CSIRO

Proximity Detection Device Interoperability ACARP C24034

Final Report

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April 2016

Contents

1 Executive Summary

This report presents the results of research and industry collaborations undertaken as part of ACARP project C24034. The primary task of the project was to facilitate and assist the working group gathered together by EMESRT as representatives of the major OEM and proximity system vendors. The end outcome of this work has been envisaged as a standard, open architecture protocol with wide acceptance and uptake by the entire industry.

This project has supported the working group by providing technical information and direction, as well as providing literature and background reviews where appropriate.

A primary outcome of this project has been the framework for a common protocol for communications between PDS and OEM devices in the mining industry. It was resolved by the working group that, due to its familiarity and broad industry acceptance, the preferred basis for the protocol should be the J1939 standards as established by the Society of Automotive Engineers (SAE). There are a number of documented limitations of this approach, however it has been agreed by the group that these are surmountable, and that the advantages (primarily reduced development time) outweigh the limitations.

This report provides an overview of the J1939 protocol in light of the vehicle interaction requirements defined by EMESRT. The EMESRT workshop also defined a set of fundamental signals or messages between the PDS and OEM systems that would be required for compliance with the proposed industry standard: these signals, and the J1939 protocol messages necessary to implement them, are documented. Some key issues remain to be addressed as part of the implementation process, such as the need for an agreed hardwired interface for communication with non-computerised vehicles. Of particular note in this category is the question of the extensibility of the proposed protocol, and the need for an ongoing roadmap to carefully manage the implementation process.

This report concludes with several recommendations for ongoing actions:
- Regular review and monitoring of similar technologies in the automotive field should be undertaken
- A project to implement a testing and compliance verification suite to validate systems in development or production
- Ongoing refinement of the protocol under development by the EMESRT group should address the identified issues, preferably with reference back to the SAE standards, as well as the LISCA framework where appropriate.

2 Definitions

2.1 Stakeholder Definitions

ACARP   Australian Coal Association Research Program

CSIRO   Commonwealth Scientific and Industrial Research Organisation (AUS)

MSHA   Mine Safety and Health Administration (USA)

MEPIAG   Mobile Equipment, Personnel Interaction Advisory Group (AUS)

NIOSH   National Institute for Occupational Safety and Health (USA)

OEM   Original Equipment Manufacturer

OMSHR   Office of Mine Safety and Health Research (USA)

2.2 Other Definitions

Terms defined by the NSW Government Trade and Investment department (NSW Government Dept of Trade and Investment - Mine Safety, 2013).

ALARA   **As Low As Reasonably Achievable**

ALARP   **As Low As Reasonably Practicable**
The level of risk between tolerable and intolerable levels that can be achieved without expenditure of a disproportionate cost in relation to a benefit gained.

CAS   **Collision Avoidance System**
The combination of technologies (SAT, PAT, PDT, and CAT) to form a system.

CAT   **Collision Avoidance Technology**
Technology that actively scans for other personnel, vehicles or infrastructure and takes automatic action to render the equipment to a safe state. E.g.: Reversing radar with brake control.

CAT Zone   **CAT Zone**
The CAT Zone is the area in which CAT is primarily required to operate. PDT and PAT may overlap this zone. CAT zones are identified in these series of documents by red colouring.

CWA   **Controlled Work Area**
An area, defined by a site-specific risk assessment, where trained persons can enter to work and operate the machine. This type of control is considered to be low on the hierarchy of controls. A collision awareness system will elevate the controls within the hierarchy of controls.

E/E/PES   **Electrical/Electronic/Programmable Electronic System**
(A61508 Term) System for control, protection or monitoring based on one or more E/E/PE devices, including all elements of the system such as power supplies, sensors and other input devices, data highways and other communication paths, and actuators and other output device.

EMESRT

Earth Moving Equipment Safety Round Table.
A global initiative involving major mining companies. EMESRT engages with key mining industry Original Equipment Manufacturers (OEMs) to advance the design of the equipment to improve safe operability and maintainability beyond Standards.

EQ

Equipment
One of the key system elements (after Nertney et al) related to achieving safe production.

EUC

Equipment Under Control
(AS61508 Term) Equipment, machinery, apparatus or plant used for manufacturing, process, transportation, medical or other activities.

Functional Safety

(AS61508 Term) Part of the overall safety relating to the EUC and the EUC control system, which depends on the correct functioning of the E/E/PE safety related systems. Also refers to other technology safety related systems and external risk reduction facilities.

Interaction

Defines as an intentional or unintentional close encounter between two or more objects. This may be;
- *Equipment to Personnel*
- *Equipment to Equipment*
- *Equipment to Infrastructure*

LISCA

LASC Interoperability Specification for Collision Avoidance

Mine

Refers to the following types of operations;
- *Underground Coal Mine*
- *Surface Coal Mine*
- *Underground Metalliferous Mine*
- *Surface Metalliferous Mine*
- *Extractive Operations (Quarries)*

Mobile Equipment

Includes all equipment that can move under its own power on wheels, crawler tracks or on rails.

Moveable Plant

Plant that is mounted on skid plates and is normally stationary, however it can move under its own power using a walking mechanism, external hydraulic supply or by cable winch (e.g., Dragline, Longwall Roof Support)

OEM

Original Equipment Manufacturer

PAT

Proximity Awareness Technology
Technologies that aid personnel to identify they are converging to another vehicle, person or infrastructure. E.g.: Reversing mirrors, flashing lights.

PAT Zone

The PAT Zone is the area in which PAT is primarily required to operate. PAT zones are identified in these series of documents by yellow colouring.

PD/CA

Proximity Detection and/or Collision Avoidance

PDS   **Proximity Detection System**

PDT   **Proximity Detection Technology**
Technologies that actively scans for other personnel, vehicles or infrastructure and warn of their presence. This technology does not automatically take action to prevent a collision. E.g.: Reversing camera with distance alarm.

PDT Zone   *The PDT Zone is the area in which PDT is primarily required to operate. PDT zones are identified in these series of documents by orange colouring.*

PE   **People**
One of the key system elements (after Nertney et al) related to achieving safe production.

Safety Function *(AS61508 Term) Function to be implemented by an E/E/PE safety related system, other technology related system or external risk reduction facilities, which is intended to achieve or maintain a safe state for the EUC, in respect of a hazardous event.*

Safety Requirement Specifications *(AS61508 Term) Specification containing all the requirements of the safety functions that have to be performed by the safety related systems.*

SAT   **Safety Adherence Technology**
Technologies that track and record the operation and performance of equipment for post event analysis and training. E.g. SCADA systems, event databases, chart recorders

SCADA   **Supervisory Control and Data Acquisition**
Industrial computer systems that monitor and control industrial, infrastructure or facility based processes.

SIL   **Safety Integrity Level**
(AS61508 Term) Discrete level (one out of a possible four) for specifying the safety integrity requirements of the safety functions to be allocated to the E/E/PE safety-related systems, where safety integrity level 4 has the highest level and safety integrity level 1 has the lowest.

SOP   **Standard Operating Procedure**
Technologies that track and record the operation and performance of equipment for post-event analysis and training. E.g.: SCADA Systems, Event Databases, Chart Recorders.

Stationary Plant *Plant that cannot move under its own power and may be either fixed or relocated from time to time, using other equipment.*

Void (No-Go) *In some instances, mobile equipment and personnel may be prohibited from entering areas that may include;*

- *Unstable ground*
- *Open stopes*
- *Highwalls*
- *Out-of-bounds areas around machines*
- *Other off limit areas*

Worker   *Persons working on site, including: Management, Maintainers, Equipment Operators, Supervisors, Contractors, Suppliers, Consultants, and Authorised Officers*

3 Literature Review

See Appendix A for a compiled list of relevant sources of information for technology used in proximity detection and collision avoidance systems.

From	Total	Proximity Detection Device	Collision Management	Technology Used						Industry	
				RFID	Magnetic	Radar	Video	GPS	Other	Coal Mining	Heavy Industries
ACARP	12	10	12	2	0	3	0	0	0	12	0
Patents	50	50	42	7	28	3	0	10	14	44	16
Commercial papers	35	35	35	8	10	9	1	11	11	35	0
Other Papers	84	84	84	12	23	13	0	14	12	80	4

3.1 Previous ACARP projects

The majority of the ACARP projects undertaken to date have had a specific focus on particular technologies or areas of concern related to the risk profile of particular mining processes. With C22012 and this project C24034, focus is shifting to addressing the system wide requirements, starting with the ability for multiple and diverse systems to communicate data in the same format and ensure interoperability between systems.

3.2 Patents

In general, the existing patents are owned by a diverse group of companies. Most focus on systems or techniques for detecting the proximity between vehicles or people or objects. These patents form the base IP platform for many of the current proximity detection devices on the market. There appears to be no freedom to operate issues regarding to the use of particular protocols in proximity detection systems. There is a significantly higher number of patents addressing the use of electromagnetic techniques for personnel detection, indicating a strong research push in this direction. Interestingly, the use of video techniques (including thermal infrared) seem under-represented given the capabilities of these technologies.

3.3 Commercial Papers

Similar to the patents, these papers are fairly focussed on particular systems being developed and actively marketed by PDS vendors. There is a wide spread across a range of different technologies indicating a broad base of available equipment. Note that these papers are in the main marketing and publicity documents, and do not necessarily represent unbiased, comparable descriptions of reliability, robustness and accuracy.

3.4 Other Publications

There has been a growing awareness internationally of the issues being faced by the mining industry in the field of vehicle interaction and collision avoidance, and this is demonstrated by the increasing number of journal and magazine articles on the topic. The publications in this list are a combination of case studies and reviews, as well as indications of emerging technologies.

4 The Need for Collision Avoidance Technologies

4.1 Automotive Industry

Across both Europe and the US there has been a push towards collision avoidance in vehicles to prevent collisions and incidents, to help ease traffic congestion and to create smarter road networks. This has been recognized by the US Department of Transportation, who state that "vehicle crashes account for more than 32,000 deaths worldwide each year and are the leading cause of death of Americans between the ages of 4 and 35" (Research and Innovative Technology Administration, 2013). Collision avoidance technologies between vehicles are seen as "the most promising, near-term opportunity for crash reductions" (Intelligent Transportation Systems Joint Program Office, 2013).

It has also been found that forward collisions (head-on crashes) of vehicles, are the most common cause of road fatalities in Queensland (QLD Department of Transport and Main Roads, 2013). They further state that collision avoidance technologies would have reduced the number of fatalities and severity of injuries:

- 20-40% reduction in number and severity of fatal crashes
- 30-50% reduction of all injuries.

The European Car-2-Car Communication Consortium sees the application of collision avoidance technologies (through communication techniques) as the means to:

- "Advance driver assistance increasing road safety by reducing the number of accidents as well as reducing the impact in case of non-avoidable accidents.
- Increase traffic efficiency with traffic congestion control resulting in reduced transport time, fuel consumption and thus contributing to improving the environment.
- User communications and information services offering comfort and business applications to driver and passengers."

Taken from (Car 2 Car Communication Consortium, 2013).

All of the reasons stated above provide a necessary case for the use of collision avoidance technologies within the automotive industry.

4.1.1 Legislation

At this stage, there is no country in the world that has formally legislated the need for collision avoidance technologies within the automotive industry.

There are pushes in Europe towards formally defining an open communications protocol for car-to-car communications which will encourage wider adoption of inter-vehicle collision avoidance technologies.

The US is currently conducting the largest trial of vehicle-to-vehicle communications collision avoidance technologies to be performed. The outcomes from this trial will determine the US Department of Transportation's decision regarding the legislation of such technologies.

Australia does not have formal legislation regarding collision avoidance technologies for the automotive industry. However, individual states such as Queensland have recommended the use of collision avoidance technologies (QLD Department of Transport and Main Roads, 2013).

4.2 Aviation Industry

Aircraft mid-air collision has been a catastrophic threat present since the aviation industry first started. Incidents involving mid-air collisions between two aircraft are rarely survivable, and hundreds of people can die in a single incident. Furthermore, collisions with terrain are just as undesirable and collision avoidance in this area is also important.

4.2.1 Legislation

The two different areas of collision avoidance are legislated separately.

4.2.2 Mid-Air Collisions

According to the International Civil Aviation Organisation (ICAO), regional and global groups have mandated Airborne Collision Avoidance Systems (ACAS). The ICAO also states "to support safe air traffic operation ACAS has been standardized by ICAO. TCAS is the implementation available today. Traffic alert and Collision Avoidance Systems (TCAS) are divided into TCAS I, which is mainly operated by commuter aircraft, helicopters and general aviation, and TCAS II, which is operated on turbine-powered business aircraft and commercial air transport aircraft. While TCAS I supports 'see and avoid' with the capability to generate Traffic Advisories (TAs), TCAS II is also capable of generating Resolution Advisories (RAs) against potential threat aircraft. TCAS II (Version 7) is compliant with ICAO ACAS II standards." (International Civil Aviation Organisation, 2006)
More recently, the ICAO has mandated that ACAS be installed on all new aircraft as of 1/1/2014, and all aircraft as of 1/1/2017. (International Civil Aviaion Organisation, 2012).

4.2.3 Terrain / Ground Based Object Collisions

Terrain Avoidance and Warning Systems (TAWS) are classified as either Class A or Class B according to the sophistication of the system. Table 1 shows the requirements to carry TAWS equipment as specified by the ICAO.

Table 1 ICAO Requirement to Carry TAWS Equipment - *Taken from* (SkyBrary, 2013)

Aircraft Class	Engine Type	MTOM		Passengers	Mandated	Remark	Recommended
Commercial Air Transport	Turbine	More 5700kg	than	More than 9	Class A		
Commercial Air Transport	Turbine	Less 5700kg	than	5-9	No		Class B
Commercial Air Transport	Piston	More 5700kg	than	More than 9	Class B		
General Aviation	Turbine	More 5700kg	than	More than 9	Class B	Class A for aircraft first registered after 1 Jan 2011	Class A
General Aviation	Turbine	Less 5700kg	than	5-9	No		Class B
Commercial Air Transport	Piston	More 5700kg	than	More than 9	Class B		
Helicopter		More 3175kg	than	More than 9	Class B	For IFR Flight	

4.3 Mining Industry

It has become evident in recent years that proximity detection is necessary for aiding in preventing injuries in the mining industry.

4.3.1 Surface

The trend in surface mining over the last decade has been towards increased vehicle size, speed and carrying capacity. This has resulted in reduced visibility and greater numbers of incidents relating to collisions between vehicles.

4.3.2 Underground

The need for collision avoidance technologies has been found through theoretical analysis of operator behaviour, in conjunction with studies which analysed the root cause of collision incidents. Furthermore, the statistics of incidents within the industry indicate the need for collision avoidance.

4.3.3 Incident Statistics

From 2004-2009, 35% of fatalities at mine sites were due to vehicle interaction incidents and 53% of these involved pedestrians. By 2009, 75% of fatalities were vehicle related. (Rasche, 2010).

4.3.4 Legislation

The status of legislation regarding proximity detection and collision avoidance around the globe seems consistent in that it is not formalized; however, there is an observed trend towards legislation being put into place across several countries.

Australia

The Queensland Department of Natural Resources and Mines does not have legislation in place regarding collision avoidance and proximity detection.

The New South Wales Department of Trade and Investment (Mine Safety) also does not legislate the requirement for proximity detection or collision avoidance in underground mines, and has not stated any intention to do so in the near future, as discussed at Mine Equipment / Personnel Interaction Advisory Group meetings.

United States of America

In January 2015, a Final Rule was published by the Mine Safety and Health Administration that requires underground coal mine operators to equip continuous mining machines, except full-face continuous mining machines, with proximity detection systems. Miners working near continuous mining machines face pinning, crushing, and striking hazards that result in accidents involving life-threatening injuries and death. This final rule strengthens protections for miners by reducing the potential for pinning, crushing, or striking accidents in underground coal mines. Full text available here:
https://www.federalregister.gov/articles/2015/01/15/2015-00319/proximity-detection-systems-for-continuous-mining-machines-in-underground-coal-mines

South Africa

Legislation has been published as of 27 February 2015. Appendix D is the relevant published legislation. (https://www.greengazette.co.za/notices/mine-health-and-safety-act-29-1996-regulations-relating-to-machinery-and-equipment_20150227-GGR-38493-00125)

In summary, in the context of the proximity detection, the employer is required to take reasonably practicable measures to ensure that pedestrians are prevented from injury from collisions with trackless mobile machines. The legislation then defines the minimum measures as including automatic detection of pedestrians on trackless mobile machines, with automatic speed reduction and application of brakes to be undertaken if the operator does not take action to prevent potential collisions.

5   Detection Technologies

This section aims to give a review of some of the detection technologies currently used across a variety of industries. Appendix C Detection gives a brief summary of some of the technologies discussed.

5.1   Automotive Industry

Within the automotive industry, there appears to be two key strategies being undertaken to provide collision avoidance capabilities to vehicles. The first is the use of on-board sensors, such as radars, to provide relative information about the current environment in which the vehicle is travelling. This first approach will be discussed within this section. The second approach is the idea of having a vehicle-to-vehicle, vehicle-to-infrastructure, and vehicle-to-mobile (e.g. person) network, which allows the transfer of information between vehicles so that collisions can be avoided. It is important to note that the detection technologies utilised are different to those employed underground due to the availability of accurate positioning information by the use of GPS technologies.

Maturity: Varying systems, full authority (e.g., Google Car) and advisory (e.g., Lane Departure Warning) currently exist.
Standards: Currently no unified industry standard.
Regulation: Awaiting regulation.

5.1.1   Current Detection Technologies Used Commercially

Within Europe, Radar technology is a key technology used in the automotive industry for proximity detection and collision avoidance. There are two specific types of radar currently used, as defined by the ETSI (European Telecommunications Standards Institute); long range radar, for automatic cruise control, which operate at 77GHz; and short range radar, for pending collision automatic brake control, which operate at 24GHz and 79GHz (ETSI, 2012).

The 24GHz frequency range is a short term frequency allocation within the European Union, with all radar and equipment to be moved to the 79GHz frequency spectrum in the long term.

- Forward collision avoidance systems – Laser and camera based distance sensing to detect possible collision and excessive closure rates. Varying levels of collision mitigation ranging from applying or pre-charging brakes to tightening seatbelts and/or aural warnings.
- Lane departure warning systems – Camera based lane tracking that alerts drivers to unintentional lane departure.
- Google Car example – Combination of Laser scanning and GPS to interpret surroundings which is able to respond to changes in conditions and environments such as pedestrians and cyclists
- No unified industry standard as of yet.
- The NTSB has released a report *The Use of Forward Collision Avoidance Systems to Prevent and Mitigate Rear-End Crashes (2015).* Of the recommendations it notes the slow development of performance standards and lack of regulatory action which has delayed deployment of such systems.
- Organisations such as the Intelligent Car Coalition evangelize the benefits of connected car technologies for consumers. They advocate for policies that speed beneficial technologies to market, and help policymakers think about new ways to resolve challenges arise.

5.1.1.1   Dynamic Cruise Control

As of 2010, Audi has been making adaptive cruise control available on all engine/transmission configurations for many models, such as the A8. There are a variety of technologies used on this model including: two radar at the front of the car, video camera for lane assist, rear radar sensors for side assist and four ultrasonic sensors for parking assist. These sensors perform a variety of functions including:

- Automatic Brake to Standstill if Required
- Start off monitoring of surroundings

- Lane change assistance through blind spot checks
- Provide operational and driver information

As discussed by (Rohan Kumar, 2012)*.*

BMW also has a dynamic cruise control system, called Active Cruise Control, which operates in a similar manner. Three radar sensors monitor the road ahead and maintain a set distance (in seconds) between vehicles. There are also many other manufacturers that implement a dynamic cruise control including Jeep, Ford, Honda, Mazda, Nissan, amongst others. The majority of these systems utilise a combination of camera and radar to achieve the required reliability of detection.

Bosch was one of the first developers of the sensors required in such systems. The criteria by which they identify these systems being of use to the driver are as follows:

- Continuous scanning of the environment
- Decision on required action, incorporating situation and environment, then warn driver of recommended action
- Automatically take action to prevent collision.

5.1.2 Key Findings of Relevance to the Coal Mining Industry

The environmental conditions under which automotive proximity detection technologies operate are quite different to those of the coal mining industry, thus a wider range of technologies are used for automotive applications, for example: video, laser scanners, and cameras.

The Collision Avoidance System model of operation is a process that would be highly applicable to the coal mining industry, namely:

1. Continuously scan the environment
2. Decide on the required action – incorporating situation and environment.
3. Warn driver of recommended action and/or
4. Automatically take action to prevent collision.

The use of radar for mid-long range detection is believed to be particularly important; as radar should not be affected by the dusty conditions experienced underground, even though it relies on line of sight.

5.2 Aviation Industry

Collision avoidance is a major concern within the aviation industry and there are a range of systems and technologies that are used throughout the commercial industry to prevent collisions. There are two key types of collisions being detected: mid-air collisions and aircraft to terrain/ground based objects.

Maturity: Airborne/Traffic Collision Avoidance System (ACAS/TCAS)

Standards: Airborne Collision Avoidance System (ACAS) Manual.

Regulation: Legislated by National Airworthiness Authorities e.g. Civil Aviation Safety Regulations (CASRs) in Australia.

5.2.1 Mid-Air Collision Avoidance

To prevent mid-air collisions, the initial onus is on the pilot under Visual Flight Rules (VFR) to maintain the correct scanning pattern of the horizon (AOPA Air Safety Foundation, 2004) (Civil Aviation Safety Authority, 2010). Beyond VFR, there are a variety of electronic systems that aid to prevent collisions, as summarised in Table 2.

Table 2 Summary of Mid-Air Collision Avoidance Systems

Acronym	Collision Avoidance System	Description
ASAS	Airborne Separation Assurance System	This system enables the flight crew to maintain long distance, standard flight path separation from surrounding air traffic. There are twelve operational applications within ASAS, divided between Ground Surveillance and Airborne Surveillance.

ACAS	Airborne Collision Avoidance System	An airborne system independent of ground operations that reduces the potential for mid-air collision. There are three defined levels of ACAS: - ACAS I – Gives traffic advisories. - ACAS II – Gives traffic advisories and Resolution Advisories in the vertical sense. - ACAS III – Gives traffic and resolution advisories in vertical and/or horizontal directions – currently not implemented and unlikely to be in the near future. Currently, only one system exists that is an ACAS system; the TCAS system. (SkyBrary, 2013)
TCAS	Traffic alert and Collision Avoidance System	An airborne system that operates independently of ground based stations; there are two levels of TCAS. TCAS I – communicates with the transponder of nearby aircraft to determine locations of one another and provides early warning to pilots. TCAS II – determines the projected flight path of both aircrafts and actively issues Resolution Advisories to resolve potential mid-air collisions. This system is only effective between aircraft when both have the system installed. (Federal Aviation Administration, 2012)
ADS-B	Automatic dependent surveillance broadcast	A surveillance technology in which an aircraft determines its position via satellite navigation and periodically broadcasts it, enabling it to be tracked. The information can be received by air traffic control ground stations as a replacement for secondary radar. It can also be received by other aircraft to provide situational awareness and allow self-separation. **Mandatory in many countries, including Australia.** (http://www.airservicesaustralia.com/projects/ads-b/other-mandates-2014-2017/)

5.2.2 Terrain & Ground Based Object Collision Avoidance

There are four primary systems used to prevent collisions with the terrain or ground based objects such as power poles, and antennas on tall buildings. These systems are collectively known as Terrain Avoidance and Warning Systems (TAWS), and further details are given in Table 3.

Table 3 Summary of Terrain Avoidance and Warning Systems

Acronym	Collision Avoidance System	Description
GPWS	Ground Proximity Warning System	This system generally utilises radar aimed at the earth below the aircraft; an automatic warning is generated to the flight crew when entering a potentially hazardous proximity to the surface. (SkyBrary, 2013) This system is limited to examining the distance below the aircraft but not in the direction of travel.
EGPWS	Enhanced GPWS	Enhanced GPWS systems utilise accurate 3D maps of the terrain, in combination with accurate aircraft position information, usually via GPS, to generate warnings of potential collisions with terrain.
FLTA	Forward Looking Terrain Avoidance	This system uses radar to 'look ahead of the aircraft along and below its lateral and vertical flight path and provide suitable alerts' if the potential for collision exists. (SkyBrary, 2013)

| OCAS | Obstacle Collision Avoidance System | Obstacle Collision Avoidance Systems provide an on-demand warning to pilots on a collision course with an aviation obstacle (such as a wind turbine, or tower). The obstacle transmits a radio frequency notification of its presence; all aircraft within the vicinity will be able to receive the warning and be made aware of its presence. More sophisticated systems are capable of features such as keeping a wind farm 'dark' at all times, unless an aircraft is within the vicinity, in which case red lights are lit on all towers for visual indications, as well as radio warning transmission sent to the aircraft. (OCAS, 2013) |

5.2.3   Key Findings of Relevance to the Coal Mining Industry

An important factor in the success of the TCAS-II system is its ability to determine the current situation (via many different technologies), apply the relevant rules and regulations, and recommend to both pilots the Resolution Advisory to be taken to avoid a collision.

It is also interesting to note that the system utilises the same collision avoidance model as is used in the automotive industry, namely; 1) detect nearby objects (in this case called traffic), 2) determine the correct action given the current scenario and applicable rules and regulations, and 3) implement the recommended action. In the aviation industry, the implemented action is still under pilot control and is not an automated process.

An important differentiator for the use of the newer ADS-B protocol in the aviation industry is that every aircraft knows its precise position and heading, via GPS technologies. This is the information that each aircraft is broadcasting about itself, and is fundamental to the operation of the entire system.

5.3   Maritime Industry

Maturity: Automatic Identification system (AIS)
Standards: Development similar to TCAS. Class A (Large Vessels) and Class B (recreational non-mandated)
Regulation: Regulated by National Maritime bodies
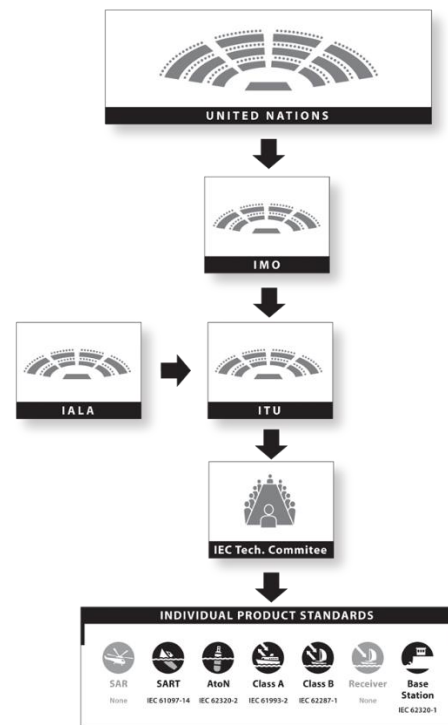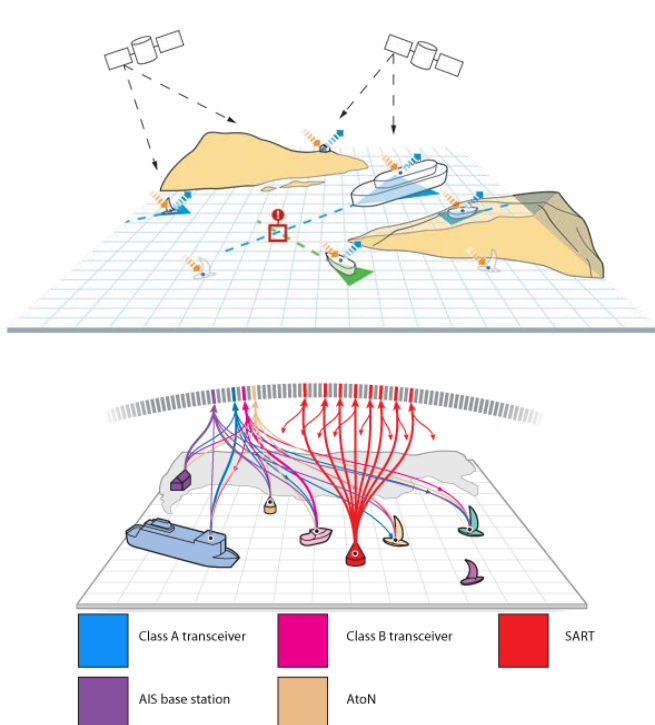
Automatic Identification system (AIS)
- In 1990, Congress passed the Oil Pollution Act which participation in Vessel Tracking System mandatory and directed the USCG to seek ways to have 'dependent surveillance' of all tankers bound for Valdez, Alaska.
- To that end, in 1993 the USCG developed Automated Dependent Surveillance Shipboard Equipment (ADSSE), based on Digital Selective Calling (DSC) protocol.
- In 1997, Congress…stated that AIS "technology should be the foundation of any future VTS system" and that it "strongly believes that this technology will significantly improve navigational safety, not just in select VTS target ports, but throughout the navigable waters of the U.S", and, that we "continue working with stakeholders…"
- In 1999, the National Dialog Group, comprised of the marine private and public representatives, stated they: "strongly endorse the widespread use of AIS employing dGPS and on-board transponder technologies.

Automatic Identification system (AIS)
- International requirements are created by the International Maritime Organisation (IMO) who lay down carriage requirements for Class A and Search and Rescue Transponders (SARTs).
- The AIS standards are then created by International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) and the International Telecommunication Union (ITU). The International Electrotechnical Commission (IEC) creates test standards for AIS following regulations laid down by IALA and ITU.
- It is then up to national bodies to interpret those standards when creating their own approvals. However, countries can take those regulations further and create their own national standards which products need to meet in order to be sold in those countries.

5.4   Rail Industry

Maturity: European Rail Traffic Management System (ERTMS)

Standards: Originally developed by railway operators, then transferred to Industry group (UNISIG). Consists of Levels 1-3, 3 being semi-autonomous.

Regulation: Managed by UNIFE (Industry partners) in close cooperation with the European Union, railway stakeholders and the GSM-R industry.
- The European Train Control System (ETCS) has been legislated by the European Railway Agency that all new trains/track are to adopt ETCS technology.
- There are three different levels to the ETCS system. Level 3 offers the most automation.
- It uses beacons installed along the railway to determine train positions, train positions between beacons are interpolated using speeds determined from axle transducers, accelerometers and radar.
- This data is then transmitted to the Control Centre via GSM-R. Note that all control authority is issued from the Control Centre.
- Another system that is available from Intelligence on Wheels uses a GPS and camera based system where trains communicate their position and speed to one another in order to determine collisions (Similar to TCAS). This system does not require any trackside equipment to be installed plus everything is handled on board.

5.5   Surface Mining Industry

Detection technologies within the surface mining industry are far more prevalent than within the underground sector. This is partially because of enabling technologies such as GPS that is unavailable underground. Furthermore, the number of OEMs supporting proximity detection is much higher in the surface environment due to the lack of severe restrictions, such as the need for flameproof enclosures or intrinsically safe instruments that are required underground.

5.5.1   Research

A variety of collision avoidance studies have been undertaken on surface mines. These include examining preventing single vehicle incidents, a vehicle with another vehicle, and a vehicle with personnel.

5.5.1.1   Surface Studies – Single Vehicle Incidents

ACARP Project C15038 (Collision Control and Avoidance for Electric Mining Shovels) was a study focusing on preventing an electric mining shovel from striking its own crawler shoes during operation. The collision control was implemented using Model Predictive Control (MPC) theory. A three-dimensional model of the shovel was created, and along with a mathematical model of the DC motors, rigid body dynamics of the machine and the dynamics of the OEM control system. These models were tied to the system input (the joystick) to predict future impacts between the dipper, crawler tracks and floor. The collision control activates only when a collision is predicted based on the current input to the joystick (CRC Mining, 2007). This technology is being commercialized by P&H.

5.5.1.2   Surface Studies – Vehicle to Object/Vehicle/Personnel

Surface mining machines comprise some of the largest vehicles used in Australia. Unfortunately, as the vehicle size increases, the visibility of the operator decreases. This means greater use of supportive technologies such as video cameras, proximity detection and collision avoidance are required to prevent accidents.

For surface vehicles, the safe operation of a mine haul truck requires a Collision Avoidance System with a minimum of 15 metres detection for a human target at truck sides, 50 metres to the rear and 100 metres to the front. These figures were calculated from the half second average reaction time of the driver allied to the ability of the mine haul truck to brake and stop within these distances (CSIRO Mining and Exploration, 2007).

5.5.1.2.1   ACARP Projects: Collision Avoidance System 1-4

The ACARP Project C7012 (Collision Avoidance System 1) developed and demonstrated a collision prevention system for surface vehicles at a mine site using a combination of Radio Frequency Tags and High Definition CCD Colour Video Camera and Monitor technologies. This system was capable of providing internal warning to the driver of imminent collision (reverse only) and warning to nearby personnel of an imminent collision. This system could not detect vehicles or personnel on the sides of the vehicle, a feature that is needed in proximity detection (CSIRO Exploration and Mining, 2000).
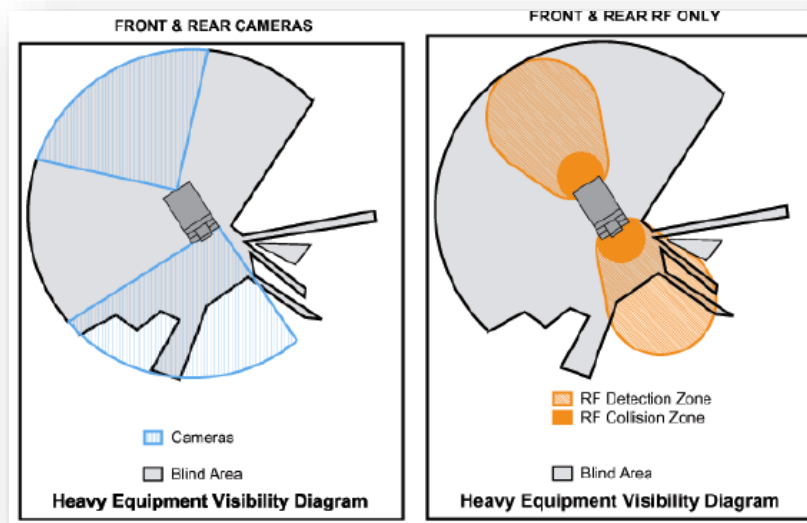
Figure 1 Heavy Equipment Driver Visibility Improvement with Detection Technologies (CSIRO Mining and Exploration, 2007)

This project was followed by ACARP Project C8034 (Collision Avoidance System 2) which addressed further surface proximity detection issues through the use of a 10.6GHz radar in combination with the CAS 1 technologies. Issues addressed included light vehicle to large mine truck collision and shovel to haul truck when loading. This involved proximity detection to a distance of 30 meters around the haul truck for light vehicle to haul truck collision (CSIRO Mining and Exploration, 2003). The technologies used were 10.6GHz Doppler radar for detection up to 30 metres, and ultrasonic Doppler detection for less than three metres.

ACARP Project C11049 (Collision Avoidance System 3) was then undertaken to finalise the work from the previous CAS projects. The system presented was novel in that it consisted of three separate, though interconnected modules. These modules included multiple radar antenna (eight on the rear, three on the sides and one on the front of the truck), a smart micro-controlled front-end, and a software information system to interface with the end user. This project resulted in the creation of a collision prevention system prototype (CSIRO Mining and Exploration, 2003). This project found that multiple Doppler radar antennas were required to ensure accurate detection.
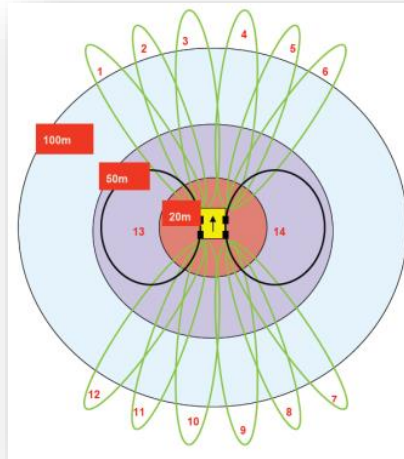
Figure 2 Proximity detection using Multiple 24 GHz Doppler Antennas (CSIRO Mining and Exploration, 2007)

Collision Avoidance System 4 was undertaken to explore the problem associated with the large amounts of data required by CAS 3 and the implementation of new smart chips for the intelligent Doppler antennae as shown in Figure 2. CAS4 expanded on the research in CAS 3 in order to increase the Doppler radar antennae functionality and so allow object detection discrimination. This achieved a reduction in the required bandwidth, and limited the driver notifications to when an object was detected.

5.5.1.2.2   NIOSH RFID Collision Avoidance Systems

In 2001, the US National Institute for Occupational Safety and Health conducted a study into the effectiveness of RFID tags for detecting personnel around equipment. This study also examined a range of technologies including radar, visual, ultrasonic, and infrared systems for their viability for use in collision avoidance. Their findings were that RFID technologies show the most promise for long term solutions in the mining environment, and that existing systems did not meet the requirements of the industry (US National Institute for Occupational Safety and Health, 2001). Some of the limitations with existing systems included "frequent false alarms, limited detection range, a lack of specific information on an obstacle (e.g. location, identity), difficulties in finding suitable mounting locations, and an inability to withstand the environment" (US National Institute for Occupational Safety and Health, 2004).

NIOSH has since undertaken a large amount of study, both underground and on the surface, to improve the reliability and availability of proximity detection technologies. Studies conducted have included radar systems, electronic tag-based systems, GPS-based proximity warning systems and computer-assisted stereo vision. Their findings were that for surface vehicles a combination of technologies proved the most successful (for example using a radar device to detect movement and notify the operator, with a camera for the operator to confirm what the object is). Tag based systems produce the least false alarms, and allow for further integration with other systems (including tracking, and zone control) (US National Institute for Occupational Safety and Health, 2001).

5.5.2 Current Detection Technologies Used Commercially

The following table shows a summary of the technologies currently used by commercial products in surface mines; see Appendix C Detection, for a summary of the capabilities of each technology.

Table 4 Detection Technologies Currently Used in Surface Mining

Detection Technologies currently used in Surface Mining
Camera
Electromagnetic (~70-140 kHz)
GPS (1.57 GHz)
Radar (2.4 GHz)
WASP Time of Flight (2.4GHz)
Radar (5.8 GHz)
RFID (433 MHz, 860 – 960 MHz)
Wifi (430 MHz)
Wifi (2.4 GHz)
Laser and Scanning Laser
Very Low Frequency RFID (<15kHz)

5.6 Underground Coal Mining Industry

Research in the area of proximity detection and collision avoidance has been addressed in a variety of ways for underground coal mining. Initially, studies have focused on current issues relating to the operation of various pieces of mine equipment; including operator positioning, incident analysis / root cause studies, and the effect of different operational speeds on incident frequency. Simultaneously, studies on detection technologies were conducted, including electromagnetic detection studies, active and passive RFID tag technology studies and development and a variety of sensors and detection methods for different ranges of operation. The result of this research has been the development of a variety of products, of varying degrees of accuracy and reliability. There is ongoing research by groups such as the US Mine Safety and Health Administration to improve the accuracy of these devices.

5.6.1 Research

A variety of studies have been conducted to develop prototype Proximity Detection Systems for use on underground machinery. One such study was the ACARP Project C15015 (Proximity Detection System Underground) that aimed to develop a Proximity Detection System to proof of concept stage. This system implemented active RFID tags and receivers to warn of approach in the 60-120 metres approach range, in combination with an electromagnetic device for detection in the range of 5-20 metres (Mine Site Technologies, 2008). This study primarily focused on out-bye equipment and did not focus on constrained environments such as around continuous miners.

The US National Institute for Occupational Safety and Health in coordination with the US Mine Safety and Health Administration, have conducted a study into the field of proximity detection technologies for use in underground coal mines. The primary result of these studies was the development of an active proximity warning system called HASARD (Hazardous Area Signalling and Ranging Device). This system utilizes electromagnetic and active tag based proximity warnings and was implemented on continuous miners. MSHA conducted an extensive technology review on existing proximity detection technologies as outlined in the report 'MSHA Proximity Detection' (US Mine Safety and Health Administration, 2009).

MSHA also conducted a variety of studies examining the parameter selection requirements for a successful Proximity Detection System; however no optimal parameter selections were identified at the time. A range of recommendations was produced as summarized in Table 5. Many discussions were held regarding the trade-off between optimal miner protection and practical operation of the system.

Table 5 MSHA Recommendations for Proximity Detection Systems as Listed in (US Mine Safety and Health Administration, 2009)

Proximity detection Active Times	Protection Zone Parameters
• Active during tramming in high or turbo speed • Not active during production • Active around entire perimeter when tramming.	• Trade-off between optimal miner protection and practical operation. • Protect the right rear quadrant of the machine. • Small protection fields during low speed tramming, large protection fields during high speed tramming. • Protecting only the machine operator. • Provide a warning zone that cause operator visual/audio warning. • Provide a shutdown zone that causes all machine movement to stop.
Proximity System Integration • Interlocking with the cutter head to disable proximity detection while in cutting and loading mode.	

Further improvements to the HASARD system included the addition of accessories such as remote alarms, data logging, and shut down features. The system has been extensively tested both on surface and underground as outlined in (US National Institute for Occupational Safety and Health, 2001; US National Institute for Occupational Safety and Health, 2002).

5.6.1.1 Ongoing Research

Ongoing research in the field of proximity detection is being undertaken by the US NIOSH group as outlined in (US National Institute for Occupational Safety and Health, 2012). Existing electromagnetic field generation and detection systems for the purpose of proximity detection utilize only one field, allowing the presence of a person to be detected, but not identifying the exact location within the field. This project aims to overcome this limitation through the use of multiple electromagnetic fields, and the use of triangulation to pinpoint the exact location of the person in proximity, as shown in Figure 3. This exact position knowledge will allow the Proximity Detection System to disable only those functions that would directly threaten the workers safety, given their current position. The NIOSH Intelligent Proximity Detection System aims to "reduce operator frustration through reduction of false alarms and full stoppages of all machine operations" (US Centers for Disease Control and Prevention, 2011).
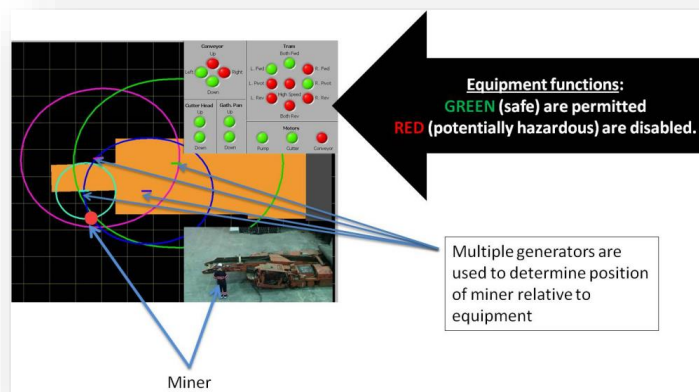
Figure 3 Detection of Person through Multiple Generators (US Centre for Disease Control and Prevention, 2011)

5.6.2 Current Detection Technologies Used Commercially

The following table shows a summary of the technologies currently used by commercial products in underground coal mines; see Appendix C Detection, for a summary of the capabilities of each technology.

Table 6 Detection Technologies Currently Used in Underground Coal Mines

Detection Technology currently used in Underground Coal Mines
Electromagnetic (~70-140 kHz)
Radar RFID (2.4 GHz)
Ultra-High Frequency RFID (433 MHz, 860 – 960 MHz)
Very Low Frequency RFID (<15kHz)
Wifi (2.4 GHz)

6   Communications architectures

The concept of open communication architectures has been around for many years. An early example of the implementation of open architectures was within image communication technology. It was found that standards for imaging and communication had developed separately from each other, and within imaging there were many standards in use. The Image Communication Open Architecture project aimed to define the physics of an image, and to define a standard structure for communicating an image and how it should be stored. This allowed the development of the Image Communication Open Architecture (Rudiger STrack, 1994, pp. 21-34). Within digital communications, the concept of open communications and architecture is the subject of thousands of studies into developing open protocols such as Modbus and TCP/IP. Furthermore, individual products and vendors often create open communications through the use of application programming interfaces, which provide programmer independence from communication protocols (Cypser, 1992, pp. 161-188).

There are four main focuses of open communications architectures as summarized in (Cypser, 1992);

- Interoperability of diverse users and platforms, unhindered by specific transport protocols.
- Sharing of transmission facilities among multiple and independent users.
- Consolidation of protocol diversity so as to improve manageability and efficiency of operation.
- High performance and multimedia capabilities.

A fifth area of prime importance is customer return on investment.

Systems have been developed in a range of industries to achieve interoperability. For example, the Telephonics C-17 open architecture communications system allowed all communication and navigation assets to be managed by the aircrew from one interface. Furthermore in 2010, Raytheon and PlantCML produced a civil communications open architecture standard that allowed multiple systems of public services to be integrated. The reasoning behind the development of the system was "the open standards approach promotes competition, drives down costs and gives our customers low-risk procurement flexibility". This system created the building blocks to allow nationwide standards-based interoperability, for daily operations and post catastrophe response (PR Newswire, 2010).

6.1   Criteria for an Open Communications Platform

A successful open communications platform will meet the following criteria, as defined by the (US Research and Innovative Technology Administration, 2013):

- The platform will allow for growth, expandability, and incorporation of newly evolving technologies.
- In knowing the architectural configuration and definition of interfaces, creative private-sector firms will be able to develop new applications that are not yet envisioned but remain for future imagination.
- And finally, the platform will be developed based on the complexity and range of human behaviours that will interact with and impact upon the system.

6.2   Communications Protocols

A variety of communications protocols have been summarised in Appendix B - Communications.

6.3   Automotive Industry

The automotive industry has progressed much further than the mining industry in terms of inter-car open communications, however, this is still a relatively new technology and rollout to the industry has not yet been finalised.

6.3.1   Connected Vehicle Technology

As with the mining industry, the automotive industry has many stakeholders, with manufacturers and third party suppliers providing a variety of communications solutions for vehicle-vehicle, vehicle-person and vehicle-object communications. This includes products such as BMW Assist, HD Traffic, Go-Box Tall system amongst many others. Kosch (Timo Kosch, 2012) states that the automotive industry faces the following challenges:

- Lack of standardized communication protocols prevents interoperability between applications.
- The cost of developing applications is high, and few are successfully introduced to the market for financial reasons.
- Applications are limited until fixed infrastructure is available.
- Most applications are limited to a specific static function due to the closed design from third party providers.

These are very similar to the limitations seen within communications in the mining industry, and are then compounded further due to stringent regulations and approval processes required to introduce a product to the coal mining industry.

The automotive industry has gone further than the mining industry in terms of specifically defining the applications that could take advantage of clearly defined inter-vehicle communication protocols, as shown in Figure 4.
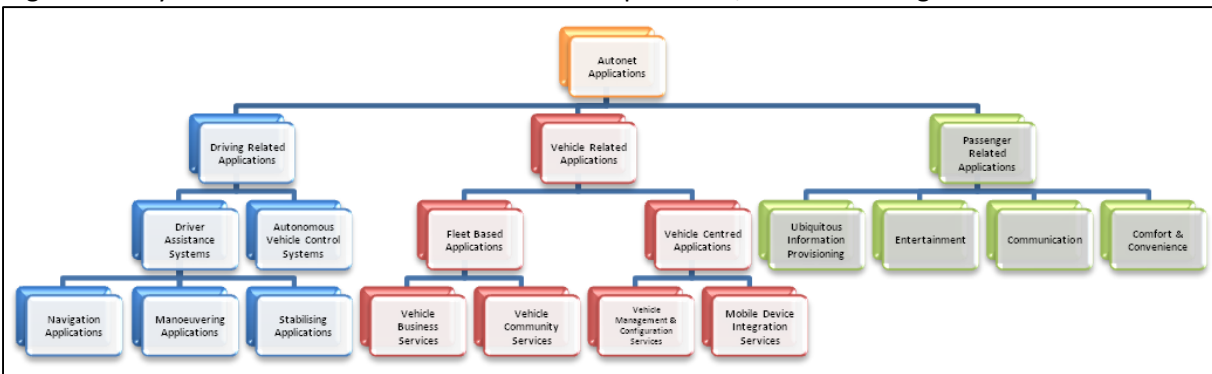
Figure 4 Applications using Vehicle and Inter-vehicle Communications (Timo Kosch, 2012)

As can be seen, these applications are divided into three key areas: driving related applications, providing support and assistance to drivers; vehicle-related applications, giving improved vehicle operations; and passenger related applications, for comfort, convenience and entertainment.

(Timo Kosch, 2012) discuss the need for varying levels of reliability across the different applications, with reliability needs increasing as the time frame required for action decreases. For example, autonomous vehicle control and stabilising applications require extremely low latency and high reliability, manoeuvring applications require less speed and reliability, with navigation applications requiring the lowest speed and reliability. He also identifies information types in terms of the required level of reliability. Proximity detection information requires a very high level of reliability, as opposed to environmental information such as traffic conditions. He goes on to identify the properties required for an open communications specification as, optimal utilisation of available bandwidth, fine granular prioritisation of messages, scalability, prioritisation, mobility and situation adaptability. Some further factors that are defined by the needs of the application are the overall system latency, availability, fault tolerance and security.

6.3.2 European Vehicle-To-Vehicle Communications Status

The Car 2 Car Communication Consortium is an industrial driven, non-profit cooperation between European vehicle manufacturers, suppliers and research organizations, which aims to develop a European standard for interoperable communications between vehicles (Car 2 Car Communication Consortium, 2013). As with the US, the communication used for interoperable communications is derived from the standard IEEE 802.11, also known as Wireless LAN and operates in the 5.9GHz frequency spectrum.

It works through automatically connecting vehicles that are within range of each other, and establishing an ad hoc network transferring key information between vehicles. The key information transferred is the position, speed, and direction of the vehicle, along with warnings and other information. The priority information is sent directly, whilst supporting information can be transmitted using multi-hop transmission (Car 2 Car Communication Consortium, 2013).

The European Telecommunications Standards Institute is also within the drafting stage of producing standards for a variety of aspects of the Car 2 Car communication consortium's intelligent transportation systems goals, including:

- Communications Architecture
- Vehicular Communications;
  - Basic Set of Applications
    - Functional Requirements
    - Definitions
  - Local Dynamic Map Specification
  - GeoNetworking
    - Network Architecture
    - Geographical Addressing and forwarding for point-to-point and point-to-multipoint communications
- Testing
- Security - Trust and Privacy Management
- Harmonized Channel Specifications for Intelligent Transport Systems Operating in the 5 GHz Frequency Band
- OSI Cross Layer Topics

  As covered in (ETSI, 2013)*.*

6.3.3 US Vehicle-To-Vehicle Communications Status

The US Department of Transportation has work ongoing in defining a Connected Cars communication protocol that started in 2011 (American Association of State Highway and Transportation Officials, 2011). From 2011 to 2013, the US Department of Transportation, in conjunction with the University of Michigan, is conducting a trial with 3000 cars and trucks. The Connected Vehicle Safety Pilot Program (Sayer, 2013), (Pina, 2013) aims to examine the effectiveness and user approval of a specific set of vehicle-to-vehicle technologies. The outcomes of this trial will be used by the US Department of Transport to decide whether to legislate the need for all vehicles to have such systems installed (Anderson, 2013)[1].

The system uses Dedicated Short-Range Communications (DSRC) to communicate to both other vehicles and fixed infrastructure stations. The Intelligent Transportation Systems Joint Program Office views DSRC as the only technology, available in the near-term, that offers the required latency, accuracy and reliability needed for active safety (Intelligent Transportation Systems Joint Program Office, 2012).

The communications band for DSRC differs from country to country. In 1999, the US Federal Communications Commission allocated 75MHz or spectrum in the 5.9GHz band for use, whilst the European Telecommunications Standards Institute allocated 30MHz of spectrum in the same band in 2008.

The following image shows the key data elements that are transmitted in a Basic Safety Message from vehicle-to-vehicle in the US system. Note that Part 1 is transmitted at approximately 10Hz over DSRC, whilst the Part 2 is transmitted at a much lower frequency using a variety of technologies such as cellular, and infrastructure related transmissions.

BSM Part 1	BSM Part 2
Position (local 3D): • Latitude • Longitude • Elevation • Positional accuracy	Road coefficient of friction
Motion: • Transmission state • Speed • Heading • Steering wheel angle • Acceleration Set (4-way): this includes 3 axes of acceleration plus yaw rate	Rain sensor (called a Rain sensor in J2735, but it is a precipitation sensor. J2735 states "The "Rain Sensor" Probe Data Element is intended to inform Probe Data Users as to how hard it was raining/snowing…")
Vehicle size	Traction Control System active over 100 msec
	Antilock Brake System active over 100 msec
	Lights changed and Exterior lights (status)
	Wipers changed and wiper status
	Ambient air temperature
	Ambient air pressure
	Vehicle type (BSM currently only includes this for fleet vehicles)

Figure 5 Basic Safety Message Data Elements Transmitted in the US System (Research and Innovative Technology Administration, 2012)

An example of an existing implementation of this is Cohda Wireless Systems, which use an 802.11p compliant radio developed specifically to cope with simultaneous multipath and mobility conditions. (http://cohdawireless.com/ConnectedCars/AutomotiveSafety.aspx)

6.3.4 Ongoing Collaboration

There are ongoing collaboration efforts between the US and the EU, in the EU-US Cooperative Systems Standards Harmonisation Action Plan (EU-US Cooperation, 2012), and the US and Japan to:

• "Identify research and development areas that would benefit from joint development

• Share information on ongoing research and development projects, estimated benefits, research outcomes, and field demonstration results

• Inform stakeholders involved in the development of cooperative systems about continuing cooperation and progress between the countries and promote active participation and exchange among stakeholders by jointly organizing symposiums, seminars, and meetings

• Support development of global, open standards that ensure interoperability. Globally harmonized standards are essential to support and accelerate the deployment and adoption of cooperative systems based on ITS technologies."

6.3.5 Key Findings of Relevance to the Coal Mining Industry

It is important to note that the automotive industry currently is working on Vehicle-to-Vehicle technologies with the assumption that each individual vehicle knows its own position through the use of the Global Positioning System. This fact alone inherently renders this approach less viable for the underground or pit environment where exact vehicle positions are unknown, and only relative positional information is available. However, it is possible to consider transmitting the perceived distance and relative velocities from Vehicle A to Vehicle B, along with its position, accurately.

Following the lead of the automotive industry; a subset of relevant applications specific to the mining industry are shown in Figure 6, as a subset of those for the automotive industry.

Table 7 provides a summary of the definitions of these subsystems.
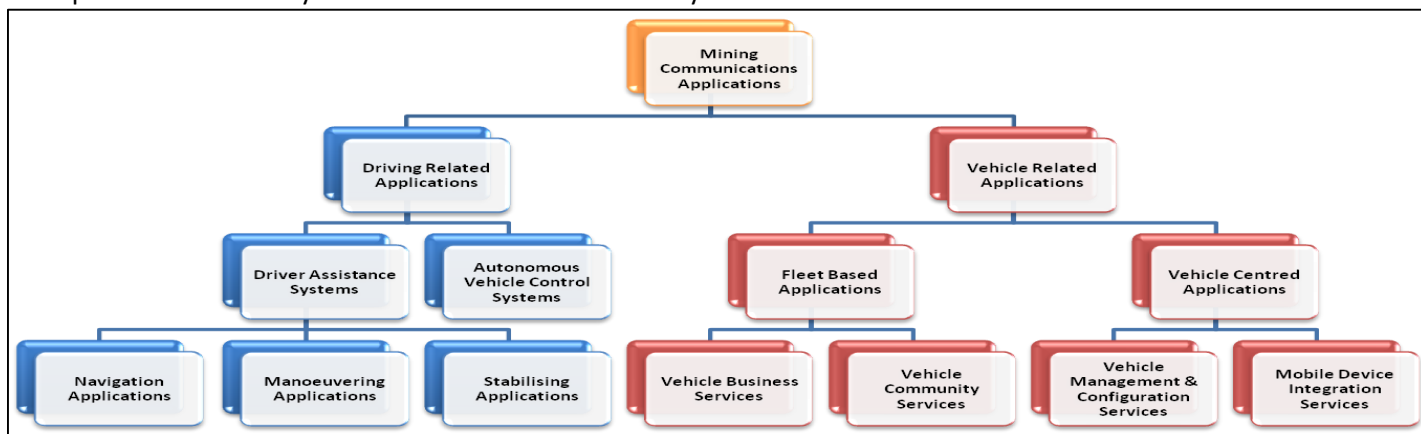
Figure 6 Subset of Mining Specific Applications adapted from (Timo Kosch, 2012)

Table 7 Definitions of Applications by (Timo Kosch, 2012)

Application Area	Area Set Sub Application	Definition
Driving Related Applications	**Driver Assistance Systems**	Providing support and assistance to drivers.
	Navigation Applications	At a wider knowledge level, provide knowledge to the driver and facilitate the decision making process. E.g. provide information on traffic conditions and navigation advice.
	Manoeuvring Applications	At a rule based level, assist drivers in following road rules. E.g. provide information for active cruise control or lane change assistance
	Stabilising Applications	Improve driving safety by controlling actions or driving situations of a vehicle. E.g. anti-lock braking, traction control systems.
	Autonomous Vehicle Control Systems	Systems that make purely autonomous decisions on driving dynamics such as acceleration, braking or steering.
Vehicle Related Applications	**Fleet Based Applications**	Services for a group of vehicles that form a fleet or are hosted by one operator.
	Vehicle Business Services	Fleet management planning services including vehicle planning vehicle scheduling, goods transportation and also vehicle maintenance.
	Vehicle Community Services	Social services for groups of vehicles for example, a given brand or type. For example, automatic vehicle inspection reminders.
	Vehicle Centred Applications	Services addressing a single vehicle
	Vehicle Management and Configuration Services	For example, remote failure diagnosis, remote version management and update of non-critical software in the control units of the vehicle
	Mobile Device Integration Services	Connection of mobile devices to vehicles. For example, to monitor fuel consumption and vehicle performance from a smartphone

Although there are many similarities between the automotive and mining industries, there are also key differences:

- Within the automotive industry there is a large focus on balancing the trustworthiness of a provided message against maintaining the privacy of the road user (Qianhong Wu, 2010). This would not be a concern in the mining environment where all vehicles and drivers are known, and privacy of driver identification is not desirable (for example, in the tracking of personnel and monitoring driving behaviours).
- Within the automotive industry there is also considerable thought being given to the presence of 'malicious' vehicles. For example, terrorist or illegal organisation cars which could potentially project false or misleading messages in order

to disturb nearby road users (Qianhong Wu, 2010). This would not be an issue within the mining environment due to the existing rules and regulations addressing all vehicles on site.

- It is necessary for the automotive industry to address other possible criminal activities including tracking stolen vehicles, driving unregistered vehicles etc. (American Association of State Highway and Transportation Officials, 2011), which is also unnecessary for the mining industry.

6.4 Surface Mining Industry

This section examines a case study where open communications has attempted to be implemented in a surface mining scenario.

6.4.1 Case STUDY: ACARP Project C17026

The ACARP Project C17026 (Open Platform Mine Equipment Communications and Proximity Warning System) developed an open communications structure to allow data sharing between different mobile equipment in an open-cut mine. This system primarily shares GPS positioning information between various plant for a high level proximity detection application. The advantage of the developed system was that it utilized existing hardware and software infrastructure to achieve its primary goals.

There were three key phases in the implementation of this project; firstly, the selection of an open communication protocol for sharing information between different vendor's systems; secondly, the development of a central relational database system; and thirdly, adapting the vendor systems to display the real time positional information (MineWare, 2009).

To achieve these solutions, four components were used as summarized by (MineWare, 2009).

- **Node Configuration Management**

  Each node was required to be capable of handling structured data, to be non-proprietary, robust and flexible, with a small footprint and with ease of access for editing and maintenance. XML files, which are open standard and platform independent, were chosen to configure the nodes that were located on-board each individual plant.

- **Communications and Data Transfer between Nodes and Devices**

  Variability in devices and mine setups meant the solution chosen needed to be flexible enough to handle different communications scenarios. The variety of communications was achieved through the use of the Node Communications Library (NCL) that managed inter-node communications, and node to device communications. The NCL ran on each node and was configured via the XML document for that node. The NCL supported communications to a variety of devices and was an interface to multiple other communications protocols including serial, Modbus, Profibus, deviceNET, Modbus/TCP and TCP/IP.

- **3rd Party System Integration**

  An additional software tool was developed to provide a generic interface to the NCL. This interface hid the underlying intricacies of the open communications network and allowed individual systems to share and access data on the network.

- **Data Storage and Historian Functionality**

  The developed software allowed each node to share information with other nodes but also to selectively record data from the open communications network for long term storage. Short term storage is first performed at the node, and then compressed log files are transmitted to a central data repository via the network.

There is limited information available about where this system has been implemented.

6.5 Underground Coal Mining Industry

This section examines a case study where an open communications protocol was developed with wide industry support, including all interested OEMs, PDS vendors and mine sites.

ACARP project C22012 was undertaken by CSIRO in 2012-13 as an independent technical advisor to bring the various stakeholders to a common starting point, and work with them to develop a practical, flexible protocol capable of meeting immediate requirements, as well as being fully extensible for future use. Funded via the underground ACARP committee, it was tasked with being specific to the underground coal mining equipment first and foremost.

6.5.1 LISCA

LISCA is an abbreviation for the LASC Interoperability Specification for Collision Avoidance. This open communication specification is designed allow interoperability between OEMs of plant and OEMs of Collision Avoidance Systems (CAS) or Proximity Detection Systems (PDS). This specification does not propose any technical method for detection, nor specify rules for behaviour to be undertaken if an unwanted interaction is imminent, however it does provide the enabling capability for these systems to be implemented by components that can operate in an integrated fashion.
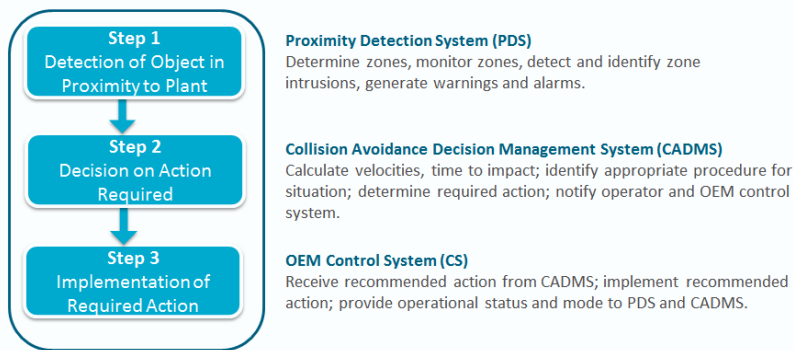
Figure 7 Generic system functionality

A generic Collision Avoidance System has been modelled as a process with 3 components (Figure 7)
•   Detect objects in proximity   (PDS)
•   Decide whether an unwanted interaction is imminent   (CADMS)
•   Act to avoid the unwanted interaction   (CS)
Some OEMs or Vendors may implement more than one of these components.

6.5.2 Development rationale

One of the major problems in getting proximity detection and collision avoidance systems integrated and tested has been the requirement to custom-build every implementation. This specification, when implemented, will remove much of this burden of customised implementation, and has wide support from all sectors of the industry, including Plant manufacturers, Proximity Detection System manufacturers, and mine sites.

The LISCA specification outlines the method for Proximity Detection Systems and Plant Equipment to communicate in a standard, pre-defined manner, as well as specifying basic data items that will be accessible for higher-level functionality (such as traffic management).

This does not specify a standard detection technology that must be used by all systems, nor preclude the use of additional proprietary communications between systems or subsystems.

6.5.3   LISCA Level 1

Level 1 is simply an agreed set of 12 connections between any Proximity Detection System, and the Control System of mobile equipment (The CADMS component is not involved in this level). These signals indicate critical data transfer between the subsystems, as well as a level of verification that the devices are in working condition. It should be noted that the Control System of the plant has the final responsibility for the actions being undertaken by the plant, so the signals generated by the Proximity Detection System are to be interpreted as recommendations, and implemented by the Control System as such.
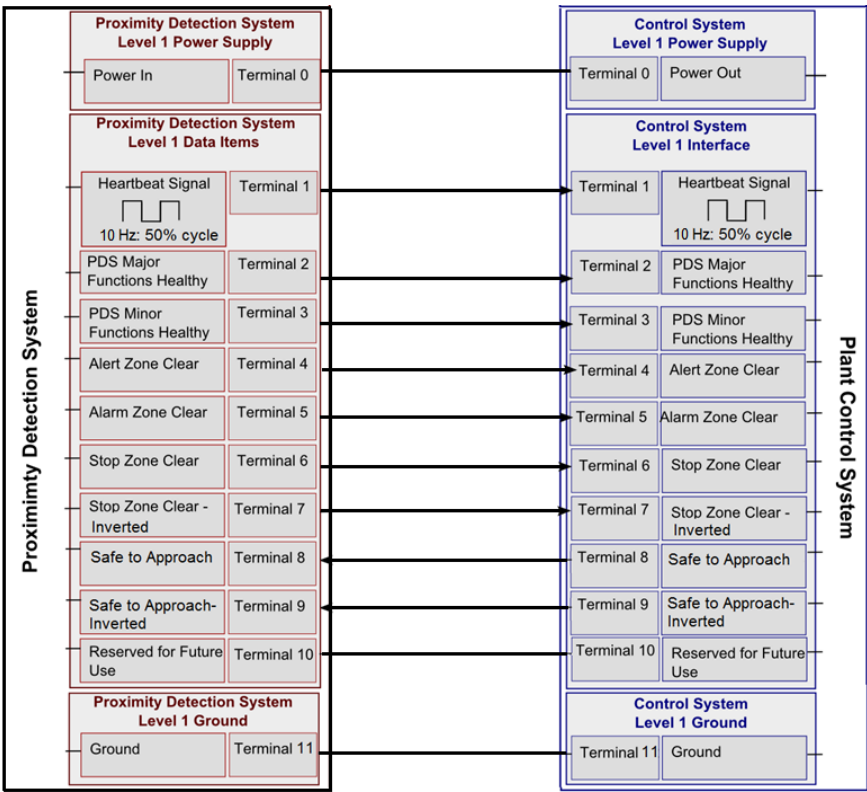
Figure 8 LISCA Level 1

6.5.4   LISCA Level 2

Level 2 defines a soft communications protocol to allow for detailed information to be passed between the subsystems. This will allow more intelligent decision making and ensure extensibility of the system into the future. At this level there can be a deeper role for decision making, taking more complex data and allowing more complex actions, rather than just go/slow/stop. The Control System of the plant has the final responsibility of the actions being undertaken by the plant, so the signals generated by the Proximity Detection System and the CADMS are to be interpreted as recommendations, and implemented by the Control System as such.

The Level 2 specification is based on Common Industrial Protocol (CIP) which is implemented as EtherNet/IP over Ethernet hardware or DeviceNet on CANbus. Each component acts as both a producer and consumer of data, allowing the base set of data to be available to all other components, while also notifying of events.

The outcomes of these specifications are to improve industry safety through promoting the uptake of Proximity Detection and Collision Avoidance systems, identify technology gaps in Proximity Detection Systems and encouraging investment in collision avoidance technologies.
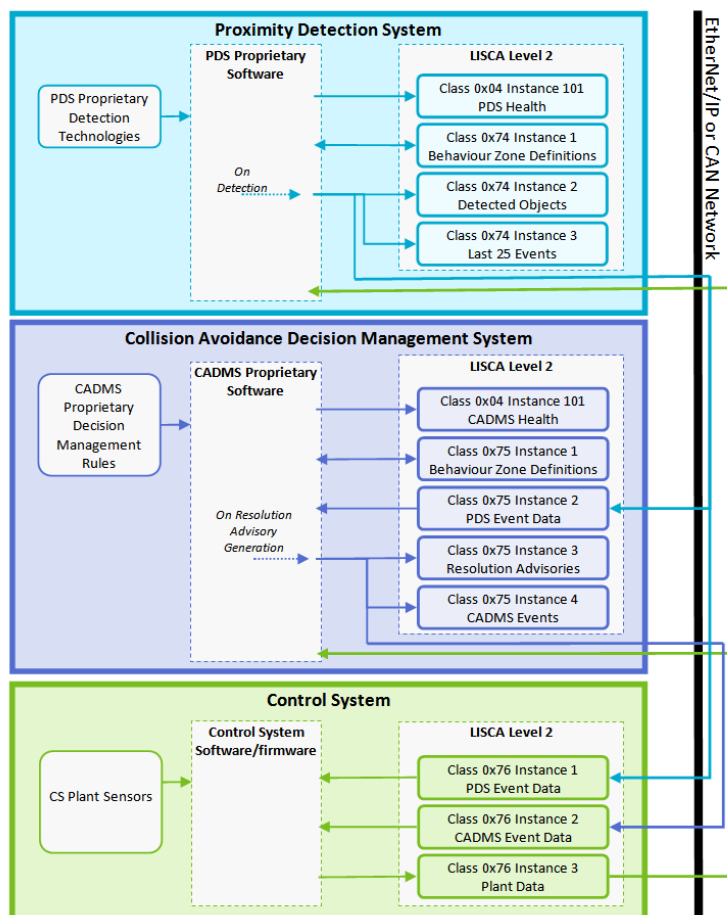
Figure 9 LISCA Level 2

6.5.5 Conclusions

This project was well supported and drew a lot of interest and input from all the stakeholders. Many manufacturer visits and interviews were undertaken, and a workshop was held to achieve full awareness of the specification. Despite this, there has been no appreciable uptake of the protocol. This appears to be due to the fact that vendors are waiting for someone to ask for it in a tender, and mine sites are waiting for someone to advertise it as available.

Nevertheless, the framework developed for this protocol has a number of major advantages over the J1939 protocol developed in the current C24034 project:

- There is clear delineation of responsibilities for each of the components of the system
- It can use Ethernet **or** CanBus physical layer
- It can be easily retrofitted to existing vehicles with no communications capability
- Level 1 has been reviewed for conformance to the principals of functional safety as it applies to protocols.

7   Workshops

There have been a number of ongoing EMESRT group workshops undertake to progress the requirements, design, and uptake of this technology by OEMs to design 'fit for purpose' machines, as per the EMESRT design philosophies. This has culminated in the most recent workshop which is defining a draft protocol and a roadmap to progress to full industry interoperability.

7.1   September 2014 – EMESRT Vehicle Interaction & Mobile Equipment Technology Workshop

Venue: Northparkes Mine, Parkes, NSW.
In attendance: miners, research providers, no OEM representation (apart from invited appearance from Sandvik).
Objectives: This three day workshop was convened in order to:
1. Generate an industry position on the technology requirements for vehicle interaction controls;
2. To develop understanding and information that helps both companies and sites manage the selection and use of mobile equipment technology to manage vehicle interaction risks;
3. Provide attendees with an improved understanding of the available mobile equipment technology, as well as:
    - How to analyse the company or sites' exposure to unacceptable vehicle interaction risks;
    - How to match the company or site needs to the available technology, existing or as required in future;
    - How to address the challenges of the new technology – infrastructure requirements such as maintenance, potential related hardware and human failures, etc.
4. Produce information useful to EMESRT in its process of engaging major OEMs about industry needs and design goals for new technology.

Outcomes: There was general agreement at the workshop that it is vital for the industry to establish a framework to allow rapid development of an industry-wide protocol and specification for proximity detection and vehicle interaction. The primary action items were:
1. Need to develop a risk management strategy for implementing such a protocol specification, identify risks such as lack openness (OEM proprietary systems), difficulties of standardisation, mechanisms for assessing competency of PDS technologies, etc.
2. Need to ensure that there are mechanisms to achieve a baseline compliance with any new standards for older mining equipment by integration of interfaces to achieve such minimal conformance.
3. Establishment of a select working group to spearhead these initiatives through interactions with miners, other research and/or standards bodies (e.g., GMSG), OEMs and PDS manufacturers.

7.2   August 2015 – EMESRT Vehicle Interaction Control Requirements Workshop

Venue: ACARP Offices, Brisbane, QLD.
In attendance: EMESRT members, CSIRO.
Objectives: This half-day workshop was convened primarily as a preparatory event for the planned week-long workshop with OEMs and PDS manufacturers in September/October. The specific goals of the meeting were:
1. To develop a strategy to engage the OEMs and PDS manufacturers in the EMESRT process;
2. To clarify the level (7-9) to which the various OEMs and PDS manufacturers are planning to develop their technology;
3. To plan the major workshop in Sep/Oct, including CSIRO involvement in the process on the final day (Friday 2 Oct).

Outcomes: A plan was established for the week-long series of workshops, and CSIRO developed a draft agenda for the final day. This agenda was further refined during the following weeks leading up to the OEM/Prox Vendor workshop.

7.3   September-October 2015 – EMESRT Vehicle Interaction OEM and Proximity Vendor Workshop

Venue: Rio Tinto Offices, Brisbane, QLD.
In attendance: EMESRT members, OEMs, PDS Manufacturers, CSIRO.
Objectives:
1. To highlight the need for an integrated systems approach and to propose pathways to establish a common interoperability framework;
2. To identify, at least provisionally, an agreed set of minimal critical signals to be established for interaction between vehicles;
3. To discuss strategies for dealing with the range if different vehicles typically encountered at a mine site, e.g., legacy equipment with no automation through to modern fleets with sophisticated on-board computer systems;
4. To develop a roadmap for implementation of the vehicle interaction specifications.

These objectives were to be achieved via an open forum with directed discussion sessions to include all stakeholders. The agenda for the workshop follows below:

Session	Topic	Moderator
1	Workshop Purpose and Rationale	Jim Joy
2	Discussion of interdependency issues	Chad Hargrave
3	An example of underground interdependencies	Jonathon Ralston
4	Brainstorming Session – Directed Discussion	Tony Egan
5	Shaping the Future	Jim Joy
6	Summary and Next Steps	CSIRO/EMESRT

Outcomes: The workshop was successful in engaging the OEMs and PDS vendors in the process, and generating broad support for the EMESRT goals. The primary action outcomes from the meeting were as follows:
1. CSIRO to collate and assemble comprehensive summary of workshop
2. EMERST to capture insights from this workshop
3. EMERST nominate a candidate from stakeholder from working groups and specific dates
4. These subgroup/stakeholders to define the terms of reference, meeting and reporting
5. EMERST to provide clarity on specific hazard scenarios (TE)
6. EMERST to suggest a broad timeline for roadmap development
7. EMERST to approach Susan Grandone to monitor/facilitate progress on above
8. EMESRT to collate and assemble broad topics/categories:

- Three layer model
- Technical challenges
- Strategic directions for implementation plans

7.4   December 2015 – EMESRT Vehicle Interaction OEM and Proximity Vendor Workshop

Venue: CRC Mining Offices, Pinjarra Hills, QLD.
In attendance: EMESRT members, OEMs, PDS Manufacturers, CSIRO, CRC Mining.
Objectives: This workshop sought to focus on specific technical details of the proposed vehicle interaction standard, by seeking consensus from the OEMs and PDS vendors regarding:
1. Selection of a suitable protocol for implementing the VI standards;
2. Clarifying agreement regarding the many scenarios proposed in the standard, including speed ranges for different scenarios;
3. Establishing the core inputs and outputs between the OEMs and the PDSs;

The workshop also sought to further develop the roadmap for implementation by defining a communications and implementation strategy.
Outcomes:

VI- Workshop Agreement Summary

- Use J1939 standard as the pilot
- Current scenarios
- Current speed ranges

A	B	C	D
(0-3kph	3-10kph	10-30kph	30-55+kph

- Core inputs from OEM to PDS:
  - Velocity
  - Direction
  - Machine state
  - Payload
  - Machine type
  - Steering angle
  - Slope (surface), roll/pitch (underground)
  - Traction control (surface), slip status (underground)
- Core outputs from PDS to OEM:
  - Emergency stop
  - Slow down
  - Controlled stop
  - Health
- Defined input/output units, minimum update rate, failure modes, and descriptions

EMESRT

EMESRT VI Workshop Action Items

ACTION	CSIRO will be conducting a literature search on related protocols, and circulate to the group as a whole (OEMs/PDSs) PDSs to provide their documentation to EMESRT and EMESRT to CSIRO who will collate and circulate to the group.
ACTION	PDS folks to connect with Mark to discuss what needs to be done, the format and the path forward. Mark to schedule a conference call to this end. OBJECTIVE: review key issues and complexities. GOAL: develop a framework of a protocol
ACTION	OEM participants need things prioritised.OEMS also going back to their business to socialise the workshop outputs. OEMS to identify all information available for Haul Trucks at this time - will explore LHDs but no promises at this time. All above information will come back to EMESRT and from EMESRT to CSIRO for collaboration and circulation.
ACTION	EMESRT: Provide more details on scenarios to user groups (e.g., individual mines and how things might vary)
ACTION	EMESRT will be 'applying for air time' at the February 2016 ISO TC127 meeting in Sydney and will keep this group advised
ACTION	EMESRT explore developing a Bulletin Board on the EMESRT Webpage

7.5   March 2016 – EMESRT Vehicle Interaction OEM and Proximity Vendor Workshop 3

Venue: CRC Mining Offices, Pinjarra Hills, QLD.
In attendance: EMESRT members, OEMs, PDS Manufacturers, CSIRO, CRC Mining.
Objectives: This workshop sought to focus on completing the proposed vehicle interaction standard:

- Review, edit, and agree upon semi-final protocol document to be used for field testing
- Establish the evaluation scope and criteria: concept / partial / complete
- Assess practicality / gaps / timelines

The workshop also sought to further develop the roadmap for implementation by defining a communications and implementation strategy.
Outcomes:

- The consensus was also if we are already going to the trouble of defining new PGNs lets make it the way we want it.
- Decided against using existing 1939 data exclusively for the PDS systems as the consensus was that the rates/resolution for some of the data were unreasonable and unattainable. However they weren't opposed if people still wanted to get data via these PGNs if they were available. There was also talk of network/processing issues that trying to aggregate all this data from different messages could be troublesome.

- EMESRT should continue as the coordinators and facilitators at least until the standards working group is finalized
- A charter for the working group should be developed collaboratively to ensure that all members have the same understanding of the scope of work.
- The next working group will be by webinar before 25 May, to finalise proposed protocol and forward the

Action Items

- **CSIRO** to complete document (separate Strategic Protocol document – attached) before 25 March 2016
- **Members** to take the information from this workshop back to the businesses, to confirm approval within 2 weeks
- **Members** to have a web meeting in May 2016 weeks to :
    1. ratify protocol as it exists at that point
    2. ratify process of TC127
    3. Finalise charter
- **Komatsu and Caterpillar** representatives to ask internally for an SAE contact to start the approach for progression
- **Anglo** representative is progressing discussions with ISO/TC127 - work item paper before 25th May
- **EMESRT** to approach an independent expert do complete a Functional Safety review.
- **EMESRT** will attempt to facilitate beyond bench testing with appropriate minesites where possible.
- **Members** to review PR5a documentation and all to provide feedback/comments
- **EMESRT** to complete performance requirements and criteria for technologies and scenarios
- **Members** to provide input to the charter paragraph and send to **EMESRT** for dissemination.
- **EMESRT** to put out a flyer/information to all to ensure that member's internal stakeholders and customers attend the information webinar.

8 Forward Plan

This project has been approved by the Industry monitors to work closely with the current EMESRT endeavours on the Vehicle Interaction topic. During 2014-2015, this has included multiple workshops that have targeted a number of outcomes:
- Industry Engagement
- OEM and Vendor Engagement
- Assess and monitor OEMs and Vendors on the supplier relationship maturity model
- Progress towards an industry accepted interoperability methodology

As a process, this has involved:
- The analysis of the high risk scenarios (originally defined by Anglo's document PR5A) from the analysis of past incidents.
- Using a set of speed ranges that can be defined as functionally diverse in terms of actions resulting in these ranges
- The definition of high priority data items to be passed between elements of the system (e.g. vehicle and PDS) to increase the effectiveness of the entire system
- The ongoing development of a protocol and open specification to provide interoperability on an industry wide basis
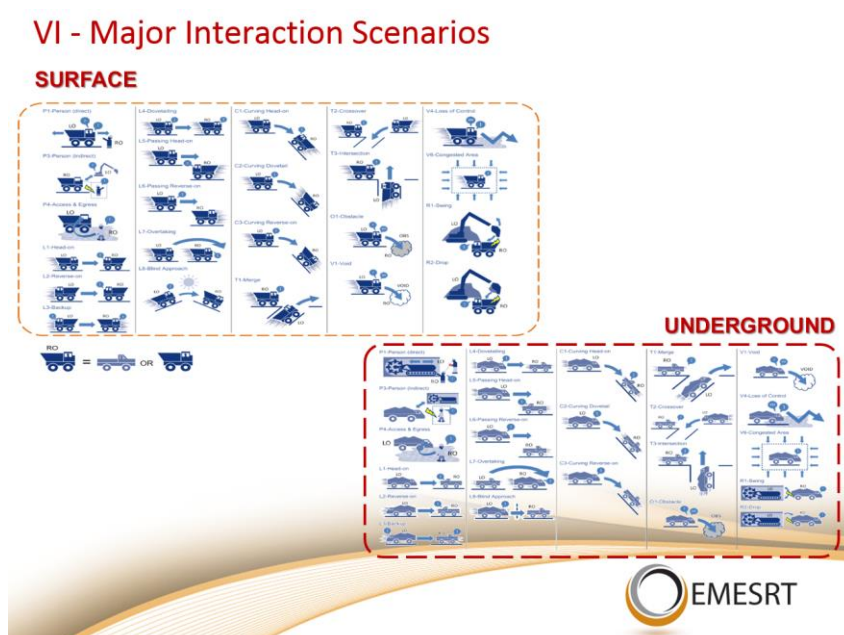
As per the action items of the workshop in December 2015, there was a set plan for the finalization of this project to fit with the requirements of the industry forum. This is summarized by the following action items:
- CSIRO will be conducting a literature search on related protocols, and circulate to the group as a whole (OEMs/PDSs)
  - **completed as part of this report, however not circulated to whole group**
  - **perceived as possibly confusing the issue, given the recommendation away from J1939**
- PDSs to provide their documentation to EMESRT to pass to CSIRO to collate, analyse and circulate to the group
  - **Completed as part of this report**
- Develop a framework of a protocol
  - **Completed as part of this report**
  - **Reviewed and modified by workshop 3**

9 Protocol Section (Separate document)

C24034 Strategic Protocol.

10 Recommendations and Conclusions

The work undertaken by this project has primarily been in conjunction with the EMESRT group, and this has been a very productive collaboration.

While this project has not provided a complete published specification, the process of working with industry representatives from mining companies, OEMs and proximity system vendors has provided a broader industry awareness of the issues regarding interoperability of these systems. This is a fast moving space in many industries, particularly automotive, and an undertaking should be made to regularly review and report on the current state of the art in these fields and how it could influence ongoing work in the coal mining industry.

To date, the proposed protocol based on J1939 has been through a second round of drafts, and consideration is being made towards a request for formalising as part of the SAE standards.

An important next phase of this work will be the creation of a compliance suite for the protocol, a critical component for ongoing relevance of any protocol being developed by multiple parties. This process should create a software (and possibly hardware) system capable of testing that each type of system implementing the protocol performs and responds in a defined manner.

There are, however, a number of unresolved arising from the selection of J1939 as the architecture for this protocol. These issues should be reviewed by the EMESRT group, whilst also referring back to the published LISCA specification documentation.

1. **Redundant physical wires**
   One issue in the application of this protocol to the general mining industry will be the compatibility with both existing equipment as well as new equipment. On older machines without control systems or CAN bus, consideration should be made for the definition of a hard wired, lower level implementation of the critical components of this data transfer. Considerable effort went into this task in previous ACARP project C22012.

2. **Heartbeat**
   Timing discussions should incorporate the use of the bi-directional transfer of heartbeat, or system health, using the "Machine State" (OEM->PDS) and "Health" (PDS->OEM) messages.

3. **Decision/accountability**
   This protocol in its current state is facilitating the transfer of several critical pieces of information between OEM and PDS. This inherently limits the implementation of the "rules" layer, or decision system, to reside within the PDS system. Referring again back to C22012, there was general agreement that this functionality may be implemented by either PDS, OEM, or indeed a third party, and as such the protocol should define messages between each of these system components.
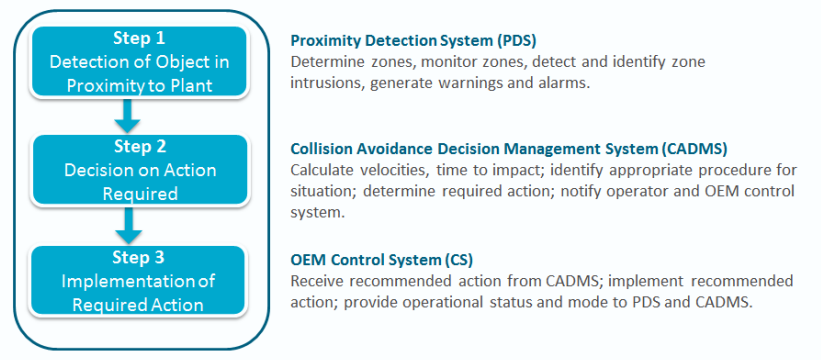
Figure 10 C22012 system analysis
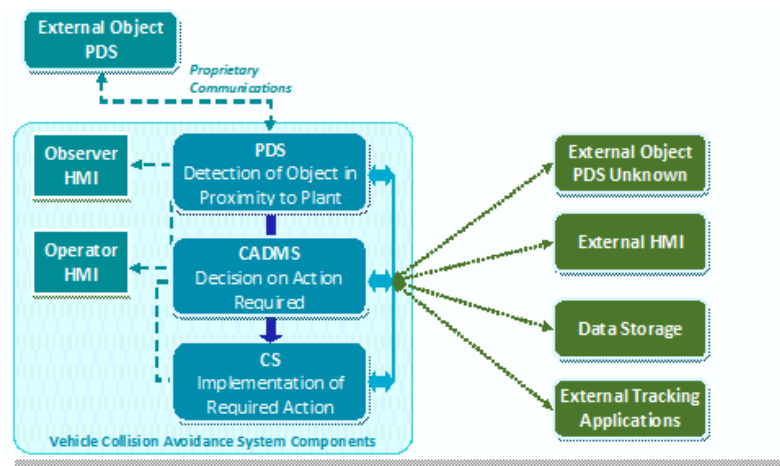
Figure 11 ACARP C22012 system model

4. **Data Logging**

The data logging requirements for a system do not belong in the communication protocol, however this should be addresses as a part of system requirements.

5. **Protocol limitation concerns**

The use of J1939 at this time provides short term advantages in the form of ease of implementation, however it is envisaged that there are a number of future scenarios that will be limited by this protocol:

- Off vehicle communications (v2v, back to base)
- Multiple systems on-vehicle
- Sites with a mixed fleet (either different vehicles or different PDS)

This is especially problematic in the assumption that only a single PDS system will be on board any given vehicle. As an example, it was found in the Shovel SLAP project that 3 different technologies with different failure modes were required to raise the system confidence to the appropriate level. This could also be a conceivable outcome with this technology, with multi-vendor solutions required.

6. **Protocol standardisation concerns**

It is not clear that the request/reply messaging protocol defined in this document fits with the basic definition of J1939. Independent advice will be sought on this issue, however there is a risk that considerable rework will need to be undertaken if this methodology is not consistent with the architecture.

Also, from the definitions in this document:

- The resolution and range cannot actually be correct. 0xFA = 250, but the 0xFA cannot be used as it is being used for the **GENERAL FAULT** indication.

- The use of a 'user configurable field' is contrary to the very concept of clear, well defined, open architecture protocol definitions.

11 Appendices

A.1   Previous ACARP Papers

Proj	Title	Device	Collision Management	RFID	Magnetic	Radar	Video	GPS	Other	Coal Mining	Heavy Industries
				Technology Used						Industry	
C1502	Proximity Detection System Underground	Y	Y	Y						Y	
C8034	Collision Prevention System	Y	Y*			Y				Y	
C19032	A Vehicle Interaction Causal Factors Database And Risk Management Decision Making Tool	Y*	Y							Y	
C17026	Open Platform Mine Equipment Communications and Proximity Warning System	Y*	Y							Y	
C14044	Collision Avoidance for Mine Haul Trucks	Y	Y*			Y				Y	
C21029	Fit For Purpose' Tyre Maintenance Equipment And Management Practises For Non-earthmover Mining Vehicles	Y*	Y							Y	
C18034	Emissions from Blasting in Open Cut Coal Mining	Y*	Y (toxic gas)							Y	
C15008	High Capacity Underground Coal Mining: Scoping Study - Defining the System Needs for a 15MTPA Longwall Operation	Y	Y*							Y	
C150038	Collision Control and Avoidance for Electric Mining Shovels	Y*	Y							Y	
C22012	LISCA - LASC Interoperability Specifications for Collision Avoidance		Y							Y	
C11049	Collision Avoidance Syetem 3	Y	Y	Y		Y				Y	
C18025	New Knowledge Elicitation Methods to Capture Risks Related to Mobile Mining Equipment		Y							Y	

A.2 Patents

Publication Number	Title	Patent Focus		Device	Collision Management	Technology Used						Inter System Protocol used	Industry	
		Method	Product			RFID	Magnetic	Radar	Visual	GPS	Other		Coal Mining	Heavy Industries
US20140077961A1	Integrated alarm device	Y	Y	Y	Y		Y					communication protocol	Y	Y
US8816850B2	Tracking and monitoring system for opencast mines	Y		Y	Y	Y						IEEE 802.15.4	Y	
US20060087443A1	Safety system for mining equipment	Y	Y	Y	Y		Y					RS485	Y	
US2012327261A1	Method and apparatus for generating an indication of an object within an operating ambit of heavy loading equipment	Y	Y	Y	Y			Y		Y		RS-232, RS-422, CAN bus	Y	Y
WO2014071451A1	A proximity awareness safety device and system	Y	Y	Y	Y		Y					Zigbee, WIFI (IEEE 802.11 standards) or any other proprietary protocol, Trivial File Transfer Protocol (TFTP)	Y	
AU2015201402A1	Safety system for mining equipment	Y	Y	Y	Y		Y					RS485	Y	
WO2014056099A1	Context-aware collision avoidance devices and collision avoidance system comprising the same	Y	Y	Y	Y		Y	Y			Y	wireless LAN	Y	
US8294568B2	Wireless mine tracking, monitoring, and rescue communications system	Y		Y	Y	Y						high level communications protocol	Y	
US20140191869A1	Mechanized area controller	Y	Y	Y	Y		Y						Y	
US20130038320A1	Proximity detection system with concurrent rf and magnetic fields	Y	Y	Y	Y		Y						Y	Y
US8847780B2	Proximity detection system and method and collision avoidance system and method using proximity detection	Y		Y	Y		Y						Y	Y
US6810353B2	Non-directional magnet field based proximity receiver with multiple warning and machine shutdown capability	Y		Y	Y		Y						Y*	

WO2004090830A1	Collision avoidance method and system	Y		Y	Y		Y					Y	
US7509008B2	Method and apparatus for locating a localized temperature change in a workspace	Y	Y	Y	Y					fiber optic DTS		Y	
US6469619B1	Intrinsically-safe roof hazard alert module	Y	Y	Y	Y		Y					Y	
JP7168985A	Proximity warning system	Y		Y	Y		Y						Y
CN102877888A	Proximity warning system	Y	Y	Y	Y		Y					Y	
CA2810051A1	Worksite proximity warning and collision avoidance system	Y		Y	Y				Y			Y	Y
AU2014100468A4	Operator drowsiness detection in mines	Y		Y	Y	Y			Y	radio		Y	
US8552882B2	Proximity detection systems and method for internal traffic control	Y		Y	Y		Y					Y	
CA2851055A1	Operator drowsiness detection in mines	Y		Y	Y	Y			Y	radio		Y	
US8477021B2	Worksite proximity warning and collision avoidance system	Y		Y	Y				Y			Y	
US2014266759A1	System and method for position detection	Y	Y	Y	Y		Y					Y	
FR2493567A1	Proximity sensor for automatic control of mining machine - uses ultrasonic transmitter to provide threshold level signal for safety control via UHF control transmitter	Y		Y	Y		Y					Y	
WO2004032091A1	Proximity detection system and method	Y	Y	Y	Y					ASP		Y	Y
US20120287277A1	Machine display system	Y	Y	Y		Y		Y		Y		Y	Y
WO2010132927A1	Forward looking borehole radar to determine proximity of adjacent interface of different seams or layers	Y		Y			Y					Y	Y
US8766639B2	Proximity detection method and system	Y		Y	Y*		Y						Y
CN202896572U	Cable dropping protecting device of coal mine underground man holding machine		Y	Y	Y*					PLC		Y	Y
CN103397909A	Coal mine rail transport monitoring system	Y	Y	Y					Y*			Y	
CN203419515U	Coal belt conveyor with anti-blocking device on cement production line		Y	Y	Y*					PLC		Y	
US8872643B2	Enhanced heavy equipment proximity sensor	Y	Y	Y	Y*				Y			Y	
US8289170B2	System and method for proximity detection	Y	Y	Y			Y					Y	
US4524931A	Device for indicating a certain proximity between movable units	Y	Y	Y	Y*		Y						Y
US20100221071A1	Remotely controlled mining machines, control systems, and related methods	Y		Y		Y						Y	
WO2014043824A1	Method and device for generating proximity warnings	Y		Y			Y				Y	Y	Y

ID	Description										Tech		
WO2011130861A1	Object proximity warning system and method	Y		Y	Y*					Y	RTLS	Y	
WO2005024536A1	Heavy vehicle guidance system	Y		Y	Y*					Y	ad-hoc wireless network	Y	
KR1212657B1	Intelligent safety management system	Y	Y	Y	Y*	Y					NFC		Y
JP2001171983A	Air type rotary warning device	Y	Y	Y	Y*		Y				IR		Y
DE3730372C1	Method and device for the control of the movement of a drill carriage	Y	Y	Y	Y*		Y*					Y	
CN202558805U	Rope break detection device of coke oven coal charging car		Y	Y	Y*						PLC	Y	
CN202296637U	Double-reaching display device for coal mine raw coal loading chamber	Y	Y	Y			Y					Y	
WO2015006824A1	Low-frequency magnetic field synchronisation for proximity detection systems	Y		Y	Y*				Y			Y	
CN203544012U	Speed reducer of automatic sliding mine car	Y	Y	Y	Y*						EMC	Y	
CN103693077A	Device for derailment monitoring of coal mine endless rope towing vehicle	Y	Y	Y	Y*						PLC	Y	
CN204239213U	Coal mine drainage automatic control device		Y	Y	Y*		Y					Y	
EP274342A1	Device for detecting disc cutter wear at roller bit drilling tools		Y	Y			Y					Y	
US8710979B2	Personal alarm device for headwear for proximity detection	Y	Y	Y*	Y*		Y					Y	
CN203628496U	Automatic control lighting device in shaft hoist cage		Y	Y	Y*		Y					Y	

A.3 Commercial Papers

Link	Title	Proximity	Collision Management	RFID	Magne	Radar	Video	GPS	Other	Coal Mining	Heavy Industries
				Technology Used						**Industry**	
http://pbegrp.com/proximity-alert-system http://www.sudburyminingsolutions.com/pbe-group-introduces-proximity-alert-system.html	Proximity Alert System detection technology is designed to enhance job site performance through safety of personnel and equipment.	Y	Y	Y	Y	Y		Y	camera	Y	
http://www.acumine.com/_Products/Proximity.php	Acumine Collision Avoidance Safety System (4CAST)	Y	Y					Y		Y	
http://www.booyco-electronics.co.za/pds/uptake-of-man-machine-interface-technology-on-mines-poised-to-	Uptake of man-machine interface technology on mines poised to increase exponentially	Y	Y	Y		Y			Y	Y	
http://www.strataworldwide.com/electronic-safety/hazardavert-proximity http://www.strataworldwide.com/sites/default/files/platform//brochure/Strata%20Proximity%20Detection%20Systems2014.pdf http://www.msha.gov/Accident_Prevention/NewTechnologies/ProximityDetection/ProximitydetectionSingleSource.asp	Proximity Detection/Collision Warning Information from Technical Support	Y	Y			Y				Y	
http://www.matrixteam.com/products/m3-1000.htm http://www.matrixteam.com/products/proximity-detection.htm	Matrix M3-1000 Proximity Detection	Y	Y						PDS	Y	
http://www.safe-mine.com/	The First Choice for Traffic Safety in Surface Mining	Y	Y			Y				Y	
http://www.nautilus-intl.com/proximity-detection/nautilus-coal-buddy-operators-proximity-detection-system-for-underground-	Nautilus-Coal-Buddy	Y	Y*			Y				Y	
http://www.modularmining.com/medias/new-modular-technology-minimizes-risk-increases-mine-safety/	New Modular Technology Minimizes Risk, Increases Mine Safety	Y	Y					Y		Y	
http://www.getransportation.com/mining/ge-mining-industrea-technology	GE Mining Industrea Technology	Y	Y			Y*		Y		Y	

Link	Title	Proximity	Collision Management	RFID	Magne	Radar	Video	GPS	Other	Coal Mining	Heavy Industries
http://www.smartmines.com/minutes/oct2013/GE_Mining_CAS_SMART_Group_17_Oct_2013.pdf http://www.geminingcas.com/#home											
https://mining.cat.com/cda/search/search/search?searchField=collision&s=4&m=434859&x=7	Proximity Awareness brings new level of safety to surface mines by expanding machine operator awareness of the working environment	Y	Y						GNSS	Y	
http://previewradar.com/products/xtreme-preview	Xtreme PreView® Rugged, Proven proximity detection solution	Y	Y			Y				Y	
http://exms.co.za/about.html	HazardAvert	Y	Y		Y					Y	
http://www.miningconnection.com/longwall/featured_stories/article/acquisition_gives_strata_competitive_edge_in_proximity_detection/	Acquisition Gives Strata Competitive Edge in Proximity Detection	Y	Y		Y					Y	
http://www.mining-technology.com/contractors/communications/proximity-detection/	HazardAlarm™	Y	Y		Y					Y	
http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.179.1447&rep=rep1&type=pdf	MSHA Proximity Detection	Y*	Y		Y					Y	
http://hit-not.com/	HIT-NOT® Proximity Detection	Y	Y		Y					Y	
https://www.sick.com/media/pdf/4/04/504/IM0052504.PDF https://www.sick.com/media/pdf/3/03/503/IM0052503.PDF	MINESIC100 WPS Wheel Loader Protection System	Y	Y	Y				Y		Y	
http://www.minetec.com.au/our-products/safety/safedetect-ii/ http://www.minetec.com.au/our-products/safety/safedetect/	Proximity detection software for mining safety	Y	Y	Y	Y					Y	
http://www.modularmining.com/wp-content/uploads/NewModularTechnologyMinimizesRiskIncreasesMineSafety_20071.pdf	New Modular Technology Minimizes Risk, Increases Mine Safety	Y	Y					Y		Y	
http://www.leica-geosystems.in/en/Dez2004_mining_engineering_GPS.pdf#search="proximity mining"	GPS for machine guidance improves safety at Borax mine	Y	Y					Y		Y	

Link	Title	Proximity	Collision Management	Technology Used						Industry	
				RFID	Magne	Radar	Video	GPS	Other	Coal Mining	Heavy Industries
http://www.motionmetrics.com/shovels/?section=ProximityDetection	Collision mitigation using ShovelMetrics™	Y	Y			Y				Y	
http://www.za.becker-mining.com/runtime/cms.run/doc/English/41/News.html?newsid=109	New ICAS surface collision avoidance safety system	Y*	Y					Y	radio wireless network	Y	
http://www.sick.com/us/en-us/home/solutions/industries/mining/Documents/Collision-avoidance-and-operator-	Collision avoidance and operator guidance - Innovating mine vehicle safety	Y	Y*	Y	Y*	Y*	Y*		LIDAR, ultrasound	Y	
https://www.engineersaustralia.org.au/sites/default/files/shado/Events/Conferences/MEMMESConvention2013/1_sick_cas_praesentation_conf											
http://www.3dlasermapping.com/sitemonitor-rt/	SiteMonitor RT	Y*	Y						Waste Spreader	Y	
http://www.hexagonmining.com/safety.htm	Mine Safety	Y*	Y							Y	
http://www.otnsystems.com/market/mining	Mining	Y*	Y							Y	
http://www.meshdynamics.com/Mesh-Network-Coal-Mining.html	MeshDynamics Third Generation Wireless Mesh Networks for Underground Coal Mine and Surface Mining	Y*	Y							Y	
http://www.mining-journal.com/technology/general-technology/mst-closes-proximity-safety-gap/	MST closes proximity safety gap	Y*	Y							Y	
http://www.mining-journal.com/technology/mining-ict/skyangle-adds-to-peripheral-vision/	SkyAngle adds to peripheral vision	Y*	Y*							Y	
http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=5764606&queryText=(((proximity)+AND+mining)+AND+safety)&matchBoolean=true	SmartHat: A battery-free worker safety device employing passive UHF RFID technology	Y*	Y	Y						Y	
http://www.undergroundcoal.com.au/acarp_dev/May%202011/Proximity%20Detection%20and%20Collision%20Avoidance%20-	Systems for mobile mining equipment:	Y	Y	Y		Y		Y	Laser, Ultrasonic. IR	Y	
http://mstglobal.com/?s=proximity	NA	Y	Y	Y						Y	
http://www.mining-technology.com/contractors/communications/mine-site/pressproximity-detection-initiative-in-											
http://www.guardvant.com/proxguard-gps-helps-south-african-mines-comply-with-new-safety-regulations/	ProxGuard GPS Helps South African Mines Comply with New Safety Regulations	Y	Y			Y		Y	camera	Y	

Link	Title	Proximity	Collision Management	Technology Used						Industry	
				RFID	Magne	Radar	Video	GPS	Other	Coal Mining	Heavy Industries
http://www.minlog.com/offerings/proximity-awareness/	MineSuite Fleet Management System Proximity Awareness Module	Y	Y	Y					Wi-fi	Y	
http://www.becker-mining.com/en/products/smartcom/non%20intrinsically%20safe/Collision%20Avoidance%20Syst	Collision Avoidance System	Y	Y						Digital POD Antenna	Y	

A.4 Other Publications

Link	Title	Proximity Detection	Collision Management	Technology Used						Industry	
				RFID	Magnetic	Radar	Video	GPS	Other	Coal Mining	Heavy Industries
http://www.coalage.com/features/3604-united-coal-charts-a-new-course-with-proximity-detection.html#.VYgUYvmqqko	United Coal Charts a New Course with Proximity Detection	Y	Y		Y					Y	
http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=6425458&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D6425458	Comparison of Magnetic Field Distribution Models for a Magnetic Proximity Detection System	Y	Y		Y					Y	
http://pro.sagepub.com/content/57/1/265.short	A Visual Warning System for the Identification of Proximity Detection Events around a Continuous Mining Machine	Y	Y		Y					Y	
http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=6074392&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D6074392	Determining proximity warning and action zones for a magnetic proximity detection system	Y	Y		Y					Y	
http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=5675319&queryText=coal+mining+.PLS.+proximity+detection&newsearch=true&searchField=Search_All	Development of a method to determine operator location using electromagnetic proximity detection	Y	Y		Y					Y	
http://www.resourcesandenergy.nsw.gov.au/__data/assets/pdf_file/0004/507316/MDG-2007-Guideline-for-the-selection-and-implementation-of-collision-management-systems-for-mining-2014.pdf	Guideline for the selection and implementation of collision management systems for mining	Y	Y		Y					Y	
https://www.federalregister.gov/articles/2015/01/15/2015-00319/proximity-detection-systems-for-continuous-mining-machines-in-underground-coal-mines	Proximity Detection Systems for Continuous Mining Machines in Underground Coal Mines	Y	Y		Y					Y	
http://www.oemoffhighway.com/article/10166326/youre-in-my-personal-bubble	You're in My Personal Bubble	Y	Y		Y	Y				Y	
http://www.mining-technology.com/features/featuresafety-first-top-mine-tech-for-prevention-and-response/	Top mine tech for prevention and response	Y	Y		Y					Y	
http://www.cdc.gov/niosh/mining/topics/ProximityDetection.html	Mining Topic: Proximity Detection	Y	Y		Y					Y	
http://www.cdc.gov/niosh/mining/content/pwsselection.html	Engineering Considerations and Selection Criteria for Proximity Warning Systems for Mining Operations	Y	Y		Y					Y	
http://webapps.dol.gov/federalregister/HtmlDisplay.aspx?DocId=25272&Month=8&Year=2011	Proximity Detection Systems for Continuous Mining Machines in Underground Coal Mines	Y	Y		Y					Y	
http://www.longwallusa.com/mmi_ConferenceDL/2013LWUSA/LWDuCarme.pdf	Intelligent Proximity Detection Technology for Underground Coal Mines	Y	Y		Y					Y	

URL	Title											
http://www.cdc.gov/niosh/mining/UserFiles/works/pdfs/eoaap.pdf	Evaluation of an Advanced Proximity Detection System for Continuous Mining Machines	Y	Y		Y						Y	
http://ascelibrary.org/doi/abs/10.1061/9780784412329.099	Proximity Sensing and Warning Technology for Heavy Construction Equipment Operation	Y	Y	Y								Y
http://www.tandfonline.com/doi/abs/10.1080/09205071.2013.852487	Environmental impact on the magnetic field distribution of a magnetic proximity detection system in an underground coal mine	Y	Y		Y						Y	
http://www.sciencedirect.com/science/article/pii/S0925753511002785	A shell-based magnetic field model for magnetic proximity detection systems	Y	Y		Y						Y	
http://stacks.cdc.gov/view/cdc/8494	Recommendations For Evaluating And Implementing Proximity Warning Systems On Surface Mining	Y	Y			Y		Y	Y		Y	
https://magazine.cim.org/en/2013/October/technology/Proximity-detection.aspx	Proximity detection takes root underground	Y	Y		Y						Y	
http://www.sciencedirect.com/science/article/pii/S0001457505001259	Evaluation of a radar-based proximity warning system for off-highway dump trucks	Y	Y			Y					Y	
http://im-mining.com/2012/05/01/underground-mine-communications-monitoring/ http://im-mining.com/2013/08/21/becker-mining-launches-economical-gps-vhf-collision-avoidance-system/	Underground Mine Communications & Monitoring	Y	Y	Y							Y	
http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0019/412228/Collision-Avoidance-John-Snape.pdf	XCAP Collision Avoidance	Y	Y	Y		Y		Y	cameras		Y	
http://espace.library.uq.edu.au/view/UQ:238561/UQ238561_fulltext.pdf	Collision detection and proximity warning	Y	Y	Y		Y		Y	Camera, Wi-Fi, Ultrasonic		Y	
http://ro.uow.edu.au/cgi/viewcontent.cgi?article=2018&context=coal	Human factors exploration	Y	Y	Y	Y*						Y	
https://mining.cat.com/cda/files/2782968/7/Detect_Brochure_VIEW_9_4_12.pdf	Improving Awareness For Better Mine Safety	Y	Y			Y			GNSS		Y	
http://www.cdc.gov/niosh/mining/UserFiles/works/pdfs/2007-146.pdf	Recommendations for Evaluating and Implementing Proximity Warning Systems on Surface Mining Equipment	Y	Y					Y			Y	
http://www.ambriefonline.com/2014/07/collision-avoidance-systems/24/	Collision Avoidance Systems	Y	Y	Y							Y	

URL	Title								
http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6199218&queryText=((mining)+AND+proximity)&refinements%5B%5D=4294967269&refinements%5B%5D=&ranges%5B%5D=2005_2015_Year&sortType=desc_p_Publication_Year&matchBoolean=true&rowsPerPage=100&searchFiel	3D Assisted driving system for haul trucks in surface mining	Y	Y		Y			Y	
http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6074391&queryText=((proximity)+AND+collision)&refinements%5B%5D=4294967269&refinements%5B%5D=&ranges%5B%5D=2005_2015_Year&sortType=desc_p_Publication_Year&matchBoolean=true&rowsPerPage=100&searchF	Comparison of magnetic field distribution models for a magnetic proximity detection system	Y	Y	Y				Y	
http://www.mining-journal.com/technology/mining-ict/it-notebook-quintiq-lsm-technologies-maptek-immersive-technologies-itasca/	IT notebook: Quintiq, LSM Technologies, Maptek, Immersive Technologies, Itasca	Y	Y		Y		camera	Y	
http://www.mining-journal.com/technology/general-technology/standards-bring-new-focus-on-cameras/	Standards bring new focus on cameras	Y	Y		Y			Y	
http://www.mining-journal.com/technology/mining-ict/minestar-at-the-coalface/	MineStar at the coalface	Y	Y	Y				Y	
http://www.mining-journal.com/technology/general-technology/minings-new-tech-boom/	Mining's new tech boom	Y	Y		Y			Y	
http://www.mining-journal.com/technology/general-technology/raising-the-bar/	Raising the bar	Y	Y		Y	Y	Y	Y	
http://www.mining-journal.com/world/north-america/a-union-of-technology-and-culture/	A union of technology and culture	Y	Y			Y		Y	
http://papers.sae.org/2007-01-4233/	Development and Testing of a Tag-based Backup Warning System for Construction Equipment	Y	Y		Y				Y
http://www.sciencedirect.com/science/article/pii/S0925753510002006	An integrated information technology assisted driving system to improve mine trucks-related safety	Y	Y*			Y		Y	
http://www.sciencedirect.com/science/article/pii/S0926580510000361	Autonomous pro-active real-time construction worker and equipment operator proximity safety alert system	Y	Y*	Y					Y
http://www.tandfonline.com/doi/abs/10.1080/01446193.2013.783705	Method for testing proximity detection and alert technology for safe construction equipment operation	Y	Y*	Y					Y
http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6689292&queryText=((mining)+AND+proximity)&refinements%5B%5D=4294967269&refinements%5B%5D=&ranges%5B%5D=2005_2015_Year&sortType=desc_p_Publication_Year	Intelligent Machine Guard Monitoring: A Wireless System to Improve Miner Safety	Y*	Y*		Y	Y		Y	

URL	Title									
&matchBoolean=true&rowsPerPage=100&searchFiel										
http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=4039618&queryText=((mining)+AND+proximity)&refinements%5B%5D=4294967269&refinements%5B%5D=&ranges%5B%5D=2005_2015_Year&sortType=desc_p_Publication_Year&matchBoolean=true&pageNumber=2&rowsPerPage=1	Detection of Antipersonnel Mines by Using the Factorization Method on Multistatic Ground-Penetrating Radar Measurements	Y*	Y*		Y				Y	
http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=1639820&queryText=((mining)+AND+proximity)&refinements%5B%5D=4294967269&refinements%5B%5D=&ranges%5B%5D=2005_2015_Year&sortType=desc_p_Publication_Year&matchBoolean=true&pageNumber=3&rowsPerPage=1	Magnetic field measurements of limpet mines attached to a ship's steel hull	Y*	Y*		Y				Y	
http://www.mining-journal.com/technology/general-technology/time-to-confront-collisions-head-on/	Time to confront collisions head on	Y*	Y					Camera	Y	
http://www.mining-journal.com/technology/general-technology/digital-age-has-arrived/	Digital age has arrived	Y*	Y	Y				wifi	Y	
http://www.mining-journal.com/technology/mining-ict/sky-no-longer-the-limit-for-fleet-management/	Sky no longer the limit for fleet management	Y*	Y				Y		Y	
http://www.mining-journal.com/technology/mining-ict/mining-it-product-releases-to-fill-2012-calendar/	Mining IT: product releases to fill 2012 calendar	Y	Y*					wifi	Y	
http://www.mining-journal.com/technology/mining-ict/in-brief-coal-india-mincom-oz-minerals/	In brief: Coal India, Mincom, OZ Minerals	Y	Y*				Y		Y	
http://www.mining-journal.com/technology/general-technology/the-communication-revolution/	The communication revolution	Y*	Y				Y	wifi	Y	
http://www.mining-journal.com/technology/mining-ict/numbers-signal-growth/	Numbers signal growth	Y*	Y*					ptx	Y	
http://www.mining-journal.com/financeinvestment/production/big-bodd-finding-its-rhythm/	Big Bodd finding its rhythm	Y*	Y*				Y*		Y	
http://www.mining-journal.com/world/north-america/keeping-in-touch/	Keeping in touch	Y*	Y	Y*					Y	
http://espace.library.uq.edu.au/view/UQ:238561	Collision detection and proximity warning systems for mobile mining equipment: A human factors exploration	Y*	Y						Y	
http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6629441&queryText=((mining)+AND+proximity)&refinements%5B%5D=4294967269&refinements%5B%5D=&ranges%5B%5D=2005_	Vehicle operation safety monitoring using context based metrics: A case study	Y*	Y						Y	

URL	Title										
2015_Year&sortType=desc_p_Publication_Year &matchBoolean=true&rowsPerPage=100&searc hFiel											
http://ieeexplore.ieee.org/xpl/articleDetails.jsp? arnumber=6519871&queryText=((mining)+AND +proximity)&refinements%5B%5D=4294967269 &refinements%5B%5D=&ranges%5B%5D=2005_ 2015_Year&sortType=desc_p_Publication_Year &matchBoolean=true&rowsPerPage=100&searc hFiel	Performance qualification of instrumentation, telemetry & data acquisition system for underwater mining machine with manganese nodule collection and crushing system	Y*	Y*							Y	
http://articles.sae.org/11492/	Hauler features Hitachi's new ac drive control	Y*	Y*							Y	
http://papers.sae.org/2008-01-1911/	Analyzing Factors Influencing Struck-By Accidents of a Moving Mining Machine by using Motion Capture and DHM Simulations	Y*	Y*							Y	
http://papers.sae.org/2007-01-4298/	Foundations of Commercial Vehicle Safety: Laws, Regulations, and Standards	Y*	Y*							Y	
http://minestories.com/proper-copper/	proper copper	Y*	Y							Y	
http://www.mining-journal.com/world/australia/green-light-for-cas-investment/	Green light for CAS investment	Y*	Y							Y	
http://www.mining-journal.com/world/australia/pe-firm-makes-first-mets-call/	PE firm makes first METS call	Y*	Y*							Y	
http://www.mining-journal.com/technology/mining-ict/meeting-of-mines/	Meeting of mines	Y*	Y*							Y	
http://www.mining-journal.com/technology/mining-ict/it-notebook-modular-mining-mintec/	IT notebook: Modular Mining, Mintec	Y*	Y*							Y	
http://www.mining-journal.com/services/contracting/haves-and-have-nots/	Haves and have-nots	Y*	Y*							Y	
http://www.mining-journal.com/technology/mining-ict/whats-new-in-2009-and-2010/	What's new in 2009, and 2010	Y*	Y							Y	
http://www.mining-journal.com/technology/mining-ict/mining-it-2011-rebooted/	Mining IT: 2011 rebooted	Y*	Y							Y	
http://www.mining-journal.com/technology/mining-ict/it-notebook-datamine-gbi-micromine-maptek/	IT Notebook: Datamine, GBI, Micromine, Maptek	Y*	Y*							Y	
http://www.mining-journal.com/technology/mining-ict/long-haul-starts-again/	Long haul starts again	Y*	Y*							Y	
http://www.dol.gov/opa/media/press/msha/MSHA20150035.htm	Proximity detection final rule will save miners' lives'	Y*	Y							Y	

URL	Title	1	2	3	4	5	6	7	8	9	10
http://www.wvgazette.com/News/2013111900 60	Few mining machines in W.Va. have proximity detectors	Y*	Y							Y	
http://www.wvgazette.com/article/20140409/G Z01/140409207	Coal firms get 3 years for 'proximity' technology	Y*	Y							Y	
http://mstglobal.com/improving-safety-productivity/	Improving Safety and Productivity	Y*	Y							Y	
https://ohsonline.com/Articles/2015/01/14/MS HA-Issues-Proximity-Detection-Rule.aspx	MSHA Issues Proximity Detection Final Rule	Y*	Y							Y	
https://blog.dol.gov/2013/12/07/improving-miners-safety-and-health/	Improving Miners' Safety and Health	Y*	Y							Y	
http://www.wdtv.com/wdtv.cfm?func=view&se ction=5-News&item=New-Regulation-to-Make-Coal-Mining-Safer-15405	New Regulation to Make Coal Mining Safer	Y*	Y							Y	
http://www.safetytrainingmsha.com/tag/workpl ace-safety-2/	Mine Safety Stand-Down Announced in West Virginia	Y*	Y							Y	
http://www.kyenvironmentalfoundation.org/co al-mining-health-risks.html	Health risks associated with Coal mining	Y*	Y							Y	
http://www.dailymail.co.uk/wires/ap/article-2908960/New-federal-rule-seeks-reduce-machine-related-coal-deaths.html	New federal rule seeks to reduce machine-related coal deaths	Y*	Y							Y	
http://workplacesafetyreport.com/2015/01/pro ximity-detection-rule-goes-final/	Proximity detection rule goes final	Y*	Y							Y	
http://www.jacksonlewis.com/media/pnc/6/me dia.2786.pdf	MSHA Mandates New Safety Devices in Underground Coal Mines	Y*	Y						Y	Y	
http://me.smenet.org/abstract.cfm?preview=1& articleID=5791&page=20	Field tests of second generation proximity detection systems on continuous miners	Y*	Y							Y	
http://www.coalage.com/features/3523-teck-safemine-team-up-for-collision-avoidance-program.html#.VZJgi_mqqkp	Teck, SAFEmine Team Up for Collision Avoidance Program	Y	Y*			Y*		Y*		Y	
http://www.longwallusa.com/mmi_Conference DL/2013LWUSA/LWPryor.pdf	Safer Mining Technologies Session New Proximity Detection Technology	Y*	Y							Y	
http://www.designworldonline.com/detection-diverse-outdoor-applications/	Detection in Diverse Outdoor Applications	Y	Y*			Y				Y	
http://www.google.co.in/url?sa=t&rct=j&q=&es rc=s&source=web&cd=8&cad=rja&uact=8&ved= 0CFMQFjAH&url=http%3A%2F%2Fwww.cdc.gov %2Fniosh%2Fmining%2FUserFiles%2Fworkshops %2Fproximityworkshop2010%2FRuff-NIOSH-PDWorkshop2010-508.pdf&ei=uNWUVbL0NYmIuAS4u5G4DA&usg =A	Overview of proximity warning technology and approach	Y	Y	Y	Y					Y	

Appendix B Communications

The common method of discussing data transmission is through the use of the OSI model that consists of seven layers:

- Application
- Presentation
- Session
- Transport
- Network
- Data Link
- Physical

The relationship to the OSI model of a variety of the protocols discussed is shown in the following figure.
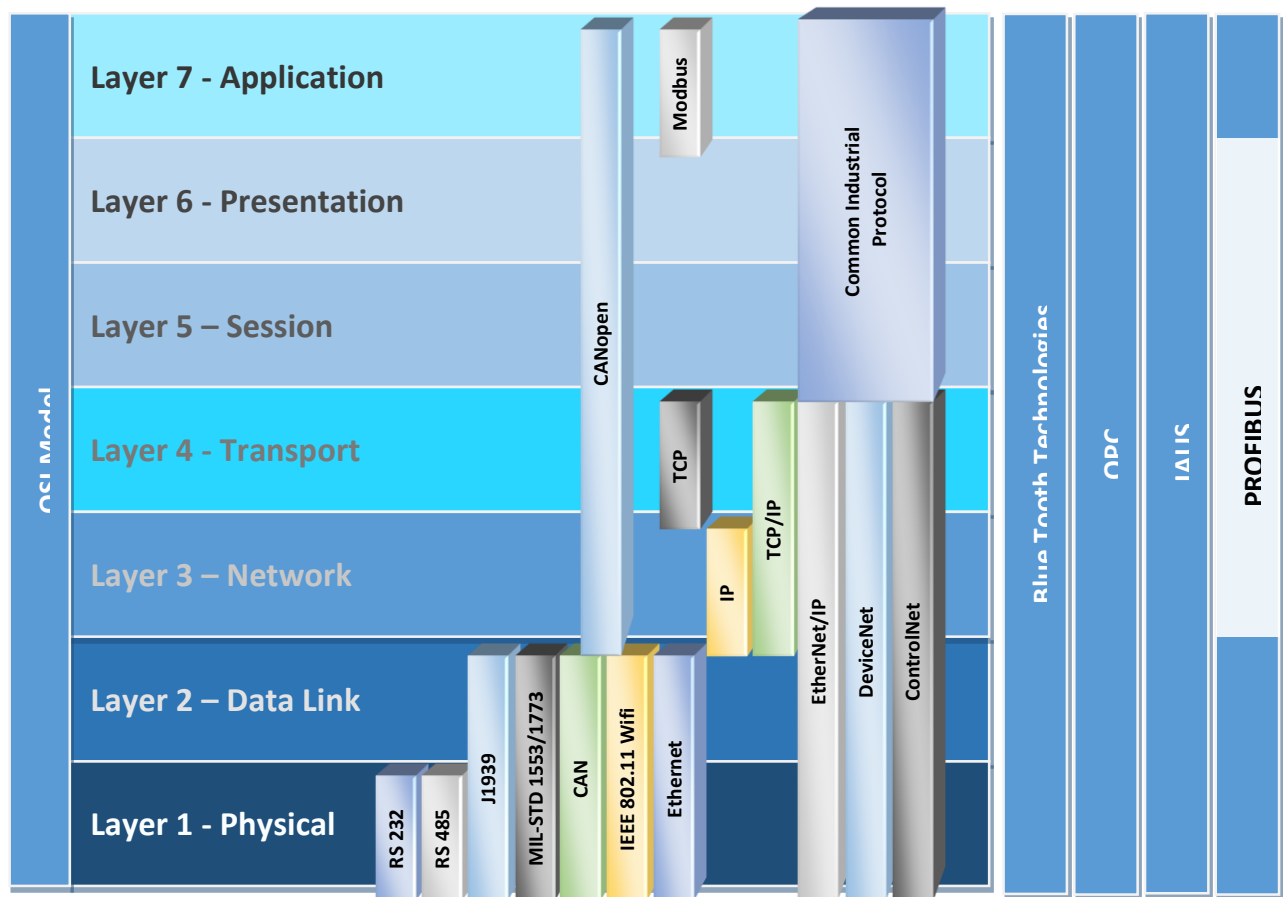

Figure 12 OSI Model and Relationship to Various Protocols

This section attempts to give a brief overview of some of the technologies available that may be of use for the CAS open specification.

B.1   Physical Transmission Options

A brief summary follows of the most common transmission mediums that could be considered for use in the underground coal environment.

B.1.1   SINGLE WIRE

Utilises only a single electrical conductor to transmit a signal.

B.1.2   TWO WIRE BUS (CAN BUS)

. The wires are 120 Ω nominal twisted pair.
- **ISO 11898-2**, also called high speed CAN, uses a linear bus terminated at each end with 120 Ω resistors.
- **ISO 11898-3**, also called low speed or fault tolerant CAN, uses a linear bus, star bus or multiple star buses connected by a linear bus and is terminated at each node by a fraction of the overall termination resistance. The overall termination resistance should be about 100 Ω, but not less than 100 Ω.

B.1.3   TWISTED PAIR

A twisted pair 'consists of two insulated copper wires arranged in a regular spiral pattern, acting as a single communication link'. The twisting helps to decrease the cross talk interference between adjacent pairs in a cable. This is the most commonly used transmission medium for communications and would definitely be suitable for use within the underground coal environment. There are many different rated cables types for twisted pair communications, as defined by (Wtuto, 2013);
- **CAT 1** – Currently unrecognised
- **CAT 2** – Currently Unrecognised
- **CAT 3** – Used for data networks using frequencies up to 16MHz. Historically popular for 10Mbit/s Ethernet networks.
- **CAT 4** – Currently unrecognised
- **CAT 5** – Defined up to 100MHz and was frequently used on 100MBig/s Ethernet networks. Maximum speed 100Mbs, maximum distance 100m - cost factor of 1.
- **CAT 5e** – Defined up to 100MHzand is frequently used for both 100 MBit/s and 1000BASE-T Gigabit Ethernet networks. Maximum speed 1000Mbs, maximum distance 100m - cost factor of 1.
- **CAT 6** – Defined up to 250 MHz. Maximum speed 1000Mbs, maximum distance 100m - cost factor of 1.3x.
- **CAT 6a** – Defined up to 500 MHz; suitable for 10GBase-T.
- **CAT 7** – informally defined up to 600MHz.
- **CAT 7a** – informally defined up to 1000MHz.

B.1.4   FIBRE OPTIC

A flexible transparent fibre made of high quality extruded glass or plastic which functions as a light pipe to transmit light between two ends of the fibre. Optical fibres are non-flammable, capable of withstanding high temperatures and vibration and have less signal degradation than copper wires. Fibre optic cable cannot be bent to a radius smaller than 30 mm and it requires specific termination equipment of a high standard and with more training for personnel required. Optical fibres are

more fragile than electrical wires and are quite expensive. (Barrie, 2013) Their suitability for use in underground coal mining equipment has been proven in different projects and equipment, yet is not widespread in industry due to the volume of older plant still in service.

B.1.5 POWER LINE COMMUNICATION

A communication technology that enables sending data in half-duplex mode by using a modulated carrier signal which is induced into the existing power cables. This is currently used in a variety of industries and is best suited for low frequency long range communications. This is not the desired communication type for the collision avoidance open communications specification that is aimed at high speed short range applications.

B.1.6 WIRELESS TRANSMISSION

A variety of wireless transmission technologies exist including WiFi, Bluetooth, Infrared, Microwave and Satellite. For use in underground coal mines only Satellite and Microwave technologies will not be examined.

11.1.1.1 Wifi

Wifi transmission occurs at either 2.4 or 5 GHz frequencies allowing high data transmission. The standards for Wifi networking are the 802.11 standards of which there are several (Marshall Brain, 2013):
- 802.11a – Uses orthogonal frequency division multiplexing (OFDM), transmits up to 54Mbps at 5GHz.
- 802.11b – Uses Complementary Code Keying (CCK) modulation. Slowest and least expensive. Transmits up to 11Mbps at 2.4GHz.
- 802.11g – Uses OFDM and transmits up to 54Mbps at 2.4GHz.
- 802.11n – Compatible with a, b and g standards. Transmits 150Mbps at 2.4 GHz. Most widely available.
- 802.11ac – Newest standard as of 2013. Still in drafting with the IEEE. Transmits at 450 Mbps at 5GHz.
- 802.11ad – Also known as WiGig (60Ghz). Designed to support speeds to 7Gbps (higher speeds to come).

For the case of the underground coal collision avoidance open communications specification Wifi technologies will be considered.

11.1.1.2 Bluetooth

Bluetooth technology uses short-range radio waves to transmit data between two Bluetooth devices. The data transfers at a rate of 1Mbps. The two devices must be within approximately 10 metres of one another for successful communications. (Yong, 2013)

11.1.1.3 Infrared

Infrared communications can only be used for short-range communication and require direct-line-of-sight to work. The devices use infrared light-emitting diodes to emit infrared radiation that is digitally pulsed on and off. This is not suitable for the Collision Avoidance System open communications specification.

B.2   Serial Communications

This section aims to give a brief review of some serial communications protocols which could be considered for use within the open communications specification for underground coal collision avoidance.

B.2.1   ETHERNET

The IEEE controls the standard 802.11 that standardises local area networks. It utilises twisted pair, fibre optics or wireless technologies to transfer data. Ethernet utilises Media Access Control (MAC) addresses to specify the destination and source of each individual packet sent, and furthermore, within each packet frame a type field identifies which protocol should be used to interpret it (for example, Internet Protocol – IP).

B.2.2   MIL-STD 1553 / 1773

MIL-STD 1553 / 1773 is a military standard from the US Department of Defence that "defines the mechanical, electrical and functional characteristics of a serial data bus, for use with military avionics". It features a "dual redundant balanced line physical layer, a differential network interface, time division multiplexing, half-duplex command/response protocol and up to 31 remote terminals". (MIL-STD-1553, 2013) It uses a twisted pair shielded cable as the conductor.
This is a very high performance communications standard and as such may be over-engineered (costly) for the application of the Collision Avoidance System open communications specification.

B.2.3   RS-232

The RS-232 standard defines three major parts; the electrical signal characteristics, the mechanical characteristics of the interface and a functional description of the interchange circuits. This protocol is for point-to-point communications only; it uses asynchronous serial communications; data is transmitted within a frame that includes a start bit, parity bit and stop bits. Also definable is the baud rate. This is a very common protocol, however it is also outdated and no longer used in most industrial applications.

B.2.4   RS-485

The official name of the RS-485 standard is the *Electrical Characteristics of Generators and Receivers for Use in Balanced Digital Multipoint Systems.* RS-485 is a multi-drop specification that allows only one driver to send data at a time (half-duplex operation) and up to 32 devices can be placed on the bus. RS-485 can operate in a balanced digital multiplexing system and enables the configuration of inexpensive local networks. It allows data transmission speeds of up to 35 Mbps up to 10m and 100 kbps at 1200 metres. This protocol operates on a twisted pair medium. This protocol is recommended to be implemented in a line or bus configuration, not a star or ring topology. This protocol only defines the physical layer of the communications (in the OSI model).

B.2.5   USB – UNIVERSAL SERIAL BUS

The universal serial bus is an industry standard initially defined to allow standardisation of computer peripheral device inputs. It consists of a host with multiple peripheral devices connected in a star topology. This communications interface utilises both streams and messages, depending upon the needs of the endpoint (e.g. streaming video or audio or short command messages). The theoretical maximum data rate of USB 2.0 is 480 Mbps; the protocols uses packets to transfer handshakes, tokens, data and low bandwidth marked packets. (USB Implementers Forum Inc, 2013)

B.3   Process Automation / Industrial / Vehicle Protocols

B.3.1   CAN – CONTROLLER AREA NETWORK

The CAN protocol was originally developed for use within automotive control systems. It is a broadcast bus type and can be implemented with a variety of physical layers including RS485, as well as single and twisted pair. CAN uses short messages with four different types: Data, Remote, Error and Overload. (Kvaser, 2013)
There are also a large variety of standards surrounding CAN including:

- ISO 11898-1 The CAN Protocol
- ISO 11898-2 High Speed Physical Layer for CAN
- ISO 11898-3 Low Speed Fault Tolerant Physical Layer for CAN
- ISO 11898-4 Time Triggered CAN
- ISO 11898-5 High Speed Medium Access Unit with Low Power Mode
- ISO 11519-2 Obsolete
- ISO 15765 Standard that defines diagnostics on a CAN bus
- SAE J1939 CAN based higher layer protocol for trucks and busses.
- ISO 11786 Similar to J1939 for agricultural / tractor use
- ISO 11992 Defines an interface between trucks and trailers
- NMEA 2000 Based on J1939 for marine use

As Listed By (Kvaser AB, 2013)
It is usually assumed that the word CAN, without further specification, refers to the protocol standard ISO 11898-1 and the physical layer standard ISO 11898-2.
The CAN protocol is used within many other automation protocols including CANopen and DeviceNet. (ODVA, 2013)

B.3.2   CANOPEN

The CAN specification defines only the physical and data link layers in the OSI Model; CANopen provides an open and standardized description of how to transfer data between nodes and how to access the data within the node. CANopen is an international standard produced by the CAN in Automation (CiA) group. (ESD Electronics, 2013)

B.3.3   CIP – COMMON INDUSTRIAL PROTOCOL

The Common Industrial Protocol is a media independent protocol for advanced communication and network integration. CIP allows integration of I/O control, device configuration and data collection across multiple networks. (ODVA, 2013) Overall it meets the needs of the Session, Presentation and Application layers within the OSI model, and is commonly supported by a DeviceNet, CompNt, ControlNet or Ethernet/IP implementation.

B.3.4   CONTROLNET

ControlNet is a "real-time, control-layer network that provides high-speed transport of both time critical I/O data and messaging data, upload/download of programming configuration, and peer-to-peer messaging on a single physical media link." (ODVA, 2013).
ControlNet is usually combined with CIP for the upper layers of the OSI model. The suitability for ControlNet for the open communications specification will be examined

B.3.5   DEVICENET

DeviceNet is a "digital, multi-drop network that connects and serves as a communication network between industrial controllers and I/O devices (nodes). DeviceNet supports multiple communication hierarchies and message prioritisation." (ODVA, 2013) DeviceNet utilises the CAN protocol for the Data Link layer.

DeviceNet is usually combined with CIP for the upper layers of the OSI model. The suitability for DeviceNet for the open communications specification will be examined.

B.3.6   ETHERNET/IP

Ethernet/IP is intrinsically linked to the TCP/IP and follows the Open Systems Interconnection Model (OSI). Ethernet/IP uses standard IEEE 802 Ethernet at the Physical and Data Link layers, and then uses the TCP/IP Suite to send messages at the Network and Transport Layers. Ethernet/IP has two types of messaging connections, as defined by (ODVA Inc, 2008):

- "Explicit Messaging Connections – point to point relationships that facilitate request/response between two nodes.
- Implicit Messaging Connections – Established to move application specific I/O data at regular intervals. Set up as one-to-many relationships to take advantage of the multicast model."

EtherNet/IP is usually combined with CIP for the upper layers of the OSI model. The suitability of Ethernet/IP for the open communications specification will be examined.

B.3.7   MODBUS

Modbus is an application layer protocol. Modbus works over both serial and TCP communications and is strictly a request/response protocol; there is no support for exceptions or unsolicited responses. There are a limited number of function codes such as read single coils, write single register etc. Due to the lack of security, and the inability for unsolicited responses, within the Modbus protocol, it will not be appropriate for use within the open communications specification. (Digital Bond, 2013)

B.3.8   OPC – OLE FOR PROCESS CONTROL

OLE, being Object Linking and Embedding, for Process Control, is a suite of open connectivity via open standards for a variety of areas. OPC is a three-layer architecture that uses some of the same terms as the OSI model, but is not directly comparable. The three-layers defined are the 'Application Layer, Communications Layer, and the Transport Layer'. (Digital Bond, 2013) This particular protocol is overly complex for the requirements of a collision avoidance open communication specification.

B.3.9   PROFIBUS

PROFIBUS exists at both the device and controller level. It is a master/slave protocol with the controller as the master and the instruments as the slaves. It generally covers the applications and data link layers with some physical layer specifications. (Digital Bond, 2013) There are a variety of physical layers used that includes RS485, Fibre-Optic and MBP.

B.3.10   SAE J1939

J1939 is a set of standards defined by the Society of Automotive Engineers (SAE) for use within heavy-duty vehicles such as trucks, busses and mobile hydraulics. It is based upon the CAN protocol and operates at speeds of approximately 250kbps. It describes the physical and data link layers of the OSI model. (Kvaser, 2013)

B.3.11 TCP/IP – TRANSMISSION CONTROL PROTOCOL / INTERNET PROTOCOL

TCP/IP exists at the Network and Transport layers within the OSI model. TCP/IP encapsulation allows 'a node on the network to embed a message as the data portion in an Ethernet message'. (ODVA Inc, 2008) The TCP portion is connection oriented, uni-cast transport that provides data flow control amongst other things; the IP portion ensures packet routing through multiple possible paths and includes added diagnostics capabilities.

B.4   Other Protocols Examined

B.4.1   JAUS – JOINT ARCHITECTURE FOR UNMANNED SYSTEMS

JAUS (Joint Architecture for Unmanned Systems) is 'an international standard that defines communication protocols for unmanned vehicle systems, some of their internal components, and their interaction with operator control stations'. [2] (OpenJAUS, 2013) The JAUS protocol defines an entire network and the communication and interoperation of unmanned components within the network; this is achieved through defining hierarchical layers as shown in Figure 13.
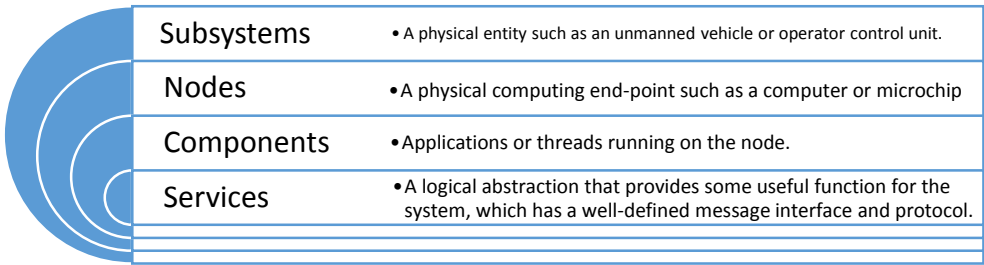
Subsystems	• A physical entity such as an unmanned vehicle or operator control unit.
Nodes	• A physical computing end-point such as a computer or microchip
Components	• Applications or threads running on the node.
Services	• A logical abstraction that provides some useful function for the system, which has a well-defined message interface and protocol.

Figure 13 JAUS System Architecture (OpenJAUS, 2013)

For the purposes of the collision avoidance open communications specification, this protocol is too bulky with a large amount of unnecessary layers and detail.

B.4.2   XMPP – EXTENSIBLE MESSAGING AND PRESENCE PROTOCOL

XMPP "defines a set of open technologies for instant messaging, presence, multi-party chat, voice and video calls, collaboration, lightweight middleware, content syndication and generalized routing of XML data." (XMPP, 2013) The strengths of this standard are that it is open, standard, proven, decentralized, secure, extensible, flexible and diverse. XMPP utilises a client-server structure; clients do not talk directly to one another, however, it is also decentralised in that there is no one authoritarian server; and any entity can implement a server. This protocol is not suitable for the collision avoidance open communications specification due to the need to preregister a given resource with the relevant server. (XMPP, 2013)

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[2] The JAUS standards are owned and developed by the Society of Automotive Engineers

Appendix C Detection

C.1   Camera

Cameras are passive sensors that receive reflected light from the environment and store the information. Cameras are primarily used in surface applications rather than underground (due to the dusty environment). Image processing allows greater identification of objects within the environment. For the purposes of proximity detection these are currently used primarily as an aid for operators to overcome machine blind spots.

It is worth noting that there is a stronger push for deploying cameras across the longwall face. The flameproof technologies to support this are not yet in place, but are coming soon.

C.2   Electromagnetic (~70 – 140 kHz)

Electromagnetic systems are used for very close proximity detection. They typically operate by mounting electromagnetic field generators at key points across the machine/object such that an electromagnetic field with the desired footprint exists up to 10 metres from the machine. When personnel or other objects wearing the required tag enter the electromagnetic field, the tag measures the strength/orientation of the field and transmits the information to the receiver on board the machine. This receiver then identifies the position of objects within range.

C.3   GPS (1.56 GHz)

GPS stands for the Global Positioning System. It is a space based satellite navigation system that provides location and time information to receivers. This system is one-way communication only with passive receivers. Limitations of this system are the requirement for line of sight communication with minimum three to four of the GPS satellites and therefore can only be used for surface applications. The accuracy of GPS is (worst-case scenario) approximately 7.8 meters at 95% confidence (GPS.Gov, 2012); it is therefore not suitable for close range collision avoidance applications but rather for mid-range surface monitoring.

C.4   Depth Sensors

There are a variety of depth sensors. These include shaped light sensors (such as on-board the Kinect), time-of-flight cameras as well as other sensors based on lasers, Lidar and radar detection abilities.

C.5   Radar (2.4 GHz, 5.8GHz) and Radar RFID

Radar stands for Radio Detection and Ranging. A radar device produces a signal at a set frequency and measures the reflections that echo back to it. When a radar signal strikes an object, some energy is absorbed, whilst some is reflected back. The type of material of which an object is composed determines the amount of energy reflected. The Doppler Effect is used within radar applications to measure relative motion. As an object approaches the radar the frequency of the reflected wave increases whilst the wavelength decreases (and vice versa for movement away from the radar). The wavelength shift can be measured and tracked such that a radar device can calculate the objects velocity.

A radar device is known as an active sensor as it emits a burst of energy to the surrounding environment. Radar technology is capable of determining the distance and angle of arrival of an incoming signal. A radar device can be used as a standalone

sensor, which is examining the environment and processing its results, or it can be used in combination with an RFID tag to retrieve identification information. Radar addresses midrange detection (20-50 meters) for underground applications.

C.6   Ultra High Frequency RFID (433 MHz & 860-960 MHz)

Ultra High Frequency RFID systems are among the most common solutions in proximity detection. These operate in a similar fashion to Radar RFID in which a radio signal is sent out and an active or passive RFID tag within range responds with identification information. These systems are suitable for mid to long range detection (20 – 100 meters) in both above and underground systems.

C.7   Very Low Frequency RFID(<15kHz)

Very Low Frequency RFID systems are also used for proximity detection. These operate in a similar fashion to UHF RFID in which a radio signal is transmitted and an active or passive RFID tag within range responds with identification information. These systems are suitable for mid to long range detection (20 – 100 meters) in both above and underground systems.

C.8   Wasp Time of Flight Technologies

Produced by CSIRO, WASP uses a robust mesh data Wifi communication to detect distances to fixed nodes using time of flight calculations. This system is suitable for up to 400 metres detection (line of sight) and is typically capable of producing better than 0.25 metres resolution. The typical update rate of the system is approximately 1-10Hz. A drawback of the system is the infrastructure required for implementation.

C.9   WiFi (430 MHz, 2.4GHz)

This system is similar to an RFID tagged system. Each object to be detected uses a wireless adapter that translates identification information into a radio signal and transmits it at the required frequency to the router. The router receives the signal and decodes it. The router is also able to transmit an interrogation radio signal to the object. These systems are suitable for mid to long range (20-100 meter) detection applications both underground and on surface.

C.10   Active and Passive RFID Tags

Several of the detection technologies rely upon the presence of a tag attached to the object to be detected. RFID communication can be either one or two way depending on the configuration of the system. There are three different configurations available for RFID systems.

- **Passive Reader Active Tag**
  The reader is a passive device that only receives signals transmitted from an active tag. An active tag has an on-board battery   and   periodically   transmits   its   identification   signal   to   the   reader.

- **Active Reader Passive Tag**
  The reader transmits interrogation signals, and upon receiving the signal, the passive tag uses the energy transmitted by the reader as its energy source, which it then uses to send a return identification signal. These tags work only in very close proximity for the radio frequency field to be strong enough to transfer sufficient power to the tag.

- **Active Reader Active Tag**

   This mode allows for the tag to be awoken upon receiving an interrogation signal from the reader. The battery is then used to transmit identification signals to the reader.

The primary drawback of RFID technologies is that when many tags are in one vicinity the system can become overloaded and fail to detect tags.

Appendix D South Africa Legislation

Reproduced in full from www.gpwonline.co.za as an important reference document for this project report and ongoing Proximity Detection System Interoperability discussions.

DEPARTMENT OF MINERAL RESOURCES

No. R. 125   27 February 2015

MINE HEALTH AND SAFETY ACT, 1996 (ACT NO 29 OF 1996)

REGULATIONS RELATING TO MACHINERY AND EQUIPMENT

I, **ADV.N.A.RAMATLHODI,** Minister of Mineral Resources, under section 98(1) of the Mine Health and Safety Act, 1996 (Act No. 29 of 1996) and after consultation with the Council, hereby amend Chapter 8 of the regulations made in terms of the Mine Health and Safety Act, as set out in the Schedule.

The Regulations shall come into operation 3 months after the date of publication in the government gazette, with the exception of sub-regulations 8.10.1.2(b) and 8.10.2.1(b).

ADV N.A RAMATLHODI, MP
MINISTER OF MINERAL RESOURCES

SCHEDULE

REGULATION AMENDMENTS

CHAPTER 8

TRACKLESS MOBILE MACHINERY

Amendment of Chapter 8 of the regulations

Chapter 8 of the regulations is amended by the addition of the following regulations:

Definitions

For purposes of regulation 8.10, unless the context otherwise indicates-

"Braking System" means a device or combination of devices capable of reducing the speed of a **trackless mobile machine** to a standstill;

"Combined Braking Systems" means a **braking system** consisting of a **service brake** and at least one of the following: either a **park brake** or an **emergency brake**;

"Emergency Brake" means an easily accessible device, which when applied, will bring the **trackless mobile machine** to a standstill under all operating and emergency conditions;

"Fail to Safe" means so designed as to activate and effectively perform its intended function without harm to persons and without human intervention;

"Park Brake" means a brake capable of holding fully loaded, parked **trackless mobile machine** stationary, at the maximum safe operating **gradient**, without the support of any other **braking system**;

"Remote Controlled" means the control and operation of a trackless mobile machine by an operator, by means of a wireless remote control device or a remote control device by means of a cable system, where the operator has direct physical sight of the **trackless mobile machine**;

"Service Brake" means the primary operating brake capable of retarding and stopping the fully loaded **trackless mobile machine**;

"Static Test" means a test carried out to determine the compliance of the brake holding power of a **trackless mobile machine** measured against the design specification or an appropriate safety standard;

"Trackless Mobile Machine" means any self propelled mobile machine that is used for the purpose of performing mining, transport or associated operations underground or on surface at a mine and is mobile by virtue of its movement on wheels, skids, tracks, mechanical shoes or any other device fitted to the machine, but excludes rail bound equipment, scraper winches, mono rail installations, static winches, draglines, winding machinery installations, track mounted conveyors and any equipment attached thereto;

"Trailer" means any vehicle that is not self propelled and needs to be towed by a **trackless mobile machine** by design.

Regulations

Collisions between trackless mobile machines and pedestrians

8.10.1   The **employer** must take **reasonably practicable measures** to ensure that pedestrian are prevented from being injured as a result of collisions between **trackless mobile machines** and pedestrian. At any mine where there is a significant risk of such collisions, such measures must include at least the following:

8.10.1.1   All electrically or battery powered **trackless mobile machines**, excluding shovels, bucket wheel excavators and overburden drills, must be provided with means to automatically detect the presence of any pedestrian within its vicinity. Upon detecting the presence of a pedestrian, the operator of the **trackless mobile machine** and the pedestrian must be warned of each other's presence by means of an effective warning. In the event where no action is taken to prevent potential collision, further means must be provided to retard the **trackless mobile machine** to a safe speed where after the brakes of the **trackless mobile machine** are automatically applied without human intervention.

8.10.1.2   All underground diesel powered **trackless mobile machines** must be provided with means:

8.10.1.2(a)   to automatically detect the presence of any pedestrian within its vicinity. Upon detecting the presence of a pedestrian, the operator of the diesel powered **trackless mobile machine** and the pedestrian shall be warned of each other's presence by means of an effective warning; and

8.10.1.2(b)   in the event where no action is taken to prevent potential collision, further means shall be provided to retard the diesel powered **trackless mobile machine** to a safe speed where after the brakes of the diesel powered **trackless mobile machine** are automatically applied. The prevent potential collision system on the diesel powered **trackless mobile machine** must **fail to safe** without human intervention.

Collisions between diesel powered trackless mobile machines

8.10.2   The **employer** must take **reasonably practicable measures** to ensure that persons are prevented from being injured as a result of collisions between diesel powered **trackless mobile machines**. At any opencast or open pit mine where there is a significant risk of such collisions, such measures must include:

8.10.2.1   Every diesel powered **trackless mobile machine** must be provided with means to automatically detect the presence of any other diesel powered **trackless mobile machine** within its vicinity; and

8.10.2.1(a)　　upon detecting the presence of another diesel powered **trackless mobile machine**, the operators of both diesel powered **trackless mobile machines** shall be warned of each other's presence by means of an effective warning; and

8.10.2.1(b)　　in the event where no action is taken to prevent potential collision, further means shall be provided to retard the diesel powered **trackless mobile machine** to a safe speed where after the brakes of the diesel powered **trackless mobile machine** are automatically applied. The prevent potential collision system on the diesel powered **trackless mobile machine** must **"fail to safe"** without human intervention.

Collisions between trackless mobile machines and rail bound equipment

8.10.2.2　　The **employer** must take **reasonably practicable measures** to ensure that persons are prevented from being injured as a result of collisions between **trackless mobile machines** and **rail bound equipment.** At underground operations where there ie a significant risk of such collisions, such measures must include warning the operators of the **trackless mobile machine** and the locomotive of each other's presence by means of an effective warning.

Trackless mobile machines running uncontrolled

8.10.3　　The **employer** must take **reasonably practicable measures** to prevent *trackless mobile machines* running uncontrolled.

Overturning of any trackless mobile machine

8.10.4　　The **employer** must take **reasonably practicable measures** to ensure that persons are prevented from being injured as a result of overturning of any **trackless mobile machine**. Roll overprotection structures must be fitted on **trackless mobile machines** if required in terms of the mine's risk assessment.

Objects falling onto operators and/or passengers of trackless mobile machines

8.10.5　　The **employer** must take **reasonably practicable measures** to ensure that persons are prevented from being injured as a result of objects falling onto operators and/or passengers of **trackless mobile machines. Trackless mobile machines** must be fitted with falling object protection structures to protect operators and passengers from falling objects if required in terms of the mine's risk assessment.

Persons inadvertently falling out of or being ejected from trackless mobile machines.

8.10.6   The **employer** must take **reasonably practicable measures** to ensure that persons are prevented from being injured as a result of operators and/or passengers inadvertently falling out of or being ejected from any **trackless mobile machine** in motion.

Braking systems

8.10.7   The **employer** must take **reasonably practicable measures** to ensure that persons are prevented from being injured as a result of brake failure. Such measures must include ensuring:

8.10.7.1   that *trackless mobile machines* are operated with adequate and effective braking systems;

8.10.7.2   all braking systems are adequately and routinely tested for intended functionality;

8.10.7.3   all braking systems are regularly maintained; and

8.10.7.4   that where a combined braking system is used, the design of the braking system is such that it complies with the requirements for the separate systems and that it **fails to safe**.

Restricted operator visibility.

8.10.8   The **employer** must take **reasonably practicable measures** to ensure that persons are prevented from being injured as a result of restricted operator visibility.

Fatigue while operating a trackless mobile machine.

8.10.9   The **employer** must take **reasonably practicable measures** to ensure that persons are prevented from being injured as a result of fatigue of operators. Such measures must include a fatigue management procedure for operators.

Battery charging facilities

8.10.10   The **employer** must take **reasonably practicable measures** to ensure that battery charging facilities are ergonomically designed, constructed and equipped with the following:
i) Adequate through ventilation;

ii) Adequate fire suppression equipment;

iii) Effective provisions to treat persons in the event of acid spillage; and

iv) Appropriate and adequate lighting.

Diesel refuelling facilities

8.10.11 The **employer** must take **reasonably practicable measures** to ensure that diesel refueling facilities are ergonomically designed, constructed and equipped with the following:
i) Adequate through ventilation;

ii) Adequate fire suppression equipment;

iii) Effective provisions to cater for oil and diesel spillages; and

iv) Appropriate and adequate lighting.

v) Surface diesel refueling facilities are in accordance with:

    a. SANS 10089-1 (2008): The petroleum industry Part 1: Storage and distribution of petroleum products in above-ground bulk installations.

    b. SANS 10089-2 (2007): The petroleum industry Part 2: Electrical and other installations in the distribution and marketing sector.

    c. SANS 10089-3 (2010): The petroleum industry Part 3: The installation, modification, and decommissioning of underground storage tanks, pumps/dispensers and pipe work at service stations and consumer installations.

Wheels, tyres and rims

8.10.12   The **employer** must take **reasonably practicable measures** to ensure that procedures are prepared and implemented to prevent persons from being injured as a result of the use, storage and handling of wheels, tyres and rims.

Access of persons to and from the trackless mobile machines

8.10.13   The **employer** must take **reasonably practicable measures** to ensure that **trackless mobile machines** are designed, constructed and maintained such that persons getting on and off, or working on them can do so safely.

Visibility of trackless mobile machines, skid mounted machinery and *trailers* to persons.

8.10.14   The **employer** must take **reasonably practicable measures** to ensure that **trackless mobile machines,** skid mounted machinery and *trailers* are visible to persons in their vicinity.

Unauthorised access to or operation of trackless mobile machines.

8.10.15   The **employer** must take **reasonably practicable measures** to ensure that unauthorised persons do not ride on or operate **trackless mobile machines.**

Isolation and lock-out of *trackless mobile machines*

8.10.16   The **employer** must take **reasonably practicable measures** to ensure that procedures are prepared and implemented for the safe isolation and lockout of **trackless mobile machines.**

Operating procedures

8.10.*17*   The **employer** must take **reasonably practicable measures** to ensure that procedures are prepared and implemented for the safe operation of **trackless mobile machines**.

Maintenance standards and procedures

8.10.18   The **employer** must take **reasonably practicable measures** to ensure that procedures and standards are prepared and implemented for maintaining **trackless mobile machines** in a safe operating condition.

Remote and remotely controlled trackless mobile machines

8.10.19   The **employer** must take **reasonably practicable measures** to ensure that remote control devices for **trackless mobile machines** using a wireless remote control device comply with:

a)   SANS 61000-4-2 (IEC 61000-4-2) Electrostatic immunity discharge test;

b)   SANS 61000-4-3 (IEC 61000-4-3) Radiated, radio frequency, electromagnetic field immunity test;.

c)   SANS 61000-4-4 (IEC 61000-4-4) Electrical fast transient/burst immunity test;

d)   SANS 61000-4-5 (IEC 61000-4-5) Surge immunity test.

e) SANS 61000-4-6 (IEC 61000-4-6) Immunity to conducted disturbances, induced by radio-frequency fields;

f) SANS 61000-4-8 (IEC 61000-4-8) Power frequency magnetic field immunity test; and.

g) SANS 61000-4-11 (IEC 61000-4-11) Voltage dips, short interruptions and voltage variations immunity test..

Trailers

8.10.20　　The **employer** must take **reasonably practicable measures** to ensure that:

a) the design and construction of any **trailer** is in accordance with specifications approved by a competent person, which specifications must take into account the intended use of the **trailer**;

b) the design and construction of **trailer** coupling and uncoupling mechanisms is such that coupling and uncoupling can be done safely and that no inadvertent uncoupling of the **trailer** can take place; and

c) procedures are prepared and implemented for the safe operation of **trailers**.

Towing and recovery of trackless mobile machines

8.10.21　　The **employer** must take **reasonably practicable measures** to ensure that procedures are prepared and implemented for the safe recovery and towing of **trackless mobile machines**.

Roadway conditions

8.10.22　　The **employer** must take **reasonably practicable measures** to ensure that the design, construction and maintenance of roadways are appropriate for the type and category of **trackless mobile machine**

Selection, training, appointment and licensing of trackless mobile machine operators

8.10.23.1 The **employer** must take **reasonably practicable measures** to　ensure that procedures are prepared and implemented for the selection, training, appointment and licensing of **trackless mobile machine** operators, which procedures must include:

8.10.23.1 physical and psychological pre-selection criteria;

8.10.23.2　a training programme for **trackless mobile machine** operators, covering:

i) theoretical training in a training Centre;

ii) practical training; and

iii) on the job training.

8.10.23.3 assessment of the trainee, on successful completion of the training programme, by a competent person;

8.10.23.4 that only operators, assessed to be competent are authorised in writing by the responsible engineer to operate **trackless mobile machines;**

8.10.23.5 that operators of **trackless mobile machines** are authorized in writing by their supervisor to operate **trackless mobile machines**. Such authorization must detail their duties, responsibilities, limitations and areas of operation.

8.10.23.6 when an operator has not operated a **trackless mobile machine** for a period of two years, such operator is re-assessed to be competent by a competent person prior to being issued with a new license.

8.10.23.7 that every operator of **trackless mobile machines** is issued with a license containing at least the following:

i) a photograph to positively identify the operator;

ii) the **trackless mobile machine** types which the operator may operate;

iii) date of issue and expiry date; and

iv) the operator's company identification number.

Pre-use inspection procedures

8.10.24 The **employer** must take **reasonably practicable measures** to ensure that procedures are prepared and implemented for inspecting **trackless mobile machines** immediately prior to use, which procedures must include:

8.10.24.1 that the operator of the **trackless mobile machines** physically inspects and ensures that the brakes, lights and any other defined safety features and devices are functioning as intended prior to setting such **trackless mobile machines** in motion;

8.10.24.2 pre-use check lists that have to be completed by all operators of **trackless mobile machines** at the beginning of their shift. Such check lists must clearly identify all the components, features and functionalities to be inspected by the operator. For each component, feature or functionality, the check list must clearly indicate the pre-established criteria under which the **trackless mobile machines** may or may not be put in motion.

Reversing over the edge of a stockpile

8.10.25 The **employer** must take **reasonably practicable measures** to prevent any **trackless mobile machine** reversing over the edge of a stockpile or dump.

Inadvertent movement of the trackless mobile machine

8.10.26 The **employer** must take **reasonably practicable measures** to prevent inadvertent movement of any **trackless mobile machine** whilst parked.

Mandatory carrying of license

8.10.27 All operators of **trackless mobile machines** must have their originally issued license on their person whilst operating any **trackless mobile machine**.

Certain regulations not applicable

8.10.28 Regulations 8.10.23 and 8.10.27 do not apply to **trackless mobile machines** licensed under the National Road Transportation Act 2000 and not used for primary mining activities.