Can Improvements in Design of Mobile Plant Improve Safety Outcomes in the Mining Sector

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Abstract

Regulators continue to review legislation through out the country. The Victorian Occupational Health and Safety Act 2004, Section 28 was reviewed due to continued elements of design featuring in accidents. The new legislation has increased penalties fourfold for manufacturers, suppliers, construction and designers. The new penalties came into force in July 2006 and now carries the same penalties for employers-$1m. Queensland mining legislators are currently reviewing its penalties provisions.

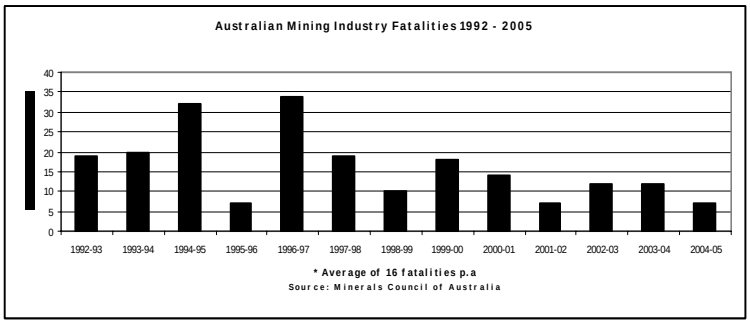
The mining industry is no exception to these problems in design related incidents and accidents where large materials handling equipment is required in the mining industry could result in indiscriminate death of employees. Mining equipment manufactures now realise that the needs of people must be incorporated in the life cycle of mining equipment, both operationally and from a maintenance point of view.

Australia's major mining states have enshrined rigorous risk management techniques for all major hazards. They are inclusive of a facility description, safety management system and risk management analysis with associated controls. Greater employee involvement at the design stages for such equipment is thought to provide the key to improve safety in the mining sector but is not enshrined in the new legislation.

Given the enormous resources and effort by the industry and regulators over the past decade to improve safety in the mining industry, can improvements in mining equipment design approach assist in the elimination of death, injury and illness in the mining industry?

Introduction

The Australia mining industry provides fifty percent of all export earning through the sale of extractive commodities. Since the early 1970's the Mining Industry has grown at an enormous rate in the area of production and technology. The quadrupling in the size and complexity of specialised equipment to extract minerals is a vast mechanised material handling exercise (Minerals Council of Australia, 2005). Although the mining industry in Australia has made improvements in its safety performance over the last decade (Figure 1), it is still an industry, which has a comparatively high death rate. There have been 211 fatalities in the past 13 years according to the Minerals Council of Australia. Death in the industry has no consistent trend nor are there signs of a reduction in number.



Recent Studies

The National Occupational Health and Safety Commission of Australia (NOHSC) have recently released a study based on the National Coroners Information into workplace deaths and their primary causes (July 2004). The study from 1997 to 2002 identified that 35% of the identified workplace fatalities were likely to have design related issues, a further 14 % were implied or suggested design issues particularly guarding machinery and fixed and mobile plant. Other issues were poorly situated controls, inadequate interlock systems, absent or inadequate rollover protective structures (or seatbelts) inadequate fall protection and failed hydraulic lifting systems. This was compared to a similar report from 1989 to 1992 where 54% of deaths were attributed to design (NOHSC July 2004).

NOHSC (August 2004) in conjunction with the International Labour Organisation (ILO) reported that mining and quarrying recorded the highest fatality rates in most countries as an industry. Australia's fatality incident rate per 100,000 employees is 2.6 and for the mining and quarry industry it is 20.4. The study also analysed work related traffic deaths in the mining industry and reports for the period 1988 to 2001 that 4 out of every 10 deaths is traffic related (NOHSC, August 2004).

According to the Queensland Minerals Industry Safety Health Centre (MISHC 2005) in Queensland reports that the fatal injury frequency rate (FIFR) of 0.06 deaths per million man hours in coal mines compared to an overall industry average of 0.05 deaths per million man hours. The MISHC report suggested that the FIFR for a safe industry is about 0.005 or a factor of 10 lower than currently reported in the mining industry.

Majority of mobile mining equipment comes from Europe, Japan or the USA. European regulations are aligned to the European Union (EU) Machinery Directives for Design and Manufacture of Machines that are safe to use. A study by Ashton University (Nicholas 1998), UK found only 62% compliance with EU Machinery Directives for Design.

USA suppliers and employers are required to comply with Occupational Safety and Health Association (OSHA) regulations. Safety performance standards required by both USA and EU are very similar but are not identical. There is no requirement for a risk assessment for machines in the USA; however a Job Hazard Analysis is required. Australian requirements are similar EU and USA.

A study by the U.S. Bureau of Mines (now NIOSH) found that 50% of accidents involved underground mining equipment of which 11% of such equipment was the primary causal factor and a further 10% being the secondary causal factor (Sanders & Shaw, 1988). An overall conclusion found poor original design or redesign with little consideration for human factors.

Defining Mobile Equipment

The definition of machinery (equipment) according to the European Standard EN 292 Safety of Machinery

An assembly of linked parts or components, at least one of which moves, with the appropriate machine actuator, control and power circuit joined together for a specific application for the processing, treatment, moving or packaging of a material. The term machinery also covers an assembly of machines, which, in order to achieve a common function or deliver a product, are arranged and controlled so that they function as an integral whole.

It stands to reason that a multiple of machines becomes a machinery system and that any assembly of devices to protect people from hazards or injury that could arise from the use of the machine is a *machinery safety system*. In the mining industry a good example would be a truck and shovel fleet, dragline and dozer operation or bucket wheel and conveyor system. Drilling and blasting operations can also be considered to be a machinery system.

In giving some perspective to mobile mining equipment in Queensland a Dragline can weigh as much as 5000 tonnes, stands as tall as a 7 store building and lifts 150 cubic metres of dirt in a single pass with its bucket. In the Victorian brown coal fields a bucket wheel can stretch the length of the Melbourne cricket ground. Trucks are capable of carrying 350 tonnes of waste or ore and front end loaders to fill these trucks lifting 40 cubic metres bucket in a single lift.

There is no doubt that mining equipment manufacturers and employers have provided a catalyst for change through the design and use of larger and larger equipment.

What is Design?

Goetsch (2005) quotes Professor William S. Chalk on the design process as "Is a plan of action for reaching a goal. The plan is used by engineers, designers, drafters, scientists, technologists, and a multitude of professionals." As noted by MacDonald (2004)
The Victorian *Occupational Health and Safety Act 2004* (OHSA) introduces a duty for designers of buildings or structures or parts of a building or structure for use as a workplace. This duty appears in Part 3 General Duties Relating to Health and Safety. Section 28 came into force in 1 July 2006.

This duty states that:
A person who designs a machine, building or structure or part of a building or structure who knows, or ought reasonably to know, that the building or structure or the part of the building or structure is to be used as a workplace must ensure, so far as is reasonably practicable, that it is designed to be safe and without risks to the health of persons using it as a workplace for a purpose for which it was designed.

Although this duty is placed on a 'person' who designs, it is expected that there will be a 'chain' of duty holders who are involved in the design, who have a duty under this section.
Section 27 of the OHSA requires manufacturers and suppliers to provide equipment that is safe to use. Safety legislation requires the designer have the major responsibility to make the machine safe to use within foreseeable range of applications (MacDonald 2004).

The employer (or owner) also has a responsibility (Section 21, OHS Act 2004). The employer should ensure that all safety measures are in place prior to commissioning, a risk management study completed, and involve employees as far as possible. Where two or more machines are implemented further risk assessments should be undertaken given that new and often unique hazards have been introduced.

Creighton & Rozen(1997) in their analysis of Occupational Health & Safety law in Victoria notes that OHSA does not contain any definition of the term "design", "manufacturer" or "importer". However, in their application of the English Language they suggest that design would be the development of the concept, drawing up preliminary and detailed plans. The manufacture would put the concept into practical effect of construction. For importers of mobile equipment the Macquarie Dictionary's primary meaning of import is "to bring in from a foreign country, as merchandise or commodities, for sale, use, processing, or re-export". Supplier and designers can be prosecuted with various sections of the Victoria Plant Regulations and OHSA but very few have.

Legal History

The problem with the old section 24 of the previous OHSA 1985 extends back as far as the forming of the British OHSA 1974 developed from the Roben's Report. In 1981 the British Trade Unions[1] sought clarification of the British Act section 6 (Equivalent Duty) due to the short coming of the duty required of designers, manufacturers and suppliers. The problem is linked to the fact that an operator of a machine will contribute error to create the operation of the machine in an

[1] Trade Union Congress to House Commons 1981-1982

unsafe condition. The term “when properly used” places the onus on unsafe behaviour and unsafe condition rather than poor design.

Secondly, the fact suppliers are required to provide instruction for “proper use” in the form of training and manuals is almost impossible to comply with. Thirdly the fact that proper use of plant is preceded by when has been taken as that the plant must actually be used. Further, the term “for use at work” excludes storage, carriage and processing (Creighton & Rosen 1997).
Lastly, the requirement for information does not extend to additional information as it becomes available for the life cycle of the machine including storage and disposal. The best point to eliminate the risk is at the point of manufacture before there is any imminent risk.

The Designers perspective is not always aligned with purchaser’s perspective and how the equipment needs to be used by the operators and maintainers. The term “when properly used” can provide a framework for the analysis of design of mobile equipment in the mining industry. Further, the improper use of mobile equipment will give a framework for error or at least a richer understanding of error (Reason & Hobbs 2003). Reason and Hobbs maintain that there is a Gulf of Execution and a Gulf of Evaluation between the User of Equipment and the Equipment (Diagram 2).
The fragmented and dynamic nature of the mining industry means that there is not the same amount of published or readily available data on failure rates of equipment and the failure modes of major mining hazards. This means that it may be difficult to obtain quantitative data to undertake accurate quantitative risk similar to the petroleum industry (Safety Case Legislation). Once completed, the Safety Case comprises a formal safety assessment, the safety ensuring programmes and the documentation of the principles, processes and design in a generative goal based safety system.

The difficulty with pre design in mining equipment is that it is technically more challenging for both the industry and the suppliers (Mitas 2004). It requires a high level of training and involvement of the workforce. Initially it is time and resources intensive and complex to demonstrate the safety of operations rather than compliance with regulations (Mitas 2004).

Some Case Studies

A rare example of a prosecution under the previous OHSA 1985, Section 24(2) is illustrated by Inspector Marsich v Race Industries Pty Ltd[2] An installer had installed a cable tray at a work place to carry electrical cables. The installer’s poor workmanship allowed a cable to split in the tray and some wires were left contacting the metal making it live. One year later and employee of the occupier of the building working at the premises fell to his death when he touched the tray. The fault was traced back to the installer who was successfully prosecuted under section 24(2) of the then current Act and was fined $7,500 out of a possible of $10,000. New penalties have a maximum of $250,000 for the Designer and $923,000 for the manufacturer. The stakes have increased in line with employer’s responsibilities and penalties.

A modification to a drill hydraulic interlock system restricting all means of power to rotary components of the drill when the operator leaves his seat was too little to late. Sadly, this followed a fatality with a similar drill in another mining operation through entanglement. A similar accident in New Zealand occurred two years prior to this but the industry and manufactures made little attempt to engineer out the problem.

In another mining fatality a young employee was crushed beneath the bonnet of an underground haulage truck, while attempting to jump start the truck. There were no remote battery “plug in’s” at ground level which was a common modification to trucks as far back as the early 1990’s due to multi skilling requirements in the mining industry.

[2] Broadmeadows Magistrates Court Vic, 18 November 1991.

In another mining fatality, a maintenance employee was killed while attempting to remove a wear plate from the jaw crusher in a quarry when it released suddenly falling on the employee. The design of the plate removal was not adequately documented. The plant was manufactured in United Kingdom, supplied from NSW and was only 2 years old. These cases illustrate and are well documented to include design errors in which mining equipment is expected to operate.

In the current competitive economic environment there is extreme pressure on the operators of mines to be efficient and reduce costs. In the same economic environment there is also pressure on governments of all persuasions to reduce red tape and attract business and employment opportunities to their respective states. Hopkins sums up this dilemma by stating that "Designate Authorities have a vested interest at a local level to be conservative with the enforcement of Health & Safety to keep operators in business" (Hopkins 1996). These aligned interests have the potential under current mine design requirements to compromise health and safety standards. "The cost to industry in a political economic context creates an environment where the protection from harm is not as high as it should be" (Hopkins 1996).

National Strategies

The Office of the Australian Safety and Compensation Council (ASCC) is currently producing guidance for the 'Eliminate Hazards at the Design Stage,' a priority of The National Occupational Health and Safety Strategy 2002-2012. These principles are outlined in the recent draft of these 'Safe Design Guidelines' prepared by the ASCC consider:
Responsibilities of those who control or have influence over the design of products or systems of work;

- A lifecycle approach that considers all phases of the machine building or structures throughout its life.
- Systematic risk management; and
- Reciprocal transfer and feedback of information to all involved.

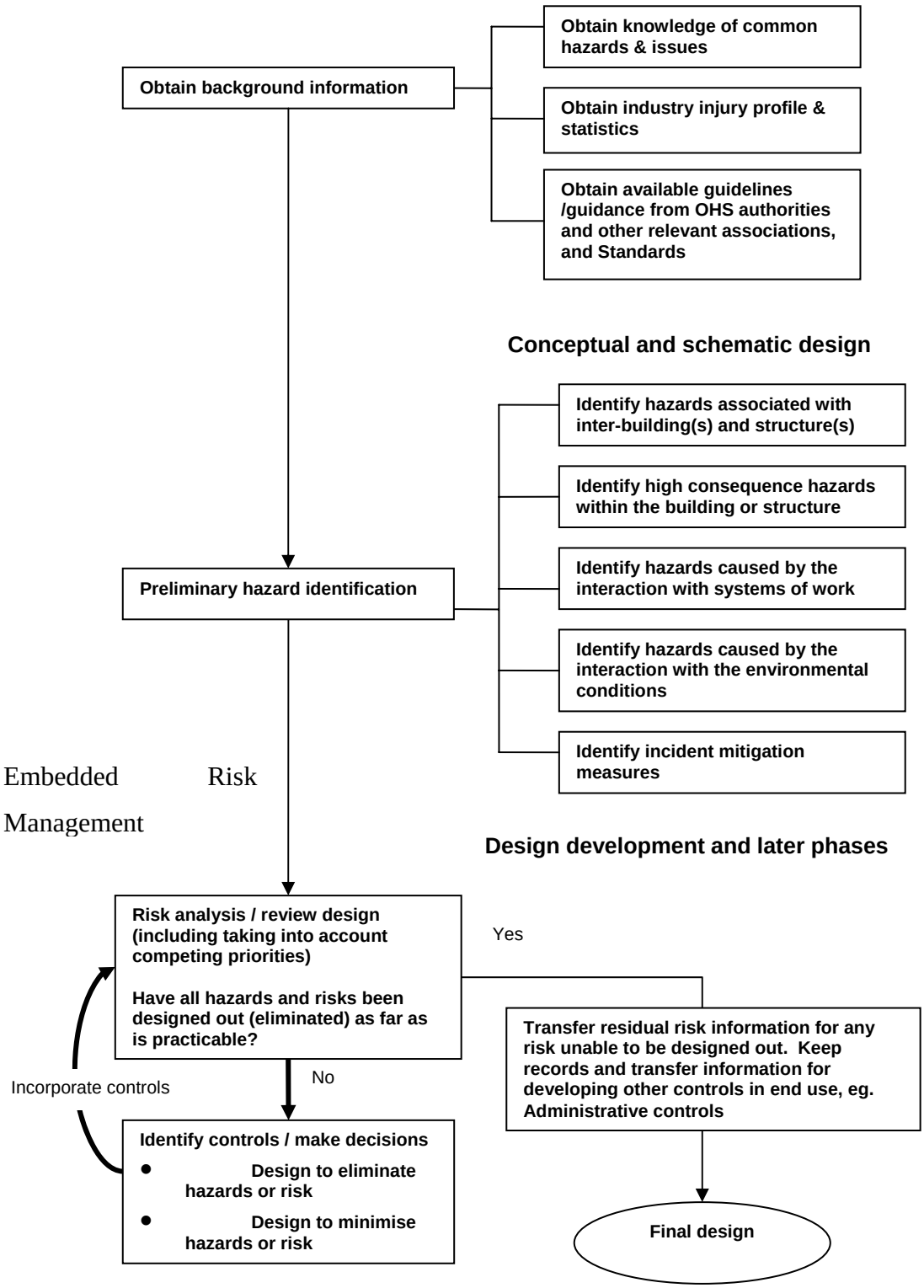
In the New South Wales the Construction Industry facilitators (NSW CI 2003) are being used to optimise safe design in the planning stages. In Queensland the Earth Moving Equipment Safety Round Table (EMESRT) has been established within the Minerals Industry Safety and Health Centre (MISHC). EMESRT are developing and making available design information for operability & maintainability concepts for risk assessments to be used by equipment manufacturers. In Victoria (VWA 2005) supports national consistency and has formed a task team to prepare guidelines for the implementation of the new Act as it relates to design. Diagram 1 indicates the Worksafe's process for implementation of pre design process.

According to Worksafe's process (VWA 2005) embedded risk management is required in the design process supposedly for the life cycle of the equipment. The pitfalls that organisation and individuals in delivering risk management out comes are waste, disorder, avoidance, arrogance, ignorance, apathy and complacency (Cater2004).

Reason & Hobbs (1998) imply that maintenance error from human performance problems ranks highest in the nuclear power plant industry and the world aviation industry. Many maintenance errors have there origin in inadequate system design. It is believed a gulf of execution between the user and the equipment exists. The user is not sure what they can do to the system to achieve their goals and it is not sure what changes our actions have brought about within the system (Diagram 2)

System designers generally give a low priority to maintainability of equipment. Design principles should include easy access, components labeled clearly and informatively, minimal need for special tools, field adjustments avoided and the equipment designed to facilitate fault isolation.

Diagram 1 (Worksafe,Vic)
Preliminary assessment



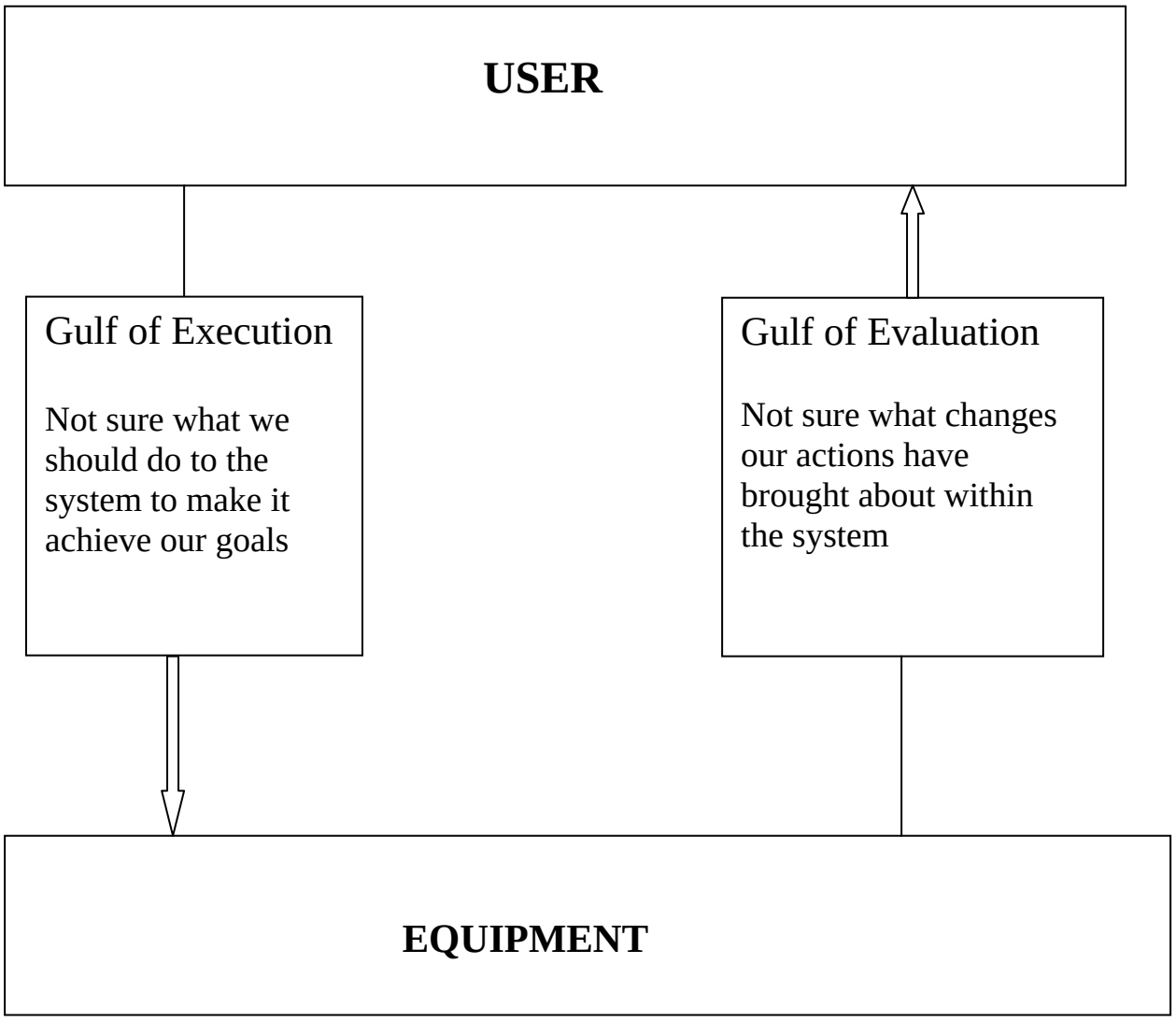


Diagram 2 Design Evaluation (Reason & Hobbs 2003).

Hazards in Mining Equipment

MISCH analysis of mining industry fatalities over a 15 year period(MISCH 2004 web) showed that over 85 per cent of fatalities occurred under the following eight categories.
Collision between vehicles.
Accidents involving the driver or passenger of a vehicle.
Electrocution (Mostly Underground)
Person Falling
Person hit by falling or flying object (Mostly underground)
Fire or explosion (Mostly Underground)
These hazards can be categorised in generic terms as
Maintenance Operator

- Access & Egress
- Confined Spaces
- Falling from heights
- Manual Handling
- Electrical Hazards

Machine Operator

- Traffic Management
- Fatigue
- Ergonomics
- Noise & Vibration
- Equipment impact

Machine control systems have become more sophisticated with on board computers that indicate various alarms and the ability to down load information to maintenance and operating staff. This will assist the operators in areas of training to ensure the equipment is within “proper use.” Some examples of these are engine over speed, transmission abuse, load distribution, grade inconsistencies and braking pressures.
The operators and maintainer of this equipment are required to operate this equipment safely. When properly used what remains constant is the operator-machine interface and their control systems.

.Operator
Operator interface
Machine Control System
Machine

The U.S. NIOSH (1998) explains that equipment was implemented in accidents in the following areas;
Poor original design or redesign
Control-display layout.
Exposed wiring and hot surfaces
Exposed sharp surfaces or pinch points
Unguarded moving parts
Restricted visibility

The report concludes that the typical engineer does not consider human factors when designing.

Case Studies of Good Design

A qualitative and quantitative study of major mining companies in Victoria, Queensland and Indonesia who operates truck shovel fleets found reviewed the use of on board computers for down loading information about machine abuse. The companies attributed any failures due to operator abuse to accident damage via an accounting management process against the operator of the equipment (Operations). The effect ensured operators were held accountable for damage, the supplier noted for poor rework on component change outs and the designers of the mine ensuring no unsafe conditions exist in which the equipment needed to operate. An example of this was found when 127 operator abuse faults in a transmission of a haul truck just prior to destruction at its half life. The emphasis is on the proper use of equipment, training of operators and safe conditions for equipment to operate in.

As mentioned above the New South Wales construction industry (NSW 2004) has now developed guidelines for the facilitation of safety requirements through better design prior to construction commencement. The facilitation process involves a cross section of professionals and employees. In large open cut mine in central Queensland maintenance, operations, engineers and supplier were involved in major modifications to a new overburden drill. Primarily for access and egress to the mast and other areas of the 120 tonne drill, the manufacture was required to recalculate the finite engineering analysis of the mast to ensure structural integrity of the drill. The importance of this example is the combined efforts of the manufacturer, the company and all employees were committed to improving safety by minimizing the probability of a fall from heights.

The simple inclusion of a hydraulic shut down sensor switches to the cabin door of a smaller mobile drill could have saved a mans life in Victoria (Quarry Drill). A manual handling example of a jig developed to overcome the lifting of 28 kg pin when replacing the rear struts on a 200 tonne rear dump truck. This job is performed every 20, 000 hours on each machine. This equates to approximately every two years. On a large fleet site as found in Indonesia this job would be performed every two months. The pin is of a size that it isn't practical for a two man lift. This is a good example of applying the hierarchy of control to engineer out the manual handling problems.

Most major mining companies are now recognizing the need to introduce Fatal Risk Control Protocols. In line with widely available reports in Australia, these protocols include;
Light Vehicles
Surface Mining equipment
Underground Mining Equipment
Underground Ground Control
Hazardous Materials Management
Equipment Safe Guarding
Molten Materials Management
Isolation
Working at Heights
Lifting Operations

Standardizing mobile equipment with additional safety features through out Australia is becoming the norm. From a legal perspective (VWA 2003), the State of Knowledge for mobile mining equipment manufacturers, suppliers, construction and designer will be the new bench mark for pending litigation and possible prosecution under the new legislation.

Conclusion

Good design requires adherence to all standards and compliance certification. Further improvements to design will require the involvement of the end user to assist designers and manufacturers to relay safety requirement learnt from experiences in field operations. Mines, mine owners, unions and governments need to place pressure on the manufacturers to involve end users in the design of mobile plant and equipment to reduce the incidence and impact of occupational injuries and illness in the mining industry.

Victoria's new OHS Act 2004 and the legislation regarding designers does not involve end users, however the Plant Regulations 1985 does place requirement for risk assessments (Regulation 703). Safety Case regime in the petroleum industry and most State Major Hazard Facilities legislation does require Health and Safety Representatives (HSR'S) to be equally involve with company representatives. The effectiveness of legislation on most plant importers is required through the duty of care and State of Knowledge in the industry. The cost to retro fit either to comply with Australian law, standards or major company policies but most mining companies now see the need to reduce death in the industry through fatal risk control. There is no doubt that poor or inadequate design is a major contributor to death in the industry.

Employees involved in the operation and maintenance of mobile mining equipment will face less risk and be safer when equipment is properly used and designed for all environments by involving the end users at the design stages. Penalties of 1 million dollars will propagate keen interest from other state authorities and manufacturers alike.

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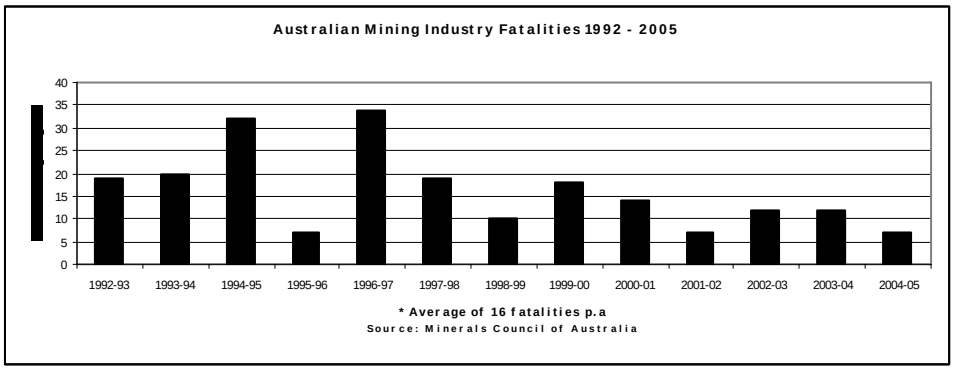
Australian Mining Industry Fatalities 1992 - 2005
40
35
30
25
20
15
10
5
0
1992-93
1993-94
1994-95
1995-96
1996-97
1997-98
1998-99
1999-00
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2002-03
2003-04
2004-05
* Average of 16 fatalities p.a
Source: Minerals Council of Australia

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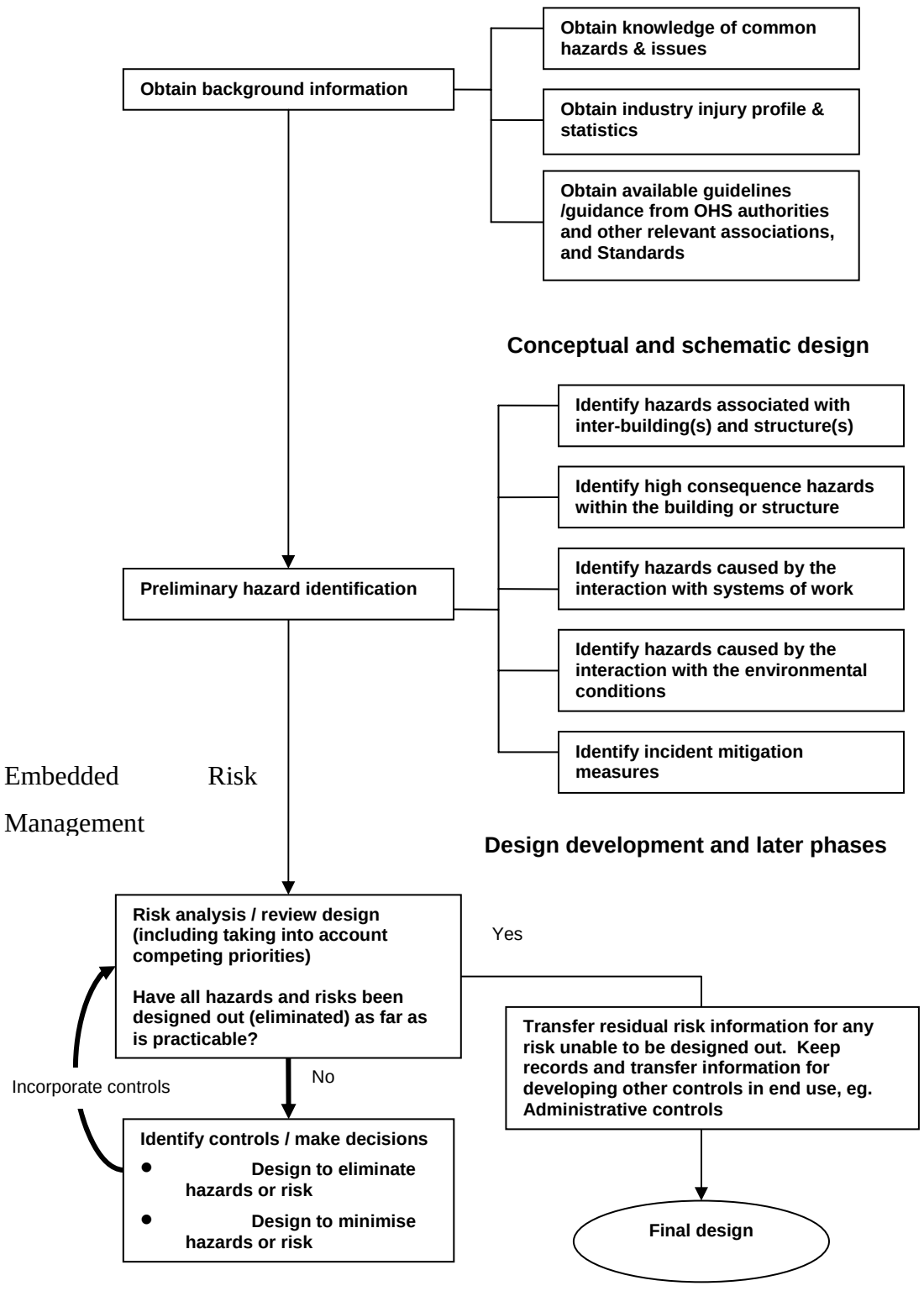
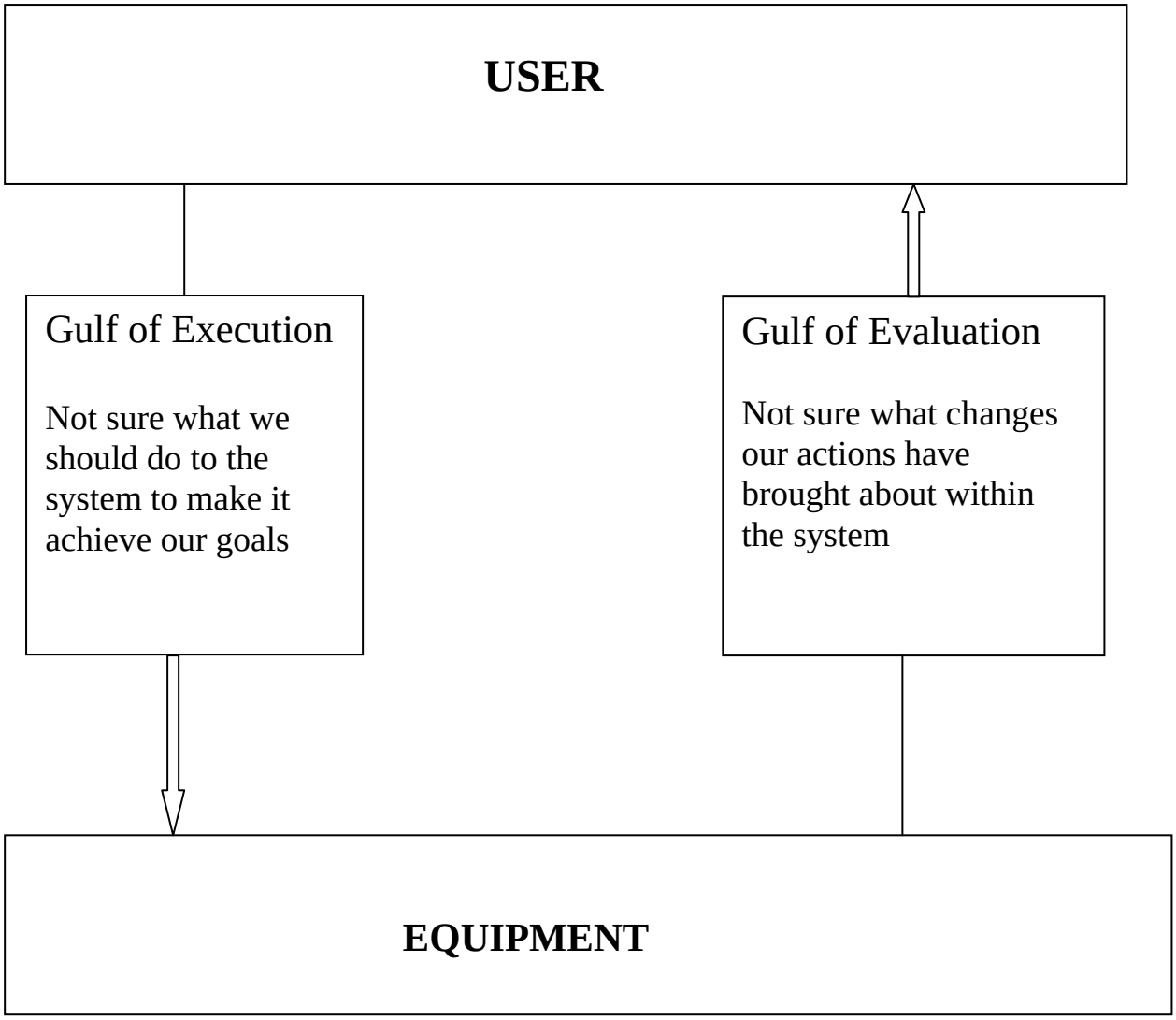
Preliminary assessment





.Operator
Operator interface
Machine Control System
Machine