Final Report:

C18025: New Knowledge Elicitation Methods to Capture Risks Related to Mobile Mining Equipment

Sue Leveritt, Tim Horberry and Tristan Cooke

Minerals Industry Safety and Health Centre,

University of Queensland,

Brisbane, Qld 4072

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Abstract

This report describes research that examined two innovative knowledge elicitation techniques to collect information about mobile mining equipment risks and to ultimately help identify potential controls. It focused on both experienced and inexperienced operators. The work was in three parts:

Part 1. The use of the technique called 'Critical Decision Method' to analyse incidents involving mobile mining equipment- especially for experienced operators of such equipment. It was found that this technique was highly effective in uncovering how operators make sense of their working environments. By 'getting inside the heads of operators' it revealed important aspects that were not uncovered in previous incident investigations that used other techniques.

Part 2. The development of a process for informal feedback, specifically verbal interactions, to be used to capture information about risks - especially for inexperienced operators during simulator training. The work focussed on informal feedback regarding mobile mining equipment use as part of a wider work system. As such, issues identified included communication drivers and barriers, equipment design risks, training deficiencies or limitations and types of verbal interactions. The interactions model shows potential as a process for facilitating improved training outcomes, such as operator decision making and situational awareness. It could also be used to identify training needs triggered by equipment reliability data and other operator issues.

Part 3. Ongoing dissemination of the results from Parts 1 and 2 to the Minerals Industry via the EMESRTgate web portal (www.mirmgate.com/emesrt), to member companies of the Earth Moving Equipment Safety Round Table (EMESRT) and through teaching materials at the University of Queensland. Project outcomes are also being presented at relevant industry conferences and other forums, and will be published in recognised journals- examples of these are shown in the Appendix.

Overall, the results of the research are a better user-centred understanding of equipment/operator related risks and where improvements could be implemented in incident investigation, communications, equipment design and training. In addition, the knowledge elicitation techniques developed and tested could be suitable for use in other coal mining situations, for example, in risk assessments.

Executive Summary

Project Objectives

The objective of this project was to examine two innovative knowledge elicitation techniques to collect operator-centred information about equipment design issues, training gaps, incident investigation gaps and communication risks. In more detail, the aims of this project were to:

- Capture the verbal exchanges between experienced trainers and less experienced trainees during training delivered via simulation and other equipment training aids as a means of identifying issues that impact directly on normal truck operation;
- Review this information feedback about operational tasks, in conjunction with data collected during simulator training, with a view to further understanding the operational risks involved in haul trucks and other mobile equipment;
- Use the Critical Decision Method (CDM) to enhance knowledge about near misses and incidents through worker interviews and thereby uncover processes by which a critical incident is detected and causal factors are arrived at;
- Compare the CDM results obtained to other incident investigation methods, thereby, validating the use of the CDM tool in the mining industry;
- For both parts of the project, collect data in a naturalistic or simulation setting with a focus on critical events to further understand these events in the worksite context;
- Improve identification and understanding of risks related to mobile equipment, and using this body of knowledge to further improve training techniques, incident investigations and equipment designs.

Scope

This project targeted the *Improved Health and Safety Program* category of the 2008 ACARP call for Research Proposals, Open Cut Mining Priorities section, namely *General improvement to the safety of mining and maintenance operations through novel procedural, operating, or equipment changes*.

The focus for data collection was limited to three key areas at each of the participating sites – the simulator training environment, mobile mining equipment operators and field trainers involved in pre-strip and mining production, and to a lesser extent, the maintenance sections, both workshop and field maintenance.

Main Findings and Conclusions

The report is in two parts; the first part describes the Critical Decision Method research, and part two describes the Informal Feedback work. For both parts, a review of literature is presented, the methods used are described, and then the obtained results/findings are presented. Also for each part, a discussion is presented and conclusions and recommendations are made. The main findings of each part are:

Part 1: Critical Decision Method

The Critical Decision Method (CDM) is a structured interview process that can be used to elicit knowledge from operators about their decision-making and problem-solving processes during critical incidents. The method involves the use of 'probe' questions to uncover the kinds of knowledge on which decisions are based, and the technique allows interviews to shift operators' thinking from operational and general accounts of an incident into more descriptive retelling of how they solved problems, including using cues from their environment, during the critical incident.

Following CDM's successful use in other industries, it was anticipated that capturing and analysing information on mobile equipment related coal mining critical incidents and the decision making around these incidents will result in valuable information. The main findings of the research supported that, and showed that CDM is indeed a very useful tool to '*get in the head*' and better understand the mindset of the personnel involved in incidents. The method is of increasing value with more complex incidents. The research also found that CDM uncovered important details not in current incident investigation reports - it is believed that such information could have a key benefit to help fully understand (and learn lessons from) the incident. As an example, one incident examined was a haul truck with its dump tray raised striking a reject bin chute. In this incident the CDM process found that a visual warning of the tray up was possibly obscured/made less conspicuous by sun glare, a potentially important factor that was not included in the previous incident report.

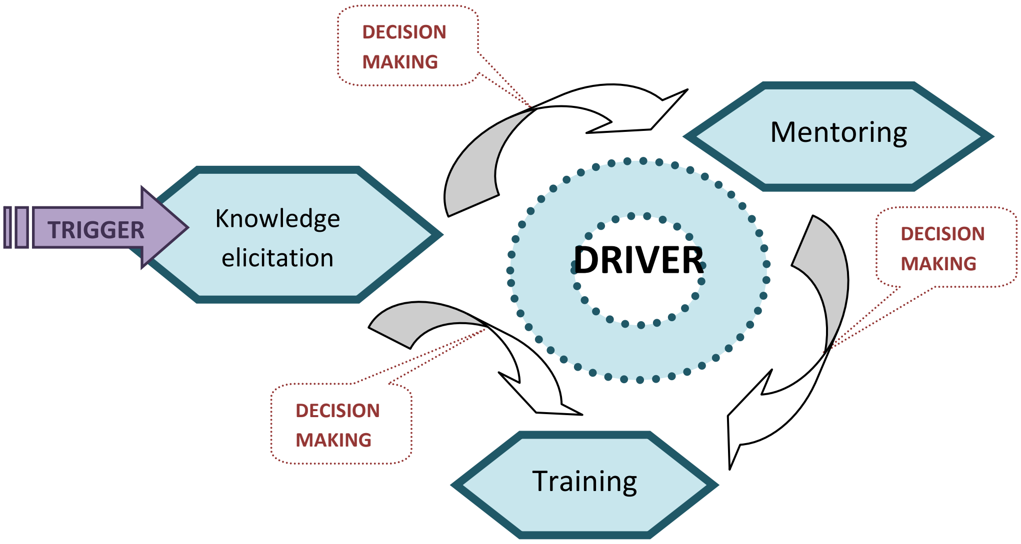
As such, further work with this technique (to integrate it into incident investigations and to use it proactively) is strongly recommended.

Part 2: Informal Feedback

Mining is a dynamic, people intensive industry where communication is predominantly verbal. The high level of interaction between people, equipment and the natural environment demands a heightened level of situational awareness to ensure good decision making to manage the hazards associated with these interactions.

It was anticipated that experienced operators would be a valuable source of information to help improve trainee operator performance and decision making. Analysis of the data confirmed this expectation and also highlighted the potential to capture information about equipment design inadequacies that impacted on routine operation.

Information about interaction types, nodes and communication flow was used to construct a model of workforce engagement based on the existing organisational framework and preferred methods of communication that could provide useful knowledge for training about issues such as sensory cues and equipment design limitations.



This type of knowledge could inform training strategies to

- Refresh operator skills, regardless of experience
- Improve situational awareness related to mobile equipment performance, equipment design issues, site hazards and procedures

Improved human performance in these areas could reasonably be expected to lead to better decision making during critical events.

The future step is to validate this model of workforce engagement by applying it for a specific purpose, such as improved understanding about risks associated with the introduction of proximity detection equipment and design of training to incorporate this knowledge.

Industrial Applications

The primary industrial applications are for individual mine sites, corporate level policy (eg incident investigation techniques and a framework for training needs identification that focuses on improving decision making and situational awareness), and through improved equipment design and training packages. In all applications, the emphasis is upon an operator-centred approach to training, routine operations and incident investigation.

Outcomes and Benefits

A raft of outcomes and benefits are being produced from this work which is specifically addressing the following ACARP Open Cut Mining Priorities:

- General improvement to the safety of mining and maintenance operations through novel procedural, operating, or equipment changes (eg the successful CDM work for incident investigation)

  - Development of training tools to transfer the benefits of improved techniques to operators (as evidence in the model created in the Informal Feedback component)
  - The development of practical methods to understand and reduce the negative impact of operational practices (again, the ultimate goal of both components of this project is to eventually develop practical tools to assess risks, improve training and learn better lessons from incidents)

Specific outcomes:

- Development of a communication/data collection process for capturing and analysing informal feedback about haul trucks and other mobile equipment operation and design issues.
- Adoption of a human factors approach to improving performance
  - The proposed informal feedback model harnesses verbal interactions, the most common form of communication at mine sites, as the primary source of information for improving decision making skills through simulator training. This strategy represents a human factors approach to improving communication across three key areas of the business - training, operations & maintenance – by implementing a process that fits comfortably with the characteristics of the workforce.
- Development of draft behavioural data collection processes for capturing and analysing narratives of critical incidents/decisions from mobile equipment operators. In particular, the Critical Decision Method revealed important aspects that were not uncovered in previous incident investigations that used different techniques.

Industry wide outcomes:

- The knowledge elicitation techniques developed and tested could be suitable for use in other mining sectors, so may be powerful additions to help capture risks associated with other types of equipment and general mining activities such as risk assessments.
- It is also expected that adoption of the proposed verbal interactions model will necessitate improvement in the capacity of individuals to participate in meaningful consultation about mobile equipment and other risks, contributing ultimately to a mining OHS culture that is considered to be leading practice

Benefits:

- Ultimately, improved training techniques for simulator training, including coaching and mentoring skills, training materials development and an innovative approach to identifying training needs
- Improved associated non-technical skills, such as communication and leadership, that drive consultation between management and workers

- Improved incident analysis techniques, which capture an operator-centred perspective better than current investigation methods.
- Eventually, improved equipment designs and better integration of new equipment
    - CDM is generally applied to the investigation of actual incidents with existing equipment, so its primary use in the Asset Lifecycle is the operation and training stage, with the potential to lead to modifications or retrofits. In this manner the method could be used to determine how a design of mobile mining equipment might be modified to facilitate improved decision making. This may be through, for example, greater relevance of audible and visual information given by in-cab displays to haul truck operators or how to better reveal the information that maintainers used to diagnose equipment faults.
    - There is also the potential to use CDM at the concept stage and prototyping within the design stage. Designers may use the CDM process to engage experts in a forwards-looking CDM in a conjured situation to anticipate how design changes might affect their decisions. It could also be used to explore actual human performance on a prototype or simulator to predict how decisions will be made in the field. This is a promising new direction, but the research needed to achieve this is outside the scope of the current project.

Technology Transfer

To meet the main objectives of this work, the two streams of this research project have been disseminated in several ways to date.

1. Mine site level
    a. A presentation about the informal feedback aim, objectives & work program was delivered to the training forum in November 2009 of the coal mining company supporting this research
    b. A future presentation outlining the findings of the project will be delivered to the training forum (in late 2010 or early 2011) of the coal mining company supporting this research
2. Corporate level
    a. Presentations of the findings emerging and methods used have been given to corporate level representatives of the coal mining company supporting this research; the worth of the work was acknowledged by these professionals and it is hoped that further work in these areas might result (for example, in using CDM in future incident investigations)
    b. The research team will also seek opportunities to disseminate the findings to the Safety Sub Group of the ACARP Open Cut Committee.
3. Original Equipment Manufacturers (OEMs) and simulator developers.
    a. Ongoing discussions with a leading simulator manufacturer about how to use the informal feedback findings.

b. Initial discussions from both parts of the project about ultimately passing onto OEMs the results that may be related to mobile mining equipment by linking project outcomes to EMESRTgate (www.mirmgate.com/emesrt). This is the online information dissemination tool managed by MISHC and used by the Earth Moving Equipment Safety Round Table (EMESRT) to provide information to OEMs about equipment risks. To date, the initial discussions have focused on the methods used in this project; should further ACARP-funded research be conducted, then specific results would be disseminated via EMESRTgate.

4. Initial publications have included (see Appendix 9 for further details)

   a. A presentation at a conference about operator-centred design of transport and industrial equipment (Horberry and Cooke, 2010).

   b. A poster displayed at the NSW Minerals Council OHS Conference (Leveritt, May 2010).

   c. Poster accepted for presentation at the Human Factors & Ergonomic Society's Annual Conference in November 2010.

   d. A presentation accepted for the Queensland Mining Industry Safety & Health Conference in August 2010 (Leveritt, 2010).

   e. Poster accepted for presentation at the Human Factors & Ergonomic Society Europe Annual Conference in October 2010 (Horberry, 2010).

   f. A presentation at the Safety Institute of Australia's Visions 2010 Conference will be presented in October 2010 (Leveritt, 2010).

In addition, in the longer term, it is the intention to disseminate the results of this work through other mining conference presentations, scientific journal papers and ongoing PhD research at the University of Queensland by one or more of the report authors.

Recommendations for Future Research

Two recommendations for future work in this area are proposed, these are:

1. To conduct further work with CDM in three areas: apply it to 'repeat' mobile equipment incidents, employ in an actual incident investigation (integrate, apply and evaluate it in an ICAM investigation) and trial the technique's use as a proactive method, such as when introducing new controls or equipment (eg collision detection systems).

2. Given the need for the mining industry to provide new starters with as much experience as possible, and for the existing workforce to maintain currency with new equipment technology and designs, it is strongly recommended that the proposed workforce engagement model be implemented as a protocol for improving operator performance through simulator training.

Part 1: The Critical Decision Method

Review of literature

The review of literature presented gives important background information about the Critical Decision Method (CDM) and how it has been successfully used in other work domains.

What is the Critical Decision Method?

The Critical Decision Method (CDM) is a structured interview process that can be used to elicit information and knowledge from experienced operators about their decision-making, understanding and problem-solving processes during non-routine critical incidents (Crandall, Klein and Hoffman, 2006). The method involves the use of 'probe' questions to uncover the kinds of knowledge on which decisions are based, and the technique allows interviews to shift operators' thinking from operational and general accounts of an incident into more descriptive retelling of their problem solving processes during the critical incident.

The Critical Decision Method builds on the earlier Critical Incident Technique that was first developed during World War II that was applied in a variety of situations through the study of near misses (Flanagan, 1954). Going beyond the Critical Incident Technique in terms of a more structured and detailed method, the CDM is often found to be effective in revealing expert's knowledge, especially tacit knowledge, reasoning, sense-making and decision strategies (Crandall, Klein and Hoffman, 2006). Although it relies in part on memory, it has been argued that experts mostly have clear memories of salient or unusual safety-related incidents (Crandall, Klein and Hoffman, 2006). Previous work has examined CDM in other fields such as nuclear power, aviation and medical error, especially to identify perceptual and cognitive needs for aiding decision making, and to investigate incidents by reconstructing and understanding how operators made sense of the situation they were faced with (Hoffman, 2008).

Coal Mining Incident Investigations and Operator Narratives

Traditional incident investigation techniques deal mainly with the identification of a sequence of events hoping to identify unsafe acts or conditions: that is, ***what*** happened (Doytchev and Szwillus, 2009). Some go beyond looking at causal analysis to identify the relationship between incident events and the breakdown of any controls; ***how*** it happened (Simpson, Horberry and Joy, 2009). However, it has been suggested that newer techniques are required to better understand what factors influence and predispose the decisions of mining equipment operators (Horberry, Burgess-Limerick and Steiner, 2010). Innovative investigation techniques are needed to help understand the incident, and decisions, from the perspective of the person making those decisions to give an appropriate representation of why the incident occurred. They would be particularly useful in real world situations where people made critical decisions that significantly contributed to the occurrence or prevention of an incident. The CDM is perhaps the most commonly used and researched method here. For example, Tichon successfully used CDM to elicit knowledge from train drivers, finding significant numbers of environmental cues, actions to be taken and possible errors (Tichon, 2007). It assumes that people were attempting to make sense - sensemaking - of the information and situation at hand (Klein, 2008).

Therefore, this part of the research reported here aims to understand the incident, and decisions, from the perspective of the person making those decisions: ***why*** it happened.

Decisions in Complex Sociotechnical Systems are often made using tacit or inert knowledge; knowledge that persons have but never previously explicitly considered or expressed (Simpson et al, 2009). Therefore, simply asking operators what they were thinking at the time of an incident is unlikely to be enough. So, in complex situations, knowledge has to be specifically elicited from the persons involved.

To the knowledge of the authors, no systematic investigation of CDM has been undertaken in coal mining. Perhaps the closest study to apply something similar in the minerals industry was performed by Dal Santo (2005). Her work investigated ground control (that is, rockfall prevention) decisions made by mining engineers working in underground mines. Two of her main findings were the importance of situation assessment (that is, the ability of mining engineers to be able to 'read the ground') and how the characteristics of decision making changed not only with experience, but also with motivation, expectation and specific hazard knowledge. The key focus of Dal Santo's work was improving the design of ground control education and training; it appeared that CDM and related approaches could be of considerable benefit in understanding ground control decisions in mining, and developing better training based on this understanding.

In sum, CDM is seemingly well suited to understanding incidents related to coal mining equipment from an operator-centred perspective, where the decisions of the operators in a complex work environment are often linked to causing, or preventing, accidents and incidents.

Previous CDM work

Aside from the Tichon (2007) work mentioned above that applied CDM to train driving in Australia, previous work has examined CDM in other fields such as nuclear power, aviation and medical error. In such work, CDM has been used for (Hoffman, 2008):

- Identifying perceptual cues in various work situations and therefore how tasks, equipment and procedures can be redesigned to improve safety;
- Identifying the level and nature of expertise required for different jobs;
- Understanding decision making and identifying perceptual and cognitive needs for aiding decision making; and
- Investigating incidents by reconstructing and understanding how operators made sense of the situation they were faced with.

For example, the CDM technique has been used within the aviation industry to identify Expected Safety Behaviours and Markers (Simpson, Edkins and Owens, 2002) which identify a list of expected safety behaviours which are then further used to enhance training programs, identify human factors issues and enhance crew resource management skills. The information obtained about the cognitive aspects of critical incident situations has proved a valuable resource for future training, providing scenarios for organisation and site specific purposes in error management.

The CDM has therefore proved successful in a variety of naturalistic environments and is recognised as a valid method of knowledge elicitation (Crandall, Klein and Hoffman, 2006). Following CDM's use in other occupations, it was envisaged that capturing and analysing information on mobile equipment related critical incidents and the decision making around these incidents would result valuable information emerging for the coal mining industry. The use of this technique within the mining industry may therefore enable the assessment of skilled operators' perception and decision making during critical incidents involving mobile mining equipment.

Scope of the Research

The overall goal was to investigate if CDM could provide valuable information about the decision making of operators involved in mobile mining equipment incidents or near miss events. One particular aim was to establish if CDM revealed additional important information about operator decision making and sensemaking compared to current incident investigation methods.

Method

Procedure: CDM-Mining Process Description

The research employed a 'classic' CDM method (as outlined by Crandall, Klein and Hoffman, 2006), adapted where required to the coal mining context (eg in the terminology used). The CDM interview process was undertaken by two researchers; one primarily an interviewer and one primarily a note-taker. The interviewee was expert in the work domain (ie an experienced mining equipment operator) but who had previously been involved in an incident. The interview took up to two hours, though significantly more time was needed for the preparation and analysis before and after the interview respectively. It took place in an office or other location that was suitably quiet and largely free of interruptions.

The CDM process used in this research occurred in four stages (also known as 'sweeps'), with a series of structured probes to re-construct the incident. The multiple 'sweeps' were made to progressively deepen understand the challenges faced and strategies employed by decision makers to cope with the situational, environmental and domain demands [Crandall et al, 2006]. The four stages used, know as sweeps, are described below and more details of them are given in Appendix 1.

Sweep 1: Incident Identification and Selection

This stage focused on selecting an appropriate incident which would benefit from greater understanding. It was required that the interviewee must have been a decision maker or 'doer' in the incident.

A review or screening of multiple incidents was often required in order to find one that was appropriate for the purpose of this research. The review was required to make sure that the interviewee was an active decision maker in the incident, and also that they were willing to discuss it (as the research was voluntary). Once an appropriate incident has been identified the interviewee was asked to give a brief account of the story from start to end. They often needed to be guided through the process and kept on track by not talking about other aspects that were not relevant to the purpose here. Notes were taken whilst the interviewee talked to provide the 'bones' for the subsequent Sweeps.

Sweep 2: Timeline Construction and Verification

This sweep of the incident aimed to gain a clear structure of the incident that was refined and verified with the interviewee. During this sweep the initial account of the incident was expanded. It began with a merge from Sweep 1 where an interviewer repeats what they have recorded with any additional comments or corrections by the interviewee. So the interviewee was encouraged to correct faults and add relevant information to ensure the account was consistent, accurate and appropriately detailed. The researchers then constructed a timeline of the incident in relevant chunks: distinct actions, occurrences or decisions. The timeline constructed was visible to the interviewee - using a whiteboard or large pieces of paper. Figure 1 shows one of the interviewers with a drawing of the incident location and a list of the order of events.

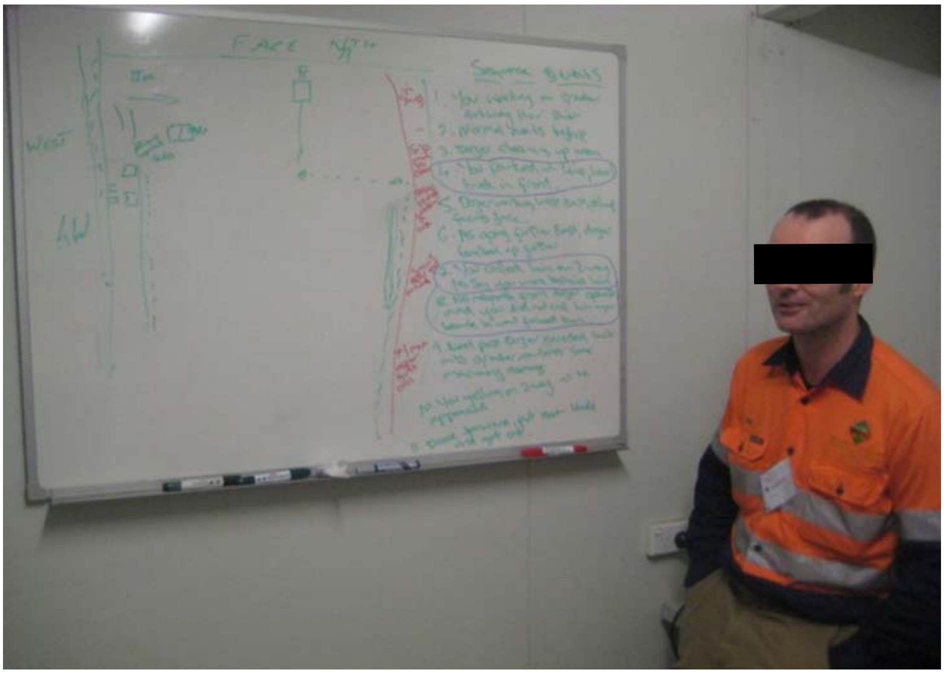


Figure 1: CDM in process at a mine site

Following construction of the timeline, the critical junctures, or decision points, where decisions were made (and actions subsequently undertaken) were identified by the interviewers. This was done by examining the timeline and identifying exactly where the interviewee made such decisions- i.e. he/she was an active decision maker at that point. Following this, the CDM moved to the next Sweep.

Sweep 3: Deepening Understanding

In this Sweep, the researchers attempted to understand the interviewees' sensemaking of the situation. It followed previous CDM researchers' recommendations who stated that it needs to:

> *"…get inside the experts head and see the world through his or her eyes... What is the story behind the story? Based on the first two steps (the researchers) know what happened... but what did (the interviewee) know, when did they know it, how did they know, and what did they do with what they knew?"* (Crandall, Klein and Hoffman 2006, 78-79).

To gain this information the researchers reviewed the critical junctures again, asking the interviewee a series of deepening probe questions. The probes used depended on the event but were generally aimed at determining the information available in the incident, the meaning of this information as interpreted by the interviewee and the thoughts and issues they provoked. At this stage the interviewee usually gave a rich understanding of the event, though occasionally, they may have been unable or unwilling to share their experiences (as the research used volunteer participants then they were more likely to be unwilling as compared to during an actual incident investigation; hence using CDM as part of a real investigation should mean that there would be far fewer unwilling participants as they are 'compelled' to be part of the investigation. Of course, where the mine site culture is proactive or generative then the unwillingness would be reduced even further). A regular pitfall was for participants to drift to generalisations and, whilst this might reflect their experience, skills and knowledge, it was important that the interviewee gave information on the selected incident.

The CDM deepening probe questions, developed by Crandall, Klein and Hoffman (2006) from their previous experience of the technique were used; these are shown in Appendix 1 and the data collection sheets used are shown in Appendix 2. These probes were not a complete list of what could be asked, nor were they necessarily relevant in all situations, but rather they provided a starting point for the researchers to begin the deepening process.

Sweep 4: "What if" Queries

The last Sweep involved the interviewers posing a number of hypothetical changes to the event in the form of 'what if' questions. The participant was asked how their responses would have altered and/or if the outcome might have changed. This was to gain a deeper understanding of the experience, skills and knowledge of the interviewee. It was also useful in seeing if the information gained could be generalisable. The CDM "what if" probes, previously developed by Crandall, Klein and Hoffman [2006] from their experience of the technique, are listed in Appendix 1, together with the data collection sheet used (Appendix 2). Again, not all of these probes were necessary in all situations.

Data collected

Before data collection, the research was approved by the University of Queensland's Human Ethics Committee.

Ten CDM interviews were successfully completed at site visits made to two open cut operations (surface coal mines) in Central Queensland. In addition to purely analyzing the data for the ten incidents, in approximately half of these events a formal local site incident investigation had previously taken place using the standardised Incident Cause Analysis Method (I-CAM). I-CAM is a prevalent incident investigation method used in mining (De Landre and Gibb, 2006); it is based on James Reason's models of organisational accident causation (Reason, 1997) and Jens Rasmussen's skill/rule/knowledge model of human error (Rasmussen, 2005). I-CAM provides a classification system for various local or latent factors that may be involved in an incident (De Landre and Gibb, 2006). The CDM results were compared to these existing incident reports, in particular examining where CDM added additional insights.

To test the robustness of the CDM method, seven CDM interviews at an underground gold mine in Queensland were also completed; these focused on investigating the need for, and effectiveness of, a proximity detection system.

Open Cut Coal Mines

The following is a brief description the ten incidents studied at the two open cut coal mines. Interviews comprised eight specific incidents and two general categories of incidents. The interviews were conducted with operators of mobile mining equipment of various levels of experience, but mainly experienced operators now working primarily as trainers mainly due to them being more easily available (of course the method is applicable to be used with all operators). The specific incidents reviewed were:

1. Uncontrolled Drop of Shovel Bucket Colliding with Reversing Haul Truck

> Interviewee was operating a shovel when the bucket of the shovel dropped suddenly whilst loaded. A haul truck was backing towards the shovel at that time and reversed into the shovel, though if the bucket had dropped slightly later it would have landed in the tray of the haul truck.

2. Rollover of Bulldozer Whilst Pushing/Cleaning Overburden

> Interviewee was operating a Bulldozer, whilst being supervised by another operator in a nearby bulldozer, to clean overburden when the shovel had recently been. When reversing backwards the interviewee veered slightly to the left into the lower cut made by the other dozer resulting in the interviewee's dozer rolling onto its roof.

3. Fire at a Fuelling Station

> Operator was an apprentice offsider to a fuel truck driver who connected the fuel hoses to fuelling stations that usually automatically stop when being full. However, on this occasion the fuel started to spray out of the top of the fuelling station landing on the turbo engine of the fuel truck, eventually starting a fire that destroyed the fuel station and the truck.

4. Drove Haul Truck with Dump Tray Up striking Reject Bin Chute

Interviewee was the operator of a haul truck that was not limiting gear and speed of haul truck when tray is up. After parking up near reject bin, maintainer attempted to fix the problem. On test run to see if the problem was corrected the tray did not descend and struck the reject bin chute causing damage to the truck and chute.

5. Rollover of Troop Carrier

A rollover of a troop carrier occurred when descending a haul road at the mine where the interviewee was the operator.

6. Collision between Bulldozer and Grader

A collision when a bulldozer cleaning the face near a digger reversed into a stationary grader. The grader, driven by the interviewee was parked behind haul trucks waiting to be loaded by the digger. The nature of the situation was that though the bulldozer reversed into the grader the interviewee made critical decisions.

7. Engine Fire in Digger

An engine fire of when the interviewee was operating a Leibher 994 digger with the potential for serious injury.

8. Loss of control of Haul Truck Down Ramp

The interviewee was operating a haul truck and, not long after it had begun raining, spun out of control whilst exiting the dump site and descending a cornered haul road ramp spinning over 180 degrees and striking a bund wall.

The two general types of decisions incidents reviewed were:

9. Decision Making of Maintenance when Haul Truck Engine shows Low Horse Power

This CDM interview was conducted with a haul truck maintenance supervisor. The supervisor was unable to recall any specific incidents related to haul truck maintenance. Therefore, a CDM was conducted on the common and complex decision making task when a haul truck engine shows low power. Decisions were interestingly made with competing demands between operation and maintenance and trial and error process starting with the most cost-effective option that has often remedied this type of problem in the past.

10. Missing Alignment when Reversing Haul Truck into Shovel.

The interviewee in this case was a contract haul truck driver. Again the interviewee was unable to discuss a particular incident (again, it is stressed that they were volunteers in this research, so not compelled to take part here). However, they noted that one of the most difficult task was reversing the haul trucks into the shovel. The usual strategies and decisions related to this task were analysed that could be used to consider general incident causation and prevention when reversing haul trucks.

Application of CDM to another area of mining

Additional, seven CDM interviews were also conducted at an underground gold mine, relating to the use of a proximity detection system.

Knowledge and experiences were elicited from operators involved in previous mobile equipment collisions or who used the current proximity detection system. This allowed a detailed user-centred perspective of equipment operation tasks and the current controls in place. Initially, it was planned to directly use the CDM to elicit knowledge about vehicle incidents and near misses, on the basis that these represented 'tough cases' which has previously been found to be an efficient way of eliciting knowledge from experts. However, the interviewees were unable to recall real incidents to analyse (partly because of the newness of the system, in which no incidents had been formally reported at that time).

Instead, a modified CDM was used where the operators were asked to consider where they felt the more complex areas of road and vehicle interaction were in a mine and construct a fictional, but possible, scenario of a collision occurring. This included the position of the vehicles in the mine and the other barriers that would need to fail in order for proximity detection to be useful. Though not real scenarios, it did show a logical path to failure, and helped determine what features a proximity detection would need for it to be effective. These features could then be compared to the current RFID (Radio Frequency Identification) proximity detection system in place. Seven operators were interviewed by two experimenters. In every interview the operator was able to construct plausible, though admittedly unlikely, scenarios where a collision could occur and a proximity detection system could be useful should other controls fail. This included scenarios in the underground, on surface haul roads and around workshop areas.

Results

Coal Mining Incident Results

The main findings obtained for the 10 incidents examined at the open cut coal mines are shown in Table 1 below[1].

[1] Regarding the I-CAM comparison aspect, it should be noted that it is unknown how rigorous these previous I-CAMs were. Future research is planned to use an expert to do an ICAM and a CDM to see what additional information is collected by the CDM.

Also, it should be noted that the CDM findings below have only one interviewee, therefore were potentially one sided. Further CDM research should interview all the people involved (supported by documents/technical experts as required) to help further validate the process.

Table 1: CDM findings for the ten coal mining incidents

#	Incident description	Main Incident Notes from CDM	Main CDM Findings and Key Decisions	Compared to I-CAM	Additional findings compared with I-CAM
1	Uncontrolled drop of shovel bucket, so colliding with a reversing haul truck.	• Interviewee was operating a shovel and loading haul trucks when there was an uncontrolled drop of the bucket. • At the time a haul truck was backing under the shovel. The bucket dropped just before the haul truck was under the shovel but it could not stop before reversing into it. • Had the drop happened later it could have fallen into the tray of the haul truck.	• There is a tendency for the bucket to 'drift' downwards if not actively pulled back. This might have caused the operator to pull back on the leaver when the bucket fell, rather than pressing the emergency stop button. • Operator noted that a fault error displayed on the screen that he had not previously seen, and was not in the instruction manual.	YES	• The I-CAM report does not note how the driver attempted to halt the bucket. • Error message that the driver claims to have seen is not noted. • It also has only a very short description of the incident and one word answers to I-CAM questions, which would make it difficult to ascertain a pattern should a similar event reoccur.
2	Rollover of bulldozer whilst pushing/cleanin g overburden (top soil)	• Interviewee was a trainee bulldozer driver pushing back overburden alongside a trainer operator. • The trainer was working on the overburden in another bulldozer and paying only little attention to the trainee. • At the point of the rollover he was working in a 'cut' directly next to the trainee and creating a lower level. • Trainee was attempting to reverse straight back, but was actually going at an inaccurate angle and the vehicle fell into the trainer's 'cut'.	• The lack of awareness by the trainee that he was not reversing in a straight line was a key cause of this incident. • Factors increasing the likelihood of this error included the limited rear vision, the lack of light (night shift) and perceived pressure to keep up with the trainer's pace. • The trainer's lack of intervention (eg by radio communication) in this was also a key cause. • Additionally, having another bulldozer working in close proximity created the conditions (ie the 'cut') where the bulldozer could roll.	YES	• The supervision of the trainee was the key factor noted in the I-CAM and the practice of having a trainer work next to a trainee was ceased. • Key factors relating to the error reversing appear to have been overlooked or not identified, such as the low lighting, perceived time pressure and lack of vision out of the cab.

#	Incident description	Main Incident Notes from CDM	Main CDM Findings and Key Decisions	Compared to I-CAM	Additional findings compared with I-CAM
3	Fire at a fuelling station	• The fire occurred at the fuelling station when the interviewee was working as an offsider (helper) to a fuelling serviceman. • Sometime after connecting a 'wiggins fitting', which automatically fills the fuel station using the engine of the pump, both participants noticed that fuel was spraying out of the top of the fuel station. • This fuel landed on the top of the turbo of the refuelling truck and caught fire immediately, at which point both the serviceman and the interviewee fled the area and a large fire ensued.	• The serviceman attempted to cancel pumping using the control system, indicating that an emergency stop was not fitted or available. This may have been exacerbated by the fuel auto shut off not working in the first place and therefore possibly leading to operator inattention due to their expectation that it will shut off (ie over-reliance on a system /process) • Vehicle movement was isolated using the park break. In another case this might have prevented the vehicle being moved which would have stopped the fuel hitting the fire. • There was no protection/barrier between the hot engine and the fuel exiting.	**YES**	• The I-CAM noted a corrective action was fit a 'deflector' on the fuel tank to assist in preventing fuel heading in the direction of the pumping vehicle. Additionally, a cover was placed over the engines. • The difficulty in cancelling the fuel flow, and the emergency stop, was not noted. • The potential issue of unengaging park brake isolation in an emergency was not addressed.
4	Drove Haul Truck with Dump Tray Up and Striking the Reject Bins	• Whilst working as a haul truck driver the interviewee noticed that after dumping a load and driving away from an area whilst the tray descended the truck was able to shift up to second gear and pass 8km/h without an alarm sounding. • Shifting up gears should be prevented automatically and an alarm set off if the truck passes 8km/h without the tray fully descended. • The driver called maintenance to notify them of the issue. After some time they notified him that an electrician was available and to park the truck up. • The driver did this on his way collect a load from the reject bin; an overhead chute which transfers waste from the process plant into the truck. • The electrician worked on the issue, thought it was solved, and sat in dicky (spare) seat to catch a ride to the maintenance shed. • Driver forgets to pull leaver to take tray down, the alarm does not sound and the upright tray strikes the reject bin.	• The reject bin is surrounded by 'idiot balls': large balls on wire that would normally be contacted before entering the area of the reject bin if a tray is in the upright position. However, the park up bay that the driver selected was past these idiot balls. • The electrician felt he had fixed the issue of the lack of tray alarm, but this was not tested or the test was accidently missed. • Other than the tray alarm, there may have been a display showing the driver that the tray was in the upright position. • The alarm may actually have been working but the truck not at 8km/h before striking the reject bin. • The driver and the electrician knew each other and were friendly. They may have been distracted whilst chatting, so not noticing the tray.	**YES**	• The I-CAMs corrective actions were re-enforce the need for walk around inspections, the installation of sacrificial devices close to the reject bin to prevent collisions. • The I-CAM did not note that the roadway was designed such that a park-up bay was past the 'idiot balls'. • I-CAM did not investigate how the driver may have missed pulling the leaver to flatten the tray. However, the CDM found it was probably because he usually does not pull the leaver at start-up and preformed his usual start-up movements whilst talking to the electrician. This could probably be prevented by having an audible tray up alarm on startup.

#	Incident description	Main Incident Notes from CDM	Main CDM Findings and Key Decisions	Compared to I-CAM	Additional findings compared with I-CAM
5	Rollover of troop-carrier	• Rollover occurred on a 10% grade ramp. Just prior to the rollover a water truck had watered one side of the ramp. • Driver was moving off the 'rough' road and skidded when one side of the vehicle hit wet but hard and slippery clay. • Vehicle had 4-wheel-drive but was engaged in 2 wheel drive at that time.	• The watering of the ramp was an important primary causal factor. • Subsequently, the judgement of the road conditions and speed was an important causal factor in the rollover. • This was, potentially, made more likely by the type of vehicle and non-engagement of 4WD.	**Results of I-CAM reported by interviewee, but not confirmed in writing.**	• Main result of the I-CAM was to re-write watering policy on ramps, changing from continuous to spot watering. • Input of troop carrier factors appears overlooked: such as speed, driver judgement and the engaging 4WD.
6	Collision between bulldozer and grader	• A grader, driven by the interviewee, was parked in a line of trucks waiting for a shovel load, meaning that the grader could not move significantly. • The bulldozer that was cleaning up the face where the shovel had been backed to within 10-20m of the grader. At this time the grader operator radioed the bulldozer operator and at the same time the bulldozer moved forwards. • The bulldozer involved had limited rear vision and significant noise, which can mask radio calls.	• The grader operator perceived that the bulldozer operator had heard him because of the timing of change in direction. But this turned out to be a coincidence. • The lack of vision and significant noise, in the bulldozer was a significant cause of the collision. • The design of roadways and vehicle separation may have also played a role.	**Results of Investigation reported by interviewee, but not confirmed in writing.**	• The interviewee noted that the investigation attributed the cause of the accident to be primarily due to lack of confirmation that a radio call had been heard. • The CDM investigation found that the incident was much more complex, and continued radio calls by the interviewee was unlikely to have prevented the collision.
7	Engine Fire in Digger	• Machine was an older model with existing issues. • Operators stated that the engine was 'surging' during driver 'hot seat' change. • At this stage, a general/informal inspection was conducted for 'something out of the ordinary'. • However, a driver would not necessarily know the specific cause for surging- it is up to the judgement of the operator to notify maintenance. • Operator continued to operate the equipment after the fire began, as it was at the rear of the machine and not visible to the driver. He was notified of smoke by a haul truck driver. • In this case he manually pressed the fire-suppression. Usually operators would not press the fire suppression unless they saw flames, as it was known to be costly. Newer equipment automatically sets off fire suppression on smoke/fire detection.	• Driver of equipment must informally check equipment in the field, making judgements on the seriousness of issues. This is solely based on their experience and instinct. • The communication between equipment operators can be key to identifying if smoke is abnormal and the presence of fires in their early stage. • The high financial cost of falsely pressing the fire suppression system does influence the operator's decision to engage the system.	**No.** **No I-CAM available**	

#	Incident description	Main Incident Notes from CDM	Main CDM Findings and Key Decisions	Compared to I-CAM	Additional findings compared with I-CAM
8	Loss of control of haul truck down a ramp	• The loss of control took place on a wet ramp in rainy conditions. The operators had been discussing the conditions, and whether they warranted 'parking up'. • Loss of control took place when vehicle was unloaded it descending the ramp on approximately the 30th run of the day. • Usually a slip is more likely when descending unloaded, and whilst a driver may notice some issues when ascending loaded they are generally committed to an entire run once loaded. • The road was 'cambered, seemingly encouraging higher speeds to the interviewee driving the truck.	. • The judgement of when rain causes the roads to become dangerous is a key decision made by the team. This decision is not black and white and would have external influences, such as production pressure/competition. • The misjudgement of safe speed, set by the auto-retarder, down a ramp was a key cause of the accident worthy of further investigation. • The roadway design, with a ramp that included a banked corner, could have also been a cause of the accident.	**No.** **Investigation was not conducted.** **Incident prior to site I-CAM use.**	
9	Decision Making of Maintenance when Haul Truck Engine shows Low Horse Power	• This interview regarding how a maintenance manager would typically address the issue of 'low horse power' on a haul truck. • The interview revealed that the maintenance checks followed more of a 'trial and error' pattern than absolute diagnosis of the problem. • As maintenance managers have their KPI as 'availability', this tends to mean that more cost effective options that have fixed the problem in the past are tested first.	• Generally the driver would be told to continue using the truck until a mobile 'breakdown' unit can attend. In this case the mobile breakdown unit usually checks for blow/leaking hoses. • If this is not found the oil and air filters are replaced, even if no obvious issues are noted, as this is cost effective. Occasionally, air filters and oil filters have been changed multiple times by alternate shifts due to poor communications. • It is then left to the operator to note if the problem has been 'fixed' or 'not fixed'; which is not a totally objective judgement and operators have been known to have different opinions. • Only when these field options have failed is the truck brought in for maintenance where more cost effective options are trialled (eg replace injectors) before more expensive options (eg turbo). • Hierarchical expenditure approval caps reinforced this situation. For example, fitters can approve up to $2,000 of expenditure, but need to go to their supervisor for higher expenditure who is, in turn, must go higher for approval of expenditure over $4,000.	**No.** **Not a specific incident.**	

#	Incident description	Main Incident Notes from CDM	Main CDM Findings and Key Decisions	Compared to I-CAM	Additional findings compared with I-CAM
10	Missing Alignment when Reversing Haul Truck to Shovel for loading	• This interview regarding the general issues with alignment of the haul truck when backing into a shovel. • The interviewee (a driver) was asked to describe in detail how this task is typically achieved. • For the future, this type of information could be checked against training manuals to see if taught practices are actually used or are simply a hindrance to the process • Finally, for future research, both cases 9 & 10 could be useful if done in a group- especially where CDM is being used as a proactive risk management tool.	• The driver used a number of 'tricks' and cues when reversing. This included using just the left mirror, past tracks of haul trucks, horn or radio from the shovel operator to correct positioning. • If the first truck to reverse to a particular position of the shovel lines up poorly there is a tendency for future drivers to use their tracks as a guide and repeat the mistake. • The reversing camera is not very useful in lining up correctly but may help the driver pick up any rocks dropped by previous drivers. • The glare from the sun in the side mirror, causing the driver to lose vision of the shovel for a short time, was thought to be the most common cause of lining up incorrectly.	**No.** **Not a specific incident**	

To illustrate more findings from the process, one of the incidents (#4 'Drove Haul Truck with Dump Tray Up striking Reject Bin Chute') is used as the example. A flowchart of the incident is show in Figure 2 below. This shows the major stages of the event (in text boxes and the key decision points (as rectangles- after boxes 3, 6, 11 and 13).

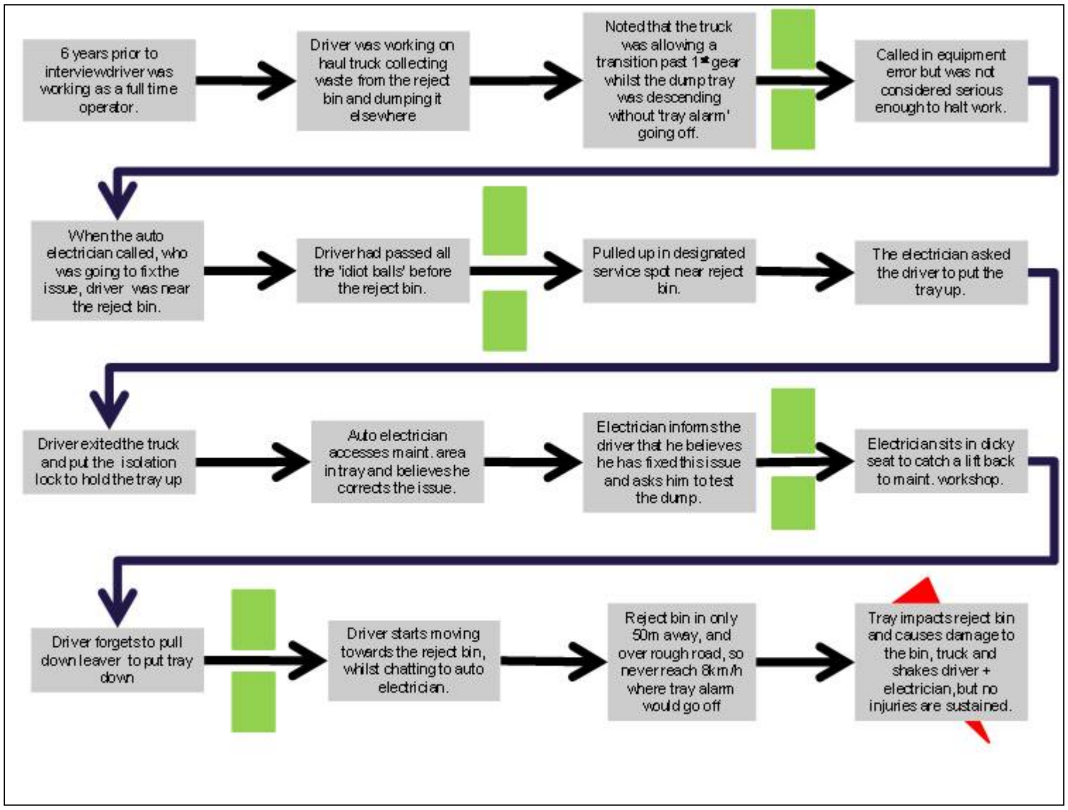


Figure 2: Flowchart of one incident

For these key decision points, the decisions made were further explored. In terms of the content of this examination, examples of what the deepening probes found in Sweep 3 (but not noted in the I-CAM incident investigation) included:

- The driver had rarely previously started the truck with the tray up.
- "Idiot Balls" were placed around the mine, but the park up bay was past the last idiot ball
- The display for tray up was only visual.
- The display was possibly obscured/made less conspicuous by sun glare
- The driver was talking to the electrician during the drive.
- No visual feedback on tray from the driver's position

Similarly, example findings from the “What if” inquiries (Sweep 4) that were not noted in the previous I-CAM investigation report were:

- An audible signal might have alerted the driver to the fact the tray was up.
- If the driver was not friendly with the electrician he may have noticed the tray (due to him being partially distracted by their conversation).
- If the park up bay was further from the reject bin or the road conditions were better, the driver would have reached 8km/h and set off the tray up alarm.

The use of the CDM technique in the analysis of mobile equipment incidents has therefore shown that the knowledge elicited from the operators involved in these events provided valuable ‘extra’ information compared to the incident analysis methods currently in use (eg I-CAM).

Therefore, by focusing on the key decision points for operators, and unpicking the cues, information, goals, prior experience and related probes the research was able to obtain a much deeper description of the incident event than the standard narratives used in much of the minerals industry today. However, these conclusions are still only tentative - data have not been validated (eg compared to objective recordings such as photos taken at the incident) and are based on one interviewee only per incident at this stage.

For example, the current technique used for the investigation of an incident involving a road grader and a bulldozer found that breaching procedures and not establishing radio contact between operators was the primary ‘*cause*’ of the accident. Therefore, a reminder to operators to follow procedures about radio contact was the sole action taken to prevent a repeat collision. However, the CDM methodology used identified that the background noise of the bulldozer and the hearing protection worn by the operator meant that it was likely that the operator could not hear the supplied radio and positive radio contact could not be established in this situation if repeated (however, more generally, it must be stressed that it is important for the dozer operator to have positive radio contact in high use areas especially if reversing - so if he/she cannot hear he/she should not operate).

Critical Decision Method at a Gold Mine

As noted previously, as this site had no previous incidents involving collision detection systems, a modified version of CDM was used that focused on scenarios. The separate interviews were successful in determining scenarios where proximity detection, if effective, may prevent collisions.

Each scenario was represented using Energy Trace and Barrier Analysis (ETBA) (a risk assessment procedure to detect hazards by focusing in detail on the presence of energy in a system and the barriers for controlling that energy) to qualitatively show how the scenario might develop.

In all scenarios, additional controls that assist operator knowledge of the location of other vehicles were required to fail for a collision incident to possibly occur. These additional controls include:

- radio communication (where drivers are required to regularly 'call' their position and direction), and
- visual location of the vehicle (either directly or through a reverse angle camera mounted in the cab).

Figure 3 below an example of where a proximity detection system may act as a control should these other controls fail.

1

Truck 1 has reversed into a stockpile and dumped a load of waste and waiting until the roadway is clear to descend the mine.

2

Truck 2 is ascending the mine's main drive with a full load of ore and a light vehicle (LV) following.

3

Radio communication has failed and Truck 1 is not aware that the light vehicle is following Truck 2.

4

Truck 1 exits the stockpile after Truck 2 has passed

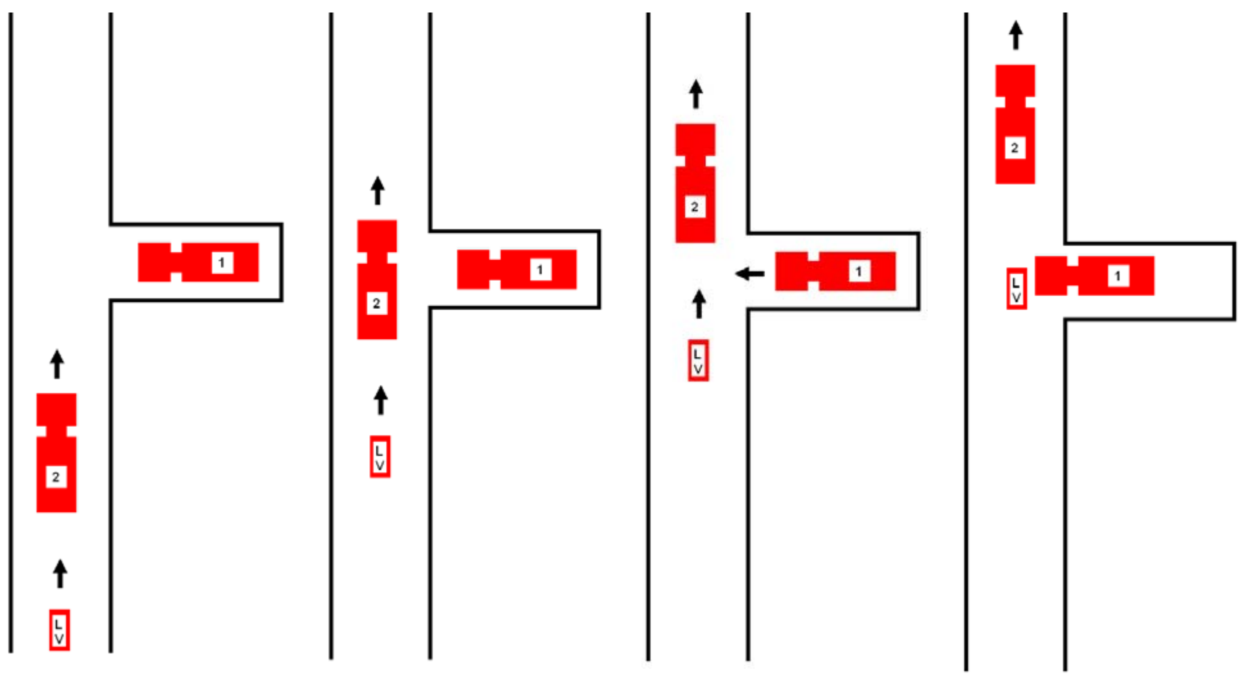


Figure 3: Example scenario where proximity detection system may act as the key control.

In this scenario, there would be potential for Truck 1 to hit Truck 2 if radio communications were the only barrier, however the second barrier of direct visual location of another vehicle may prevent truck 1 from hitting truck 2, but it may still hit the light vehicle (which would be largely obscured to Truck 1 because the light vehicle was closely following Truck 2).

CDM Discussion

The CDM method was adapted to the mining context and was successfully applied to incidents in both open cut coal mining and an additional area (underground gold mining). Five key discussion points emerge from these results.

1. **Mobile Mining Equipment Incidents are regularly complex**

The CDM revealed many of the incidents related to mining equipment to be complex in nature involving the alignment of a number of events allowing the failure of numerous barriers of defence, commonly triggered by local atypical conditions. This aligns well with the James Reason model of the dynamics of organisational accident causation (Reason, 1990 & 1997) and supports the view that CDM could be a valuable tool to add to complex incident investigation (ie higher risk events only). For example, in the above-reported incident where a bulldozer struck a grader, the immediate causes of unsafe acts involved the parking of the grader and loss of situational awareness by the bulldozer operator. However, upstream the local workplace factor of the design of traffic flow on site and possible organisational pressures made the unsafe acts more likely to result in an incident.

2. **CDM increases in value with complexity**

In general, the CDM interview process was able to establish a good understanding of the incident in most applications. In complex situations, the interview was successful not only in establishing the story of what happened, but also the critical decisions made and the operator's sensemaking related to these decisions. With less complex events, involving simpler decisions the first two stages of the CDM were helpful in establishing the circumstances surrounding the incident. However, if the decisions made were relatively straightforward using obvious environmental cues then the deepening and 'what if' probes did not add significantly to the understanding of the event.

For example, the latter stages of CDM for the engine fire in the digger example (#7 in the results list) did not gain significant information because the cue of smoke and the action of pressing the fire suppression system was not a complex decision. In contrast, the incident where a haul truck lost control whilst descending a ramp at first appeared to be a simple case of excessive speed for the conditions. However, further probing in the CDM found the decisions were significantly more complex, such as the complex team decision on judging when wet weather makes conditions too dangerous.

3. **CDM Uncovers Important Details not in Site Investigation Reports**

Upon reviewing the incidents it was obvious to researchers that the CDM interviews often identified information not contained in the I-CAM report. For example, in the incident where an overhead chute was impacted by a haul truck with the tray in the upright position (#4 in the results list), large colorful balls on wires – locally known as 'idiot balls' – were set below the height of the chute, and were located surrounding the area. These serve as height indicators for drivers, similar to chains on low bridges or entering suburban car parks. They would have usually been contacted before the chute if a tray was in the upright position. However, a designated park up position for the haul truck was located past these balls. In this park up location the operator raised the tray for a maintenance task and either forgot to lower it or did not notice that it had failed to lower before driving towards the reject bin. The location of the park-up bay and the idiot balls were not included in the incident investigation, despite this appearing to be a contributory factor.

Therefore, the provisional conclusion is that using the CDM method could assist in the data gathering and building a rich incident narrative for I-CAM or similar investigation processes. This provisional conclusion would be strengthened by future research where it is recommended that the CDM is compared directly to an I-CAM performed by an experienced investigator, more than one person is interviewed (to get a more complete picture) and the CDM findings are validated by means of both documentation reviews and through the use of additional objective incident data (eg photos). Similarly, although it has been found in other domains that experts mostly have clear memories of salient or unusual safety-related incidents (Crandall, Klein and Hoffman, 2006), this further research would overcome the possible argument that the current CDM process was applied long after the event, therefore memories could be clouded, selective or influenced by more recent events.

4. CDM is a robust method that can be applied to a variety of situations

As seen above, the CDM method was applied to open cut coal mining and to an underground gold mine. The results showed that the method was successful for both mining environments.

Of course, these two sets of case studies are not directly comparable as the open cut coal mining was totally post-event and the underground gold mining totally proactive. But the successful use in both situations points to the possible benefits of CDM both for post-event analysis and for proactive risk management to explore different scenarios by which controls might fail and an incident might potentially result.

Further, CDM was found to be useful with a variety of incident situations, involving different types of mining equipment and for both routine and non-routine situations.

5. Site culture and hindsight appeared needed to be managed

During a number of interviews it appeared that a site safety culture affected the interviewee's perspective of the incidents. Specifically, the interviewees generally appeared reluctant to consider the influence of a system and more likely to blame the actions of people, including their own. They were often heard to use phrases like '*I should have*' or '*he was meant to*' and drift into generalisations about what was required by a specified procedure.

In one case the participant noted that he and another participant shared the blame for a collision by not establishing positive radio contact when, in fact, it is likely that the radio system was unusable in the situation. Although it could be argued that they should have spoken up to have the radio system corrected if it didn't work properly, if the culture is to view such problems as failures of individuals rather than of the system (ie the safety culture was not proactive) then it is partially understandable that the unusable radio system was not reported here. This reflects Dekker's 'Bad Apple Theory' of human error where failures are introduced into a system due to unreliable persons and corrected by tightening procedures (Dekker, 2006). Therefore, occasionally it was difficult to get employees to investigate alternatives, they used phrases like '*that would never happen*'. This was especially where investigations had already been undertaken and the findings had been widely disseminated.

CDM Conclusions and Recommendations

Overall, by focusing on decision making in real mining environments, it is contended that this project successfully modified and applied the CDM technique to coal mining and the comparison mining area. Further work to now integrate it into incident investigation and risk management processes are strongly recommended. In more depth, future CDM-related work in this domain might include the following:

1. Refining data collection methods and tools. As mentioned earlier, the amount of time to collect human-related data in mining can be extremely limited. Flexible, reliable, valid and quick methods are needed. A shortened version of CDM, or being able to split the CDM session into several 'chunks' to fit with an operator's free time would be valuable.

2. Looking deeper at human error in mining incidents to understand how and why these errors occurred rather than to simply stopping any analysis when a 'human error' label can be attached. The label 'Human Error' explains nothing in itself - it does not show what caused the error, what could have been done to prevent it or what measures could be put in place to limit the occurrence of similar errors in future (Simpson, Horberry and Joy, 2009). This move away from the '*train and blame*' view will help to generate a better understanding of the human element in incidents, and so will ultimately help develop safer systems. The knowledge elicitation approaches and emphasis on design for critical events of CDM are firmly within this framework. Ultimately it should lead to a greater awareness by all stakeholders in this industry (e.g. managers, designers, contractors, regulators, operators and maintainers) of the benefits of applying a user-centered approach in mining.

3. Considering issues around motivational aspects of a task, work process or interacting with a piece of equipment, as these can have a strong influence on performance (e.g. equipment misuse). As with CDM research in other domains (Mosier and Fischer, 2009), the emphasis on such aspects in mining is important.

4. Finally, and most concretely, further work with CDM is strongly recommended in three key areas: i. apply it to ‘repeat’ mobile equipment incidents, ii. employ CDM in an actual incident investigation (integrate, apply and evaluate it in an I-CAM investigation) and iii. trial the technique’s use as a proactive method, such as when introducing new controls or equipment (eg collision detection systems).

Overall, focusing on how decisions are actually made by experienced operators in the field, and then incorporating this into designing effective mining equipment, tasks, incident investigation procedures and training to take these into account will be key challenges over the next 10 years in coal mining. The work contained in this report should form a good base upon which to undertake continuing systematic human factors work in mining.

Part 2: Informal Feedback

Review of Informal Feedback Literature

The current minerals industry skills shortage has driven the need to reduce the time required for trainees to acquire the desired skills and experience. Many training aids for new equipment, including simulators and audiovisual equipment are currently being used by sites. The introduction of mobile simulators has further increased the availability of these training aids, prompting the establishment of company wide training programs designed to achieve a range of consistent outcomes.

While skills acquisition mandated by training competencies is the primary outcome of most training programs, mining companies also strive to equip employees with the ability to recognise and act on hazards as part of their routine activities. Pre-start checks undertaken by operators address many of the hazards related to the ability of the equipment to function as expected, but do not necessarily address the ability of the operator to interact safely with the equipment. Training to identify operational hazards is generally limited to service related items that are essential for the equipment to function as expected. It does not always address the human factors hazards that operators may need to manage when they interact with the equipment.

The ACARP project C13078 *Communication strategies and mechanisms that maximise the effectiveness of informal/mental risk assessment programs* (2007) identified the need to develop a process for gathering and disseminating informal feedback as a tool for improving the quality of informal risk assessment. This need underpins the approach to the Informal Feedback section of the current Knowledge Elicitation project (C18025) project, where the research program has been designed to develop a recognised process for workers to exchange information that is filtered and channelled into useful outputs.

A variety of training delivery modes are used to train people in skills specific to coal mining operation and maintenance. Data gathered during the ACARP project C13078 showed a marked preference, by coal mining workers in both the underground and open cut sector, for training delivery to take the form of face to face discussions. This project did not report on simulator training, which was not widespread in 2004 when data collection for this project commenced. Simulator training offers personal ‘coaching’ style training combined with a practical, hands-on approach that simulates real-life operating experience without exposure to the actual risks associated with the task. The interaction between trainee operators and their trainers during simulator training is purposeful, and in the hands of a skilled trainer, can lead to an effective mentoring relationship when training has been completed.

The Risk Elimination Training Aid Concept (RETAC), which was showcased at the 2006 Queensland Mining Industry Innovation Awards, is another example of one-on-one training, although in this case, the trainer is separated physically from the hazards associated with the traditional approach to training where the trainer hangs out of the cabin while watching both the blade and trainee actions. Instead, the dozer is equipped with audiovisual equipment that relays the trainee’s actions and comments to the remotely located trainer. Audio is two-way, allowing the trainer and trainee to communicate verbally. The trainer is able to view the trainee's actions with the controls in the operator workstation and the resultant dozer blade actions.

Training aids such as simulators and the RETAC offer opportunities to capture informal, verbal exchanges between the experienced trainer and the novice trainee that may help to identify risks related to poorly designed controls and displays.

Several Open Cut mine sites use simulators for operator training such as those developed by Immersive Technologies for the CAT 797B Haul Truck. These simulators can be used for both screening and training purposes. The supporting software programs are designed to capture data about operator response rates that can be used to assess competency levels, but this data does not necessarily uncover design issues or information about site specific hazards that may impact competency levels. This type of information could be gathered through informal conversations with experienced operators.

In the past few decades there have been major advances in the technology used to monitor machine functions and outputs, resulting in an increasingly complex arrangement of computer screens and associated equipment for operators to deal with in the course of routine operations. This increase in human machine interface has been reported by the European Agency for the Safety and Health at Work (2009) as an 'emerging risk' for all work places. The agency notes that the systems of work that support these complex designs are constructed as socio-technical systems, incorporating workers, tools, tasks and work contexts.

While these areas have not traditionally been viewed in the same light as technical issues, which tend to be better understood, there is a growing awareness of their importance as evidenced in the Mine Safety Advisory Council's (NSW Industry & Investment) three year OHS Culture Improvement Action Plan to 2012. The plan has reported the need for improved Associated Non-technical skills in the mining industry to support the improvement of safety culture in the industry.

Scope of the project

When the **scope of this research** was initially developed, the methodology for data collection was based on the expectation that there would be a ready supply of trainees, particularly new recruits, undertaking simulator training. The use of RETAC – Risk Elimination Training Aid Concept – was also considered, but not followed through, as RETAC was not used for haul truck training. By the time data collection was underway, external factors (particularly the Global Financial Crisis) forced a change to recruitment plans, which severely restricted the intake of new trainees available for participation in this research. The scope was subsequently expanded to include maintenance and production areas, providing opportunities to connect people and information across work groups.

Data Collection Methods for Informal Feedback

To capture data about informal feedback or exchanges of information between experienced trainers and less experienced trainees, the initial strategy was to target interactions occurring during simulator training as the primary source of data collection.

An **initial methodology** for gathering data about interaction between trainers and trainees Was trialled during the first site visit. The methodology was then reviewed and finetuned for use at subsequent sites.

In all, five different data collection methods were used to gather information about simulator training and trainer/trainee exchanges, allowing multiple perspectives to be captured. The five methods used were:

1. **Semi-structured interviews with trainers** to gain an understanding of the training process in place and the extent of the training material
2. **Observations** made during training sessions, including coaching tips about verbal & non-verbal cues designed to help trainees to develop the required operational skills
3. **Scrutinising simulator session reports** to gain a good understanding of the desired training outcomes related to trainee performance during routine and critical events
4. **Structured interviews with trainees** to gather information about their experience levels
5. **Semi-structured interviews with trainees** conducted post training to collect feedback about the training experience

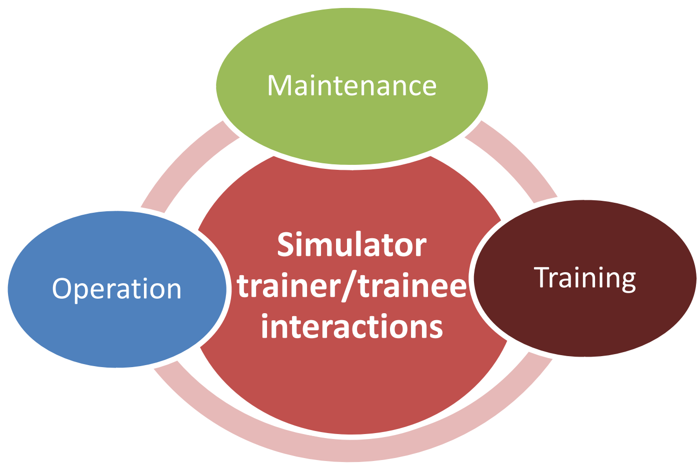
Limitations of the data collection methodology

Post-training interviews with trainees at one site revealed that the reason for a new instruction about braking was not fully understood or appreciated by trainers or trainees. The new process had been prompted by maintenance concerns about unusual wear and tear, but as the reason for the change was not communicated to either the trainer or trainees, there was a very good likelihood that trainees would not adopt the practice once they were back in the field. This scenario suggested that simulator training data of trainer / trainee interactions represented only one aspect of the information exchange required for quality training outcomes.

The narrow scope of data collection and fewer than expected participants prompted a change to the scope of data collection for the remainder of the project. The agreed solution was to broaden the scope of data collection to include interviews with personnel working in the related areas of haul truck operation and maintenance.

The revised **scope of remaining data collection** was outlined to site training personnel and agreement reached to develop interview templates for data collection from the wider work system as shown in Figure 4 below.

Figure 4 shows the wider work system to be targeted for data collection



Additional data collection to encompass the wider work system

Data collection methods used to gather data about information exchanged across the targeted work areas – Training, Operation & Maintenance – included semi-structured interviews based on the interview template shown in Appendix 5. The aim of these interviews was to establish the topics most commonly discussed in relation to:

- Skill levels, behaviours and performance of haul truck operators
- Issues impacting on the safe operation and maintenance of the equipment

Participants were also asked to estimate the strength of each interaction node by rating the frequency of communication according to the following table:

Table 2

Communication frequency measures		
0	Never	Never
1	Rarely	1-3 times per month
2	Occasionally	1-3 times per rotation/week
3	Often	More than once per shift

During these interviews participants were asked to comment on communication flow patterns and likely strengths of interactions, prompted by a diagram showing possible interaction among people across different work areas. As comments on the actual communication flow were provided, the diagram was updated and the latest version shown to the next participant. This interative process was continued across all three participating sites producing a broad view of communication flow across the production, maintenance and training work areas (see Figure 14 on page 44).

In total, 33 people from within the training, maintenance and production work areas participated across the three sites, covering the roles shown in **Table 3** below.

Table 3 List of participants

Participant role	**Number of participants**
Trainee	10
Simulator trainer/assessor	6
Training & Safety	6
Trainer – maintenance	2
Maintenance supervisor/superintendent	2
Maintenance reliability engineer	1
Maintainer	1
Operator	2
Pre-strip Supervisor	1
Production Coordinator	1
Contractor - H& S Advisor, maintenance	1

Informal Feedback Findings

Participants were extremely cooperative and provided valuable insights into the communication practices occurring at site.

Findings from observations of, and interviews about, simulator training

1. **Overview of the simulator training program (more detail in Appendix 6)**

Simulator training for new starters was well planned. The approach was similar at each site, with scope for individual trainer/assessors to drive effectiveness in different ways according to their skills and abilities. The simulator software module being used for instruction (Caterpillar 797B) could be configured for a range of events or scenarios to test developing skills according to the requirements for operator training. These included skills for dumping, loading, braking in emergency situations and responses that demonstrated their ability to respond to non-routine situations such as rocks on the haul road.

Generally, simulator trainers took new trainees undertaking the haul truck operator package through three discreet stages:

1. The Pre-simulator familiarisation session
2. The initial simulator session
3. Additional simulator training sessions to develop and assess skills for
    a. Routine haul truck operation
    b. Operator responses to critical events

The next step in the skills acquisition process was spent out in the field under an assigned trainer/mentor. When the field trainer considered the trainee had gained the desired level of competence, the trainee's skill level was assessed via a session in the simulator. The computer printout provided an unbiased assessment of the trainee's ability to perform specified tasks.

Figure 5 Pre-simulator familiarisation session for new starters includes an introduction to terminology and symbols used for quick and easy recognition, as depicted in this photo.

The obvious advantage of simulator training over other training delivery modes is that it offers a 'safe' way to learn new skills. Training aids built into the program (eg on screen messages) help to improve situational awareness and understanding, particularly when reinforced by input from the trainer. The system can be paused at any time during training to focus the discussion on the reasons for particular situations occurring.

More experienced operators undertaking simulator training agreed with its value for refresher training for emergency response skills, although considered the virtual reality environment not 'real' enough for people with field experience.

2. Trainer skills and abilities

Simulator trainers were generally experienced operators with prior experience as field trainer/assessors and formal training qualifications. The experience level of simulator trainers was a key factor in determining their ability to explain confidently why certain actions should be taken, and was seriously impeded when they had no practical experience with or knowledge of new procedures.

Trainers adopted a coaching style of training delivery, using a combination of **instructional and mentoring techniques**, based on the skill level of the trainee. In the initial stage of training, new starters received detailed instructions for routine tasks and procedures that had to be memorised and followed without deviation. When trainees progressed to the field experience stage, they were required to log the day's work with the simulator trainer, a strategy which facilitated the mentoring process. This ongoing contact also provided time for the trainer to establish a relationship of trust with the trainee, providing the building blocks for effective communication about what was happening in the field and for ongoing mentoring once the trainee graduated to operator status.

The skills of the simulator trainer to coach, mentor, customise training for new starters with some level of prior experience, and to maintain currency of site specific conditions, appeared to be key factors that influenced the quality of training outcomes, although these were not analysed as part of this current research.

Simulator training was also used to refresh skills and to practice those that could not be done during normal operation, such as training for response to engine fires. While initial skills training was well planned, refresher training tended to occur on an ad hoc basis when conditions in the field and availability of operators provided an opportunity, rather than as an integral part of further skills development and optimisation. Refresher training could be triggered by incidents involving mobile equipment, changes to mine rules and routine operation or unplanned maintenance that may be occurring due to less than adequate operator was one source of information used to trigger refresher training needs.

3. Simulator scenarios

Three scenarios were identified (loading, dumping and engine fire) where verbal exchange and trainer feedback played a significant role in trainee acquisition of skills. Information was collected about the type of prompts that trainers use to prepare trainees for scenarios where responses are measured by the simulator computer.

Trainees were introduced to the use of sensory cues to perfect **routine tasks** such as dumping and loading. The trainer pointed out visual and audible cues and then used a range of prompts, reminders and warnings to help them through the learning process. Shadows on the bund wall (Fig.6 below) were used to judge how far back to take the vehicle. Cues such as this helped to minimise the time required to position the truck ready for loading or dumping, which was an important factor in the truck loading & dumping production cycle. Timing is considered an important skill as loading that delays the following trucks may lead to risk taking behaviours by other operators in an attempt to make up time lost during delays.

Figure 6 Trainees use visual cues such as shadows to guide them during the dumping scenario

Analysis of the data collected about non-verbal cues, such as the positioning of the dozer blade to confirm where the operator should locate the truck in relation to the dozer, indicated that these types of cues should not be relied upon as the sole means of positive communication between vehicles. This non-verbal cue is a soft control measure that could be made more effective by adding confirmation and comprehension of the message by 2-way.

2-way radio communiqués can also be unreliable because of poor quality transmission, transmission failure and the need to interpret the audible message for its exact meaning eg the instruction “bring it back” from dozer to truck operator doesn’t clearly indicate “**where** the vehicle should be brought”. The language that develops within a crew working closely together can easily be misinterpreted by someone joining the crew for the first time, with dire consequences.

Additional feedback about how well tasks were being performed was provided by the simulator software. Messages appearing on the ‘windscreen’ section of the simulator covered start up procedures, routine and critical tasks, while information about engine speed, oil pressure etc was delivered via a display built into the dash (Fig.7).

Figure 7 The photo to the left shows how trainees are informed about the position of their haul truck during the loading scenario. The trainer enriches this information by explaining the importance of truck position for ensuring that coal is loaded in the planned timeframe.

Trainers also explained the reasoning behind the specific sequence of actions and the adverse outcomes that could ensue if these were not followed. This mentoring approach was used to help the trainee gain situational awareness and to enhance decision making skills during routine tasks such as the dumping sequence outlined below.

Table 4 below demonstrates the **nature of the input about the dumping scenario provided by the simulator trainer to improve the trainee's understanding of the task**

SCENARIO	**WHAT/HOW** to do it **(Instructions** for the task**)**	**WHAT to look/listen for (Cues** for ***Situational Awareness*****)**	**WHY (Reasoning** behind the ***Decision Making*****)**
Backing up to bund wall	Put into reverse	Back up until shadow is at a certain point on bund wall	Visual cues help to minimise time taken to perform the task
Dumping	Pull retarder on → into neutral → apply park brake → release retarder → raise tray → dump load	Check the gauge for 1500 revs	Avoid heating engine oil
Lowering tray & driving off	let hoist down → into first gear → release retarder → idle away from bund wall → tray down → drive on	Check position of body as it comes down while idling away from bund wall	Idling while lowering tray reduces time required to lower tray & drive off

4. Training evaluation

Following each simulator session, trainers used computer reports to facilitate feedback about how well trainees performed each routine task or event, a process which helped them understand the required training outcomes and provide a focus for improvement. The session report provided some information about the specific components of each task that had not been performed correctly.

The session report provided limited data about **critical or non-routine events**, such as the response to engine fire and loss of function (brakes, oil pressure). Feedback was generally limited to a 'success' or 'failure' statement. It was up to each trainer to help explain why the trainee had succeeded or failed the task and to reinforce the need to react quickly and know the best exit strategy if required.

5. Trainee evaluation of simulator training

Trainees who were completely new to mining and haul truck operation considered simulator training to be a safe and effective way to develop basic skills and gain confidence before being exposed to the reality of the pre-strip or production environment.

Experienced operators undertaking simulator training for the first time were more critical of the inadequacies of the simulator software in replicating the exact situation at site. Some issues, such as signs showing the speed limit in miles per hour instead of kilometres per hour, could be easily updated, but others posed more of a challenge. The sense of real danger during an engine fire was difficult to replicate, but the race against the clock to complete the emergency response actions precisely within a given time limit, provided a different challenge that enhanced the learning process.

6. Training triggers

For experienced operators, simulator training offers an opportunity to refresh skills and to exchange information with trainers about issues that may be impacting optimal operation. While initial skills training sessions were well planned, refresher training tended to occur on an ad hoc basis when conditions in the field and availability of operators provided an opportunity, rather than as an integral part of further skills development and optimisation.

Refresher training could be triggered by incidents involving mobile equipment, changes to mine rules and routine operation or unplanned maintenance that may be occurring due to less than adequate operator performance. Assessment of the data provided via the MINEcare program, which is part of the despatch module, is a useful source of information that can be used to trigger refresher training needs.

7. Equipment design issues

During the course of training information was sometimes elicited about problems with the design of equipment, although most people accepted poor design as a matter of course, expecting that the onus would be on them to make adjustments to their operating techniques to account for design limitations. Feedback about potential improvements to the simulator software and useful data outputs was provided to simulator programmers for input to the next update of the training module.

One **equipment design issue** that came to light during data collection was the impact of changing from a steering wheel to toggles. This major design change impacted on the trainer initially, as the experienced operator had no experience with equipment driven by toggles, so would have been unable to act as mentor to any new recruits.

Another equipment design issue is identified in the photos below, taken either side of the trainee operator during a simulator training session. The trainee was unaware that the indicator light was on as he was unable to see it from his position at the wheel. The message that was sent, inadvertently to vehicles in near proximity of the truck is another example of the unreliability of non-verbal cues. In this case, the equipment design is a major contributor to the problem, rather than ‘language’ that differs from one site to the next.

Figures 8 & 9 The green indicator light on dash is not visible to the operator (as per the view in the right hand photo).

Findings across the wider work system

1. Topics covered during semi-structured interviews

Semi-structured interviews with participants in the wider work system drew out a number of common themes:

- Simulator training strategies for new starters
  - Training to improve emergency response skills
  - Training to provide new starters (and others) with heightened awareness of site specific conditions, sensory cues
  - Training to identify issues associated with the introduction and ongoing use of new technologies
  - Training to improve/refresh operator skills identified by interrogating reliability data.
  - Knowledge elicitation and engagement with targeted operators and maintenance workers
- Information elicited from experts in the field that adds value to simulator training
  - Sources
  - Knowledge elicitation tools
- Refresher training needs and strategies
  - Operator behaviours that impact on equipment reliability and safety
  - Technology changes eg hydraulics replacing winches
  - Equipment design changes
  - Unscheduled maintenance
- Sensory cues
  - Non-verbal cues that impacted on safe operation
- Communication (further detail in Appendix 7)
  - Communication flow across production, maintenance & training work areas
  - Communication strategies to enhance workforce engagement

2. Strength of interactions (detailed analysis in Appendix 8)

Data collected via the interaction nodes template and associated interviews provided an image of the flow of communication across the training, production and maintenance work groups. In analysing these self reported interactions, the frequency of interaction was used to indicate the strength of the relationship between those interacting, the **interactants**, with a measure of 3 being considered a strong relationship (see Table 2 on page 33). No attempt was made to identify the factors influencing the frequency of interaction.

Figure 10 below shows the reported strength of interaction between training personnel and others within the wider work system. It is interesting to note that the simulator trainer/assessor at each site generally had a strong relationship with other training personnel and those in the operational work area. On the other hand, the relationship with the maintenance area shows no real consistency. This finding may reflect individual relationships established on a personal basis or through prior work experience.

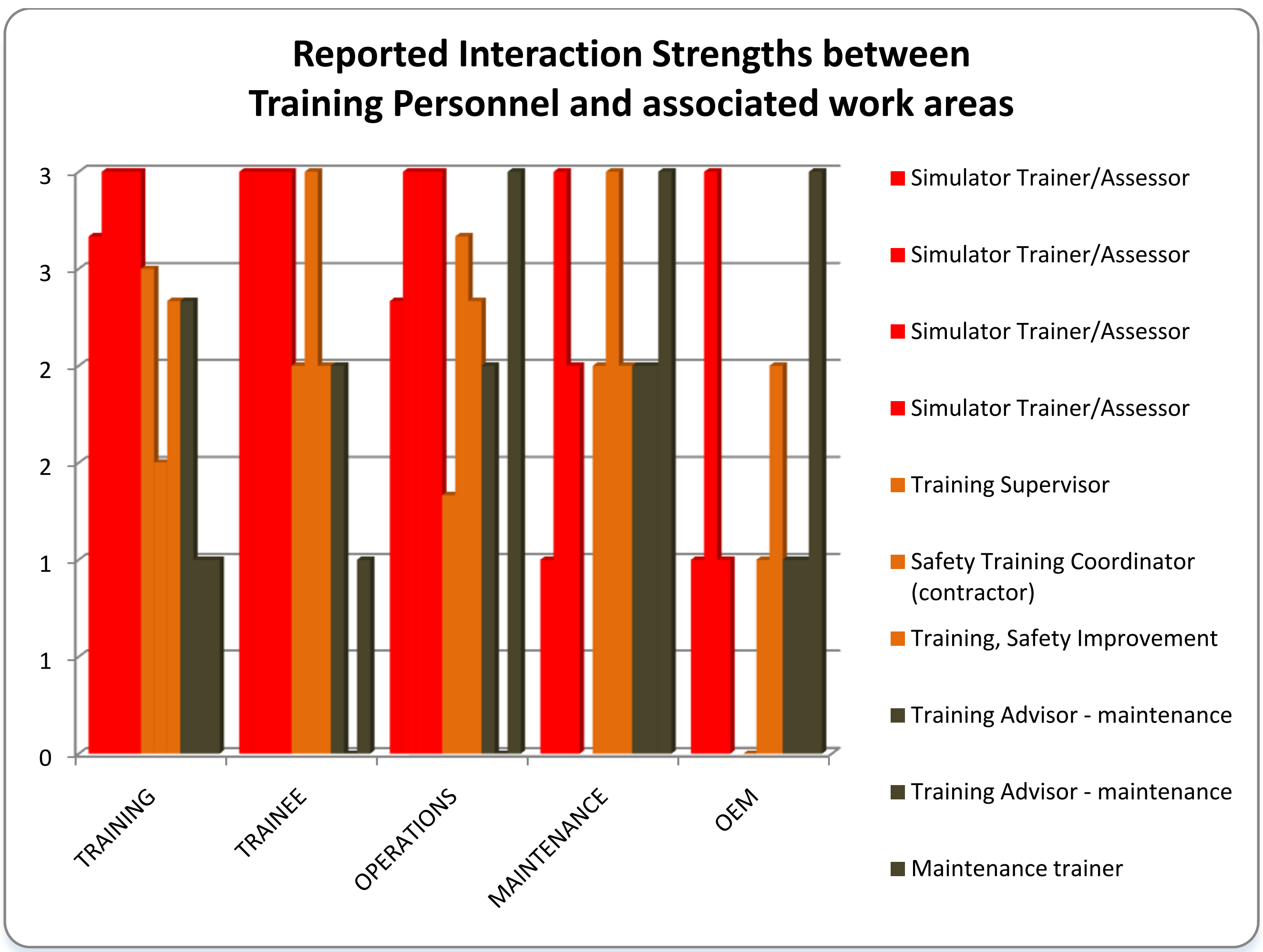


Figure 11 below shows the reported strength of interaction between maintenance personnel and others within the wider work system. There appeared to be no clear pattern of interaction strength, even between interactants within the maintenance area. Again, the reported interactions may be influenced by a number of factors, including individual relationships established on a personal basis, prior work experience and/or the organisational design of the different work areas.

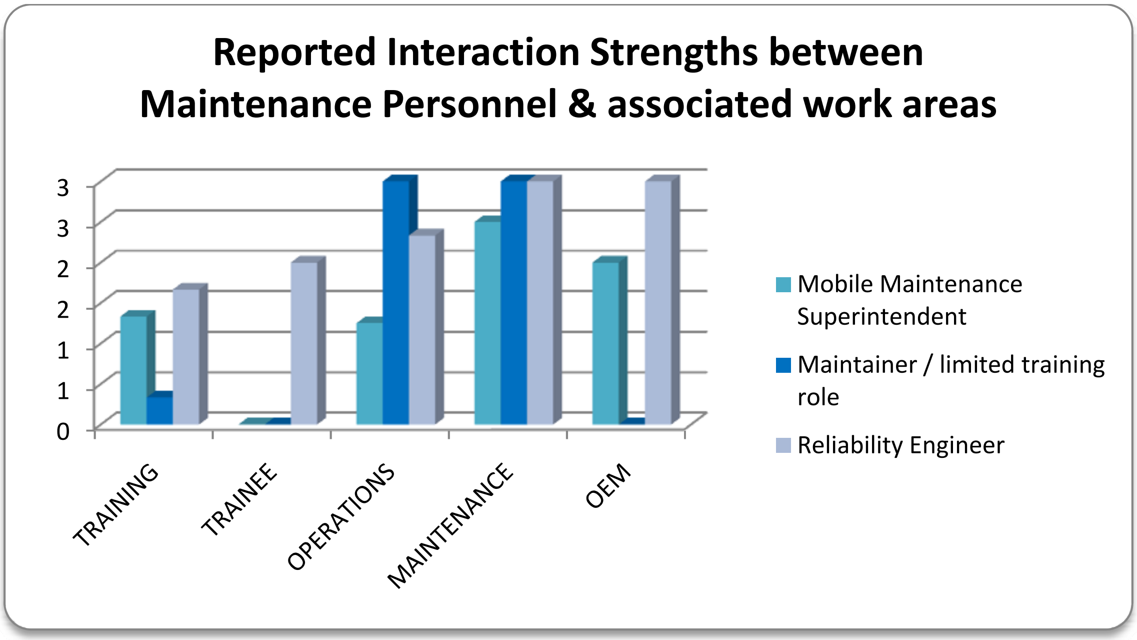
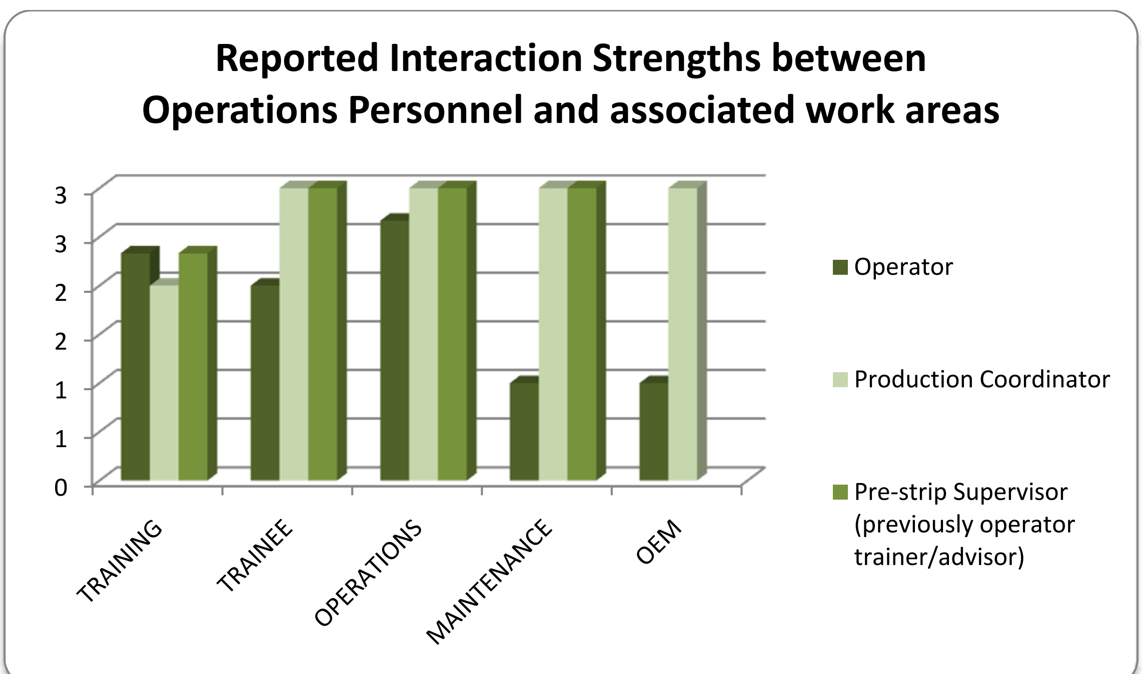


Figure 12 below shows the reported strength of interaction between operations personnel and others within the wider work system.



3. Development of the communication flowchart

At the commencement of the second phase of data collection, incorporating the wider work system, a simplistic model of the anticipated interaction nodes and associated communication flow was presented to participants from other work areas (see Figure 13).

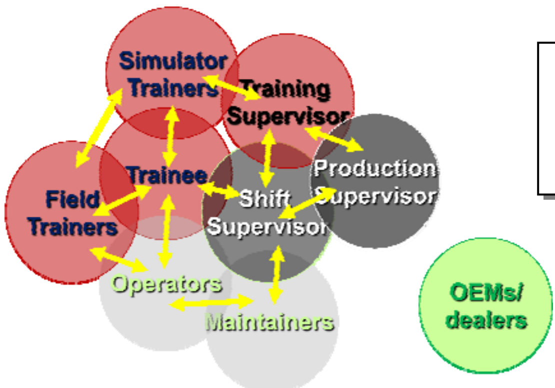


Figure 13 shows the initial model of the interaction nodes and communication flow used to prompt development of the final flow chart

The iterative process described in the data collection methods section of this report was used to construct a detailed image of interactions across the three work groups. Reported interaction strengths were used to refine the communication flowchart and produce the final version depicted in Figure 14.

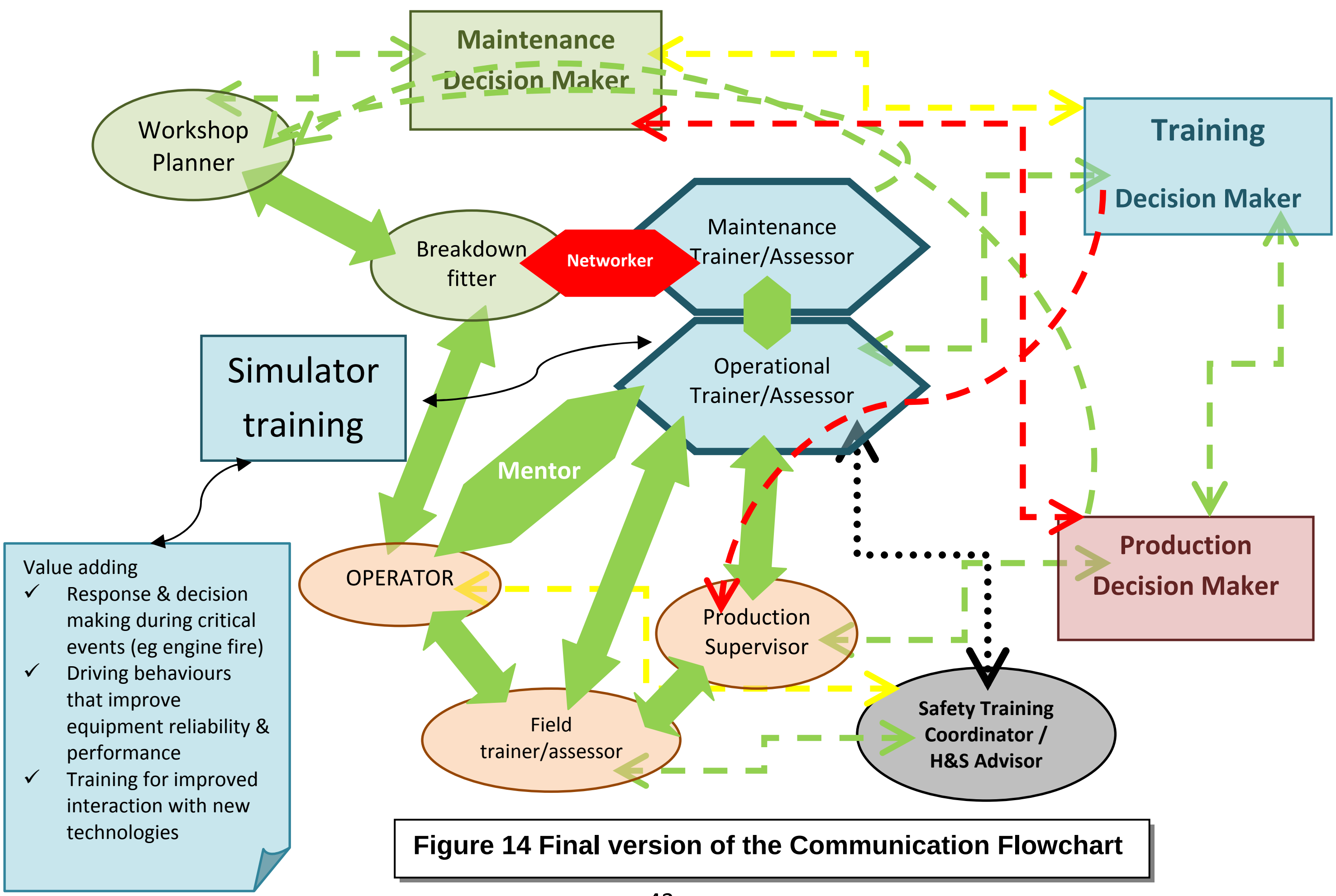


Figure 14 Final version of the Communication Flowchart

Interactions where decision making may occur are represented by dotted arrows. The strength of interaction is represented by the colour coding shown in the table below. In the case of an unscheduled breakdown, the maintenance trainer/assessor could bridge the communication gap by taking on a networking role.

Table 6

Communication frequency measures		
0	Never	Never
1	Rarely	1-3 times per month
2	Occasionally	1-3 times per rotation/week
3	Often	More than once per shift

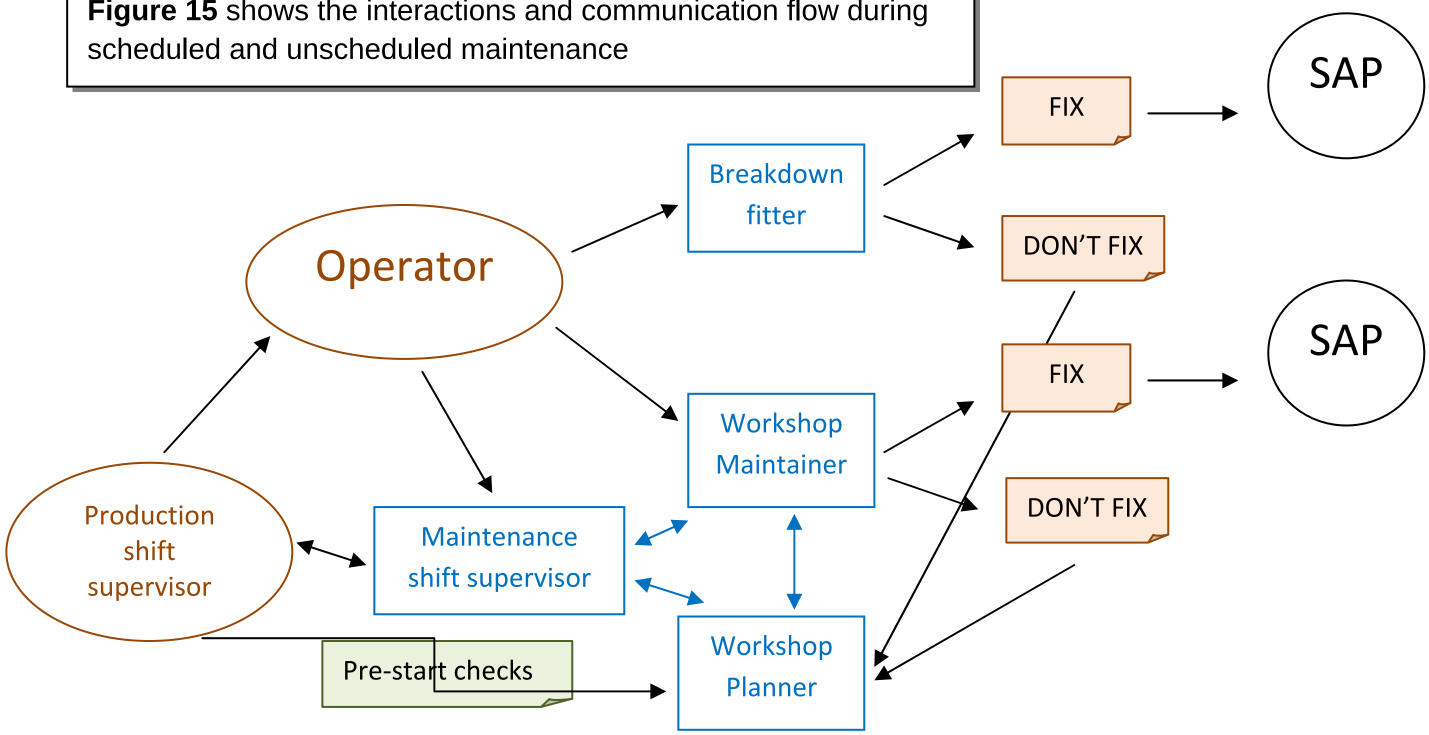
Overall, the four simulator trainer/assessors had developed strong relationships with all training personnel, including other trainer/assessors, trainees and the key decision maker in the training department. Three of the four also reported regular interactions with production personnel and one trainer also interacted more than once a shift with the maintenance work group and the OEM and/or dealer.

The Training Supervisor (representative of the key decision maker in the Training Department) reported most frequent interaction with the simulator trainer/assessor. The Production Coordinator frequently interacted with the trainee, the operations area, maintenance and the OEM representative, indicating that this person should be well informed about activities across the three work groups. The Pre-strip Supervisor was frequently in touch with the field trainer, trainee and experienced operator, as well as regularly interacting with the maintenance supervisor. The reliability engineer and health & safety personnel also reported regular interaction with maintenance.

Maintenance centred interactions and communication flow

In the diagram below, the workshop planner is a key player in the management of scheduled and unscheduled maintenance, with clear lines of communication to both maintenance and production decision makers.

Figure 15 shows the interactions and communication flow during scheduled and unscheduled maintenance



4. Interaction types

Initial analysis of the data collected during semi-structured interviews with participants across the wider work system indicated that there were three main types of verbal interactions occurring – Knowledge Elicitation, Mentoring and Training interactions.

1. *Knowledge elicitation interactions*

a. Purpose - problem solving/investigative
b. Triggered primarily by reporting systems
c. Also triggered by mentoring and/or training interactions
d. May be simple or complex (example of complex knowledge elicitation interaction shown below)
e. People – trainer/assessor interacts (planned/formal) with reporting system &/or operator, production supervisor, production decision maker, training decision maker

2. ***Mentoring interactions***

   a. Purpose – advisory
   b. Triggered primarily by mentee (operator)
   c. Usually simple
   d. People – simulator or field trainer/assessor interacts (planned/informal) with operator outside the planned training session

3. ***Training interactions***

   a. Purpose –skills development/refresher training
   b. Triggered by training matrix for new starters &/or investigations identifying the need for enhancement/refreshment of existing skills
   c. Usually simple
   d. People – trainer/assessor interacts with trainee during planned training (field/simulator) and debriefing (based on computer report) following simulator training

Examples of interactions occurring across the wider work system

Table 7 below provides some examples of these interaction types and the manner in which they are used or could be used to assist with training.

Interaction Type	Topic	Interactants	Description	Training Strategy
Knowledge Elicitation	Training documentation	Simulator trainer & field trainer	Conversation with field trainer who requests training documents to ensure currency of documentation Conversation can also be used to ensure training has been approved by the responsible person	Strategy to keep field trainers up to date & to discover any issues in the field – change management tool
	Excessive fuel consumption	Maintenance, MINEcare interrogator, simulator trainer, operators	Experts share experience to identify the factors causing excessive fuel consumption	If operator skill is implicated, correct this via mentoring, follow with formal training if necessary
	Overfilling while refuelling	Operator and OEM service rep	Design modifications to bring fill points to eye level mean that there is a delay in the levels adjusting	OEM service rep provides training

Interaction Type	Topic	Interactants	Description	Training Strategy
Mentoring	Critical events eg oil puddles	Simulator trainer & operator/trainee operator	Learnings from incidents used to remind operators of the best way to deal safely with oil puddles that may be on the haul road	***Informal refresher training*** – at pre-start meetings or other convenient times to update skills and situational awareness
Training	Routine scenarios	Simulator trainer & trainee operator	Detailed instruction about the actions, timing of actions, visual cues need to hone the skills required to perform the dumping sequence safely & with precision	***Refresher training*** – via a sequential learning process to help embed the procedure and to elicit information about problem areas

Communication triggers, drivers, barriers and training needs identification

The data has also identified **communication barriers and drivers** that have the potential to weaken or strengthen the effectiveness of verbal interactions.

Barriers: Negative cultural attitudes, inadequate leadership skills, rapidly changing workforce, an organisational framework that does not link decision makers with the communication process, resulting in a 'dead end' process, physical barriers such as the location of offices and access to information, although the latter can also be used positively to manage documentation,

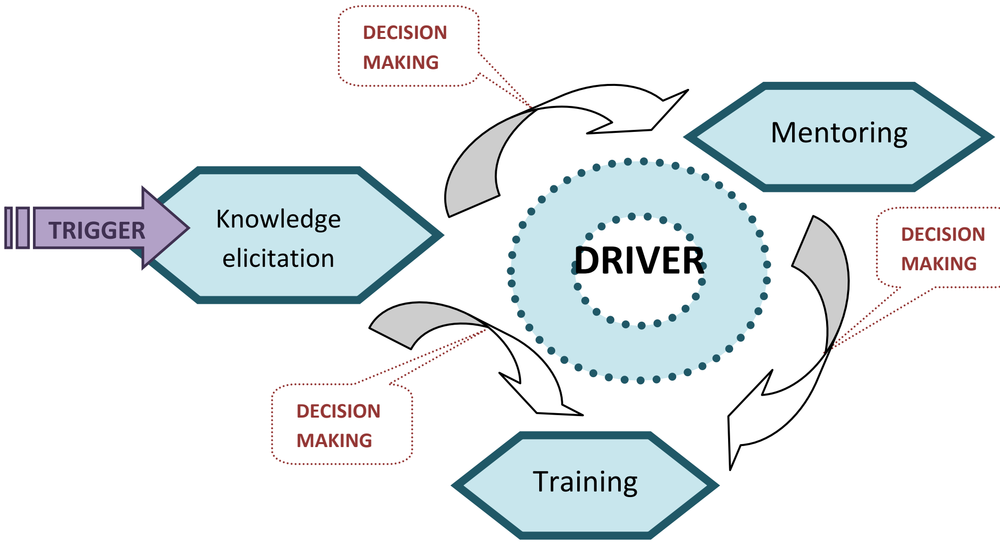
Drivers: Networkers who can connect 'strangers', effective leadership skills, positive cultural attitudes, stable workforce (relationships take time to develop).

Triggers that prompt the need for knowledge elicitation to identify the best pathway for improvements include data on truck wear & tear re brakes, gears, tyres, techniques to optimize economy of operation (use more fuel changing gears, therefore need to reduce gear shift changes).

Development of the model of verbal interactions for workforce engagement

The findings outlined in the previous section were used to construct a model of verbal interactions that could be used as a process for improving training outcomes by gathering information about haul truck operations (see **Figure 16** below).

Fig. 16 Workforce Engagement Model



The model connects each interaction type in a way that faciltates useful and purposeful responses to the outcomes of each interaction. An effective communication flow on its own is not sufficient to produce positive outcomes. Decision making is needed to move the outcomes of one interaction type on to the next logical step in the process. It is envisaged that the key driver would be the person who identifies the point at which decision making should occur and who communicates the decision making outcomes to the other interactants.

This model is intended to provide a process for continual improvement in a dynamic work envrionment where change is constantly occurring.The process for improving performance as a training outcome could be initiated by a range of triggers that prompt the need for knowledge to be elicited from experienced people at the ‘coalface’. The knowledge elicitation techniques used for this purpose could include the Critical Decision Method (CDM).

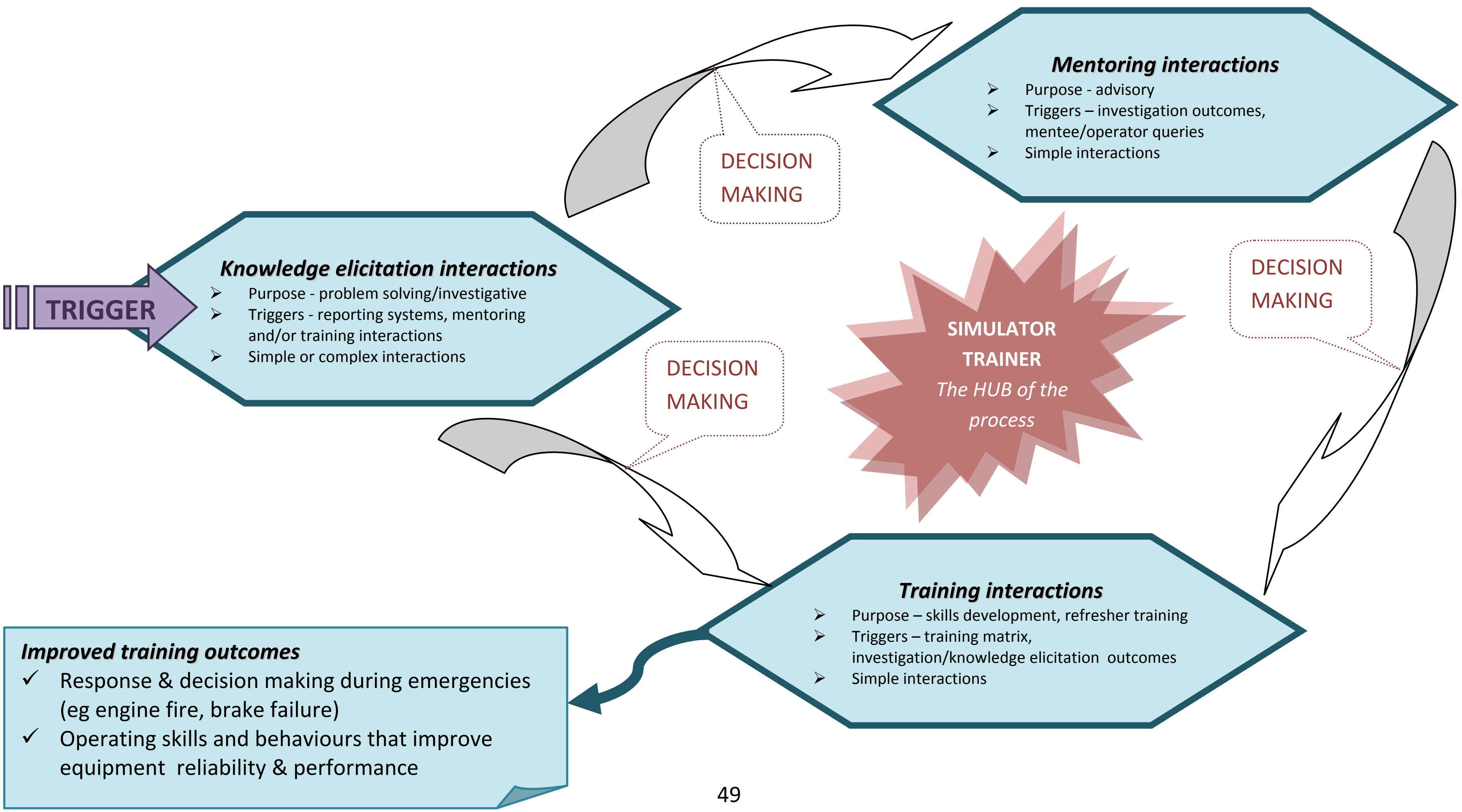
Informal Feedback Discussion

How the model might be implemented

The model incorporating the three predominant types of verbal exchanges suggests a process that could be used to achieve a range of continuous improvement and efficiency outcomes related to haul truck operation (see Figure 17 below).

Figure 17

Model of workforce Engagement for Improved Performance and Efficiency through Simulator Training Initiatives



In general, **knowledge elicitation interactions** are potentially useful for identifying mentoring and training needs. The outcomes of knowledge elicitation interactions could be utilised in a number of ways. They might be used to identify the root cause of equipment related problems early in their development so that a timely response to these issues can be determined. If a single operator's performance is implicated, the decision could be made to mentor that operator for the purpose of modifying behaviours that may be contributing to poor performance. If the problem appears widespread amongst operators, the decision might be taken to provide refresher training for the entire crew or focus on issues with the equipment that may be contributing to the problem.

Findings from the CDM section of this report support the concept of using knowledge elicitation interactions to identify mentoring and training needs. The findings and key decisions in Incident #7, for example, demonstrate the role of experience and decision making in preventing an engine fire. Similarly, Incident #10 identified glare from the sun causing temporary loss of vision for the operator as a common cause of misalignment when backing up to the shovel. The trainer might also add to this information by explaining that positioning of the truck is a key factor in ensuring a full load performed in a short timeframe. Timing is considered an important skill as loading that delays the following trucks may lead to risk taking behaviours by other operators in an attempt to catch up following delays.

Delays in loading also produce situations that are likely to result in vehicle to vehicle collisions, which are exacerbated by poor visibility due to the truck design. The recent introduction of proximity detection equipment is an area which could be investigated by applying knowledge elicitation techniques such as CDM and incorporating the CDM findings into a training needs assessment using the verbal interaction model.

Mentoring and training interactions, in turn, may also flag the existence of problems not identified by reporting systems, although their primary purpose would be to rectify problems.

Knowledge elicited during problem solving and mentoring or training interactions could be used to improve the range of operator capabilities that new starters might be expected to develop during simulator training. Simulator trainers could coach trainees to develop more advanced skills for routine tasks, such as situational awareness and decision making, before taking their first steps into the operational area.

Experienced operators, particularly those who are field trainers, could also benefit by including non-routine events in the refresher training program. Engine fire and loss of brake function are two events that demand good decision making skills and quick actions to prevent the situation from escalating. Field trainers could refresh their own skills before passing them on to other operators, a process that would provide consistency in training about new or modified skills. Used for this purpose, the verbal interactions model could be considered a **change management tool**. Where refresher training is used to introduce new equipment designs or modifications to existing equipment, knowledge elicitation could be expected to produce useful outcomes for OEM designers.

Drivers

An effective communication flow on its own is not sufficient to produce positive outcomes using the model described above. To succeed, the process needs to be driven by a central networker who has access to people within the associated work areas, and who is able to influence key decision makers. The research findings about **interaction strengths** indicate that the simulator trainer would be the ideal driver for improvements to haul truck operation, while in the maintenance section, it is suggested that the workshop planner or maintenance trainer/assessor could fulfil this role.

It is interesting to note that the simulator trainer/assessor at each site generally had a strong relationship with other training personnel and those in the operational work area. The relationship with the maintenance area was not consistently strong, perhaps influenced by the individual relationships established on a personal basis or through prior work experience and the organisational design of the different work areas that separates maintenance from training and operations. The design of shift rosters and a rapidly changing workforce are two issues that could impact negatively on networking and information flow as it takes time to build relationships and trust between individuals.

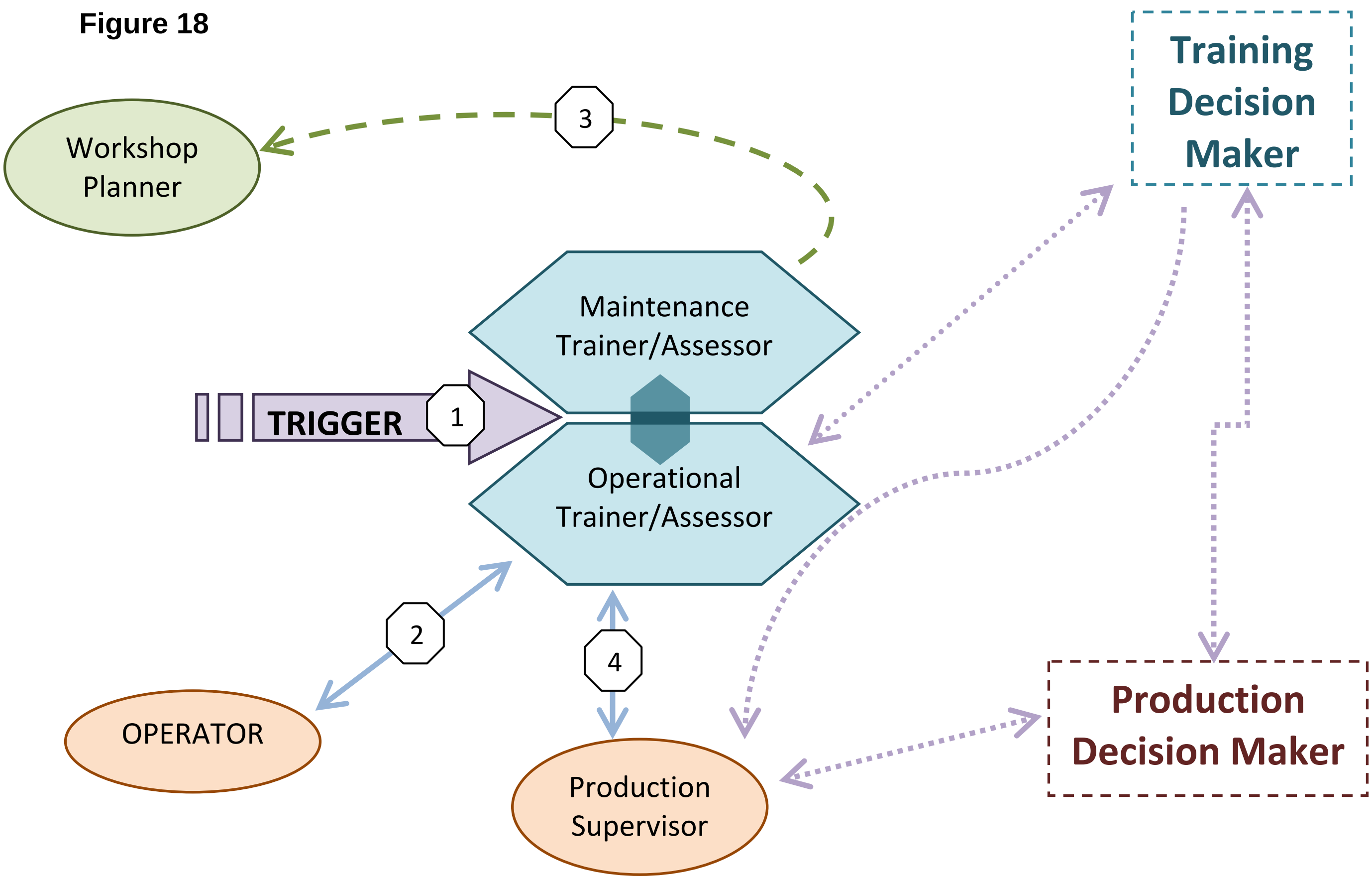
The characteristics of this role have not been fully assessed, but are likely to be built around peer respect, good networking skills, office based, and, most importantly, recognised expertise. Trainer coaching ability is an important attribute when helping trainees to understand the finer points of tasks such as dumping and loading, as the simulator session reports provide feedback about how well the trainee has aligned the truck, but is not able to explain WHY the trainee succeeded or failed.

Interaction Type	**Networker role**
Knowledge elicitation	Networker(simulator trainer/assessor) interacts with reporting system &/or operator, production supervisor, production decision maker, training decision maker
Mentoring	Networker(simulator or field trainer/assessor) interacts (planned/informal) with operator outside planned training sessions
Training	Networker (simulator or field trainer/assessor) interacts with trainee during planned training; also during debriefing (based on computer report) following simulator training

A simple version of the communication flowchart (Figure 18) has been constructed to show how knowledge elicitation could be effected by drawing on a strong relationship between the maintenance and operational trainer/assessors. The suggested steps in the knowledge elicitation process are outlined below

Step	Description	Interaction Outcome
1	Trainer monitors reports (eg incidents, reliability data) that trigger issues with either equipment or operator performance	Provides information about equipment performance; ongoing patterns suggest if cause is operator or equipment driven
2	Trainer chats to operator informally to identify issues (equipment &/or operator) that might be contributing to less than optimal performance	Provides operator input re the likely causal factors & thinking behind operator behaviours
3	Trainer verifies equipment issues with workshop personnel	**DECISION re causes**
4	Trainer discusses training needs with supervisor/production personnel	**DECISION re training needs**

Figure 18



Barriers

While barriers to free flowing communication may be viewed negatively, they may also be used to good effect. For instance, where version control of documents is important, restricting access to people in the training office forces the field trainers to interact with office based &/or simulator trainers. This forced interaction is an opportunity for both simulator trainer & field trainer to keep in touch with what's happening in the field (sim trainer) & to keep up to date with paperwork requirements (field trainer).

Informal Feedback Conclusions and Recommendations

Overall, based on the process of workforce engagement for effecting improved operator performance and efficiency, it is contended that this project successfully collected data and built a model of how informal feedback in the form of verbal interactions could be harnessed to gather information about haul truck design issues, training gaps, communication barriers and drivers. The following points should be considered carefully when applying this model for the purpose of improving training outcomes based on simulator training.

- Simulator training is a useful tool for initial skills training, particularly for new starters, and has the potential to be utilised for improved training outcomes, including
    - Improved response and decision making during emergencies
    - Improved operating skills and behaviours that improve equipment reliability and performance
- Experience level, coaching style, communication and interpersonal skills of trainers are important factors in successful delivery of training, and they may vary from trainer to trainer
- Simulator training to introduce or refresh skills needs to be reinforced by an understanding of its purpose in relation to haul truck operation- this is especially true when new technologies (eg collision detection systems) are introduced into the vehicle
- Simulator trainers need well developed networking skills to ensure access to current information about equipment performance and reliability from both the production and maintenance areas
- Refresher training is an opportunity to assess and monitor operational and emergency skill levels, introduce new skills and/or changes to existing procedures
- Refresher training can also be used as a means to correct operator behaviours that impact on equipment reliability and safety and to identify and update missing or poorly developed skills

This overall strategy represents a human factors approach to improving communication across three key areas of the business - training, operations & maintenance – by implementing a process that fits comfortably with the characteristics of the workforce.

The future step with this research is to validate the model by incorporating it as a training strategy to improve situational awareness and decision making targeting a priority area such as proximity detection and collision avoidance systems. It is hoped that this can be achieved by means of future ACARP-funded research.

Acknowledgements

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Appendices

Appendix 1: Critical Decision Method - Detailed Four Stage Process Description

Stage 1: Select Incident

1) Go through the information and consent forms with the participant.
   a) Give them the information form.
   b) Explain the experiment.
   c) Get them to sign the consent form.

2) Screen Incidents with the participant and select one that is appropriate.
   a) Must be an active decision maker.
   b) Must be a critical decision – a decision of importance that was a factor in an incident. In this case it will usually be where a significant accident/negative consequence was, or was not, avoided based on the decision of the operator.
   c) Should relate to Safety and/or Equipment Design if possible.

3) Get the participant to give an outline of the incident.
   a) One interviewer to lead the discussion.
   b) The other to type the incident into a laptop computer.
   c) Either can interrupt if necessary.

Stage 2: Construct a Timeline

1) Interviewer who was using the laptop repeats the entire incident back to the participant.
   a) Ask the participant to correct wrong information.
   b) Ask the participant make additions to the incident.

2) Interviewer who is not repeating the incident creates the information into "chunks" - task stages.
   a) May write the chucks on a whiteboard
   b) May write the chunks on card - template printed 4 to a page.

3) Sequence the chunks of information.
   a) Likely to already be in order.
   b) Add time if time is important in the situation.
   c) Lay the chunks out on the table in front of the participant.

4) Decide at what points Critical Decisions were made.
   a) This might solely related to the outcome of the incident.
   b) It might also relate to the goals of the exercise (eg equipment design issues.)

Stage 3: Deepening Understanding

1) Go through each critical chunk one at a time using the following probes to get improved information.

Cues	What were you seeing, hearing, smelling, noticing etc.?
Information	What information did you use in making this judgement? How, where and from whom did you get this information? What did you do with the information?
Analogues	Where you reminded of any previous experience? What about that previous experience seemed relevant to this case?
Standard Operating Procedures	Does this case fit a standard or particular scenario? Is this a type of event you are trained to deal with?
Goals and Priorities	What were your specific goals and objectives at the time? What was the most important thing to accomplish at this point?
Options	What other courses of action were considered or available to you? How this option was chosen or others were rejected? Was there a rule you were following in choosing this option?
Experience	What specific training or experience was necessary or helpful in making this decision?
Assessment	Suppose you were asked to describe this situation to some else at this point. How would you summarise the situation?
Mental Models	Did you imagine the possible consequences of this action? Did you create some sort of picture in your head? Did you imagine the events and how they would unfold?
Decision Making	What let you know that this was the right thing to do at this point in the incident? How much time pressure was involved in making this decision? How long did it actually take to make this decision?
Guidance	Did you seek any guidance at this point in the incident? How did you know to trust the guidance you got?

Stage 4: What if Questions

1) Go through each chunk one at a time using the following probes to get improved information.

Expert Novice Contrast	If a novice had been in charge at this particular point in the incident, what type of error might she or he have made and why? Would they have noticed what you noticed? Would they have known to do [key feature]?
Hypotheticals	If [key feature] of the situation had been different, what impact would it have had on your decision/assessment/actions/plans?
Experience	What training might have offered an advantage in this situation?
Aids	What knowledge, information or tools/technologies would have been useful/helped in this situation?

Appendix 2: CDM Data Collection Sheets

Participant ID:

Notes from Stage 1 and 2

(type details of incident and timeline)

Extra information from Stages 3 and 4

Critical Chunk (INSERT ID) (INSERT NAME)

Cues	
Information	
Analogues	
Standard Operating Procedures	
Goals and Priorities	
Options	
Experience	
Assessment	
Mental Models	
Decision Making	
Guidance	
Expert Novice Contrast	
Hypotheticals	
Experience	
Aids	

Appendix 3: Example of Raw Data Collected for CDM

Incident : Hit Dump tray.

Stages 1 and 2.

- Incident occurred approximately 3 years ago whilst full time operator.
- Doing reject the entire day. Started at 6am. Had been on shift for about 6 hours.
- You can take off from the dump with the tray still up BUT it should only work in 1st gear.
- You put the transition into 6th immediately but it stops in 1st until the tray is down.
- Takes approximately 10 seconds for the tray to go down.
- With tray up you can idle out in first but once you get over 8km then the tray alarm activates – in first you can get up to 11km.
- When the tray is up you can see it on a display but if you go over 8km there is audible alarm.
- Once you press the tray down switch it comes down automatically.
- All day it had been “up shifting” the entire shift with the tray up. Notified the maintenance crew that this was occurring and maintenance vehicle eventually came out (low priority).
- It was an auto electrician who came.
- Noted that it was a low priority because it wasn’t annoying and not stopping production.
- When he was getting close to the reject bins the electrician called up he stopped the vehicle.
- Near the reject bins there was a designated parking area – all this work has to be near the designated parking area.
- The electrician asked him to put the tray up.
- Got out of the truck.
- Put the lock on to isolate the tray.
- On the deck of the truck. Electrician goes and does something.
- Electrician informs that he thinks has fixed the problem.
- Electrician asked him to put the tray down and give it a test run.
- Electrician was in a dicky seat.
- Because the road was rough was taking it steady and only 50m from the reject bin (if had been longer then it was rough.) So you never got over 8km. Also driving slower with electrician in the dicky seat because it’s rough.
- Forgot to pull the leaver to push the leaver tray back down.
- Knew that the tray came into contact with reject bin – required structural engineers from Mackay to check the bin and they got it running again.
- Didn’t notice that the light was on.
- I-CAM was done the next week.

Stage 3: Key Decision = Decide to take off with the tray still up

- Decided to take it slow.
- Have started the truck with the tray up but rarely (2-3 times)
- 99% of the time you start off with the tray down.
- Goals, getting from a to b and also not want to give the bloke a rough ride.
- Chatting the whole time.
- There was no time pressure.
- On the reject bin there is a ‘red light’ that shows if the reject is filling up. When the red light comes on for along time the process plant shuts down. However at this time there was no time constraints and production pressure.
- Notes that the display for the ‘tray up’ is on the left of the dashboard – during the day it’s not necessarily easy to see (sun, covered in dust, bulb going).
- There was no visual from the tray. (You can’t see the top of the tray).

Stage 4: What if

- If you had not been friendly with the maintenance personnel you might not have been talking to the guy (and not been distracted).
- If it was a different driver.
- If the visual display was different (location – brightness) the it might have been noted
- If an audible alarm came on when the truck came on with the tray up.
- If the road had been in better condition.
- If he had been further from the reject bin.
- Could have an interlock with some over-ride on it.
- There is a wire that you usually contact to show that the tray is up. If you hit the wire then a second comes down in front of you to show you have your tray up.
- If the park up bay had been the other side of the wires this would have detected it.

APPENDICES

APPENDIX 4: Example of raw data collected during interviews with Trainees

Question	Response
CURRENT ROLE	Operate rear dumpers – CAT 793, 797, Komatsu 930E
HOW LONG IN CURRENT ROLE?	9 mths
PAST WORK EXPERIENCE - On this equipment - Other equipment - Other industry - Other minesite - Other	 NO Forklifts, medium vehicles Courier driver NO -
REASON FOR TRAINING	Learning skills
STAGE IN TRAINING	Feedback session
PREVIOUS EXPERIENCE WITH SIMULATOR TRAINING	2 days in simulator → 1 mth with trainer operator → on own (797) Progressed from 793 → 797 → 930E Familiarisation + 1 shift operator trainer for 930E
PREFERRED METHOD OF TRAINING	Any where trainer is focussed on what trainee can do
WHY?	More personal
WHAT'S GOOD ABOUT SIMULATOR TRAINING	Gives you confidence Helps you to know what to expect in the real world
WHAT'S BAD ABOUT SIMULATOR TRAINING?	Not real enough for experienced operators
HOW DO YOU LET YOUR TRAINER KNOW ABOUT PROBLEMS YOU HAVE ACQUIRING SKILLS?	During session – ask as it happens, trainer prepares trainee for next scenario (not what, just that it's imminent) Post session – use printout to understand impact of incorrect decisions
DO YOU PREFER TO LEARN BY TRAIL & ERROR OR A MORE STRUCTURED APPROACH?	Structured approach (went in cold 1st session – no familiarisation
ARE THERE ANY ASPECTS OF EQUIPMENT OPERATION THAT COULD BE CHANGED TO MAKEIT EASIER OR MORE INTUITIVE TO OPERATE?	930E (2 mths experience) – braking is delayed – told during verbal familiarisation) CAT rear dump trucks – gear changing is more complicated than Komatsu

Question	Response
	LIKE variety of changing from 1 vehicle to another
HOW DOES THE TRAINER HELP YOU DEVELOP YOUR SKILLS TO A HIGHER LEVEL?	- Pointers on how to do it well and then pick what suits you best - How to give operator better leeway to adjust for error (positioning under shovel) - Combine different approaches → better options, greater range
HOW DO YOU PASS ON WHAT YOU'VE LEARNED THROUGH SIMUALTOR TRAINING TO:	Other operators – exchange ideas with other trainees Trainers – not so much with simulator trainers, more with trainer operators
ARE THERE SCENARIOS THAT MAY ARISE OR YOU'VE HEARD ABOUT THAT AREN'T COVERED BY SIMULATOR TRAINING?	NO – used rocks on road, heat in tyres
DO YOU AND THE TRAINER EXHANGE INFORMATION (FEEDBACK) ABOUT ISSUES WITH ACTUAL OPERATION?	
IS INFORMATION EXCHANGE (FEEDBACK) DIFFERENT WHEN TRAINING ON THE ACTUAL EQUIPMENT?	
DO YOU HAVE ONGOING INFORMATION EXCHANGE (FEEDBACK) WITH TRAINERS AND OTHER MENTORS?	Informal – ask shovel & other truck operators
IF MENTORS, WHAT ARE THEIR ROLES AT SITE?	Alert drivers to errors No formal process, but advised by trainer to ask mentors

Appendix 5: Interaction nodes interview template

Consider any informal communication about

- Information that might influence the skill level, behaviours and performance of haul truck operators
- Issues relating to the safe operation and maintenance of the equipment

Communication frequency measures		
0	Never	Never
1	Rarely	1-3 times per month
2	Occasionally	1-3 times per rotation/week
3	Often	More than once per shift

- **Do you communicate informally with people in the following roles?**
- **Please indicate how often by placing a number from 0 – 3 in each box, according to the communication frequency measures above**

Your role	**Training Supervisor**	**Simulator Trainer**	**Field Trainer**	**Trainee Operator**	**Operator**	**Shift Supervisor**	**Production Supervisor**	**Maintainer**	**Maintenance Supervisor**	**OEM/Dealer**

Tick the boxes below where interactions occur between you and Training Supervisor, Simulator Trainer, Field Trainer, Operator, Shift Supervisor, Production Supervisor, Maintainer, Maintenance Supervisor, OEMs/Dealers

Information about haul truck activities such as......	**During planned meetings or other verbal interactions**	**During unplanned meetings or verbal interactions**	**At what time during your shift? Start, during or end?**	**Is this information passed on to others & how?**
Pre-start checks				
Normal Operation eg loading				
Normal Operation eg dumping				
Unplanned operational situations eg engine fire				
Scheduled maintenance				
Unscheduled maintenance				
Hot seat shift changes				
Scheduled down time				
Unscheduled down time				
Training				

VERBAL

- Face to face
- 2-way/phone

NON-VERBAL

- Body language
- Sign language

WRITTEN

FORMAL
- Reports/checklists

INFORMAL
- Sticky notes
- Email/notes on memory stick
- Online discussion boards

APPENDIX 6: Overview of the simulator training program

Simulator training followed a similar format at each site, with scope for individual trainer/assessors to drive effectiveness according to their skills and abilities. The simulator software module being used for instruction (Caterpillar 797B) could be configured for a range of events or scenarios to test developing skills.

Generally, there were three discreet stages of simulator training for new starters undertaking the haul truck operator package:

1. The ***Pre-simulator familiarisation session*** was designed to
    a. Introduce the trainee to the terminology specific to haul truck operation
    b. Provide a basic understanding of
        i. equipment functions (such as braking & steering)
        ii. mine site environment
        iii. pre-shift meeting areas
        iv. dumping & loading procedures
        v. actions (such as abusive gear shifts) that adversely affect equipment reliability
2. The ***initial simulator session*** was designed to familiarise the trainee with
    a. Haul truck operation
    b. Pre-start checks and visibility issues (using a parked up haul truck for walk around inspection)
    c. Work instructions
3. ***Additional simulator training sessions*** were conducted as required to ***develop and assess skills*** for
    a. Planned haul truck operation, such as
        i. reversing under loaders, shovels etc
        ii. dumping procedures
        iii. working with dozers
        iv. gear selection when going uphill & downhill – loaded and unloaded
        v. brake testing protocols & braking sequences
    b. Unplanned operator responses to site hazards & emergencies such as
        i. rocks on the haul road
        ii. engine fire
        iii. loss of brake function
        iv. low oil pressure

Once trainees had mastered the skills outlined above, the practice was to assign them to a crew and a field trainer who was a regular haul truck operator within the nominated crew. The field trainer then took over the training role, using a combination of coaching and mentoring techniques to further develop the trainee's skills and confidence. A scheduled follow up session on the simulator was designed to review skill levels and to assess the need, if any, for refresher training. This was also supported by ongoing mentoring by the simulator trainer, which was commonly initiated by the trainee 'popping in' to see the trainer at the end of the shift. This response was considered to be a reflection of the bond or trust established during simulator training.

For experienced operators, simulator training offers an opportunity to refresh skills and to exchange information with trainers about issues that may be impacting optimal operation. While initial skills training was well planned, refresher training tended to occur on an ad hoc basis when conditions in the field and availability of operators provided an opportunity, rather than as an integral part of further skills development and optimisation. Refresher training could be triggered by incidents involving mobile equipment, changes to mine rules and routine operation or unplanned maintenance that may be occurring due to less than adequate operator performance. Assessment of the data provided via the MINEcare program, which is part of the despatch module, is a useful source of information that can be used to trigger refresher training needs.

Trainees who were completely new to mining and haul truck operation considered simulator training to be a safe and effective way to develop basic skills and gain confidence before being exposed to reality of the pre-strip or production environment.

Experienced operators undertaking simulator training for the first time were more critical of the inadequacies of the simulator software in replicating the exact situation at site. Some issues, such as signs showing the speed limit in miles per hour instead of kilometres per hour, could be easily updated, but others posed more of a challenge. The sense of real danger during an engine fire was difficult to replicate, but the race against the clock to complete the emergency response actions precisely within a given time limit, provided a different challenge that enhanced the learning process.

APPENDIX 7: Notes about the strategic use of communication mechanisms to ensure consistency & currency of training documentation

Strategies needed to keep field trainer/assessors up to date and to ensure change management is effective for updated documentation [Note that the physical location of the training department can be a barrier – head of department & admin/booking system separated from simulator training area – simulator training area more accessible to field trainers – also more attracted to this area as it is less formal and more closely associated with their usual environment]

- Colour coding used to ID departments + current training competency codes on front page of document
- Field trainers/assessors have to come to training advisors for forms as they have no access to electronic copies to print and use
- Verbal interactions provide an opportunity for information exchange
- If the trainer/assessor asks for training documentation for assessment, it confirms that the training need has been identified by the supervisor
- If the operator requests training documentation, it flags the possibility that training may not have been approved according to the standard procedures

Communication Issues – rosters mean that there is little interaction across crews working in the same areas

APPENDIX 8: Interaction strengths

Role/Participant	Training Supervisor	Simulator Trainer	Field Trainer	Trainee Operator	Operator	Shift Supervisor	Production Supervisor	Production Superintendent	Maintainer	Maintenance Supervisor	OEM/Dealer
Simulator Trainer/Assessor	3	3	2	3	1	3	3		1	1	1
Simulator Trainer/Assessor	3	3	3	3	3	3	3		3	3	3
Simulator Trainer/Assessor	3	3	3	3	3	3	3		2	2	1
Simulator Trainer/Assessor	3	3	3	3	3	3					
Training Supervisor		3	2	2	1	2	1		2	2	0
Safety Training Coordinator (contractor)		0	3	3	2	3	3		3	3	1
Training, Safety Improvement	2	3	2	2	1	3	3		2	2	2
Training Advisor - maintenance	3	2	2	2	2	2	2		2	2	1
Training Advisor - maintenance	3	0	0	0	0	0	0	0	2	2	1
Maintenance trainer	0	0	3	1	3	3	3		3		3
Mobile Maintenance Superintendent	2	1	1	0	1	0	1	3	2	3	2
Maintainer / limited training role	1	0	0	0	3	3	3		3	3	0
Reliability Engineer	0	3	2	2	3	2	2		3	3	3
Operator	2	2	3	2	3	3	2		1	1	1
Production Coordinator	0	3	3	3	3	3	3		3	3	3
Pre-strip Supervisor (previously operator trainer/advisor)	2	2	3	3	3					3	
Health & Safety Advisor	1	0	0	1	2	2	2		3	3	1

APPENDIX 9: Summary of information dissemination about this research

Horberry, T. and Cooke, T. 2010. *Collision Detection and Proximity Warning Systems for Mobile Mining Equipment: A Human Factors Exploration*. Peer-reviewed and published in the proceedings of the European Conference on Human Centred Design for Intelligent Transport Systems (April 2010).

Leveritt, S. 2010. *The Performance Improvement Feedback Loop*. Poster displayed at the NSW Minerals Council OHS Conference (May 2010).

Leveritt, S., Horberry, T. and Cooke, T. 2010. *Knowledge elicitation solutions for improving performance and efficiency*. Proceedings of the Queensland Mining Industry Health & Safety Conference (August 2010).

Leveritt, S. 2010. *Let's talk about it! A novel approach to improving performance and efficiency at the coal face.* Paper accepted for the Safety Institute of Australia's Visions Conference (October 2010).

Horberry, T. and Cooke, T. 2010. *Incident Investigation in Mining Using the Critical Decision Method*. Poster and peer reviewed abstract accepted for the European Chapter of the Human Factors and Ergonomics Society Conference (October 2010).

Leveritt, S. *Informal communication: a model for improving performance and efficiency:* Poster and paper accepted for the Human Factors and Ergonomics Society of Australia (HFESA) Annual Conference (November 2010).