lifeline  
5. Using lifeline  
6. Refuge bay procedure | 1. Demonstration training (SCSR)  
2. Some mines employ experiential escape training in mock mine setup  
3. Refuge bay procedures available in refuge bays | 1. SCSR donning training lacking  
2. Experiential response training lacking in most mines. |
The red-coloured text indicates gaps in the system. It was clear from the gap analysis and the cause and effect diagram (Figure 21) that the current practices on South African mines can be improved upon.

Figure 21: Cause and Effect Diagram

7.7.2 Conclusions from Milestone 8

The gap analysis performed and the specifying of the requirements for the ideal solution (Milestone 6) have provided the basis for development of possible solutions. This was the objective of the work detailed in the following Milestone 9 report.
7.8 **MILESTONE 9: DEVELOP AND ANALYSE POSSIBLE SOLUTIONS**

By considering the ideal system referred to in Milestone 6, and the available technologies referred to in Milestones 4 through 6, it is clear that significant system improvements can be made by merely implementing existing technology which has not yet been adopted by South African mines. The following section will discuss such incremental solutions.

Overall, an integrated, holistic solution is the best approach to the problem of escape to refuge bays. Although the incremental solutions are discussed by sub-system, there are integrated components as well, which will be highlighted in the specific sections.

### 7.8.1 Results as per Milestone 9

#### 7.8.1.1 Possible Incremental System Improvements

Table 4 summarises the incremental system improvements.

<table>
<thead>
<tr>
<th>Safe escape system components</th>
<th>Ideal system functional requirements</th>
<th>Cause of failure: gap analysis</th>
<th>Proposed improvement</th>
</tr>
</thead>
</table>
| Early warning                 | 1. Quick  
2. Automated and manual activation  
3. Activation from anywhere  
4. Warning by smell, sight, sound, equipment cut  
5. Warning everywhere  
6. Fire/heat proof communication system | Inconsistent effectiveness | Centrally controlled integrated early warning system |
| Respirable air (Workplace to cache at waiting place) | 1. Ease of use  
2. Quick to initiate  
3. Comfortable  
4. Lightweight  
5. Sufficient duration | 1. Does not comply with ideal system requirements.  
2. Ineffective training | 1. Development of longer duration SCSR that can be worn on body.  
2. Implement experiential training |
| Respirable air (Cache at waiting place to refuge bay) | 1. Ease of use  
2. Quick to initiate  
3. Comfortable  
4. Lightweight  
5. Sufficient duration | 1. Insufficient available in cache.  
2. Change-over training lacking. | 1. Implement SCSR changeover experiential training  
2. Provide sufficient surplus number of Long-duration SCSRs |
| Eye protection | 1. Lightweight  
2. Compact  
3. Ease of use  
4. Airtight  
5. Available  
6. Well-fitting (all sizes). | Non-existent | OXY 6000 has goggles included |
### Safe escape system components

<table>
<thead>
<tr>
<th>Safe escape system components</th>
<th>Ideal system functional requirements</th>
<th>Cause of failure: gap analysis</th>
<th>Proposed improvement</th>
</tr>
</thead>
</table>
| Detect lifeline              | 1. Possible in low visibility  
2. Possible in zero visibility | Does not comply with ideal system requirement | Implement evacuation pulse system. |
| Reach lifeline               | 1. Not too far (horizontal distance),  
2. Within reach (not too high),  
3. Ease of tactical detection | Not easily reached in zero visibility | 1. Suspend lifelines a distance away from sidewall in every roadway. |
| Guidance to refuge bay       | 1. Minimum distance to refuge bay  
2. Robust  
3. Fire proof  
4. Allow for easy entrance to refuge bay | Not fireproof | Use steel wire lifelines, whilst taking cognizance of the hazard posed by this. Steel lifelines may not melt and disintegrate, but could heat up and burn persons who come into contact with it. |
| Refuge bay                   | 1. Large enough  
2. Sufficient fresh air-supply,  
3. Other legal requirements. | Generally no problems here. | |
| Training                     | 1. Donning an SCSR  
2. Eye protection  
3. Detecting lifeline  
4. Reaching lifeline  
5. Using lifeline  
6. Refuge bay procedure | 1. SCSR donning training lacking.  
2. Experiential response training lacking in most mines. | 1. Implement experiential SCSR donning training.  
2. Implement compulsory emergency response experiential training. |

### 7.8.1.2 Integrated Innovative Solutions

Norms must be constantly challenged if drastic improvements are to be made to existing technology and practices, such as those that influence the safety of people. In this chapter, further technologically complex solutions to the problem of escaping to refuge bays in low visibility situations were explored. The complexity and novelty of the technology proposed will no doubt add significant costs to potential escape strategies, but the costs would decline over time if more and more mines were to adopt the solutions.

#### 7.8.1.2.1 Integrated Personal Protective Equipment (IPPE)

The integrated personal protective equipment (IPPE) could provide an ideal solution to escape in poor visibility. Although little has been disclosed on the development details, the concept illustrated in Figure 22, could be envisaged.
The helmet could be designed in such a way that an integrated, gas measuring device automatically closes the atmospheric air-valve and visual display (if not closed already), forcing air to be drawn into the helmet cavity via an external compressed air or oxygen supply. Alternatively, the helmet cavity could be filled with a chemical-type oxygen-generator that automatically starts generating oxygen in an emergency.

The following main system features could be employed:
The helmet could be permanently connected to a compressed air or oxygen supply. The compressed oxygen storage could be an integrated part of the helmet or a separate, wearable cylinder.

While the air outside is not toxic, the valve is open allowing external air to enter the helmet. As soon as the external air becomes toxic, the valve closes and the permanently connected compressed air supply-valve automatically opens to allow fresh air into the helmet.

The helmet could also incorporate a system to filter out particles hazardous to the lungs.

Radar or sonar can be used to detect the distance to a wall or other obstacle in front of the helmet.

Laser-beams can also be added to assist in detecting excavations.

The visual display could be automatically activated to navigate the wearer to the nearest refuge bay. Technical characteristics such as those described for the HoloLens could effectively be integrated into the IPPE.

A microphone and speakers could also be integrated into the system, allowing for communication between central control and the individual.

An integrated battery and LED helmet-lamp would be a natural addition to the IPPE.

An IPPE with the listed characteristics would solve a significant percentage of the problems currently experienced during escape without the need for any additional measures. This type of IPPE would even make early warning systems unnecessary, although removal of early warning systems is not being suggested.

A more in-depth investigation into the possibilities and costs of providing such a solution should take place. It may be that the components suggested can be introduced in phases, thereby allowing them to be tested and perfected in real mining conditions. Table 5 summarises the potential impact of the IPPE.

Table 5: IPPE Potential Impact Analysis of the IPPE

<table>
<thead>
<tr>
<th>Safe escape system components</th>
<th>Ideal system functional requirements</th>
<th>Cause of failure: gap analysis</th>
<th>Proposed improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safe escape system components</td>
<td>Ideal system functional requirements</td>
<td>Cause of failure: gap analysis</td>
<td>Proposed improvement</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>--------------------------------------</td>
<td>------------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Respirable air (Workplace to cache at waiting place)</td>
<td>1. Ease of use 2. Quick to initiate 3. Comfortable 4. Lightweight 5. Sufficient duration</td>
<td>Does not comply with ideal system requirement or ineffective training</td>
<td>1. Integrated, automated, respirable air provision. 2. Easy, instantaneous, comfortable 3. Less duration required</td>
</tr>
<tr>
<td>Respirable air (Cache at waiting place to refuge bay)</td>
<td>1. Ease of use 2. Quick to initiate 3. Comfortable 4. Lightweight 5. Sufficient duration</td>
<td>1. Not enough available in cache 2. Change over training lacking</td>
<td>1. Cache would likely be replaced with oxygen or air refilling stations</td>
</tr>
<tr>
<td>Detect lifeline</td>
<td>1. Possible in low visibility 2. Possible in zero visibility</td>
<td>Does not comply with ideal system requirement</td>
<td>In theory no lifeline required.</td>
</tr>
<tr>
<td>Reach lifeline</td>
<td>1. Not too far (horizontal distance) 2. Within reach (not too high) 3. Ease of tactical detection</td>
<td>Not easily reached in zero visibility</td>
<td>1. In theory no lifeline required</td>
</tr>
<tr>
<td>Guidance to refuge bay</td>
<td>1. Minimum distance to refuge bay 2. Robust 3. Fireproof 4. Allow for easy entrance to refuge bay</td>
<td>Not fireproof</td>
<td>Integrated navigation system possible top reach refuge bay</td>
</tr>
<tr>
<td>Refuge bay</td>
<td>1. Large enough 2. Sufficient fresh air-supply 3. Other legal requirements</td>
<td>Generally no problems here</td>
<td></td>
</tr>
</tbody>
</table>
Safe escape system components | Ideal system functional requirements | Cause of failure: gap analysis | Proposed improvement
---|---|---|---

7.8.1.2.2 Integrated Lifeline Umbilical Cord

One of the advantages of South African coal-mines, when compared to other coal-mines in the world, is that they are relatively shallow, with most underground workings less than 200m below the surface. For this reason, escape strategies have been developed that rely on workers self-escaping into refuge bays from which they are later rescued by specialized rescue teams. When the refuge bays are created, ventilation shafts are drilled that connect them to the surface. These allow for the supply of food, water and eventual extraction, if necessary, via escape capsules such as the one used during the Chilean mine rescue effort in 2010 (refer to Figure 23).

![Figure 23: Chilean rescue capsule via reamed borehole (students, 2015)](image)

These ventilation shafts, that connect every refuge bay to the surface, could contribute to rescue strategies more than they currently do. The present researcher/author believes they present an ideal opportunity to implement an additional air-supply into the workings via the lifeline or evacuation pulse system.
Figure 24 and Figure 25 illustrate the current layout and secondary breathable air-supply via the ventilation shafts connecting the surface with refuge bays.

Figure 24: Diagrammatic plan view of section, indicating auxiliary fresh air-supply (Modified from: Hewitson, 2013)
Figure 25: Sectional view of current practice, indicating secondary air-supply into refuge bay (diagrammatic; not to scale)
Figure 26: Diagrammatic plan view indicating potential impact of secondary fresh air-supply (conceptual diagram)

Extending the secondary air-supply from the refuge bay into the sections as suggested in Figure 26 would significantly reduce the distance between each working location in the section and a source of fresh air. The green arrows indicate potential auxiliary air-supply points on the
umbilical cord. These supply points could typically be similar to the coupling points used as recharging stations in Australian mines.

Various configurations of this potential solution exist and are possible, but this report will only explore some core concepts:

- Integrating air-supply with lifeline (evacuation pulse LED system remains separate);
- Integrating tactical guidance cones and air-supply into evacuation pulse system;
- Integrating additional fresh air bases along the route of lifelines and fresh air-supply; and
- Integrating passive or active radio frequency (RF) tags into cones for directional detection from self-worn RF readers.

Integrating a fresh air-supply via a flame resistant tube in or next to the lifeline, would give escapees access to an additional fresh air-supply during escape. The exact mechanism for delivery of the air from the tube to the individuals’ existing breathing apparatus would need to be developed and tested, but is not considered a barrier. A low pressure system is envisaged, perhaps similar to airliners’ emergency air-supply systems. This would keep costs relatively low and allow for more flexibility of the tube or pipe. If successfully implemented, this type of alternate fresh air-supply could lead to the development of a modified, and possibly smaller, self-worn, breathing apparatus.

In the event of a large explosion or fire, almost any material could burn or be destroyed. In this type of situation, workers are also likely to be killed instantly. The intention here was to suggest improvements to existing systems, and, as far as possible, be cognizant of implementing solutions able to withstand heat and shockwaves. The exact material to be used and the size of pipes or hoses used to extend the secondary air-supply, will be explored in the detailed design phase.

The existing system can also be enhanced by integrating the tactical guidance cones and the alternate fresh air-supply into the LED evacuation pulse system. With a system like this, the line could be suspended from the roof by heat-resistant, elastic bands or springs, to allow the lighting to continue to be provided from the top of the tunnel. Small tethers hung from the line could allow the line to be pulled down for tactical guidance when needed.
Figure 27: Diagram of proposed integrated LED, air-supply and tactical guidance

This proposed system would provide the following benefits:

- Main lights integrated into the system;
- Evacuation pulse system integrated into the system;
- Tactical guidance integrated into the system;
- Early warning system integrated into the system;
- Reduced, self-contained air requirement per individual SCSR, and
- Additional fresh air bases possible along the lifeline route.

To assist with detecting the location of the lifeline in zero visibility, the use of RF and RF reader technology can be considered. RF technology is well-established and has been applied in many underground situations, including the tracking of trains and material cars in gold mines. A passive RF tag, such as illustrated in Figure 28, needs no power source to function; it is activated when an RF signal is received. These types of tags could be constructed as part of the lifeline and readers could be installed in cap-lamps. The detection of a tag by the reader in the cap-lamp could, for example, trigger the flashing of the cap-lamp and the activation of a buzzer in the cap. In this way, an escapee would be able to detect the direction of the tags and know which direction to walk in order to reach the lifeline. Issues such as the ability of these tags to withstand explosions and heat would need to be taken into consideration.
If fresh air were constantly flowing into the section via the lifelines, “secondary” inflatable refuge bays could quite easily be established between the main refuge bay and the faces. An option to consider is to create a series of secondary, cheap to construct, refuge bays, all of which are connected to the main refuge bay, and from which they obtain their fresh air supplies in the same excavations that contain the ventilation walls (Figure 29).

As mentioned earlier, no material is completely explosion-resistant, therefore the materials used in these inflatable refuge-bays or escape-ways, and the manner in which they are deployed, e.g. only after the explosion and from within the protected refuge bay, must be taken into account during the detailed design phase.

Table 6 summarises the impact such an “umbilical” lifeline could have on escape effectiveness.
Figure 29: Diagrammatic representation of secondary refuge bay options

Table 6: Integrated umbilical lifeline impact summary

<table>
<thead>
<tr>
<th>Safe escape system components</th>
<th>Ideal system functional requirements</th>
<th>Cause of failure: gap analysis</th>
<th>Proposed improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early warning</td>
<td>1. Quick</td>
<td>Inconsistent effectiveness</td>
<td>1. Central controlled integrated early warning system.</td>
</tr>
<tr>
<td></td>
<td>2. Automated and manual activation.</td>
<td></td>
<td>2. Warning integrated with Pulse evacuation system and all cap lamps.</td>
</tr>
<tr>
<td></td>
<td>3. Activation from anywhere.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. Warning by smell, sight, sound, equipment cut.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. Warning everywhere.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6. Fire/heat proof communication system.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safe escape system components</td>
<td>Ideal system functional requirements</td>
<td>Cause of failure: gap analysis</td>
<td>Proposed improvement</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>-------------------------------------</td>
<td>--------------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Respirable air (Workplace to cache at waiting place)</td>
<td>1. Ease of use 2. Quick to initiate 3. Comfortable 4. Lightweight 5. Sufficient duration</td>
<td>Does not comply with ideal system requirement or ineffective training</td>
<td>1. Reduced requirement due to auxiliary air-supply 2. Respirable air available in lifeline and secondary refuge bays (closer than main refuge bay)</td>
</tr>
<tr>
<td>Respirable air (Cache at waiting place to refuge bay)</td>
<td>1. Ease of use 2. Quick to initiate 3. Comfortable 4. Lightweight 5. Sufficient duration</td>
<td>1. Not enough available in cache 2. Change over training lacking</td>
<td>1. Cache may not be necessary depending on final detail design (rechargeable system)</td>
</tr>
<tr>
<td>Detect lifeline</td>
<td>1. Possible in low visibility 2. Possible in zero visibility</td>
<td>Does not comply with ideal system requirement</td>
<td>1. LED flashing lights in lifeline 2. RF id tags and readers.</td>
</tr>
<tr>
<td>Reach lifeline</td>
<td>1. Not too far (horizontal distance) 2. Within reach (not too high) 3. Ease of tactical detection</td>
<td>Not easily reached in zero visibility</td>
<td>1. Tethers hanging from lifelines and line elastically suspended</td>
</tr>
<tr>
<td>Refuge bay</td>
<td>1. Large enough 2. Sufficient fresh air-supply 3. Other legal requirements</td>
<td>Generally no problems here</td>
<td>1. Experiential SCSR donning training lacking 2. Implement compulsory emergency response experiential training</td>
</tr>
</tbody>
</table>
7.8.2 Conclusions from Milestone 9

It was concluded and recommended that the outcomes of the incremental solutions on existing technologies, as well as the integrated solutions, be tested and modified in order to make feasible recommendations in Milestone 10: Test, modify and recommend feasible solutions.
7.9 **MILESTONE 10: TEST, MODIFY AND RECOMMEND FEASIBLE SOLUTIONS**

In Milestone 9, incremental improvements on the current technologies were developed and analysed for each of the ideal system components. Apart from the incremental improvements, innovative solutions were developed and analysed. In Milestone 10, two new technologies were included as additions to those identified throughout the research and previous Milestones. These technologies only recently came to the fore.

The objective of Milestone 10 was to test, modify and recommend feasible methodologies for escape in poor visibility. Tests for two different technologies/methodologies were conducted and recommendations made. A brand new “water-assisted” escape methodology was proposed, and the fundamental hypothesis was tested and verified.

### 7.9.1 Results as per Milestone 10

This section will discuss two new technologies that have recently come to the fore, as well as their relevance. This section will also define, explain and interpret the two experiments that were conducted in order to test the effectiveness of certain aspects of the ideal escape system. This section will conclude on the findings of Milestone 10, and make recommendations for the future approach to the finalization of this study.

#### 7.9.1.1 Addition of New Technologies/Methodologies

During the completion of Milestone 10, two new technologies were discovered, and deemed to be relevant to the research work.

##### 7.9.1.1.1 Daqri Smart Helmet

The Daqri Smart Helmet is a product that is nearing the end of its testing phase, and is rumoured to become commercially available in 2017. The cost per unit is currently unavailable. Figure 30 and Figure 31 illustrate the Daqri industrial Smart Helmet.
Figure 30: Daqri Industrial Smart Helmet (Daqri, 2016)

Figure 31: Daqri Smart Helmet components (Daqri, 2016)

The smart helmet shown in Figure 30 and Figure 31 has an augmented reality display which fits in with the Integrated Personal Protective Equipment (IPPE) concept discussed in Milestone 9. The commercial release of the Daqri Helmet will make the IPPE concept more feasible, but the cost is expected to be substantial.

7.9.1.1.2 Refuge Bay Directional Light

The refuge bay directional light operates on batteries and is thus able to provide directional light even if the mine power supply is cut. It is claimed that the directional light has the ability to attract persons to its location under poor visibility conditions. Figure 32 depicts the refuge bay directional light.
The light shown in Figure 32 could potentially be used to attract persons to the lifeline under poor visibility conditions.

7.9.1.2 Tests Conducted

7.9.1.2.1 LED Strip Lights

The objective of the test with Halo Solutions’ LED strip lights, both normal lighting and emergency evacuation pulse lighting – was to determine how visible the lights would be in low to zero visibility conditions. Figure 33 shows an example of the strip lights that were tested.
The test was conducted at the Halo Solutions facilities, in their mobile, simulated mine. The mobile simulated mine, if unlit, provides zero visibility conditions. Both the normal “white light” strip lights and the red evacuation pulse strip lights were installed on the roof of the mine. A smoke machine was installed in the simulated mine and was set up such that it could be activated from outside of the sealed mock mine. Video cameras were placed within the mine in order to capture the strip light visibility levels at any given stage during the test. Figure 34 and Figure 35 show the results of the test.

Please note: The full video is available on request, and if requested will be sent via an online file-sharing service (Request video from: pierre.bredell@up.ac.za).

As can be seen in Figure 34, the white strip lights were visible up until the 135 second mark was reached, where the lights can no longer be seen. The same applies to the red evacuation
pulse lights in Figure 35. Although the lights became indistinguishable at the 125 second mark, this experiment showed that directional lights, or lights in general, will not be distinguishable under very low or zero visibility conditions.

7.9.1.2.2 Water Guided Rescue System

Following discussions with a hydraulics manufacturer (Hydustrial Distribution), the idea to use water sprays/jets to attract people to the lifeline was conceived. The hypothesis was that if a water jet were to make contact with a person, that person would be able to judge the direction from where the spray/jet came from by feel alone. Considering the main objectives of the study as well as the outcomes already achieved, the general premise is that one of the key areas of success lies with enabling personnel to reach the lifeline. Once the lifeline is reached, the tactile, directional lifeline will ensure that they reach the refuge bay.

Thus, from the aforementioned hypothesis, the idea is to use water sprays/jets to attract people to the lifeline. If the hypothesis were shown to be true, the benefits would be that it would be able to perform its function in zero visibility environments. Although absolutely zero visibility environments due to smoke may be rare, it should also be considered that low visibility environments due to smoke could cause smoke blindness. In effect, low visibility environments have the potential to become zero visibility environments if the smoke causes temporary blindness.

Apart from this, another benefit of the idea is that it would be able to perform its function in zero audibility environments e.g. very high noise levels, ear damage, etc.. Thus, if the hypothesis proves to be valid, the water guided rescue system, in combination with a lifeline and self-breather could be the most feasible solution.

The third benefit of such a system, in comparison to more high-tech solutions is that of cost. The system would receive water from the independent refuge bay water supply, and will be activated by either the surface control room or remotely by miners. The water supply will feed to specially designed and strategically-placed spray nozzles. An example of placement and layout can be seen in Figure 36.
Figure 36: Water-spray assisted lifeline detection system (conceptual diagram)

It should be noted that the layout shown in Figure 36 is a basic, conceptual, diagrammatic representation in order to convey the concept. Further, detailed design, investigation and testing needs to be conducted to determine the optimal layout. The layout in Figure 36 is most likely a gross overdesign of the water-jet assisted lifeline system as the system would most likely require much fewer water spray points.

From Figure 36 it can be seen that the water sprays/jets cover any given area in the conceptual layout. If the hypothesis were true, a person could be anywhere in the layout, and a water spray/jet would come into contact with that person. In order to test the hypothesis that a water spray/jet would be able to attract a person to its source under zero visibility and audibility conditions, a simple experiment was designed. The experiment was performed at the University of Pretoria’s Hatfield Campus, on a large open stretch of ground. Three persons were required for the experiment: One to control and direct the water spray (produced by a spray gun); one
to assume the role of the “lost” person, attempting to reach the lifeline; and one to video the experiment.

The “lost” person was dressed in a PPE overall; was blindfolded and wore headphones with loud music playing in order to eliminate any external noises/sounds. In order to disorientate the “lost” person, he was spun around several times to make him dizzy before the start of the experiment. The person in charge of the water spray sprayed at the “lost” person from a certain direction and subjectively moved to a new location just before the “lost” person reached him. He then sprayed again from the new location in order to attract the “lost” person to the new location. Figure 37 shows a layout example of the experiment (example due to the subjectivity involved with the spray-gun person’s location).

**Figure 37: Experiment example diagram of water-spray assisted location of lifeline**

From Figure 37, the proposed experimental flow was the following:

1. Spray-gun person at Position A sprayed at “Lost” person at Position 0.
2. “Lost” person walked towards Position A, guided by the water spray.
3. Just before “Lost” person reached Position A, Spray-gun person moved swiftly to Position B.

4. Spray-gun person at Position B sprayed at “Lost” person as he walked beyond Position A.

5. “Lost” person walked towards Position B, guided by the water spray.

6. Just before “Lost” person reached Position B, Spray-gun person moved swiftly to Position C.

7. Spray-gun person at Position C sprayed at “Lost” person as he walked beyond Position B.

8. “Lost” person walked towards Position C, guided by the water spray.

It should be noted that Positions A, B and C in the experiment were dynamic and arbitrary. The spray-gun person subjectively selected the three different locations. The reason was to eliminate the possibility of the “lost” person having any prior knowledge of the path that he had to follow. Screenshots of one of the experiments can be seen in Figure 38.

**Please note:** The full video is available upon request, and if requested will be sent via an online file-sharing service (Request video from: pierre.bredell@up.ac.za).
Figure 38: Testing of water-spray assisted lifeline hypothesis
As can be seen in Figure 38, the water spray/jet acted as an accurate guide towards the point of origin. The “Lost” person was able to accurately walk towards the origin of the spray/jet, and was also able to quickly change direction when the spray/jet origin changed location. Figure 38, screenshots A – D, show steps 1 – 3 in the previously mentioned experimental flow. Screenshots E – G show steps 4 – 6, and screenshots H – J show steps 7 – 8.

Thus, the results of the experiment proved the hypothesis that water spray/jets would be able to guide a person from their points of origin, in a zero visibility and audibility environment.

7.9.2 Conclusions from Milestone 10

Following the experiments conducted, as well as all the knowledge and experience gained throughout Milestones 1 – 11, the following conclusions were reached:

- The ideal system needs to enable people to reach a refuge bay under zero visibility and audibility conditions. This caters for the worst case scenario, e.g. an underground explosion/shockwave temporarily deafening a person and smoke causing temporary blindness.
- The biggest problem with escaping in poor visibility lies with detecting and reaching the lifeline. The lifeline, if installed correctly, is able to guide people to the refuge bay. The primary focus should thus be on detecting and reaching the lifeline.
- The lighting tests conducted showed that directional lights would work under low visibility conditions if protective, sealed eyewear is worn, but would become indistinguishable if the visibility conditions became too poor.
- The water spray system concept has the potential to outperform other methodologies/technologies in terms of detecting and reaching the lifeline under zero visibility and audibility conditions. It renders the “eye protection” requirement of the ideal system redundant.
- The technologies/methodologies for escape in poor visibility proposed in Milestone 9 could all be feasible, but with variable performance. The other consideration is one of cost. The potentially best performing technologies/methodologies mentioned in Milestone 9 are the most expensive to implement.
- It is the belief of the researchers conducting this study that the water spray guidance system has the potential to be the most feasible system, at the lowest cost.
Considering the ideal system requirements used as the assessment tool in Milestone 7, the water spray system will require the following ancillary equipment in order to satisfy the ideal system requirements:

- Self-rescue breather; and
- Correctly installed lifeline.

The water spray system also has the ability to act as an early warning system, although its effectiveness will have to be tested in comparison to early warning exiting systems. Minimal training, but no more than that of lifeline training, will be required. Potential additional benefits of the water spray system are as follows:

- The water sprays could assist in suppressing and diluting the amount of smoke in the air;
- The water sprays could assist in extinguishing fires; and
- The water sprays could cool the ambient air temperature.
7.10 **MILESTONE 11: CONDUCT WORKSHOP ON FINDINGS**

This section discusses the outcomes of two separate workshops that were conducted. An internal (University of Pretoria) workshop was conducted to further investigate the water spray assisted escape methodology. An industry workshop was conducted that focused on the general outcomes of the project, and greatly assisted in making recommendations on the project.

7.10.1 **Results per Milestone 11**

7.10.1.1 Internal Workshop

The workshop that was conducted included six contributors apart from the project members (Table 7).

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Company</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Eugene Preis*</td>
<td>University of Pretoria</td>
<td><a href="mailto:eugene.preis@up.ac.za">eugene.preis@up.ac.za</a></td>
</tr>
<tr>
<td>2</td>
<td>Gerco Lindeque</td>
<td>University of Pretoria</td>
<td><a href="mailto:gerco.lindeque@up.ac.za">gerco.lindeque@up.ac.za</a></td>
</tr>
<tr>
<td>3</td>
<td>Johan Roets</td>
<td>University of Pretoria</td>
<td><a href="mailto:johan.roets@up.ac.za">johan.roets@up.ac.za</a></td>
</tr>
<tr>
<td>4</td>
<td>Johannes Scholtz</td>
<td>University of Pretoria</td>
<td><a href="mailto:johannes.scholtz@up.ac.za">johannes.scholtz@up.ac.za</a></td>
</tr>
<tr>
<td>5</td>
<td>Larrance Ngwenyama</td>
<td>University of Pretoria</td>
<td><a href="mailto:larrance.ngwenyama@up.ac.za">larrance.ngwenyama@up.ac.za</a></td>
</tr>
<tr>
<td>6</td>
<td>Pierre Bredell*</td>
<td>University of Pretoria</td>
<td><a href="mailto:pierre.bredell@up.ac.za">pierre.bredell@up.ac.za</a></td>
</tr>
<tr>
<td>7</td>
<td>Sbonelo Ndhlazi</td>
<td>University of Pretoria</td>
<td><a href="mailto:sbonelo.ndhlazi@up.ac.za">sbonelo.ndhlazi@up.ac.za</a></td>
</tr>
<tr>
<td>8</td>
<td>Tonny Mavimbela</td>
<td>University of Pretoria</td>
<td><a href="mailto:tonny.mavimbela@up.ac.za">tonny.mavimbela@up.ac.za</a></td>
</tr>
</tbody>
</table>

The workshop was headed by the project team. Figure 39 shows the process that was followed.

![Figure 39: Internal Workshop process](image)

From Figure 39, the process started off by familiarizing the workshop contributors with the macro and the micro problem. The macro problem referred to the overall project objectives and the micro problem to the “reaching the lifeline” component. Once the contributors understood
the problem, some background information was given in terms of what had been achieved in the research work thus far. The ideal system requirements (Milestone 6), the gap analysis of existing technologies (Milestone 8) and the development of possible solutions (Milestone 9), were discussed in detail.

Thereafter, the testing of the hypothesis and the holistic water spray assisted escape methodology (Milestone 10) were described to the contributors. Once all the contributors fully understood the problem at hand and the proposed solution, the failure analysis commenced. The failure analysis yielded 17 potential flaws/risks/issues each with a proposed solution as well as potential mitigation measures to channel and direct future research and development efforts.

### 7.10.1.1 Flaws/Risks/Issues Identified

As stated previously, 17 flaws/risks/issues were identified with the water-assisted escape methodology (Table 8).

<table>
<thead>
<tr>
<th>No.</th>
<th>Flaw/Risk/Issue</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Water heating up and scalding workers due to pipes coming into contact with fire</td>
</tr>
<tr>
<td>2</td>
<td>Inadequate water pressure distribution across the system and spray points</td>
</tr>
<tr>
<td>3</td>
<td>Natural events rendering the system useless</td>
</tr>
<tr>
<td>4</td>
<td>One water supply source only – system too dependent</td>
</tr>
<tr>
<td>5</td>
<td>Nature of water spray delivery – what is the optimal mode of delivery?</td>
</tr>
<tr>
<td>6</td>
<td>Impacts of added water weight affecting drenched workers</td>
</tr>
<tr>
<td>7</td>
<td>Creation of water spray footprint “dead-zones” due to obstructions</td>
</tr>
<tr>
<td>8</td>
<td>Positioning of lifeline versus positioning of water spray points</td>
</tr>
<tr>
<td>9</td>
<td>Daily wear and tear – water supply pipe strength and durability</td>
</tr>
<tr>
<td>10</td>
<td>Nozzle and system maintenance</td>
</tr>
<tr>
<td>11</td>
<td>Mobility, flexibility and re-usability of system</td>
</tr>
<tr>
<td>12</td>
<td>Daily/Weekly extension of the system</td>
</tr>
<tr>
<td>13</td>
<td>Risk of flooding/high water pressure if pipes close to water source are damaged</td>
</tr>
<tr>
<td>14</td>
<td>Impact of ventilation on water spray behaviour</td>
</tr>
<tr>
<td>15</td>
<td>Increased work activities &amp; acceptance of system by workers</td>
</tr>
<tr>
<td>16</td>
<td>Lifeline not being properly installed</td>
</tr>
<tr>
<td>17</td>
<td>Ability to manufacture system locally and sustainably, as well as creating jobs</td>
</tr>
</tbody>
</table>

The flaws/risks/issues identified in Table 8 are in no particular order, and are presented as they arose during the workshop. The flaws/risks/issues form the basis for the feasible design of a water-assisted escape methodology. Mitigating these and testing mitigation measures will lead to a commercially viable future methodology.
7.10.1.1.1 Mitigation Measures and Subjective Risk Rating

As stated previously, the next step of the workshop was to identify potential mitigation measures for each flaw/risk/issue and to assign a subjective risk rating to each. The subjective risk rating was based on the project team members’ knowledge on the subject as well as the relative importance of ensuring that the flaw/risk/issue is mitigated in order for a feasible methodology and design to result. Table 9 shows the mitigation measures and subjective risk ratings for each item.

Table 9: Mitigation Measures & Subjective Risk Rating

<table>
<thead>
<tr>
<th>Flaw/Risk/Issue</th>
<th>Mitigation Measure</th>
<th>Risk Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water heating up and scalding workers due to pipes coming into contact with fire</td>
<td>Correctly insulated pipe-design (potentially a double-walled, air-gap, insulated pipe design). The mitigation measure is thus one of sound piping design, including heat and water flow principles and simulations in order to arrive at the most feasible design.</td>
<td>Partial failure</td>
</tr>
<tr>
<td>Inadequate water pressure distribution across the system and spray points</td>
<td>Mitigating the risk of unequal pressure distribution across the system, with pressure decreasing with increasing distance from the water supply will be done through sound system design. Water flow simulations and pressure simulations can be conducted in order to design the most feasible, equal pressure system. Mitigation thus lies with sound system and water-flow design.</td>
<td>Partial failure; potentially total failure of a portion of the system</td>
</tr>
<tr>
<td>Natural events rendering the system useless</td>
<td>Mitigating against the risk of natural events (e.g. seismicity) leading to damage of the system is close to impossible. It is not possible to design a system that can completely withstand e.g. a large roof collapse. The system can, however, be designed to be as rugged and damage-proof as possible, but will still not be able to fully withstand natural events. Sound material and mechanical design will mitigate this as best possible.</td>
<td>Total failure</td>
</tr>
<tr>
<td>One water supply source only – system too dependent</td>
<td>Software simulations can be run to determine the impact and probability of one source failing. Similar simulations can be run to determine what the difference would be with a secondary supply source. Decision-making tools can be used to determine whether a single, or a multiple source design should be followed, such as an in-section supply and refuge bay supply system.</td>
<td>Total failure</td>
</tr>
<tr>
<td>Nature of water spray delivery. What is the optimal mode of delivery?</td>
<td>Correct and sound nozzle and spray head design, using mechanical engineering design software and water-flow simulation software. The outcomes of the simulations will point out the most feasible design for the system.</td>
<td>Partial failure</td>
</tr>
<tr>
<td>Impacts of added water weight due to drenched workers</td>
<td>Sociology-based research will be conducted on the potential negative impacts (if any) of becoming completely drenched. The outcomes of the research will</td>
<td>Negligible</td>
</tr>
<tr>
<td>Flaw/Risk/Issue</td>
<td>Mitigation Measure</td>
<td>Risk Rating</td>
</tr>
<tr>
<td>-------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Creation of water spray footprint “dead-zones” due to obstructions</td>
<td>The potential impacts of the creation of dead zones could be determined through industrial engineering based simulations. The mitigation measure for this could potentially lie with nozzle and spray design, as proactive measures, and training as a reactive measure.</td>
<td>Partial failure</td>
</tr>
<tr>
<td>Positioning of lifeline versus positioning of water spray points</td>
<td>The potential impacts of this could be mitigated through conducting trade-off studies, where different scenarios are created e.g. the lifeline could become the water supply pipe. Essentially the ideal positioning would be where, without fail, locating the water spray point doubles as locating the lifeline.</td>
<td>Total failure</td>
</tr>
<tr>
<td>Daily wear and tear – water supply pipe strength and durability</td>
<td>The same mitigation measure will apply with this issue as with the first mitigation measure in this Table.</td>
<td>Total failure</td>
</tr>
<tr>
<td>Nozzle and system maintenance</td>
<td>The mitigation of this concern lies with a sound operational maintenance schedule and plan. This will be developed through consultation with champion mines, with an envisioned integrated, maintenance approach</td>
<td>Partial failure</td>
</tr>
<tr>
<td>Mobility, flexibility and re-usability of system</td>
<td>Achieving these three aspects will lie with the macro and micro design of the system. Mechanical design, simulation and rapid prototyping will ensure that these issues are dealt with.</td>
<td>Partial failure</td>
</tr>
<tr>
<td>Daily/Weekly extension of the system</td>
<td>See Mitigation Measure mentioned directly above.</td>
<td>Total failure</td>
</tr>
<tr>
<td>Risk of flooding/high water pressure if pipes close to water source are damaged</td>
<td>Mitigation lies firstly with sound and robust pipe design. Secondly, using water flow simulation software, the “disaster” scenario will be simulated in order to determine the impact of a disaster event. The results of this simulation will determine the following steps.</td>
<td>Negligible</td>
</tr>
<tr>
<td>Impact of ventilation on water spray behaviour</td>
<td>Mitigation of the potential impacts of ventilation-flow on water spray direction and effectiveness will be simulated through the use of ventilation and water based software. If it is determined that ventilation could adversely affect the effectiveness of the system, the mitigation measure lies with sound spray-head, nozzle and pressure design.</td>
<td>Partial failure</td>
</tr>
<tr>
<td>Increased work activities &amp; acceptance of system by workers</td>
<td>The initial roll-out of the system and continuous installations will create added work activities, which could prove to be a hurdle. The acceptance of the system by the workers is crucial to the success of the system. The mitigation measures for this would be to conduct</td>
<td>Total failure</td>
</tr>
<tr>
<td>Flaw/Risk/Issue</td>
<td>Mitigation Measure</td>
<td>Risk Rating</td>
</tr>
<tr>
<td>-----------------------------------------</td>
<td>-------------------------------------------------------------------------------------</td>
<td>------------------------------------</td>
</tr>
<tr>
<td>Lifeline not being properly installed</td>
<td>interviews/surveys from a sociology perspective, to determine what the 'fail-safe' approach would be.</td>
<td></td>
</tr>
<tr>
<td>Ability to manufacture system locally and sustainably, as well as creating jobs</td>
<td>Technically this is not a challenge in terms of the water assisted escape methodology. This is an issue that lies with the diligence of the mine. However, it is critical that the lifeline be properly installed. The proposed system has the purpose of allowing people to safely reach the lifeline. Thus, if the lifeline is not properly installed, the function of the proposed solution becomes pointless. This can be mitigated by developing new guidelines for lifeline best practice in parallel with the system.</td>
<td>Total reactive failure</td>
</tr>
<tr>
<td>Ability to manufacture system locally and sustainably, as well as creating jobs</td>
<td>The success of the system lies not only with the technical success, but also with the ability to locally manufacture and distribute the system. This will create jobs and ensure local sustainability and will be investigated in depth through the development of a sustainable business case for the insourcing of the manufacturing of the system.</td>
<td>Total socio-economic failure</td>
</tr>
</tbody>
</table>

From Table 9 it was evident that the potential mitigation measures proposed, form the basis of a future research and development programme proposal (APPENDIX F: PROPOSED FUTURE PROJECT), with the main objective being to culminate in a feasible and effective water-assisted escaped methodology accompanied by a sustainable, insourced business strategy.

### 7.10.1.2 Industry Workshop

An industry workshop was conducted on the 9th of September 2016, where relevant industry representatives were invited to provide insights, suggestions and recommendations on the findings of the project (see APPENDIX C: INDUSTRY WORKSHOP INVITATION LETTER). An overview of the project was given to the participants; the ideal system requirements were discussed; the top 3 current systems were discussed; and the three newly proposed solutions were discussed (see APPENDIX D: INDUSTRY WORKSHOP PRESENTATION).

A total of 24 persons participated in the workshop (including the project members) (Table 10). The attendance list for the workshop can be seen in APPENDIX E: INDUSTRY WORKSHOP ATTENDANCE LIST. However, it should be noted that the attendance list contains more names than in Table 10. This is due to some participants only attending the latter part of the workshop, which focused on a different project.
Workshop participants were asked to verbally engage with the project team during the workshop, but to also provide written feedback on certain aspects of the project. 14 out of the 21 non-team member participants provided written feedback (those highlighted in green in Table 10 did not provide written feedback).

The written feedback was aimed at seven key aspects of the project, namely:

- The ideal escape system
- Currently available systems
  - Lighted lifeline;
  - Pulse lights; and

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Company</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Alec Gumbie*</td>
<td>MHSC</td>
<td><a href="mailto:agumbie@mhsc.org.za">agumbie@mhsc.org.za</a></td>
</tr>
<tr>
<td>2</td>
<td>Alex Fenn</td>
<td>Sibanye Gold</td>
<td><a href="mailto:alex.fenn@sibanyeGold.co.za">alex.fenn@sibanyeGold.co.za</a></td>
</tr>
<tr>
<td>3</td>
<td>Andrew Thomson</td>
<td>Anglo Coal</td>
<td><a href="mailto:andrew.thomson@angloamerican.com">andrew.thomson@angloamerican.com</a></td>
</tr>
<tr>
<td>4</td>
<td>Danie Schoeman</td>
<td>Sasol</td>
<td><a href="mailto:danie.schoeman@sasol.com">danie.schoeman@sasol.com</a></td>
</tr>
<tr>
<td>5</td>
<td>Danie van der Merwe</td>
<td>Chamber of Mines</td>
<td><a href="mailto:danie.vanross@gmail.com">danie.vanross@gmail.com</a></td>
</tr>
<tr>
<td>6</td>
<td>Declan Vogt</td>
<td>University of Witwatersrand</td>
<td><a href="mailto:declan.vogt@wits.ac.za">declan.vogt@wits.ac.za</a></td>
</tr>
<tr>
<td>7</td>
<td>Eugene Preis**</td>
<td>University of Pretoria</td>
<td><a href="mailto:eugene.preis@up.ac.za">eugene.preis@up.ac.za</a></td>
</tr>
<tr>
<td>8</td>
<td>Francois van der Walt</td>
<td>AngloGold Ashanti</td>
<td><a href="mailto:fvanderwalt@anglogoldashanti.com">fvanderwalt@anglogoldashanti.com</a></td>
</tr>
<tr>
<td>9</td>
<td>Hanlie van Vuuren</td>
<td>Solidarity</td>
<td><a href="mailto:hanlie@solidarity.co.za">hanlie@solidarity.co.za</a></td>
</tr>
<tr>
<td>10</td>
<td>Inus Labuschagne</td>
<td>Sasol</td>
<td><a href="mailto:inus.labuschagne@sasol.com">inus.labuschagne@sasol.com</a></td>
</tr>
<tr>
<td>11</td>
<td>Jacques Oosthuysen</td>
<td>Petra Diamonds SA</td>
<td><a href="mailto:jacques.oosthuysen@petradiamonds.com">jacques.oosthuysen@petradiamonds.com</a></td>
</tr>
<tr>
<td>12</td>
<td>James Janse van Rensburg</td>
<td>Impala Platinum</td>
<td><a href="mailto:james.vanrensburg@implats.co.za">james.vanrensburg@implats.co.za</a></td>
</tr>
<tr>
<td>13</td>
<td>Jan du Plessis**</td>
<td>University of Pretoria</td>
<td><a href="mailto:jan.duplessis@up.ac.za">jan.duplessis@up.ac.za</a></td>
</tr>
<tr>
<td>14</td>
<td>Johan Wannenburg</td>
<td>University of Pretoria</td>
<td><a href="mailto:johan.wannenburg@gmail.com">johan.wannenburg@gmail.com</a></td>
</tr>
<tr>
<td>15</td>
<td>Larrance Ngwenyama</td>
<td>University of Pretoria</td>
<td><a href="mailto:larrance.ngwenyama@up.ac.za">larrance.ngwenyama@up.ac.za</a></td>
</tr>
<tr>
<td>16</td>
<td>Leon Smith</td>
<td>AngloGold Ashanti</td>
<td><a href="mailto:lsmith@anglogoldashanti.com">lsmith@anglogoldashanti.com</a></td>
</tr>
<tr>
<td>17</td>
<td>Morne Beukes</td>
<td>AngloGold Ashanti</td>
<td><a href="mailto:mbeukes@anglogoldashanti.com">mbeukes@anglogoldashanti.com</a></td>
</tr>
<tr>
<td>18</td>
<td>Navarre Kruger</td>
<td>South 32</td>
<td><a href="mailto:navarre.kruger@south32.net">navarre.kruger@south32.net</a></td>
</tr>
<tr>
<td>19</td>
<td>Navin Singh</td>
<td>CSIR</td>
<td><a href="mailto:nsingh1@csir.co.za">nsingh1@csir.co.za</a></td>
</tr>
<tr>
<td>20</td>
<td>Ntsiky Phokwana</td>
<td>Chamber of Mines</td>
<td><a href="mailto:nphokwana@chamberofmines.org.za">nphokwana@chamberofmines.org.za</a></td>
</tr>
<tr>
<td>21</td>
<td>Pierre Bredell**</td>
<td>University of Pretoria</td>
<td><a href="mailto:pierre.bredell@up.ac.za">pierre.bredell@up.ac.za</a></td>
</tr>
<tr>
<td>22</td>
<td>Steve van Reenen</td>
<td>AngloGold Ashanti</td>
<td><a href="mailto:svanreenen@anglogoldashanti.com">svanreenen@anglogoldashanti.com</a></td>
</tr>
<tr>
<td>23</td>
<td>Sydney Mitchell</td>
<td>Anglo American Platinum</td>
<td><a href="mailto:smitchell@angloplat.com">smitchell@angloplat.com</a></td>
</tr>
<tr>
<td>24</td>
<td>Vijay Nundlall</td>
<td>Sibanye Gold</td>
<td><a href="mailto:vijay.nundlall@sibanyeGold.co.za">vijay.nundlall@sibanyeGold.co.za</a></td>
</tr>
</tbody>
</table>

*MHSC Project Manager
**University of Pretoria Project Team Member
- MOSES system.
  - Future Solutions
    - IPPE;
    - Umbilical Lifeline; and
    - Water spray assisted escape methodology.

The written feedback obtained is discussed in the sub-headings that follow.

### 7.10.1.2.1 Ideal Escape System

The ideal escape system, as described in MILESTONE 6, was discussed with workshop participants in order to provide context. Participants were asked to provide feedback on the ideal escape system (Table 11). It should be noted that the feedback received was not necessarily aimed at the ideal escape system. Feedback obtained was more general in nature, but nonetheless valuable.

<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
<th>Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ntsiky Phokwana</td>
<td>Chamber of Mines</td>
<td>Early warning. Clear instruction on whether to don SCSR or not. Goggles that are sealed. Guidance to the refuge bay, whether visually or by feeling or hearing.</td>
</tr>
<tr>
<td>Danie van der Merwe</td>
<td>Chamber of Mines</td>
<td>Cost of infrastructure need to be considered. Some smaller marginal mines might not be able if the cost is too much, no matter how noble the goal of saving lives.</td>
</tr>
<tr>
<td>Jacques Oosthuysen</td>
<td>Petra Diamonds SA</td>
<td>Life line installation in block caving mining is difficult and will be intermittent. Lighting on the centre of the tunnel could be a solution. Look at laser lights</td>
</tr>
<tr>
<td>Navarre Kruger</td>
<td>South 32</td>
<td>Believe the system needs a good warning system e.g. stench gas units (manual and auto release).</td>
</tr>
<tr>
<td>Danie Schoeman</td>
<td>Sasol</td>
<td>Reliable. Fool proof. Redundancy. Need various aspects: early detection and mass communication can assist before zero visibility, but becomes an issue at all areas (limited exposure). Like audible and LED. Goggles essential.</td>
</tr>
<tr>
<td>Sydney Mitchell</td>
<td>Anglo American Platinum</td>
<td>All systems (be it installed or being designed or going forward) remains reliant on management and training. SCSR will remain with us for a long time to come. Escape strategies should be designed, or researched for every commodity as conditions differ completely. Focus must be placed on training and preventative measures.</td>
</tr>
<tr>
<td>Francois van der Walt</td>
<td>AngloGold Ashanti</td>
<td>One that will &quot;satisfy&quot; or trigger most or all of the senses would most probably be the best. I am also of the opinion that we have not applied all technologies available to us in the mining industry</td>
</tr>
<tr>
<td>Leon Smith</td>
<td>AngloGold Ashanti</td>
<td>Portable refuge bays in the working place can be ideal, reason for that is - in case of a fire the intake to the working place normally collapse by a FOG, due to the heat generated by the fire. Additional lights and audible alarms directing to the refuge bay.</td>
</tr>
<tr>
<td>Vijay Nundllall</td>
<td>Sibanye Gold</td>
<td>We need to consider the strategy (based on type of mine) on whether the need to get employees to surface quickly or to get to the closest refuge chamber. System should then be designed accordingly.</td>
</tr>
</tbody>
</table>
Training is vital - everyone who uses an SCSR should be exposed to a live simulation. This recommendation came from Pike River and elsewhere and would greatly help with survival of fires. It’s about people.

Comprehensive review of cradle to grave requirements of escaping. Would have liked to see comparisons of different mining layouts. A lot of the info wasn’t relevant to my particular environment. Otherwise, good work.

Goggles as part of the equipment included in the SCSR. Coal face, extremities to warn and guide employee to the waiting place. How people react would be the ideal the way we could evacuate safely, focus on the way we train. Coal would require separate research to address very real concerns that the mines experience (See point 2).

Need to build in a weighting of importance for different aspects (e.g. lifeline is useless if there is no alarm).

In summary, the participant feedback on the ideal escape system is as follows:

- Airtight goggles should form part of the escape system, and would prove valuable in the event of a low visibility emergency.
- Consideration needs to be given to the escape strategy. The ideal escape system, where the strategy is to reach the refuge chamber, would be different to one where the strategy is to reach surface.
- Cost should also be considered as a component of the ideal escape system. Smaller, marginal mines may not be able to afford some of the more technological systems.
- Early warning (through whichever method) is essential in increasing the probability of escape.
- Establishing escape procedures and training employees on these procedures, is critical to the success of any system. Attention should also be given to putting preventative measures in place (allowing people to escape before the conditions turn to low or zero visibility).
- The ideal system should be reliable, robust and “fool-proof”.
- A system that can guide people through the use of all senses would be the best.

Apart from the written feedback above, participants from the hard-rock mines also noted that no concrete reason exists for not using a traditional lifeline in hard-rock mines.

### 7.10.1.2.2 Top 3 Currently Available Systems

The feedback obtained on the lighted lifeline can be seen in Table 12; feedback obtained on the pulse lights can be seen in Table 13; and feedback obtained on the MOSES system can be seen in Table 14.
Table 12: SIM 140701 Industry Workshop Feedback: Lighted Lifeline

<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
<th>Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ntsiky Phokwana</td>
<td>Chamber of Mines</td>
<td>Can work but is highly dependent on visibility in environment. Will come with an infrastructure cost component and must be maintained properly. Also subject to proper installation right up to the closest point to the workings. Risk of damage in trackless environments. The lifeline as a concept is great. It does not have to be lit.</td>
</tr>
<tr>
<td>Danie van der Merwe</td>
<td>Chamber of Mines</td>
<td>Serious maintenance issue.</td>
</tr>
<tr>
<td>Jacques Oosthuysen</td>
<td>Petra Diamonds SA</td>
<td>Mining method does not allow</td>
</tr>
<tr>
<td>Navarre Kruger</td>
<td>South 32</td>
<td>Good merit though light is not very effective in smoke conditions</td>
</tr>
<tr>
<td>Danie Schoeman</td>
<td>Sasol</td>
<td>Investigate light wavelength propagation. Maintenance, add audio.</td>
</tr>
<tr>
<td>Francois van der Walt</td>
<td>AngloGold Ashanti</td>
<td>I think that timing and situation will play a big role. Should you have sufficient early warning one should be able to reach a lifeline. You can pull a lifeline into the working place to be right behind you</td>
</tr>
<tr>
<td>Leon Smith</td>
<td>AngloGold Ashanti</td>
<td>The training is critical to expose employees to the real environment. Currently we lack on our training.</td>
</tr>
<tr>
<td>Vijay Nundlall</td>
<td>Sibanye Gold</td>
<td>Good for when there is visibility - in zero visibility, this may not necessarily work.</td>
</tr>
<tr>
<td>Declan Vogt</td>
<td>University of Witwatersrand</td>
<td>Lights don’t work in total power failure</td>
</tr>
<tr>
<td>Alex Fenn</td>
<td>Sibanye Gold</td>
<td>Ineffective in zero visibility. Difficult to maintain. Very expensive</td>
</tr>
<tr>
<td>Andrew Thomson</td>
<td>Anglo Coal</td>
<td>Set a coal trial in place to test such a system.</td>
</tr>
<tr>
<td>Morne Beukes</td>
<td>AngloGold Ashanti</td>
<td>Like the idea of a lifeline, but need for it to be lighted to be debated.</td>
</tr>
</tbody>
</table>

Table 13: SIM 140701 Industry Workshop Feedback: Pulse Lights

<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
<th>Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ntsiky Phokwana</td>
<td>Chamber of Mines</td>
<td>Dependent on competent installation and maintenance. Could have a high cost implication and might fail in a fire ore power trip out. Battery back-up necessary, with associated maintenance.</td>
</tr>
<tr>
<td>Danie van der Merwe</td>
<td>Chamber of Mines</td>
<td>Serious maintenance issue.</td>
</tr>
<tr>
<td>Jacques Oosthuysen</td>
<td>Petra Diamonds SA</td>
<td>Could work</td>
</tr>
<tr>
<td>Navarre Kruger</td>
<td>South 32</td>
<td>Improvements on current system at various mines. Cost?</td>
</tr>
<tr>
<td>Danie Schoeman</td>
<td>Sasol</td>
<td>Pulse may assist in first minute or so. Laser based test?</td>
</tr>
<tr>
<td>Francois van der Walt</td>
<td>AngloGold Ashanti</td>
<td>if it can be low maintenance there is potential for the application</td>
</tr>
<tr>
<td>Leon Smith</td>
<td>AngloGold Ashanti</td>
<td>Good idea, guided in CO detectors in each caplamp to give early warning.</td>
</tr>
<tr>
<td>Vijay Nundlall</td>
<td>Sibanye Gold</td>
<td>Also in zero visibility - could be problematic.</td>
</tr>
<tr>
<td>Declan Vogt</td>
<td>University of Witwatersrand</td>
<td>Lights don’t work in total power failure</td>
</tr>
<tr>
<td>Alex Fenn</td>
<td>Sibanye Gold</td>
<td>Ineffective in zero visibility. Difficult to maintain. Very expensive</td>
</tr>
<tr>
<td>Morne Beukes</td>
<td>AngloGold Ashanti</td>
<td>Like the idea of a lifeline, but need for it to be lighted to be debated.</td>
</tr>
</tbody>
</table>
Table 14: SIM 140701 Industry Workshop Feedback: MOSES System

<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
<th>Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ntsiky Phokwana</td>
<td>Chamber of Mines</td>
<td>The pulsating lights and sound could add to the panic situation. Similar installation and maintenance issues as above.</td>
</tr>
<tr>
<td>Jacques Oosthuysen</td>
<td>Petra Diamonds SA</td>
<td>Track-less noisy</td>
</tr>
<tr>
<td>Navarre Kruger</td>
<td>South 32</td>
<td>Not effective in zero-visibility conditions</td>
</tr>
<tr>
<td>Danie Schoeman</td>
<td>Sasol</td>
<td>Same as lights</td>
</tr>
<tr>
<td>Francois van der Walt</td>
<td>AngloGold Ashanti</td>
<td>Implementation and training must be well done to be effective in emergency situations.</td>
</tr>
<tr>
<td>Leon Smith</td>
<td>AngloGold Ashanti</td>
<td>Lack of training</td>
</tr>
<tr>
<td>Alex Fenn</td>
<td>Sibanye Gold</td>
<td>Good idea. Some concerns with maintenance and cost.</td>
</tr>
<tr>
<td>Morne Beukes</td>
<td>AngloGold Ashanti</td>
<td>Good system in combination with others.</td>
</tr>
</tbody>
</table>

In summary, the participant feedback on the top 3 current solutions is as follows:

- Maintenance will be a challenge for all 3 systems.
- Installation and logistics will be a challenge for all 3 systems.
- The cost of all 3 systems may prove to be uneconomical for many mines.
- The lighting component of the systems will ultimately be completely ineffective in zero visibility conditions, and effectiveness will greatly reduce in poor (not zero) visibility conditions. However, it may prove to be effective in the short term, albeit for a short amount of time (e.g. 1 minute).
- The systems will not work in a total power failure (due to whichever root cause), and will require back-up power capacity.
- The success of any system is highly dependent on the associated training for employees using the system.
- Trackless mines (and equipment) could firstly cause damage to the installed system. Secondly, the noise from trackless equipment may render audial guidance as ineffective.
- The installation of the lighted lifeline in a block caving mine may prove to be unfeasible. However, a pulse light system may prove to be feasible (in terms of installation).
- The optimal light wavelength/colour (for smoke conditions) should be investigated, as well as lasers instead of lights.
- The need for a light-based system in hard rock mines needs to be debated. Participants believe that a traditional lifeline, if installed correctly, may be just as effective as the more expensive systems.
7.10.1.2.3 Future Solutions: IPPE

The feedback obtained on the IPPE concept can be seen in Table 15.

**Table 15: SIM 140701 Industry Workshop Feedback: IPPE**

<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
<th>Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ntsiky Phokwana</td>
<td>Chamber of Mines</td>
<td>Futuristic. Issue of practicability in current RSA environment must be considered.</td>
</tr>
<tr>
<td>Danie van der Merwe</td>
<td>Chamber of Mines</td>
<td>Sounds good but in distant future.</td>
</tr>
<tr>
<td>Jacques Oosthuysen</td>
<td>Petra Diamonds SA</td>
<td>Cost/Future</td>
</tr>
<tr>
<td>Navarre Kruger</td>
<td>South 32</td>
<td>Good idea for future but costly and need to be tested. Very exciting and good but obvious concerns at this stage e.g. cost, environments, etc.</td>
</tr>
<tr>
<td>Danie Schoeman</td>
<td>Sasol</td>
<td>Does not need to be expensive. Look at <a href="http://www.mobilaris.com">www.mobilaris.com</a>. Integrate with communication systems</td>
</tr>
<tr>
<td>Francois van der Walt</td>
<td>AngloGold Ashanti</td>
<td>Futuristic, would be great, mining industry will not be able to afford financially</td>
</tr>
<tr>
<td>Leon Smith</td>
<td>AngloGold Ashanti</td>
<td>This is far in the future, for hard rock mining it will be challenge, maintenance etc.</td>
</tr>
<tr>
<td>Vijay Nundlall</td>
<td>Sibanye Gold</td>
<td>This is futuristic - yes. Practicality could be an issue.</td>
</tr>
<tr>
<td>Declan Vogt</td>
<td>University of Witwatersrand</td>
<td>Far off, but for me it is ideal - personal, not dependant on infrastructure, doesn’t use mine power.</td>
</tr>
<tr>
<td>Alex Fenn</td>
<td>Sibanye Gold</td>
<td>Great idea. As mentioned, costly, far ahead of its time.</td>
</tr>
<tr>
<td>Morne Beukes</td>
<td>AngloGold Ashanti</td>
<td>Very expensive. Will only be economically viable in highly mechanised, low labour mines.</td>
</tr>
</tbody>
</table>

Participants generally agreed that the IPPE concept would work in zero visibility environments. However, the IPPE is too far in the future to be a solution that is currently feasible. Participants noted that the IPPE would present potential issues in terms of:

- Practicality;
- Costs; and
- Maintenance.

7.10.1.2.4 Future Solutions: Umbilical Lifeline

The feedback obtained on the umbilical lifeline concept can be seen in Table 16.

**Table 16: SIM 140701 Industry Workshop Feedback: Umbilical Lifeline**

<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
<th>Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ntsiky Phokwana</td>
<td>Chamber of Mines</td>
<td>Large infrastructure layout cost and cost of maintenance. Should cater for a large crew, with multiple connection points.</td>
</tr>
<tr>
<td>Danie van der Merwe</td>
<td>Chamber of Mines</td>
<td>Good solution.</td>
</tr>
<tr>
<td>Jacques Oosthuysen</td>
<td>Petra Diamonds SA</td>
<td>Inflatable portable refuge bays could be a solution as limited flammable material is available.</td>
</tr>
</tbody>
</table>
Participants understood the merit of the umbilical lifeline concept, and the large majority thought that it was a good idea. However, participants from coal mines noted that the system would not be practical for coal mines, and that it may only be suited to coal mines with compressed air already part of their current operations.

Participants from hard rock mines noted that although it was a good idea, the practicalities of the system would prove to be a significant challenge (and that it would most likely be best suited to mechanised mines). Participants pointed out that the system would have to be able to cater for the entire workforce, with multiple connections points.

Participants suggested that inflatable, portable refuge bays or ‘low pressure low cost’ air recharge stations may be more viable than the proposed system. Maintenance and installation will prove to be a considerable challenge with the proposed system, and in-the-field testing will be critical if the proposed system is developed any further.

### 7.10.1.2.5 Future Solutions: Water Spray Assisted Escape Methodology

The feedback obtained on the water spray assisted escape methodology concept can be seen in Table 17.

<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
<th>Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ntsiky Phokwana</td>
<td>Chamber of Mines</td>
<td>- High infrastructure cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Tricky maintainability as it must ensure that each nozzle is operating</td>
</tr>
<tr>
<td></td>
<td></td>
<td>at all times</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Could introduce health hazards that must be taken into account.</td>
</tr>
<tr>
<td>Danie van der Merwe</td>
<td>Chamber of Mines</td>
<td>Water spray as system to be further investigated. We need to consider the</td>
</tr>
<tr>
<td></td>
<td></td>
<td>newly created risks:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Health due to reduced temperature</td>
</tr>
<tr>
<td>Name</td>
<td>Company</td>
<td>Feedback</td>
</tr>
<tr>
<td>--------------------</td>
<td>--------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| Jacques Oosthuysen  | Petra Diamonds SA        | Possible creation of mud rushes due to excessive water in gulleys and ore passes  
Loss of services during fire situation and the accompanying reliance on the system.                                                                 |
| Navarre Kruger     | South 32                 | Good idea. Need to be tested in in-field conditions and different environments. Added advantage of water system:  
- Cooling power from heat of fires  
- Possible mitigation of particulates (dust, smoke, etc.)                                                                                           |
| Danie Schoeman     | Sasol                    | Good idea. Water system may have potential. Practicality:  
- Need water  
- Test of system  
- Challenge in keeping up with development pace  
- Link with service water system.                                                                                                                   |
| Francois van der Walt | AngloGold Ashanti    | I think the water idea has great potential. Maybe or potentially a big breakthrough for the mining industry.                                                                                           |
| Leon Smith         | AngloGold Ashanti        | Very good idea that needs to be developed and tested. Will give direction in zero visibility.                                                                                                         |
| Vijay Nundlall     | Sibanye Gold            | Water spray has potential - directional and training. The practicalities need to be resolved. The key needs to get visibility i.e. goggles, then add lifeline, or water sprays or any other visual or sensory aids to guide people to refuge bays. |
| Declan Vogt        | University of Witwatersrand | Needs extensive well-maintained infrastructure.                                                                                                                |
| Alex Fenn          | Sibanye Gold            | Fantastic idea. Would be difficult to install in complex deep level hard rock environment.                                                                   |
| Andrew Thomson     | Anglo Coal              | Concern for coal with regards temperature. Installation and maintenance would influence practicability of the installation.                                                                                |
| Morne Beukes       | AngloGold Ashanti       | Good idea. Exciting possibility. Will have to manage possible health effects in cold mines.                                                                    |

Workshop participants believed that the proposed water spray assisted escape methodology was a good idea, with future potential. Participants agreed that the proposed system would provide guidance to the lifeline in zero visibility and audibility conditions. However, participants agreed that the proposed system would have to be built and tested in actual underground environments, in order to ultimately determine whether the system would be effective.

Participants pointed out that the system may provide added advantages to zero visibility emergency situations (e.g. added air-cooling power and particulate mitigation). However, participants also pointed out that the proposed system will have to overcome some key challenges, and could potentially create health and safety risks. The key challenges pointed out by participants include:

- High infrastructure cost;
- Maintenance of the system may be a challenge;
- Initial and continuous installation may be a challenge;
- Could introduce new health hazards due to reducing workers’ temperature;
- Could introduce new safety risks (e.g. mud rushes); and
- Adverse effects of water in Kimberlite (diamond) ore-bodies.

In summary, participants unanimously agreed that the proposed system should be further investigated, developed and tested in order to determine the practicality and effectiveness of the proposed system.
GENERAL CONCLUSIONS

From the results obtained in Milestones 1 - 11, the following general conclusions were made:

1. The ideal escape methodology is one that will allow escape in an environment where there is zero visibility and zero audibility. This is the absolute worst-case scenario, as explained in Milestone 10.
2. The traditional lifeline, if installed correctly, will adequately serve its purpose of guiding people to the refuge bay.
3. The main problem thus lies with the ability to detect and reach the lifeline, under zero visibility and audibility conditions.
4. In Milestone 7, it was seen that the MOSES system, in conjunction with a self-breathing apparatus, lifeline and goggles, is the most viable current technology to satisfy the generic requirements for the ideal system. However, this methodology poses risks in that it relies on visual and audial guidance. The visual guidance may be successful in low visibility conditions, but not zero visibility conditions (as shown in the lighting tests conducted in Milestone 10). The audible component could create confusion, or may be rendered ineffective if other sources of noise are present, or if hearing damage has been incurred due to an explosion, shockwave, etc.
5. However, due to the visual and audible nature of the MOSES methodology described in (4) above, in the worst-case scenario (where zero visibility and audibility conditions exist) the MOSES system will not be effective.
6. The incremental improvements given in Milestone 9 would no doubt improve upon existing systems, but would still not satisfy the worst-case scenario described in (1) above. The integrated innovative solutions given in Milestone 9 have the potential to meet all the generic requirements, as well as satisfying the worst-case scenario.
7. The integrated innovative solutions i.e. Integrated Personal Protective Equipment and the Umbilical Cord Concept would however require a substantial amount of time and money in order to develop and implement the final solutions. A considerable probability of failure lies with the development of these solutions – there is a chance that money and time spent could lead to inadequate solutions. This is due to the nature of the technologies proposed in the solutions.
8. Apart from the concerns stated in (7), it is envisioned that these integrated innovative solutions, if successfully developed, would have inherent challenges in terms of implementation:
a. The solutions would be expensive to initially roll-out at mines;
b. The solutions would require an increase in the frequency and complexity of maintenance activities;
c. The solutions would require a range of modifications to work processes in order to function correctly;
d. The solutions may pose ergonomic constraints in terms of the mine workers making use of the solutions, and
e. Due to the high-tech nature of the solutions, it is envisioned that mine workers may be resistant to accepting the solutions, which is critical to the success of the solutions.

9. Considering the concerns stated in (7) and (8), it was concluded by the project team that, although the integrated innovative solutions could work, too many risks exist in terms of pursuing these solutions at this stage.

10. It was realized that a new, innovative solution was required:
   a. One that would satisfy all the system requirements (incl. zero visibility and audibility);
   b. One that could be developed “right here, right now”;
   c. One that will be happily accepted by workers and not intrude on their normal “day-to-day” activities;
   d. One that would be affordable enough for all South African underground mines to implement; and
   e. One that would be able to be manufactured locally and lead to empowerment and wealth creation.

11. In Milestone 10, the water spray assisted lifeline concept was developed. The hypothesis was that a water spray, when coming into contact with a person, would be able to guide the person to the origin of the spray in a zero visibility and audibility environment. The hypothesis was tested and verified, and a conceptual methodology and system was proposed.

12. In Milestone 11, the water spray assisted lifeline concept was discussed in detail during an internal workshop. Critical flaws, risks and issues of the system were identified in the workshop, and potential mitigation measures were proposed for each. An industry workshop was then conducted, where the following aspects of the entire project were discussed:
   a. The ideal escape system;
b. Top 3 current solutions (Lighted lifeline, strobe lights and MOSES);

c. Potential future solutions (IPPE, umbilical lifeline and water-assisted escape).

13. The workshop had the following conclusions:

a. No concrete reason exists for not using conical/directional lifelines in hard-rock mines. Workshop participants agreed that, due to the mining layouts of medium to deep level hard-rock mines, a lifeline would greatly increase the effectiveness and efficiency of escaping in poor visibility conditions.

b. Air-tight goggles would increase the probability of escape in poor visibility, as eyes would be protected against smoke and/or particulates. Participants agreed that this was the “lowest hanging fruit” in terms of benefits, ease of implementation and cost.

c. Employee escape training is of critical importance. The success of any system is based on the employees’ ability to understand and use the system effectively.

d. Participants agreed that any system based on visual guidance would ultimately be ineffective in zero visibility conditions. Systems based on audial guidance could potentially be effective in zero visibility conditions. However, participants noted that it could lead to further confusion and panic during an emergency.

e. The IPPE & Umbilical lifeline concepts were both seen as having merit, but would require extensive development and testing in order to be feasible.

f. Participants agreed that the water assisted escape concept showed the most promise out of the future solutions, and that it should be further developed and tested.
RECOMMENDATIONS FOR FURTHER RESEARCH

9.1 Further investigation of the self-breathing technologies

It is recommended that the broad umbilical lifeline value proposition be further investigated. The primary drive of the investigation should be to investigate the feasibility of alternative self-breathing technologies, as opposed the chemical SCSR.

9.2 Further investigation of the water-assisted escape concept

It is recommended that the water-assisted escape concept be further investigated. It is further recommended that this investigation should be in the form of a research and development project, where the main aim is to develop, test and implement a water-assisted escape system (refer to APPENDIX F: PROPOSED FUTURE PROJECT).

9.3 Consideration of IPPE concept in other MHSC research projects

It is recommended that the IPPE concept should be taken into consideration in other digital technology-based projects. The IPPE system could potentially be the solution in the “mine of the future”, and should thus be considered in projects that are shaping the mine of the future. Specific consideration should be given to the use of pre-programmed RFID tags as a potential form of guidance to the refuge bay, as these tags have the ability to withstand explosions and potentially underground fires.
RECOMMENDATIONS FOR IMPLEMENTATION FOR THE SECTOR

10.1 Testing of traditional lifeline at hard-rock mines
Generally, no clear reason exists as to why the traditional lifeline is not used in hard-rock mines in South Africa. It is recommended that in-field, trial testing should be conducted on the effectiveness and practicability of lifelines in hard-rock mines. Ideally, the lifeline should be tested for the full spectrum of U/G mining layouts found in the SAMI (not currently using lifelines). Realistically, the test sample size should test as many layouts as practically possible.

10.2 Issuance of air-tight goggles as part of PPE
It is recommended that air-tight goggles should form part of standard PPE requirements, in environments where low visibility conditions could be experienced.

10.3 Use of lighting-based systems
Where practical and affordable, mines could consider implementing a lighting-based system. The lighting system should be able to deliver three-fold value:
- Act as an early warning system;
- Act as static lighting under normal operating conditions;
- And provide visual guidance to refuge bays.

10.4 Lifeline maintenance and housekeeping
It is recommended that where lifelines have been installed in underground mines, specific attention needs to be paid to sound housekeeping. Daily checks should be conducted in order to ensure that the lifeline will still be functional if used.
REFERENCES


Kravitz, J.H. & Gibson, J.H. 2010. The Use of Self-Contained Self Rescuers (SCSRs) during Recent Mine Accidents in the U.S. and Subsequent Regulatory Improvements for SCSR. Colorado: SME.


LIST OF APPENDICES

12.1 APPENDIX A: FINANCIAL SUMMARY

Table 18: Overall Project Cost

<table>
<thead>
<tr>
<th>FUNDING REQUIREMENTS FOR CURRENT YEAR *</th>
<th>COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total project cost (excluding VAT)</td>
<td>R 1 111 040,00</td>
</tr>
<tr>
<td>VAT**</td>
<td>R 155 545,60</td>
</tr>
<tr>
<td>Total project cost (including VAT)</td>
<td>R 1 266 585,60</td>
</tr>
<tr>
<td>Less funding from other sources***</td>
<td>R 0,00</td>
</tr>
<tr>
<td>Total funding requested from MHSC (VAT Inclusive) ***</td>
<td>R 1 266 585,60</td>
</tr>
</tbody>
</table>

Project Duration: 8 Months

<table>
<thead>
<tr>
<th>START</th>
<th>END</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/2014</td>
<td>04/2016</td>
</tr>
</tbody>
</table>
Table 19: Project Cost by Milestones

<table>
<thead>
<tr>
<th>MILESTONE</th>
<th>MILESTONE TIMELINES (mm/yy)</th>
<th>HR COSTS (VAT inclusive)</th>
<th>OPERATING COSTS</th>
<th>SUB-CONTRACTOR COSTS</th>
<th>CAPITAL COSTS</th>
<th>COST per MILESTONE (VAT inclusive)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Project Initiation</td>
<td>12/2014 12/2014</td>
<td>R 126 658,56</td>
<td>-</td>
<td>-</td>
<td>R 126 658,56</td>
</tr>
<tr>
<td>2</td>
<td>Determine all current technologies used for escape in poor visibility</td>
<td>12/2014 01/2015</td>
<td>R 126 658,56</td>
<td>-</td>
<td>-</td>
<td>R 126 658,56</td>
</tr>
<tr>
<td>3</td>
<td>Gather and review reports and other available material on current technologies in use</td>
<td>02/2015 02/2015</td>
<td>R 63 329,28</td>
<td>-</td>
<td>-</td>
<td>R 63 329,28</td>
</tr>
<tr>
<td>4</td>
<td>Visit manufacturers and discuss current products and work on newer or improved products</td>
<td>03/2015 03/2015</td>
<td>R 126 658,56</td>
<td>-</td>
<td>-</td>
<td>R 126 658,56</td>
</tr>
<tr>
<td>5</td>
<td>Visit mines using these products and discuss problems experienced. Also review accident reports</td>
<td>04/2015 05/2015</td>
<td>R 126 658,56</td>
<td>-</td>
<td>-</td>
<td>R 126 658,56</td>
</tr>
<tr>
<td>6</td>
<td>Determine requirements for the ideal technology or system</td>
<td>06/2015 07/2015</td>
<td>R 63 329,28</td>
<td>-</td>
<td>-</td>
<td>R 63 329,28</td>
</tr>
<tr>
<td>7</td>
<td>Develop tool for assessment of current technologies</td>
<td>08/2015 08/2015</td>
<td>R 63 329,28</td>
<td>-</td>
<td>-</td>
<td>R 63 329,28</td>
</tr>
<tr>
<td>8</td>
<td>Gap Analysis - define areas where current technologies fall short of requirements</td>
<td>09/2015 09/2015</td>
<td>R 63 329,28</td>
<td>-</td>
<td>-</td>
<td>R 63 329,28</td>
</tr>
<tr>
<td>9</td>
<td>Develop and analyse possible solutions</td>
<td>10/2015 11/2015</td>
<td>R 126 658,56</td>
<td>-</td>
<td>-</td>
<td>R 126 658,56</td>
</tr>
<tr>
<td>10</td>
<td>Test, modify and recommend feasible solutions</td>
<td>12/2015 01/2016</td>
<td>R 126 658,56</td>
<td>-</td>
<td>-</td>
<td>R 126 658,56</td>
</tr>
<tr>
<td>11</td>
<td>Conduct workshops on findings</td>
<td>02/2016 02/2016</td>
<td>R 63 329,28</td>
<td>-</td>
<td>-</td>
<td>R 63 329,28</td>
</tr>
<tr>
<td>12</td>
<td>Draft Final Report (Submission)</td>
<td>03/2016 03/2016</td>
<td>R 63 329,28</td>
<td>-</td>
<td>-</td>
<td>R 63 329,28</td>
</tr>
<tr>
<td>13</td>
<td>Final Report (Approval)</td>
<td>03/2016 04/2016</td>
<td>R 126 658,56</td>
<td>-</td>
<td>-</td>
<td>R 126 658,56</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>R 1 266 585,60</strong></td>
<td>-</td>
<td>-</td>
<td><strong>R 1 266 585,60</strong></td>
</tr>
</tbody>
</table>
12.2 APPENDIX B: START-UP PRESENTATION

Mine Health and Safety Council

Project Number: SIM140701
Develop Feasible Methodologies to aid escape in poor visibility in underground environments
23 January 2015
Platinum boardroom

Prof. J JL du Plessis
Business Enterprises University of Pretoria

Presentation Outline

1. What will we achieve?
2. How will we achieve this?
3. Who will we use to achieve this?
4. Timeframes and Milestones?
5. How can the outcomes be implemented?
6. What are the risks to the research being completed on time?
7. Conclusions
1. What will this research achieve?

- Recommendations for:
  - An effective and improved escape methodology during poor visibility
  - Provide recommendations that will improve current practices

- If implemented:
  - Improved confidence of underground workers to escape safely
  - Reduced risk of injuries during emergency escape conditions
  - Reduced risk of loss of life during emergency escape conditions

2. How will the research outcomes be achieved?

- Current Hypotheses
  - Current practices does not provide a fail safe solution during emergency evacuation in poor visibility
  - Poor visibility results in disorientation
  - Positioning of lifelines
    - Location of the lifelines make it difficult to find in poor visibility
  - The above causes make it either impossible to find lifelines or it can take to long to find the lifeline and reach a refuge chamber or a place of safety in the time afforded by provided breathing apparatus
    - These being SCSR’s
    - In colliers these are often supported by cashes of additional long duration units
2. How will the research outcomes be achieved?

**Video**

**2. How will the research outcomes be achieved?**

- A Risk management approach will be followed:
  - Review of baseline emergency escape risk assessments
  - Risk identification processes (root cause analysis, FTA, interviews)
  - Apply risk control principles (come up with solutions that would address the cause/s identified)

- This research project steps entails:
  - Critical review of current technologies from all perspectives
  - Investigate and review new and developing technologies
  - Review and define user requirements for proposed ideal solution
  - Do a gap analysis between the ideal solution and existing systems.
  - Provide solutions that would address the gaps identified.
  - Identify appropriate manufacturers to work with in manufacturing the proposed solution.
  - Develop solutions in co-operation with identified technology partners
2. How will the research outcomes be achieved?

- Test solutions
  - Identify potential participating mines and or test sites:
    - Coal mine – specific mine to be confirmed
    - Hard rock mine – specific mine to be confirmed
    - Test sites – investigate suitability of using Kloppersbos (CSIR facility)
  - Smoke simulation at Kloppersbos
    - Closer to real life situation with eyes being affected
    - Potentially better than blindfolding as “poor visibility” is not necessarily the same as “no visibility”

- Report on findings and workshops to assist in technology transfer

3. Who will be involved in this research?

- Prof J.J.L. du Plessis, PhD, Pr. Eng
  - Extensive research experience (including projects with MHSC)
- Mr. P.M. Bredell, Pr. Eng
  - Extensive industry experience, including innovative problem solving and new technology implementation
- Potential HDSA involvement through identifying key research themes for students to pursue and where needed use of sub contractors
- Sub-contractors will be engaged as project develops (depends on outcome of some of the activities planned)
  - Prof Huw Philips, PhD, Pr. Eng – Extensive research experience
- HR costs estimated at 80% of total costs
4. Timeframes and Milestones for this research?

<table>
<thead>
<tr>
<th>Task</th>
<th>November</th>
<th>January</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td>Define and scope the project</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Review existing literature and identify gaps</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conduct interviews and gather data</td>
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<td>Analyse data and develop hypotheses</td>
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<td>Develop and refine research questions</td>
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<td>Conduct pilot studies</td>
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<td>Write draft report</td>
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</table>

5. Implementation of research outcomes?

- The research will deliver recommendations for improvement of emergency escape systems
- Incorporation or implementation of the recommendations will be discussed with MHSC during and at completion of the project
  - to determine the best way forward incorporating all parties
- Successful technology transfer will be achieved through
  - Communication with industry on recommended solutions
    - create ownership and buy-in
  - Investigate using of new communication methods – e.g. Virtual Reality
- Present the results of this research
  - At industry workshops
  - At the various management associations
6. What are the risks?

- Limitations of proposed solutions
  - Cost could be prohibitive
  - Solutions could possibly be different for different types of mines
  - Solution may require higher level of skill
    - requiring an industry wide retraining effort
  - Solutions may not be robust enough
    - harsh working conditions underground for e.g. implementation of SCSR’s
- Availability of or the ability to develop specific technology for the proposed solutions for testing
- Integration of proposed technology with that of technology identified in Quick Win Project 2

7. Can SIMRAC help?

- Assisting in obtaining of specific incident investigation reports relating to emergency escape
- Provision of a deeper context leading to the requirement for doing the specific research
- Assist with selection of champion sites?
- Facilitation and investigation of multi-national research efforts into this field
  - NIOSH
  - ACARP
  - CANMET
  - CEMI
8. Conclusions

- The outcome of this project should be to provide solutions that will assist workers during emergency escape conditions that will reduce risk of injury and the loss of life
- Completion of the project is planned for April 2016
- This research does have the potential to improve escape practices that can improve safety practices in mines locally and internationally
- It is important that all of the mining sector partners are involved in the project from:
  - Review and recommendation phases
  - Identification of champion mines as test sites
  - Presentations of final workshop and technology transfer

Thank you
12.3 APPENDIX C: INDUSTRY WORKSHOP INVITATION LETTER

Dear Valued Industry Partner,

The Mining Engineering Department at the University of Pretoria is currently conducting research work on several projects awarded to the department by the Mine Health and Safety Council (MHSC). At this stage, two of these projects require insights and inputs from the South African mining Industry. These two projects are explained in brief.

The first project is titled “SIM 140701 – Develop feasible methodologies to aid escape in poor visibility in underground mining environments”. The main aims of the research work is to:

- Provide solutions to enable improved probability of escape in poor visibility and in underground environments;
- Reduce risk of loss of life due to failure to locate lifelines;
- Reduce risk of injury due to failure to locate lifelines; and
- Reduce risk of loss of life due to failure to reach lifeline in time.

Currently, the project is in the “close-out” phase. The next phase of the project focuses on conducting an industry workshop on the findings of the research work (Milestone 10 in Table 1 below).

Table 1: SIM 140701 “Develop feasible methodologies to aid escape in poor visibility in underground mining environments” Broad Overview of Milestones

<table>
<thead>
<tr>
<th>No.</th>
<th>Milestone</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Literature Review of all current technologies used for escape purposes</td>
<td>Completed</td>
</tr>
<tr>
<td>2</td>
<td>Literature Review of reports and other material available on technologies currently being used</td>
<td>Completed</td>
</tr>
<tr>
<td>3</td>
<td>Visit to manufacturers of current technologies to discuss current and future escape products</td>
<td>Completed</td>
</tr>
<tr>
<td>4</td>
<td>Visit to mines to discuss problems experienced with escape</td>
<td>Completed</td>
</tr>
<tr>
<td>5</td>
<td>Development of requirements for the ideal escape technology/system</td>
<td>Completed</td>
</tr>
<tr>
<td>6</td>
<td>Development of an assessment tool to assess current technologies/systems</td>
<td>Completed</td>
</tr>
<tr>
<td>7</td>
<td>Gap analysis of current technologies/systems versus ideal requirements, to define areas where current technologies fall short of requirements</td>
<td>Completed</td>
</tr>
<tr>
<td>8</td>
<td>Development and analysis of possible solutions</td>
<td>Completed</td>
</tr>
<tr>
<td>9</td>
<td>Testing, modification and recommendation of feasible solutions</td>
<td>Completed</td>
</tr>
<tr>
<td>10</td>
<td>Conduct workshop on findings</td>
<td>To be Completed</td>
</tr>
<tr>
<td>11</td>
<td>Final Report</td>
<td>To be Completed</td>
</tr>
</tbody>
</table>

The second project is titled “CoE 150904 – Missing Person Locator System”. The main aim of the research work is to achieve zero occurrences of fatalities or continued harm to health and safety (be it physical or psychological), as a result of employees becoming lost in underground mines. Currently, the major knowledge gathering and research components of the project have been completed. The next phase of the project focuses on developing a generic list of requirements for a missing person locator system (MPLS) (Milestone 3 in Table 2 below).

Table 2: CoE 150904 “Missing Person Locator System” Broad Overview of Milestones

<table>
<thead>
<tr>
<th>No.</th>
<th>Milestone</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Literature Review of MPLS used in the local and international mining industry</td>
<td>Completed</td>
</tr>
<tr>
<td>2</td>
<td>Development of a comprehensive set of scenarios where MPLS will be critical</td>
<td>Completed</td>
</tr>
<tr>
<td>3</td>
<td>Development of a generic requirement list for a MPLS</td>
<td>Work-in-Progress</td>
</tr>
<tr>
<td>4</td>
<td>Evaluation of the effectiveness of current MPLS against the generic requirements, for different mining methods, layouts and commodities</td>
<td>To be Completed</td>
</tr>
<tr>
<td>5</td>
<td>Recommendations on MPLS that is most fit-for-purpose</td>
<td>To be Completed</td>
</tr>
<tr>
<td>6</td>
<td>Research and Development proposals to close the outstanding gaps between the generic requirements and the current systems</td>
<td>To be Completed</td>
</tr>
<tr>
<td>7</td>
<td>Final Report</td>
<td>To be Completed</td>
</tr>
</tbody>
</table>

In order for the project team to successfully complete Milestone 10 on SIM 140701 and Milestone 3 on CoE 150904, we cordially invite representatives from your company for a workshop with the project team, along with representatives from other mines:

21/07/2016
Date: 9th of September 2016
Time: 09:00 – 14:00
Venue: Department of Mining Engineering Boardroom
Room 5-22, Floor 5, Mineral Sciences Building
University of Pretoria, Hatfield Campus

The workshop will be split into two sessions – one session for SIM 140701 and the second session for CoE 150904. The proposed agenda for the workshop is as follows:

08:30 – 09:00  Tea/Coffee/Refreshments and light snacks
09:00 – 09:45  Introduction and overview of work done to date on SIM 140701
09:45 – 10:00  Detailed discussion on SIM 140701 findings
10:00 – 11:15  Industry partners engagement and feedback on SIM 140701 findings
11:15 – 12:00  Lunch
12:00 – 12:30  Introduction and overview of work done to date on CoE 150904
12:30 – 13:00  Detailed discussion on generic system requirements (from an employee perspective)
13:00 – 14:00  Industry partners engagement on generic system requirements (from an employer perspective)

Kindly provide us with the names and contact details of the nominated company representatives. Please note that maximum number of representatives is limited to three (3). The project team looks forward to engaging and collaborating with your company representatives in the workshop.

Yours sincerely,

Prof Jan du Plessis (Project Leader SIM 140701 & CoE 150904)
12.4 APPENDIX D: INDUSTRY WORKSHOP PRESENTATION

Welcome

Prof RCW Webber-Youngman
SIM 140701

DEVELOP FEASIBLE METHODOLOGIES TO AID ESCAPE IN POOR VISIBILITY IN UNDERGROUND MINING ENVIRONMENTS

- Current system and shortcomings
- Potential improvements
- Future alternatives
- Conclusion
- Further research
Current Escape System

- Early warning
- Respirable air
- Eye protection
- Detect nearest lifeline
- Reach lifeline
- Guidance to refuge bay

Early Warning

- **Ideal**
  - Automated and manual mine-wide emergency **detection**
  - Instantaneous mine-wide **warning** - visual and audible
- **Current**
  - Varied technologies implemented in SA
  - CH4, CO, O2 and particle detection systems
  - Linked to audible, visual and smell (some mines) warning
- **Shortcomings**
  - Inconsistent implementation (stench gas)
  - Response training lacking
  - Production equipment noise
  - Visual warning not where workers can see
Respirable Air

- Ideal
  - Provide oxygen from early warning until cache is reached
  - Easy to use
  - Quick to initiate
  - Comfortable (worn and use)
- Current
  - Chemical type SCSRs
- Shortcomings
  - Often of insufficient duration (duration varies with use)
  - Not comfortable to use – exothermic reaction
  - Shock users if used for the first time

Eye Protection

- Ideal
  - Lightweight
  - Compact
  - Ease of use and comfort
  - Airtight
  - Available
- Current
  - No airtight eye protection used on SA mines
- Shortcomings
  - Not implemented
Lifeline Detection

- Ideal
  - Easy to detect from anywhere in mine
- Current
  - Yellow nylon type rope connecting brown coloured cones
  - Attached by wire to sidewalls
- Shortcomings
  - Colours used not very visible underground
  - Impossible to detect from relatively short distance in low visibility

Reaching Lifeline

- Ideal
  - Not too far (horizontally)
  - Within reach (vertically)
  - Easy to distinguish in zero visibility (by hand)
- Current
  - Tied to sidewalls often onto wire mesh
  - Tied to roof bolts in roadways
- Shortcomings
  - Not easily distinguished by hand in zero visibility
  - Out of reach in roadways (attached to roof)
Guidance to Refuge Bay

- **Ideal**
  - Distance to waiting place minimised
  - Does not cross obstructions such as conveyor belts
  - Robust and fire proof
  - Attached to refuge bay door
- **Current**
  - Combustible rope and cones used
  - Laid out to RB via waiting place cache
- **Shortcomings**
  - Combustible lifeline – can be destroyed in explosions or fire
  - Availability of sufficient long duration SCSRs at cache

**Improvements**

- Early warning
- Respirable air – SCSRs Experiential Training (demonstration not good enough)
- Eye protection
- Introduce SCSRs that include goggles
Improvements

- Detect lifeline
  - Introduce LED evacuation pulse system in combination with lifeline

- Reach lifeline
  - Ensure every pillar has lifeline attached (board and pillar layouts)
  - Suspend line away from pillar sidewall
  - Evacuation strip lights only at sidewall
  - Guidance to refuge bay
  - Implement steel cable

MOSES

[Diagram of MOSES framework with labeled sections: Early Warning, Air Supply, Eye Protection, Guidance to Refuge Bay, Reaching Lifeline, Lifeline Detection, Training Required]
**Lighted Lifeline**

- Early Warning
- Training Required
- Air Supply
- Guidance to Refuge bay
- Eye protection
- Reaching Lifeline
- Lifeline Detection

**Strobe/Pulse**

- Early Warning
- Training Required
- Air Supply
- Guidance to Refuge bay
- Eye protection
- Reaching Lifeline
- Lifeline Detection
Strobe/Pulse

Start
30 sec
60 sec
90 sec
120 sec
135 sec

Strobe/Pulse

Start
30 sec
60 sec
90 sec
120 sec
125 sec
Future Alternatives

IPPE

Integrated features
- Emergency breathing apparatus
- Toxic gas detection linked to air intake control
- Particle filter
- Sonar to detect distance to sidewalls
- Integrated augmented reality screen with navigation
- Laser beams
- Communications
- Cap lamp

Umbilical Lifeline

Water Spray Assist

Industry_Workshop_09_09_2016
Umbilical Lifeline

Integrated features
- Tactical guidance
- Air supply
- Additional distributed inflatable fresh air bases
- Passive or active RFID tags
- LED evacuation pulse system

Water Spray Assisted Escape
Water Spray Assisted Escape

Emergency directional sprays

- Guidance through tactile sense
- Guidance under zero visibility & audibility
- Targets problem area of reaching lifeline
- Follow the spray – reach the lifeline

Thank You
## APPENDIX E: INDUSTRY WORKSHOP ATTENDANCE LIST

<table>
<thead>
<tr>
<th>Surname</th>
<th>Name</th>
<th>Company/Union</th>
<th>Email Address</th>
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<tbody>
<tr>
<td>1.</td>
<td>Van Reenen</td>
<td>Steve</td>
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<td>Marcel</td>
<td>Anglo Gold Mining</td>
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<td>11.</td>
<td>Navini</td>
<td>Singh</td>
<td>CSIR</td>
<td><a href="mailto:nSingh1@csir.co.za">nSingh1@csir.co.za</a></td>
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<td>Alec</td>
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<td>Johan</td>
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12.6 APPENDIX F: PROPOSED FUTURE PROJECT

The proposed future research topic/title is as follows:

“The development, testing and implementation of a feasible water-assisted escape methodology for underground mining environments”

The high-level scope of the proposed future research is as follows:

- Development, design, testing and implementation of a feasible system; considering and mitigating all the potential flaws/risks/issues;
- Investigations into the feasibility of insourcing all manufacturing activities related to the feasible system; essentially a sustainable, “Proudly South African” business plan; and,
- Successful skills transfer and human research capacity-building to HDSA researchers involved in the proposed research.

Following on from the high-level scope provided previously, the research objectives and expected outcomes were envisioned to be the following (Table 20):

**Table 20: Research objectives and expected outcomes**

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Expected Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Finalise holistic, water-assisted escape methodology</td>
<td>Problem-Solution Fit Conceptual Product Proposal</td>
</tr>
<tr>
<td>2. Clearly define issues with the solution that needs to be addressed</td>
<td>List of top issues that, if not addressed, will lead to system failure</td>
</tr>
<tr>
<td>3. Conduct investigations into the best mitigation measure for each issue (pro-active and reactive)</td>
<td>Mitigation strategies for each issue, accompanied by testing techniques and timeline</td>
</tr>
<tr>
<td>4. Design prototype and perform laboratory testing</td>
<td>System prototype final design, test results and recommendations</td>
</tr>
<tr>
<td>5. Build prototype and perform small-scale testing (e.g. in a mock mine)</td>
<td>Physical prototype, test results, recommendations</td>
</tr>
<tr>
<td>6. Make modifications to prototype, based on findings from testing</td>
<td>Final draft design of system</td>
</tr>
<tr>
<td>7. Build provisional final system and test on small scale</td>
<td>Physical prototype #2: Test results and recommendations</td>
</tr>
<tr>
<td>8. Conduct research on technology implementation and change management</td>
<td>Research findings, feasible implementation strategy/roll-out strategy</td>
</tr>
<tr>
<td>9. Perform full-scale testing at Champion Mine</td>
<td>Test results, recommendations for modifications</td>
</tr>
<tr>
<td>10. Make modifications to draft final system and build final system</td>
<td>Physical final system</td>
</tr>
<tr>
<td>11. Investigate the feasibility of insourcing manufacturing</td>
<td>Report findings, feasible insourcing strategy</td>
</tr>
<tr>
<td>12. Develop a sustainable business model</td>
<td>Sustainable business model and strategy</td>
</tr>
</tbody>
</table>
It was envisioned that the future research and development should be performed by a multi-disciplinary team, with distinct roles for each team member. The proposed project is different from traditional research-based projects, in the sense that research work will form a much smaller component and not be the primary activity. The primary activities are to be design, simulations, prototyping, pilot-testing, on-site testing and collaboration with mine workers. It is thus envisioned that the ideal team for the proposed future research and development would comprise of:

- Mining Engineers;
- Mechanical Engineers;
- Industrial Engineers;
- Industrial Psychologists; and
- HDSA Engineering Graduates.

The proposed team structure can be seen in Figure 40.

![Figure 40: Proposed Team Structure](image)

According to Figure 40, the proposed team would be headed by a mining engineer, with a mechanical engineer, industrial psychologist, industrial engineer and mining engineering
forming the core “operational” portion of the team. The HDSA engineering graduates would form the core of the research component of the proposed project, overseen by a Mining Engineer. The envisioned team is to be structured such that the secondary mining engineer’s main goal is to ensure integration between the different disciplines within the team and the different project components.