DESIGN ISSUES IN WORK-RELATED SERIOUS INJURIES

Australian Government
Department of Employment and Workplace Relations
Office of the Australian Safety and Compensation Council

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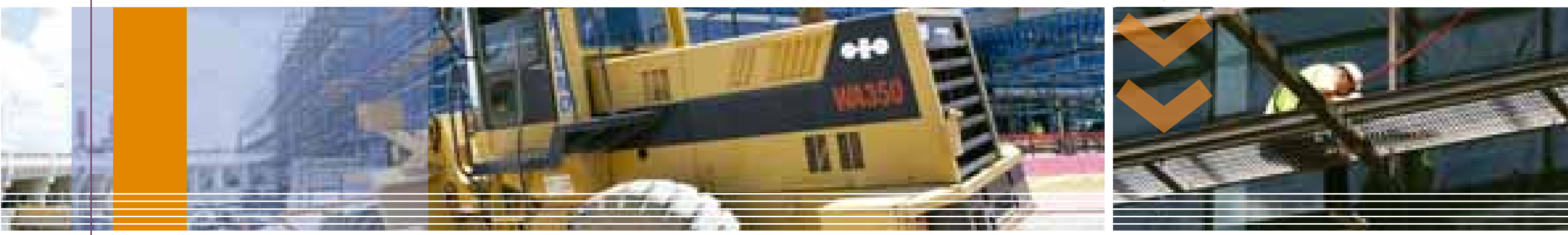

CONTENTS

LIST OF TABLES

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ABBREVIATIONS AND ACRONYMS

ABS	Australian Bureau of Statistics
MUNCCI	Monash University National Centre for Coronial Information
NCIS	National Coronial Information System
NDS	National Data Set for Compensation-based Statistics
NIOSH	National Institute for Occupational Safety and Health
NODS	Notifiable Occupational Disease System
NOHSC	National OHS Commission
OHS	OHS
RCD	Residual current device
ROPS	Roll-over protective structure

EXECUTIVE SUMMARY

BACKGROUND

This is the second report arising from an Australian Safety Compensation Council (ASCC) project to consider the contribution of design issues to the occurrence of work-related injury and fatalities in Australia and the way that contribution may best be measured and monitored. The first report for the project focused on understanding the contribution of design to workplace injuries and fatalities, and the nature and extent of these. Information on work-related fatalities was obtained from the National Coroners Information System (NCIS), and information on serious work-related non-fatal injuries was based on workers' compensation data.

This second report considers the role of design in work-related serious injury in more depth and breadth. The aim of the report is to provide the Office of the ASCC with a basis for thinking about where it could be and where it intends to be in terms of information on design-related occupational injuries. The main aspects are:

> a review of relevant literature on the role of design in serious work-related injury

> a detailed analysis of work-related fatal injury related to design, with particular focus on the construction, transport and storage, manufacturing and health and community services industries

> consideration of poor procurement practices in relation to design issues, and

> review of information barriers to monitoring design-related occupational injury and the proposal of approaches to reducing them.

Each of the above aspects is considered in a separate chapter of the report.

LITERATURE REVIEW

Very few studies describe the proportions of injuries caused by poorly designed or malfunctioning equipment in the workplace. However, from the small number that do, it is clear that poorly designed machinery, safety measures and/or workplaces play a significant role in elevating the overall risk of occupational injury.

There are many examples in the industrial safety literature of the production of new machines (and components) designed to increase safety. Commonly, the impetus for the production of these products is the tightening of legislation and guidelines by the national and international regulating bodies responsible for Occupational Health and Safety (OHS). The general OHS literature also contains many case reports of specific design failures and potential solutions.

In the past, Australian OHS regulations were primarily focused on plant and equipment. However, recently the integration of safe design principles into the construction, maintenance and use of buildings and structures has become more prominent. This represents a move away from post-hoc regulation and towards embedding safe design principles into projects and products from the planning stage onwards, an approach similar to that observed in Europe.

THE ROLE OF DESIGN IN WORK-RELATED FATAL INJURY

The first report considered work-related deaths that occurred in Australia between 1 July 2000 and 30 June 2002. Seventy-seven work-related deaths (37% of identified workplace deaths) that definitely or probably involved design-related issues were identified. A more detailed analysis of the circumstances surrounding these deaths was undertaken for this report, with particular emphasis on key circumstances surrounding these deaths, and on workers employed in the construction, transport and storage, manufacturing and health and community services industries.

There were a wide range of design issues evident in the fatal incidents, but there were also some features common to a number of incidents. The most common scenarios involved:

> problems with roll-over protective structures (ROPS) and/or associated seat belts
> inadequate guarding
> lack of residual current devices
> inadequate fall protection
> failed hydraulic lifting systems in vehicles and equipment, and
> inadequate protection mechanisms on mobile plant and vehicles (such as enclosed cabins).

The highest numbers of workplace fatalities were in the agriculture, construction, transport, manufacturing, trades and mining industries. Design-related issues were definitely or probably involved in 40% or more of the incidents in the mining, transport, agriculture, construction, trade and manufacturing industries.

Well-known solutions exist for virtually all the design problems underlying the fatal events considered in the analysis.

PROCUREMENT PRACTICES AND DESIGN

Design problems with equipment clearly made an important contribution to the fatal incidents considered in chapter 3. However, it is not clear to what extent:

> the fatally-injured person was aware of the problem
> who made the purchasing decision, and
> what consideration was given to design issues at the time relevant equipment or machinery was obtained (or not obtained).

Key issues related to procurement practices include perceived risk, availability of alternatives, costs and statutory requirements. In light of these issues, a sensible approach to procurement of machinery or equipment, taking into account design issues, would be along the lines of the following:

> involve the personnel who are likely to be using or maintaining the machinery or equipment
> conduct a risk assessment of the tasks for which the machinery or equipment is likely to be used
> consider whether the machinery or equipment has been designed taking into account the task for which the machinery or equipment is intended, and other uses to which it might reasonably be expected to be put
> consider the passive and active safety features included in the machinery or equipment, and
> consider the maintenance requirements for the machinery or equipment, and what risks are likely to arise in conducting this maintenance once the machinery or equipment is installed and in use.

DATA SOURCES AND DESIGN-RELATEDNESS

Three main factors impede and complicate measurement and monitoring of design-related occupational injuries:

1. lack of satisfactory operational definitions of design-related occupational injury
2. limited information content of available sources of data on occupational injuries, and
3. lack of empirical evidence about design-related risk factors.

The role of design in the occurrence of work-related injuries is generally abstract. Design can be defined in a range of ways, with more or less direct and obvious connections to safety. These characteristics make ‘design-relatedness’ a difficult concept for which to create a good operational definition. Suitable definitions were searched for in published literature without success.

Data sources that provide information on occupational injuries generally contain very limited information about the circumstances of injury occurrence, and what they do provide tends not to refer to design-relatedness. Some data sources relevant to occupational safety contain more extensive information, but these are generally limited to relatively small numbers of cases.

Assessment of occupational injuries as being design-related is complicated by the pervasive and complex nature and influence of design. Many characteristics of designed objects, places, processes and systems might affect the safety of workers, either positively or negatively. The presence of a potentially hazardous design characteristic may produce small or large elevation of risk of injury, and the potential consequences of exposure may be trivial or catastrophic. Relatively little quantitative and analytic evidence is available about which design-related factors and characteristics affect injury risk, how they do so, and by how much.

This report proposes a suite of four potential solutions to these problems. These are:

1. a method for monitoring design-related occupational injury using existing case data and an operational definition validated in terms of the assessments by OHS professionals,
2. a method for estimating the extent of design-related occupational injury by means of attributable fractions, which could be applied to existing data,
3. focused enhancement of existing data sources on occupational injury, to improve their utility for understanding and preventing design-related harm, and
4. a new approach to acquiring and applying information on design as a factor in safety. This method may provide a route to a deeper and more specific understanding of how and why users of particular equipment, tools, materials, et cetera are exposed to hazards, as well as a means to convey this information to designers, or others in a position to apply it for prevention.

The proposed program is strongly influenced by the scope of this project, which focuses on design as a factor involved in the occurrence and prevention of occupational injury. Design is, of course, only one of several important factors influencing safety, though it often interacts with others. The focus of these proposals on design should not be seen as downplaying the importance of other factors to occupational safety, or as being an alternative to them. Rather, the point is to ensure that the contribution of design to occupational safety becomes reasonably well understood, and to improve the likelihood that situations in which poor design is an important threat to safety will be recognised and corrected.

SUMMARY AND CONCLUSIONS

Design issues are rarely considered comprehensively in OHS research. This report presents a detailed consideration of the role of design issues in fatal work-related injury in Australia, with emphasis on recurrent circumstances and key industries. The analysis has shown that:

> similar design problems are involved in many fatal incidents

> design is an important contributor to fatal injury in many industries, and

> solutions already exist for most of the identified design problems.

There is little information on factors that influence the extent to which design issues are considered in equipment and machinery procurement decisions.

There are several information barriers that adversely affect the measurement and monitoring of design-related occupational injury. This report proposes potential solutions to these barriers.

Design issues make an important contribution to the occurrence of fatal and serious non-fatal work-related injury in Australia. Measurement and monitoring of the extent and nature of the contribution of design issues should be able to be improved through:

> the development of an agreed definition or set of definitions

> improvement of current data sources and/or introduction of new data sources, and

> the use of new research approaches.

1 INTRODUCTION

The first report for this project[1] focused on understanding the contribution of design to workplace injuries and fatalities and the nature and extent of these. Information on work-related fatalities was obtained from the National Coroners Information System (NCIS), and information on serious work-related non-fatal injuries was based on workers' compensation data.

This second report considers the role of design in work-related serious injury in more depth and breadth. The aim of the report is to provide the Office of the ASCC with a basis for thinking about where it could be and where it intends to be in terms of information on design-related occupational injuries. The main aspects are:

> a review of relevant literature on the role of design in serious work-related injury,

> a detailed analysis of work-related fatal injury related to design, with particular focus on the construction, transport and storage, manufacturing and health and community services industries,

> consideration of poor procurement practices in relation to design issues, and

> review of information barriers to monitoring design-related occupational injury and the proposed approaches to reducing them.

Each of these aspects are considered in a separate chapter of the report.

2 LITERATURE REVIEW CONCERNING THE INVOLVEMENT OF DESIGN IN WORK-RELATED INJURY

2.1 OCCUPATIONAL INJURIES ATTRIBUTED TO DESIGN

Surveillance of the rates and risks of occupational injuries are largely dependent on case records derived from workers' compensation and insurance claims and national OHS incident report collections.[2-6] Commonly, the information recorded in these data sets has little to contribute to the assessment of actual causes of specific incidents.[7, 8] While it is obvious that certain industries have inherently higher risks of serious injury, namely the forestry, fishing, mining, transport, agriculture, and construction industries,[2, 9-12] very few studies describe the proportions of injuries caused by poorly designed or malfunctioning equipment in the workplace. However, from the small number that do, it is clear that poorly designed machinery, safety measures and/or workplaces play a significant role in elevating the overall risk of occupational injury.[13-15]

2.2 THE EXTENT OF THE PROBLEM

Workplace injuries are common and costly. The Industry Commission conservatively estimates the total cost of the approximately 650,000 occupational injuries and illnesses sustained annually to be at least $20 billion a year.[16] Research from Victoria reports that more than half of the state's occupational injuries are attributable to the manufacturing, construction, primary industries and transport and storage and sectors.[17] This pattern is similar to that observed in the other states of Australia[4] as well as internationally.[18, 19]

Research in the United Kingdom (UK) indicates that approximately 64% of injuries sustained in the construction industry are attributable to poor design in one way or another ([20] cited in[14]). Further, a study by the UK Health and Safety Executive revealed that the failure to design and implement physical safeguards caused 35% of fatalities and more than 20% of non-fatal maintenance incidents in the UK petrochemical industry ([21] cited in[14]). Falls are a particularly common source of injury in the construction injury[22, 23] and in British research, design-related failings have been noted as a common causes of accidents involving temporary scaffolds.[24] The fitting of defective components, unauthorised modifications of structures, neglecting to fit barriers or safety structures, and other readily identifiable structural/design faults have been found to significantly contribute to recorded cases of injuries involving scaffolds.[24] However managerial deficiencies were also highlighted as important contributors. In response, a prototype decision aid, incorporating prescribed scaffold regulations and safety management best practices, was developed and is currently being tested to address both of these issues. Built-in system flexibility and feedback loops within the decision aid allow for application across a wide range of job specifications and iterative improvement of safety management protocols.[24]

The heavy and/or mobile machinery used in the construction and manufacturing sectors is also a common source of occupational injury.[25-27] Fork-lifts and other powered industrial vehicles have inherent significant hazards that if not well controlled can easily lead to injury.[28] Frequently, increased operator training and emphasis on appropriate safety behaviours are the primary suggestions for reducing the risk of injury.[25, 26, 29, 30] In considering the design-related aspects of injuries involving these vehicles, the design of the workplace itself is also attributed a significant role.

As a result, remedial advice often includes the designation of pedestrian-only, or vehicle-only, pathways and adequate spacings between work-stations. [14, 25, 30] Additionally, modifications of existing machinery and improved design of new vehicles so that warning devices, seat belts and safer seating are fitted to all powered industrial vehicles have been suggested.[25-27, 29] Furthermore, up to 50% of occupational incidents associated with mobile machinery occur while moving on the access paths, principally during ingress and egress from the cabin.[31] Research into the safer design of mobile machinery access paths reveals that designers require more information regarding the actual use of their machines and need to incorporate accident statistics and knowledge of natural human movement behaviours into integrated design methodologies.[31]

In Victoria, 26% of cases of occupational injuries presenting at selected emergency departments were of workers reported to be working in the manufacturing sector.[17] In the US, injuries sustained in the manufacturing sector represent more than 10% of all fatal occupational injuries and it is estimated that approximately 20% of these fatalities are machinery-related.[32] Australian research reports that small manufacturing businesses often exhibit low safety standards due to a lack of resources, facilities and work systems conducive to a high level of safety.[33] A study of 35 small businesses in New South Wales found that fewer than half of the sample of machinery which required covers or guards actually had them fitted and operational and that the majority of these guards were considered to be poorly designed.[33] In addition, the failure to adhere to known safety protocols (including the use of personal protective equipment) was found to contribute to workplace injuries and low overall safety ratings. Recommendations flowing from this study emphasise the need to address the fact that small businesses rarely have the financial and expert resources to replace or modify old and/or unsafe machinery.[33]

2.3 DESIGN SOLUTIONS FOR OCCUPATIONAL INJURY: EXAMPLES FROM THE LITERATURE

There are many examples in the industrial safety literature of the production of new machines (and components) designed to increase safety.[34-36] Commonly, the impetus for the production of these products is the tightening of legislation and guidelines by the national and international regulating bodies responsible for OHS.[35, 36] The general OHS literature also contains many case reports of specific design failures and potential solutions. These include design issues related to tractors,[37] construction machinery,[38] computer mice,[39] stepladders and augers.[40] A few detailed examples are presented here.

2.3.1 Agricultural machinery

Rates of injury in the agricultural sector are high both in Australia[41] and internationally.[10] Research conducted in India provides impressive examples of risk identification and the development and implementation of efficient design solutions.[42, 43] Injuries involving grain threshing machines represent a significant proportion of the high rate of deaths and serious injuries related to agriculture in India.[42] The study of thresher injuries and their causes in two districts of Northern India revealed that physical dimensions of threshers involved in injury incidents were significantly different to machines that had not been involved in injuries. Based on this, and the use of anthropometric data of the Indian population, the authors proposed a safer thresher design.[42] Importantly, the new design did not represent a significant increase in the cost of the threshing machine and field testing in the study area was successful – reportedly preventing injuries in at least two cases during the implementation. A further agricultural injury prevention innovation has been trialled in India in a project to develop safer fodder-cutting machines.[43] Again, fodder-cutting machines represent a significant proportion of the high injury rates prevalent in the agricultural regions of India, and a high percentage of these victims are children below the age of 15 years. The authors suggested a number of simple design modifications, principally involving the fitting of guards and covers, and field trials have indicated that these

modifications have been received favourably by users.[43] The initial success of both improved agricultural machinery designs has led the Bureau of Indian Standards to consider incorporating the modifications into national design standards.[42, 43]

Injuries sustained through tractor roll-overs are a significant source of agricultural occupational fatalities, both in Australia and internationally.[44-46] Roll-over protective structure subsidy schemes have been instigated in Victoria and New South Wales in order to address this issue. Evaluation of the Victorian program estimates that two deaths per year, for at least ten years, will be prevented by the ROPS fitted under the scheme.[47] This represents significant savings in terms of both the economic and social costs incurred as a result of these types of injuries. The New South Wales subsidy program is currently being evaluated.[48] Using a similar approach to the Indian studies described above, research conducted by the US National Institute for Occupational Safety and Health (NIOSH) sought to address a design-related contributor to the occurrence of tractor roll-overs.[45] Since 1985, US tractor manufacturers have adopted a voluntary standard to equip all new tractors with ROPS.[46]

However, in certain instances, tractors fitted with standard, fixed ROPS are not practical, as the tasks being performed require low clearance which the ROPS do not allow. To address this safety-hazard, NIOSH researchers have designed and tested an automatically-deploying ROPS (AutoROPS) which is triggered only in the event of roll-over.[45] Field tests suggest that this design improvement will successfully contribute to tractor roll-over injury reduction.

2.3.2 Portable oxygen systems

A similar 'identify-and-redesign' approach has been taken by NIOSH researchers observing increasing rates of injuries caused by explosions of portable oxygen systems.[49] Noting that such explosions have increased since the adoption of aluminium regulators in preference to brass, the researchers, in collaboration with the US Food and Drug Administration and the National Aeronautics and Space Administration, have developed and tested a provisional American Society for Testing and Materials standard. This provisional standard instructs that the oxygen system regulator be 'comparable or equivalent to brass'.[49] Additional

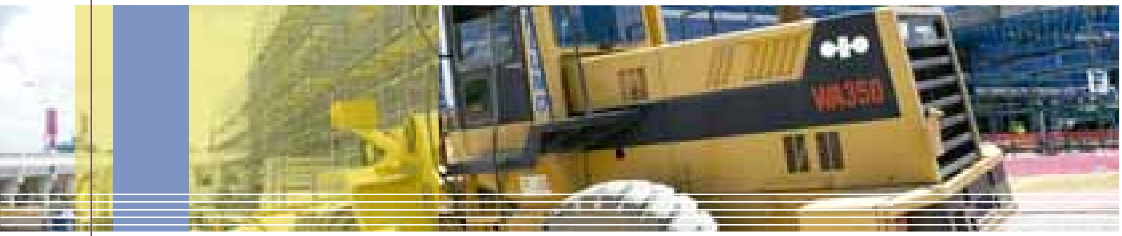
NIOSH recommendations address appropriate use and safety behaviours and suggest that warnings and guards be fitted to the systems.

2.3.3 Sharps injuries

The low cost per injury, and the relatively non-serious nature of most needle-stick or sharps injuries, belies the serious risk of transmission of blood-borne diseases. This risk increases the importance of eliminating the causes of sharps injuries, particularly in the medical professions.[50] Research conducted in the USA in the late 1980s indicated that a common feature of sharps injuries was the necessity of separating a disposable (sharp) element from a reusable holder.[51] The fragility of glass items, such as capillary tubes or ampoules, was also a common cause of sharps injuries. The authors were able to suggest a number of highly practical design solutions to reduce the occurrence of such incidents – including reducing the use of needles, incorporating safety shields into the design of scalpels and needle clamps, and the introduction of plastics to eliminate the use of fragile glass.[51] An Australian study of occupational injury in a dental school also points to the poor design of equipment as a cause of sharps injuries.[50] Since the United States (US) study, many of the design improvements suggested have been supported by more recent research and have been adopted as recommendations for eliminating injury risk by injury-prevention organisations internationally,[52] including the US National Institute for Occupational Safety and Health.[53]

2.4 INTEGRATING SAFE DESIGN THEORY AND PRACTICE

Traditionally, Australian OHS regulations were primarily focused on plant and equipment. However, recently the integration of safe design principles into the construction, maintenance and use of buildings and structures has become more prominent.[14] This represents a move away from post-hoc regulation and towards embedding safe design principles into projects and products from the planning stage onwards, an approach similar to that observed in Europe.[54] Much of the emerging research into safer design practices to prevent occupational injury is addressing managerial aspects and developing integrated managerial protocols and decision tools.[24, 54-63] Calls for multi-disciplinary collaboration amongst engineers, injury prevention researchers and representatives from the industries emphasise this change in approach. Increasingly, the need to incorporate ergonomic principles into not only actual workplace and machinery designs but also standard engineering educational programs, is gaining acceptance.[63]




3 THE ROLE OF DESIGN IN WORK-RELATED FATAL INJURY

3.1 INTRODUCTION

The first report[1] considered work-related deaths that occurred in Australia between 1July 2000 and 30 June 2002. Seventy-seven work-related deaths of workers (37% of identified workplace deaths) that definitely or probably involved design-related issues were identified. This chapter describes in more detail the circumstances surrounding these deaths, with particular emphasis on:

> key circumstances surrounding these deaths, and

> workers employed in the construction, transport and storage, manufacturing and health and community services industries.

3.2 METHODS

The methods used to identify the deaths of interest are described in detail in the first report.[1] Relevant aspects are summarised here.

3.2.1 Definitions

Work-relatedness

Only work-related cases were considered in this study. The definition of work-relatedness is that adopted by the NCIS, which was developed in close consultation with the Office of the ASCC. A work-related case is:

'A person who was fatally injured as a result of, or who died of a fatal condition caused by, exposure to their own or others' work activity or work factors; or who was fatally injured whilst travelling to or from work.' *

This definition includes workers in workplaces, persons driving for work purposes, persons driving to or from work (commuters), and bystanders.

Only persons dying directly or indirectly as a result of injury were included. (Indirect injury covers situations such as someone dying as a result of a pulmonary embolus or sepsis while hospitalised after major injury.)

Design-related

An injury was defined as a *design-related* case if:

> any aspect of the construction of equipment, plant, tools or structure involved in the incident made a meaningful contribution to the occurrence of the injury-causing incident and/or to the occurrence of fatal injury resulting from the incident; and

> it was realistic to expect that this factor could have been modified to avoid the incident or the subsequent fatal injury.

Certain groups of cases were excluded from the analysis for one or more reasons. These included groups where:

> relevant design issues were already addressed by specific authorities and did not fall within the scope of OHS design as envisaged for this project; and/or

> the available data sources were unlikely to contain information regarding design issues for these types of cases.

These groups were persons injured as a result of:

> motor vehicle incidents involving road vehicles on public roads;

> aircraft crashes

> train crashes, or

> medical misadventure.

* The full NCIS definition of work-relatedness is available at http:www.vifp.monash.edu.au/ncis/

3.2.2 Source of information

The primary source of information of fatal injuries was the NCIS. The NCIS is a national system of information and supporting infrastructure designed to provide prompt access to national coronial data to support the work of Coroners and others interested in the prevention of injury and disease. It is important for the current project because it is the only source that covers all work-related incidents (although limited to fatalities) regardless of the employment status of the injured person and the setting of the incident. It is the only accessible source likely to have detailed information on many of the deaths of interest.

Cases were eligible for inclusion if the death occurred on or between 1 July 2000 and 30 June 2002. Queensland cases could not be included because information on these cases has only recently been included in the NCIS and was not available to researchers at the time this study was conducted.

3.2.3 Identifying work-related deaths

Potential work-related cases were identified in the NCIS using the Work-relatedness and Activity variables. The available text information was then inspected before a final decision on work-relatedness was made. Those cases deemed to be work-related were then inspected to determine whether they met the study definition of work-relatedness.

3.2.4 Identifying circumstances involving design issues

All relevant information on the NCIS website was used to identify cases with design-related issues. Cases were initially coded as 'Definitely', 'Probably', 'Possibly', 'Unknown' and 'Not' design-related. For example, incidents would be coded as design-related if:

> someone fell from a height and there were no railings to prevent a fall

> someone was electrocuted by domestic current on a circuit without an earth leakage device

> a tractor or bulldozer operator was killed where there was no roll-over protection device or cabin and the machinery rolled over, or the operator was struck by a heavy object while operating the machinery, or

> someone was caught in the moving parts of machinery that could have been guarded and/or protected by a cut-off safety system.

The difference between 'Definite', 'Probable' and 'Possible' codes was primarily due to different levels of available information about the circumstances. 'Unknown' was usually used when there was little or no information available. 'Not' was used when there was sufficient information to rule out design as an issue (e.g. a police officer shot by a fugitive), although even for some of these cases it could be argued that a design-related prevention approach might have been possible.

These analyses considered design issues to have occurred if design had definitely or probably made a significant contribution to the incident and its fatal outcome. Three coders were involved in the blind coding of design-relatedness for NCIS cases. One coder coded all of these cases and each case was coded by at least two of the coders. Assigned codes were compared, and cases with differences then discussed to reach a final decision on the most appropriate code. For the purpose of the analyses presented in this report, 'Definite' and 'Probable' codes were considered to identify design-related cases, whereas 'Possible', 'Unknown' and 'Not' were combined into a second, 'Other', category. In two cases, final agreement could not be reached. These cases were given a final code of 'Unknown'. The cases categorised as Other or Unknown are not considered in this report.

For those cases identified as definitely, probably or possibly being related to design, the main apparent design problems were recorded.

3.2.5 Circumstance versus industry-based analysis

The rest of this chapter presents detailed information on the design-related fatal incidents. Section 3.3 focuses on the circumstances, particularly emphasising similarities between incidents. Section 3.4 focuses on the industry in which the worker was employed, with emphasis on

Table 1: Design-related problems in fatal workplace incidents. Australia (excluding Queensland), 1 July 2000 to 30 June 2002. Number and per cent.

Category	Definite/probable		Possible		TOTAL	
	Number	%	Number	%	Number	%
ROPS/seat belts	13	16.9	0	..	13	12.3
Guarding	11	14.3	0	..	11	10.4
RCD	9	11.7	0	..	9	8.5
Fall protection	6	7.8	4	13.8	10	9.4
Hydraulics	6	7.8	1	3.4	7	6.6
Overhead protection (cabin, etc)	5	6.5	1	3.4	6	5.7
Roof material	2	2.6	4	13.8	6	5.7
Brakes	2	2.6	3	10.3	5	4.7
All-terrain vehicles	2	2.6	1	3.4	3	2.8
Building construction	2	2.6	1	3.4	3	2.8
Safety systems	2	2.6	0	..	2	1.9
Vehicle blind spots	1	1.3	2	6.9	3	2.8
Stacking	1	1.3	1	3.4	2	1.9
Over-luffing	1	1.3	1	3.4	2	1.9
Controls	1	1.3	0	..	1	0.9
Lighting	1	1.3	0	..	1	0.9
Other	12	15.6	10	34.5	22	20.8
Total	**77**	**100.0**	**29**	**100.0**	**106**	**100.0**

the main design-related hazards and risks present in the industry. Only the industries of priority interest to the Office of the ASCC, and any other industries with five or more deaths, are separately considered.

3.3 CIRCUMSTANCE-BASED ANALYSIS

There was a wide range of design issues evident in the fatal incidents, but there were also some features common to a number of incidents. The most common scenarios involved:

> problems with roll-over protective structures (ROPS) and/or associated seat belts

> inadequate guarding

> lack of residual current devices

> inadequate fall protection

> failed hydraulic lifting systems in vehicles and mobile equipment, and

> inadequate protection mechanisms on mobile plant and vehicles (such as enclosed cabins) (Table 1).

3.3.1 ROPS/seat belts

Thirteen deaths occurred related to a design problem with ROPS and/or seat belts. Seat belts were not explicitly mentioned for any of the incidents, but the circumstances were such that seat belts were unlikely to have been present and, if they were present, were not being worn. Ten incidents involved tractors – five roll-overs and five run-overs. The other three involved other mobile mechanical equipment that rolled over.

Tractor roll-over

The circumstances of the five tractor roll-overs were similar. In each case, the tractor was being driven up or across a slope and overturned. Equipment was being towed in at least three of these incidents. The operator was either thrown out and crushed by the tractor (two incidents); thrown out and crushed by the attached equipment (one incident); or remained on the tractor and was crushed as it rolled (one incident). A fifth person was thrown out, but the cause of the fatal injuries was not clear.

One tractor had a fully enclosed cabin that sustained minimal damage in the roll-over incident, but the deceased was thrown out of the cabin. In another incident, there was an open ROPS, and this crushed the deceased as the tractor rolled over.

Tractor run-over

Five incidents involved the operator falling from a tractor and being run-over, or being crushed, either by the tractor (three incidents) or by towed equipment (two incidents).

Other equipment roll-overs

Three incidents involved the operator of mobile mechanical equipment being crushed by the equipment as it rolled over. In each case, the equipment either had no ROPS or an open frame (none had enclosed cabins) and in each case the equipment was being operated on or near a slope before overturning. The specific incidents were a forklift carrying material reversing down a slight slope; an excavator removing trees on a slope; and a road-profiling machine on a road construction site accidentally reversing over a slope.

3.3.2 Guarding

Eleven deaths involved design issues related to guarding. Six involved fixed machinery in which someone became trapped; three involved augers or associated power transfer shafts; and two involved other equipment.

Fixed machinery

A common theme with most of the incidents involving fixed equipment was the injured person coming into contact with parts of the equipment designed to generate high pressures to mould or crush material. For some of the incidents, a form of guarding or safety system was in place, but this did not function as intended, or was not designed to prevent the circumstances that occurred. The incidents involved:

> machines unexpectedly activating (plastic bottle-making machine and a foam pressing machine)

> being dragged into, or falling into, a rock crusher

> being trapped when the doors of a baler opened against concrete pylons designed to protect people getting close to the opening doors

> being trapped by moving parts of a conveyor, and

> a bystander child being caught between rails when a mechanical dairy was intentionally activated by the operator.

Augers

The three auger-related incidents were very similar. Each involved an auger being powered by a tractor, and the operator's clothing being caught in the rapidly rotating auger (two cases) or the exposed power take-off mechanism connecting the tractor to the auger. In each case, the operator received fatal injuries as the clothing was ripped from them with great force, and/or they were pulled into contact with the rotating parts.

Other equipment

One death involved a worker being struck by the rotating parts of a tractor-powered potato-bin tipper on which he was performing maintenance. The other involved a circular saw/grinder that became stuck in concrete and, on release, struck the operator in the neck.

3.3.3 Residual current devices

Nine workers were electrocuted in circumstances where residual current devices did not appear to be present, and where the presence of such a device would have been expected to prevent the fatality. Five of the incidents involved electricians and another involved a trainee avionics technician. The other three involved a computer consultant, a panel beater and a landlord performing maintenance on one of his properties.

The circumstances of the nine incidents were varied. Faulty electrical circuits were the primary problem in at least three of the incidents, and three of the incidents involved electricians working in confined ceiling cavities.

The primary design problem appeared to be the lack of residual current devices. Residual current devices would probably have prevented all nine deaths, although they were only explicitly mentioned in the available documentation for two deaths.

3.3.4 Fall protection

Six design-related incidents involved people falling from a height. Two of these incidents involved a fall from scaffolding. One person was placing ballast on a railway bridge and fell backwards nine metres off the bridge, which did not have any fall protection in place. A farmer fell seven metres from the platform of a windmill – the platform did not have any fall protection in place and the windmill design required anyone doing maintenance to be placed in a position where they were at considerable risk of falling. A building inspector fell six metres on a building site, but there was little information about the circumstances of the fall. The final incident occurred when a farmer climbed to the top of a truck trailer in an attempt to secure a tarpaulin in high winds, and was blown off, falling six metres. Although the primary design issue in this incident probably related to the need for a ground-based tarping system, a fall protection system would have been appropriate if a ground-based tarping system was not used.

3.3.5 Hydraulic lifting systems in vehicles or mobile equipment

Six incidents occurred when workers were crushed by the raised part of a vehicle or mobile equipment controlled by hydraulic mechanisms. In three of the six incidents, the worker was performing maintenance on the equipment and in the other three cases there was not enough information to determine the specific task at the time of the incident. The incidents involved the raised tray of a tip truck (two incidents); the raised cabin of a semi-trailer; the lifting arms of a front-end loader; the raised blade of a bulldozer; and a bobcat. Several specific design problems seemed to be involved.

Three incidents probably occurred with the hydraulic systems operating as they were designed to operate. In the semi-trailer cabin incident, the cabin had been raised so that the driver could inspect the engine. It appeared that the hydraulic system had been put in the 'lower' position, but had not operated because of a faulty latching mechanism. The driver appears to have leant into the area and fixed the latching mechanism, which allowed the hydraulics to operate immediately and lower the cabin onto the driver. One of the incidents involving a tipper truck probably occurred because it took several minutes after the truck engine was switched on for enough air pressure to build up to allow the hydraulic system to operate. It appears that the engine was switched on to warm up, with the tray already raised. The tray didn't lower immediately because the pressure was still building up, and the driver then leant under the tray. However, the controls were in the 'lower' position, and when the pressure reached a high enough level the hydraulics operated automatically, causing the tray to lower onto the driver. In the third such incident, hydraulic hoses were being replaced on a caterpillar loader, but there was no fail-safe mechanism to stop the bucket moving when the hydraulics were disconnected, and the worker was crushed when the bucket and support arms moved.

At least two of the other three incidents occurred because the hydraulic mechanism was faulty (that is, was not operating as intended) and there was no adequate fail-safe mechanism.

In the final incident, there was insufficient information to allow the precise circumstances to be determined.

Another three incidents involved hydraulically-operated hoists or jacks. They are considered in more detail in Section 3.4.5.

3.3.6 Overhead protection on equipment

Five deaths occurred in incidents in which an inadequately-designed or missing cabin or related structure on mobile equipment allowed the equipment operator to be crushed by falling or moving objects. Two incidents involved miners. In one, two miners were killed when the articulated rock-breaking vehicle that they were operating was hit in a rock collapse. The other mining incident involved a poorly-designed continuous miner that required the operator to move into an area that did not have adequate overhead protection to undertake some tasks. Whilst moving hoses on the machine, the operator was crushed in a roof fall. The other two incidents involved a forklift operator being crushed when a heavy crate fell onto an inadequately-braced overhead protective cage, and the operator of a front end loader, apparently without a cabin, being crushed by a log that he was moving and swung around and hit him in the chest.

3.4 INDUSTRY-BASED ANALYSIS

The highest numbers of workplace fatalities were in the agriculture, construction, transport, manufacturing, trades and mining industries. Design-related issues were definitely or probably involved in 40% or more of the incidents in the mining, transport, agriculture, construction, trade and manufacturing industries (Table 2).

3.4.1 Agriculture

Twenty-five people employed in the agriculture industry were killed in design-related incidents. This represented 52% of all work-related deaths of

Table 2: Industry identified for working persons fatally injured in workplace incidents. Australia (excluding Queensland), 2000-01 and 2001-02. Number and per cent.

Industry	Definite/Probable design-related		Total fatalities	
	Number	%	Number	%
Agriculture, Forestry and Fishing	28	38.4	73	100.0
Agriculture	*25*	*52.1*	*48*	*100.0*
Services to Agriculture; Hunting and Trapping / Forestry and Logging / Commercial Fishing	*3*	*12.0*	*25*	*100.0*
Construction	18	43.9	41	100.0
Transport and Storage	8	40.0	20	100.0
Manufacturing	7	43.8	16	100.0
Wholesale Trade/Retail Trade	7	50.0	14	100.0
Mining	4	57.1	7	100.0
Cultural and Recreational Services	2	14.3	14	100.0
Health and Community Services	1	20.0	5	100.0
Accommodation, Cafes and Restaurants	0	..	4	100.0
Finance and Insurance/Property and Business Services	1	25.0	4	100.0
Government Administration and Defence	0	..	1	100.0
Not known	0	..	4	100.0
Bystander	1	14.3	7	100.0
Total	**77**	**36.7**	**210**	**100.0**

persons employed in this industry. A child was also killed due to exposure to occupational hazards on a farm. The main recurrent circumstances were:

> falling or being thrown from a tractor and being run over by the tractor or by towed equipment (five incidents)
> tractor roll-over leading to the tractor operator being thrown from the tractor and crushed (four)
> being crushed by a truck tray or mechanical part due to problems with hydraulic lifting mechanisms (three), and
> being caught in an auger or power take-off device (three).

Other incidents involved:

> an all-terrain vehicle overturning and crushing the operator (two incidents)
> other tractor-related incidents (two)
> falling (two), and
> other incidents (five).

Tractor run-over

Five agriculture incidents involved the operator of a tractor falling from the tractor and being struck by the tractor or equipment being towed by the tractor. The design issues concerned the lack of an appropriate cabin and/or seat belt for the operator, and/or the tractor design that allowed the operator to fall in front of the back wheels of the tractor. In three incidents, the tractor collided with something, causing the operator to be thrown from the tractor. The reason for the fall in the other two incidents was not clear.

The design issues in run-over incidents probably did not lead to the initial incident. That is, they did not cause the operator to be at increased risk of falling. However, the design problem allowed the person to fall and therefore be exposed to the risk of fatal injury.

Tractor roll-over

Four agriculture incidents involved tractor rollovers. As with tractor run-over incidents, the main design issues in these four cases were related to the fatal outcome of the incident rather than to its initial occurrence. Each case involved the tractor overturning while being operated on a slope. The design issues related to the lack of ROPS, the lack of seat belt use when a ROPS was in place, or the inadequate design of the ROPS. In one incident, the tractor had a full cabin, but the farmer was thrown out of the tractor as it rolled. Of the other three incidents, one tractor definitely did not have a ROPS in place and two probably did not. The operator was thrown from the tractor in each incident and was struck by the tractor or an implement it was towing.

Other tractor-related incidents

Two other agriculture incidents directly resulted from design issues related to tractors. In one, the three-point linkage at the back of the tractor became caught on one of the back tyres, causing the tractor to shake violently and the operator to receive fatal head injuries inside the tractor cabin. The other incident involved a tractor without functioning tail lights and without a cabin travelling on a public road in poor visibility and being struck from behind by another vehicle, killing the tractor operator.

Hydraulics

Design issues related to hydraulics occurred in three agriculture incidents. The hydraulic systems failed in two instances, resulting in the worker being trapped by the part controlled by the hydraulic system (a bulldozer blade and a truck tray). In the third incident, the hydraulics probably functioned as designed, but the design was inappropriate, with the operation of the hydraulics on a tipper truck delayed by several minutes because of the need to build up enough pressure.

Augers/PTOs

Three agriculture incidents occurred due to exposed rotating parts of machinery. In two, the worker's clothing was caught by the rotating parts of an auger or an exposed power take-off (PTO) shaft. The third involved a worker being struck in the head by a potato-bin tipper as the worker was performing maintenance. All three incidents involved equipment directly connected to a tractor.

All-terrain vehicles

Two agriculture incidents related to the instability of all-terrain vehicles (ATVs) and the lack of appropriate devices to protect the operator in the event of roll-overs. Both incidents involved ATVs being used to spray herbicides, with the spray tanks mounted on the back, when the vehicle overturned, landing on the operator.

Falls

Two agriculture incidents involved falls. In one, a farmer was performing maintenance on a windmill that did not have appropriate railings to prevent falls and that was designed in such a way that maintenance required the worker to be exposed to high-risk situations. In the second incident, a farmer was blown from the top of a truck while trying to secure a tarpaulin to cover a load in high winds. The design issue related to the tarpaulin system that in this instance required the operator to climb to the top of the truck, rather than being able to be operated from the ground. Although the primary design issue in this incident probably related to the need for a ground-based tarping system, a fall protection system would have been appropriate if a ground-based tarping system was not used.

Other incidents

The five other incidents involved different circumstances and design issues:

> moving parts on a conveyor, in which the operator became caught

> lack of a protective cage on a tyre being inflated and exploded off the tyre rim that struck the worker

> brake failure on a parked truck, which rolled and struck the driver

> a truck's hay bale stacking system failing, resulting in a bale falling and crushing a worker, and

> inadequate guarding of an automatic dairy machine in which a child was crushed.

3.4.2 Manufacturing

Seven persons employed in the manufacturing industry were killed in design-related incidents. This represented 44% of all work-related deaths of persons employed in this industry. The workers were employed in a range of manufacturing sectors. Three of the incidents involved guarding, and the other four involved differing design problems.

Guarding

The three guarding-related incidents occurred when the worker came into contact with moving parts of fixed equipment. The equipment involved was a foam formation pressing machine, a scrap bailer and a compressed air, plastic bottle extruding machine.

The first incident occurred when the worker was cleaning inside the foam formation pressing machine. There was an elaborate safety system in place for maintenance, with three different safeguards – one turning off the main power; one locking in the emergency stop switch; and one safety key, associated with a safety gate, to disable the machine. However, the machine would routinely stop the press plate in one position, whereas proper cleaning required the press plate to be in another position. This meant that the safety system needed to be turned off so that the plate could be moved into the correct position for cleaning, and the safety system then switched back on. Some areas of the machine were not properly guarded, which meant that it was possible for someone to be in the machine when it was operating normally. In this case, the safety systems were switched off, the plate was manually moved into the correct position for cleaning, and the worker entered the machine to clean it. When air compressors in the factory were turned on a few minutes later, the machine started its normal cycle and the press plate crushed the worker.

The second incident occurred in a scrap bailer that had doors that opened outwards once the bail was formed. Concrete pillars were placed near the doors to prevent workers getting too close to the doors, but there was nothing to prevent workers passing between the pillars. In this incident, for some reason the worker stepped between the doors and the pillars and was crushed against a pillar when the doors opened.

In the third incident, which involved a compressed air, plastic bottle extruding machine, the worker for unknown reasons had his head inside the machine, possibly to check on something. The machine then functioned as usual, causing fatal injuries to the worker's head.

Other incidents

The four other incidents involved different circumstances and design issues:

> a forklift overturned while being reversed down a slight slope, landing on the worker

> a maintenance fitter fell two metres from a scaffold

> an electrician fixing a grab crane in a factory was killed when he was struck by the crane as it moved along the main support beam, and

> a foreman was struck by a falling metal jig that had come loose from the stands that were holding it up.

3.4.3 Construction

Eighteen persons employed in the construction industry were killed in design-related incidents. This represented 44% of all work-related deaths of persons employed in this industry. The main recurrent circumstances were:

> contact with electricity in a circuit not protected by a residual current device (four incidents)

> guarding problems with fixed or other equipment (three)

> inadequate fall protection (three), and

> inadequate roll-over protective structure and/or seat belts (two).

Other incidents involved design problems with:

> roofing material

> hydraulics

> building construction, and

> other equipment (three incidents).

Contact with electricity

Four of the nine workers who were electrocuted in circumstances where it appeared that residual current devices were not present were working in the construction industry. All involved electricians. Three of the workers were working in ceiling cavities and the fourth was working on a roof. In each instance, it was likely that the worker would not have received a fatal electric shock if the relevant electrical circuit had been protected by a residual current device. Another construction worker was electrocuted, but the incident occurred when the worker was pushing a metal scaffold that came in contact with overhead high voltage electric wires, and it is unlikely that a residual current device would have prevented the worker receiving a fatal electric shock. However, the death would probably have been prevented by other design approaches.

Guarding

The three deaths that involved design issues related to guarding occurred in different circumstances. One involved the operator of a demolition rock crusher falling into, or being dragged into, the crusher. In the second incident, a worker who was renovating two demountable houses was killed when his clothing became caught in an auger he was operating. The third incident involved a worker operating a circular concrete saw. The saw became caught in the concrete and when it was finally released it struck the worker in the neck, causing fatal injuries.

Falls

Three incidents involved people falling from a height in circumstances where fall protection devices would probably have prevented the incident from occurring. In one incident, an electrician fell backwards three metres from scaffolding, and in a second, a building inspector fell six metres on a building site, but there was little information about the circumstances of either fall. A third incident occurred when a worker fell backwards nine metres off a railway bridge. The worker was placing ballast. Fall protection had been used several months earlier during other construction work, but had been removed and not replaced once the ballast was available to be installed. A fourth construction worker was killed when he fell through a skylight whilst doing maintenance on a roof. In this incident, the main design issue was probably related to the design and construction of the skylight rather than the absence of fall protection structures.

Roll-overs

Two incidents involved the operator of mobile mechanical equipment being crushed by the equipment as it rolled over. In one, an excavator operator was removing trees on a sloped portion of a building site when the excavator rolled over.

The operator was thrown to the ground and struck by the excavator as it rolled over. The second case involved road construction. A road profiling machine rolled over an embankment, striking the operator who had either been thrown out or attempted to jump once he realised the machine was going to overturn.

Other incidents

The four other incidents involved different circumstances and design issues:

> an engineer being crushed when hit by an earth moving vacuum cleaner he was attempting to reassemble and which had a design that made safe reassembly difficult

> a landscaper becoming trapped in the hydraulics of a bobcat

> another landscaper being killed when a retaining wall collapsed, causing a driveway to subside and the worker's truck to fall sideways onto him, and

> a concrete pourer being struck by a falling concrete boom, the design of which predisposed it to corrosion and potentially catastrophic failure.

3.4.4 Transport and Storage

Eight persons employed in the transport industry were killed in design-related incidents, 40% of all work-related deaths of persons employed in this industry. Five of the incidents involved workers in road transport, two in air transport and one in sea transport. Different design issues were involved in each incident.

Road transport

One incident involved a semi-trailer driver. The driver had raised the cabin to inspect the engine. It appeared that the hydraulic system had been put in the 'lower' position, but had not operated because of a faulty latching mechanism. The driver appears to have leant into the area and fixed the latching mechanism, which allowed the hydraulics to operate immediately and lower the cabin onto the driver.

A removalist was crushed as he tried to connect a trailer to the back of a truck. The stand used to support the draw bar while the trailer was attached was rigid and required the worker to be exposed to a high-risk situation as he stood between the trailer and the truck. Following the incident, the trailer was fitted with a wind down leg so that the trailer could be manipulated much more easily and safely.

A bus driver was run over by his bus when the brake was automatically released after the driver, who had got off the bus, pressed a lever in order to open the doors. However, the doors were already open, and the lever system was designed to automatically close the doors and release the brake when the lever was pressed.

A cartage contractor was electrocuted when the crane he was operating to move a demountable

building came into close proximity of high voltage overhead wires. The operator was aware of the wires and appeared to knowingly operate the crane at a short distance from the wires, but the crane did not have an over luffing device present that would have prevented the crane being operated in such a hazardous situation.

The final road transport worker was a forklift driver who was killed when the forklift he was operating for a haulage contractor was crushed by a metal crate that had fallen on the forklift's protective cage.

Air transport

Both air transport workers were employed in services to air transport. One was a baggage handler who attempted to retrieve luggage that had fallen from a conveyor belt and fell through a gyprock ceiling that was inadequate to support the worker. The second worker was an avionics engineer who was electrocuted when he touched a live plug in a faulty circuit that was not protected by a residual current device.

Water transport

A bosun on a merchant ship was fatally injured while repairing a cable on a deck crane. His safety harness became entangled in the drum of the crane cable, and when the drum was operated the worker was pulled into the drum.

3.4.5 Trade

Seven persons employed in the wholesale and retail trade industry were killed in design-related incidents. This represented 50% of all work-related deaths of persons employed in this industry. Three of the incidents involved hoists, two involved circuits not protected by residual current devices, and two involved other circumstances.

Hoists

Two incidents involved equipment or a vehicle falling from a hoist or hydraulic jack and crushing a worker working underneath. Although there were not many details about either incident, it appeared that in both instances the hoist was able to operate without the lifted item being properly secured. In the third incident, a worker was lying on a hoist pad underneath a vehicle on which he was working. He had the controls for the hoist next to him. For some unknown reason, the hoist operated, crushing the worker against the underside of the vehicle.

The main design problem appeared to be that the controls allowed the hoist to accidentally operate when someone was in a hazardous position in relation to the hoist pad.

Residual current devices

Two incidents involved the electrocution of workers while working with equipment connected to circuits not protected by a residual current device. One involved a computer technician making repairs to a computer, and the other involved a panel beater using a welder. Residual current devices would probably have prevented both deaths. However, they were not explicitly mentioned in the available documentation for either.

Other circumstances

In one of the remaining incidents, hydraulic hoses were being replaced on a caterpillar loader, but there was no fail-safe mechanism to stop the bucket moving, and the worker was crushed when the bucket and support arms moved.

In the other incident, a worker was asphyxiated while leaning over a tank of methylene chloride to scrape paint from items. There appeared to be several design problems, as well as problems with the work method.

3.4.6 Health and Community Services

Only one of the five fatally-injured workers employed in health and community services was killed in an incident that involved design issues. This person was an interpreter who was one of several workers trapped in a building that had caught fire. The primary design issue related to fire exits, as all the available exits had been cut off by the fire.

3.5 DISCUSSION

3.5.1 ROPS

The exact design issues involved in most of the ROPS incidents are not clear because of incomplete information. However, the incidents involved one or more missing or inadequate ROPS; missing seat belts; and inadequate tractor design that allowed a person who falls from a tractor to fall into the path of the back wheels of the tractor and/or the path of the towed equipment. All of these issues already have practical solutions available[64-66].

The major uncertainty involves seat belts, given the anecdotal reluctance of mobile mechanical equipment operators, particularly farmers, to wear seat belts even if they are present.[67] The mobile equipment could be designed so that it would not function unless the seat belt was being worn. However, prospective purchasers might not welcome this technology. Therefore, fully-enclosed cabins on all the involved equipment are likely to be the single most effective design solution.[68]

In the eight roll-over incidents, the design issue primarily related to the outcome of the incident rather than the occurrence of the incident itself. It could be argued that the roll-over might have been prevented by certain approaches to equipment design, but the available information did not allow this aspect of design to be considered.

3.5.2 Guarding

One of the main hazards associated with fixed or other equipment is exposure to large forces and/or rapidly rotating mechanical parts. The main control mechanisms for these hazards are physical barriers to separate the worker from the hazardous parts of the machine, and safety interlock systems to prevent the equipment operating if anyone is in a hazardous position. Either or both approaches may be appropriate, depending on the probability of exposure, the size of the risk and the type of equipment. Therefore, it can be difficult to separate these aspects of equipment design.

The guarding was clearly inadequate in many of the incidents, with no physical barriers present to prevent contact with the machinery, and explicit or implicit reliance on the operator to avoid hazardous aspects of the equipment operation. However, as the auger-related incidents in particular showed, the close proximity of the operator to exposed high-velocity machinery parts is inherently very hazardous, reinforcing the importance of incorporating passive, physical barriers or interlock systems rather than relying on the behaviour of the operator to ensure worker safety.

At least three of the incidents occurred while the worker was performing maintenance. This maintenance involved the worker being placed in closer proximity to the machine than would be normal in the operation of the machine. In one instance this involved the failure of safety systems that were rendered inoperative because the design of the equipment required the operator to follow complex procedures before routine maintenance could be performed. These incidents provide graphic examples of the importance of considering maintenance when equipment is being designed. (Maintenance also needs to be considered in building design, as building maintenance has the potential to expose workers to electrical, fall and confined space hazards.)

3.5.3 Falls

Missing or inadequate fall protection was almost certainly the primary design problem in five cases, and may have been prominent in a sixth. Identifying the important design issues is particularly difficult in fall incidents because there are several different approaches that can be adopted. These include designing the structure so that work does not need to be performed at a height or near the edge of a raised structure, providing adequate fall protection structures so that the worker does not fall, and providing appropriate attachment points for fall arrest devices on raised structures. This illustrates the close connection between a design problem and one or more potential solutions, and the challenges raised when trying to identify and classify design problems in incidents.

3.5.4 Hydraulics

The key design issue with the incidents related to hydraulic systems was the lack of a failsafe backup system to operate when the system didn't function as designed, or when the system did operate as intended but when the worker was in danger of being trapped by the part being controlled by the hydraulic system. In particular, the design allowed the controls to remain in the 'lower' position even when the hydraulic system was not causing the part to be lowered immediately.

3.5.5 Varied design issues

Each of the fatal incidents involving workers in the transport industry had different design issues involved. This illustrates the variety of hazards to which workers in the industry are exposed, and the range of design issues that can arise. This was also the case in many of the other industries.

3.5.6 Intended use versus actual use

A major issue to consider with design is whether the design of the equipment takes account of the likely use as well as the intended use. This is clearly exemplified in several of the fatal incidents involving all-terrain vehicles described in this chapter. These vehicles are designed and sold, at least in part, for use in an agricultural workplace setting. Not surprisingly, farmers use them to transport equipment, and the all-terrain vehicles are commonly also used for local weed spraying, with large tanks to carry herbicide fitted to the back of the vehicles. These tanks, when full, may weigh several hundred kilograms. This extra weight can introduce considerable instability to a vehicle that is already prone to overturning because of its relatively high centre of gravity and the rough terrain over which all-terrain vehicles are commonly used. The overturning of all-terrain vehicles carrying heavy equipment might be blamed on the instability introduced by the equipment, because the vehicle was not specifically designed to carry such loads. However, such use for the vehicles is widespread, and it could be argued should be anticipated by the manufacturers.

There is an onus on the equipment operator to ensure as much as possible that the equipment is used for the purposes for which it is designed and within the limits of its design capabilities. There is also a responsibility borne by designers and manufacturers of equipment to take account of likely use, rather than just the use intended by the manufacturer, when designing and manufacturing the equipment. That is, designers and manufacturers must design and manufacture the equipment in the knowledge that equipment may be used in non-standard ways, and safety aspects must be included to take account of all reasonable circumstances. For example, it is not reasonable to

leave sharp blades in a machine unguarded and simply supply instructions to the operators to avoid placing their hands near the blades. There have been several recent examples in Australia where the courts have reinforced this responsibility. Two are considered here.

In the first incident, a worker fell and sustained a significant back injury while attempting to clear a blockage in the mechanism of a grape picking machine. In addition to the prosecution of the employer, the manufacturer of the equipment was fined $20 000 after being found guilty of '...failing to ensure that the design of a machine was safe for use in a workplace'.[69]

In another incident, a worker at a council waste transfer station had both arms amputated when feeding tree branches into a wood-chipping machine. The manufacturer/supplier had provided training regarding use of the machine and was aware that the council intended to use the machine in part for disposal of green waste, which would cause regular blockages. The manufacturer/supplier of the wood chipper was prosecuted for failing to ensure that the wood-chipping machine was safe and without risk to health. The manufacturer/supplier was initially acquitted, on the basis that the instruction manual supplied to the council was adequate to warn operators of the risks involved. However, this acquittal was overturned on appeal. The successful appeal was based on the finding that the manufacturer/supplier had supplied the machine knowing the use to which the machinery would be put and that the machine was not appropriate for this use. The charge was brought under the OHS Act 1983 – specifically, section 18 of the Act, which relates to the obligations of suppliers and manufacturers of machinery.[70]

3.5.7 Coroners' recommendations

Coroners sometimes make recommendations about fatal incidents that they investigate. Recommendations are usually only made if in the coroner's opinion there is a relevant area that is in need of change or comment. The recommendations can provide an important insight into the coroner's opinion about the relevant design issues and mechanisms for them to be addressed.

The recommendations are contained in the coroner's finding. Unfortunately, the finding was only available for a minority of the incidents included in the analysis, so the full range of recommendations was not available for consideration. Recommendations were found for six of the 77 cases. These are shown in Appendix 1. According to the NCIS, there were another two cases with recommendations. However, these were not available via the NCIS website at the time of the analysis. In addition, the accuracy of the information about the presence of recommendations is not certain, because three of the cases for which recommendations were definitely present and obtained from the NCIS website had a code indicating that they did not have recommendations.

4 PROCUREMENT PRACTICES AND DESIGN

The initial intention of this aspect of the study was to provide illustrative examples of poor procurement practices in the data sources used for Phase 2 (and considered in more detail in Chapter 3), and to summarise the key issues involved in procurement in relation to design. Unfortunately, the Phase 2 data sources provided little direct information regarding procurement practices. Therefore, this chapter is more heavily weighted to considering the key design-related issues involved in procurement of equipment and machinery.

4.1 ILLUSTRATIVE EXAMPLES

Design problems with equipment clearly made an important contribution to the fatal incidents considered in Chapter 3, but it is not clear to what extent the fatally-injured person was aware of the problem, or who made the purchasing decision and what consideration was given to design issues at the time relevant equipment or machinery was obtained (or not obtained). A few cases with relevant information are considered here.

One incident involved a worker falling from a railway bridge that was under construction. Earlier in the construction phase, there had been safety rails in place, but these had been hired and were returned once that phase of building was completed. When several months later ballast became available, it appears that a deliberate decision was made not to obtain safety rails because of the lack of available funds. The potential for falls was known, as the OHS agency had previously stopped work until fall protection was put in place. However, much of the later work was being conducted using volunteer labour, and the OHS agency therefore considered that it did not have authority over the construction. The final decision on procurement (which in this case was not to procure anything) was presumably based on a balance between perceived risk, statutory obligations and financial resources.

Another incident involved an auger with a protruding pin on which the operator's clothing became tangled. The pin was home-made, replacing the original pin that was missing for unknown reason. There was no information available as to why a home-made pin was used in preference to the properly manufactured version. Like the previous case, this was presumably based on a balance between cost, availability and perceived risk.

4.2 KEY ISSUES

The two cases discussed above illustrate some of the key issues related to procurement practices – perceived risk, availability of alternatives, costs and statutory requirements. It is difficult to gain a proper understanding of the risks involved in a particular task with a particular item of equipment, machinery or safety device. This requires a thorough risk assessment, something that should be ubiquitous in workplaces but is almost certainly patchy, especially in small workplaces.[71] Most workplaces have few serious incidents, so experience might lead the workers and management to perceive a very low risk in any single task, even though the overall probability of injury may be considerable if the task is performed hundreds or thousands of times.

If design issues are a cause for concern, alternative equipment/machinery must be available if these concerns are to be acted upon. Such alternatives may not exist, may not be readily available, may not be widely marketed, and/or may be much more costly. Even where workers are aware of design problems and better designs are available, management may find it hard to justify the replacement of equipment that is still functioning.

Problems can also arise if the person making the decision on purchasing is not aware of the relevant design issues involved in the item being purchased. This highlights the need for good communication between those using the equipment and those purchasing it. Even more important is good communication between the designers and the users of the equipment. This does not appear to be common in the occupational setting, although there are some consumer product examples in the public health setting.[72-75]

A recent example of an attempt to mandate a comprehensive approach to procurement is provided by Belgium. The Belgian OHS service set up explicit procurement guidelines in response to the apparent high rate of injury involving machines, and problems with poorly designed machinery and equipment. The procedure involved three stages. First, the employer had to discuss the intended purchase with the OHS service, and obtain from them an opinion and written authority for the purchase decision. Next, the supplier had to certify that the equipment being purchased met the health and safety requirements documented on the employer's certificate. Finally, after purchase and delivery, the OHS service had to certify that the procedure had been properly followed. The procedure was designed to ensure that the purchase of equipment was part of the overall risk assessment, taking into account the specific function required and the circumstances of its use. Initial experience with this approach (between 1996 and 2000) demonstrated that just over 50% of large companies complied and that compliance was not as good in small companies.[76]

In light of these issues, a sensible approach to procurement of machinery or equipment, taking into account design issues, would be along the lines of the following:

> involve the personnel who are likely to be using or maintaining the machinery or equipment

> conduct a risk assessment of the tasks for which the machinery or equipment is likely to be used

> consider whether the machinery or equipment has been designed taking into account the task for which the machinery or equipment is intended, and other uses to which it might reasonably be expected to be put

> consider the passive and active safety features included in the machinery or equipment, and

> consider the maintenance requirements for the machinery or equipment, and what risks are likely to arise in conducting this maintenance once the machinery or equipment is installed and in use.

5 DATA SOURCES AND DESIGN-RELATEDNESS

5.1 INTRODUCTION

In the first report of this project,[1] and in Chapter 3 of this report, we have used existing data to describe design-related occupational injury in Australia.

Several factors constrained this work. Similar factors constrain efforts to use existing data to measure and monitor design-related occupational injury.

This chapter reviews information barriers to recognising and monitoring design-related occupational injury (5.2), and proposes ways to reduce them (5.3).

The general purpose of the proposals is to enable better measurement and better understanding of design-related occupational injury with a view to monitoring and prevention. Implementation of the proposals will require investment of time and money. It is beyond the scope of this project to provide costed project plans. However, we have described the proposals in a way that identifies their strengths and limitations, approximate and relative costs, and the likely time that would be required to undertake them, if adequately funded (5.4).

5.2 INFORMATION BARRIERS

Three main factors impede and complicate measurement and monitoring of design-related occupational injuries:

1. Lack of satisfactory operational definitions of 'design-related' occupational injury.
2. Limited information content of available sources of data on occupational injuries.
3. Lack of empirical evidence about design-related risk factors.

5.2.1 Lack of satisfactory operational definitions of 'design-related' occupational injury

Measurement of design-related occupational injury requires definition of the concept in a way that:

(a) corresponds to a meaning accepted by relevant people

(b) can be applied reliably, and

(c) can be applied to existing data (or to data that it is feasible to obtain).

The role of design in the occurrence of work-related injuries is generally abstract. *Design* can be defined in a range of ways, with more or less direct and obvious connections to safety. *Design* can improve safety or diminish it. The application (by *design*) of design principles, rules-of-thumb, and standards (informal or formal; mandatory or not) to the *design* of an object (e.g. a tool or machine) or place (e.g. a workspace) or process (e.g. an assembly line) or system (e.g. a staff security system) has potential to influence safety, though safety is only sometimes the primary *design* criterion (e.g. in the case of machine guards), and it may not be an explicit criterion at all (e.g. where the focus is on aesthetic appeal of a product, or on the cost of its production).

These characteristics make 'design-relatedness' a difficult concept for which to create a good operational definition. Suitable definitions were searched for in published literature without success.

5.2.2 Limited information content of available sources of data on occupational injuries

Data sources that provide information on occupational injuries generally contain very limited information about the circumstances of injury occurrence, and what they do provide tends not to refer to 'design-relatedness'.

For example, nationally aggregated workers' compensation data provide coded data on several characteristics of cases in the form of type of occurrence classification system (TOOCS) codes. There is provision for the inclusion of text information, but this is often absent, generally very brief, and frequently uninformative.

Although safe design is recognised as a particularly good way to prevent work-related injuries (as reflected in the *National OHS Strategy 2002-2012*, in which a national priority is to 'eliminate hazards at the design stage') 'design-relatedness' has not been a prominent concept in OHS statistics. This is reflected in the absence of this concept, at least in an obvious form, from the definition of data items and categories in classifications such as TOOCS.

Some data sources relevant to occupational safety contain more extensive information, but these are generally limited to relatively small numbers of cases. For example, records in the NCIS include, in addition to coded data, up to four text documents, some of which are long and informative. On occasion, a Coroner identifies design as a potential or actual factor in the occurrence of a death. In these instances, detailed information may be available.

5.2.3 Lack of empirical evidence about design-related risk factors

Assessment of occupational injuries as being 'design related' is complicated by the pervasive and complex nature and influence of design. Very many characteristics of designed objects, places, processes and systems might affect the safety of workers, either positively or negatively. The presence of a potentially hazardous design characteristic may produce small or large elevation of risk of injury, and the potential consequences of exposure may be trivial or catastrophic.

Relatively little quantitative and analytic evidence is available about which design-related factors and characteristics affect injury risk, how they do so, and by how much (see Chapter 2 for consideration of this).

5.3 POTENTIAL SOLUTIONS

This section proposes a suite of four potential solutions to the problems described in the previous section.

Section 5.3.1 outlines a method for monitoring design-related occupational injury using existing case data and an operational definition validated in terms of assessments by OHS professionals.

Section 5.3.2 presents a method for estimating the extent of design-related occupational injury by means of attributable fractions, which could be applied to existing data.

The proposal in Section 5.3.3 is for focused enhancement of existing data sources on occupational injury, to improve their utility for understanding and preventing design-related harm.

Finally, Section 5.3.4 describes a new approach to acquiring and applying information on design as a factor in safety. This method, which is currently being developed in the context of consumer product safety, may provide a route to a deeper and more specific understanding of how and why users of particular equipment, tools, materials, et cetera are exposed to hazards, as well as a means to convey this information to designers, or others in a position to apply it for prevention.

5.3.1 Monitoring based on an operational definition derived from OHS professionals' assessments of sample cases

The first report of this project presented an analysis of available case data sources to estimate and describe design-related occupational injury. As such, an operational definition of 'design-related' cases was required.

A search of published literature revealed no suitable definitions for the project. A practical requirement for an operational definition was met by developing one for the purpose of the project. It took the form of a written statement of what was meant by 'design-related', a set of illustrative case examples, and a categorical scale to record the confidence with which cases were allocated according to the definition. Limitations of time and resources constrained the extent to which the operational definition could be validated within the study. The inter-rater reliability of assignment as 'design-related' of a sample set of cases was tested, and found it to be in excess of chance, though not very strong using the detailed categories (this pilot test is described further at the end of this subsection).

Nevertheless, this method was adequate to provide an indicative assessment of 'design-related' occupational injury. As such, it supports the view that existing data sources might be adequate for a basic form of surveillance of 'design-related' occupational injuries, though one with a number of constraints.

Development and use of the operational definition used in the test was complicated by two main factors: 'design-related' is a complex and abstract concept; and the case data sources available often did not provide much information relevant to assessing 'design-relatedness'.

Findings of the test showed agreement in excess of chance when a broad contrast was made (yes or probably yes vs all other responses). However, the concept of 'design-relatedness' was clearly not an intuitive or easy one to assign in the context of this test. More accurate and useful information could be obtained from the current data sets if a more reliable coding system was implemented. This could be achieved through the development of a more concrete, objective definition of 'design-relatedness' and an associated scoring standard for text description cases. This would improve the sensitivity and specificity with which cases are identified as design-related and increase inter-rater reliability. This approach is intuitively appealing as it enables the use of existing occupational injury data sets to assess design-related cases.

For the main analysis for this study, the validity of the categorisation was improved by reconsideration by the raters of all cases initially coded differently. This produced, in nearly all instances, an agreed categorisation of 'design-relatedness' for each case. This is a useful, practical approach for a specific study, but not optimal for an on-going measurement system, where comparability between time periods is important and where the use of multiple coders may not be possible for practical or resource reasons.

The lack of literature regarding 'design-relatedness' suggests that a more objective definition of this term must be derived from new research. This could be achieved by a study that utilises the knowledge of experts in the OHS field. Focus groups could be employed to further conceptualise the meaning of 'design-relatedness' as it relates to the current data sets. A qualitative analysis of these discussions could then be conducted to derive a concrete operational definition. This could involve the use of key terms (e.g. laceration or crushing) or specific situations (e.g. an injury resulting from mechanical tools) that indicate 'design-relatedness', or an objective scoring criteria with specific scores to indicate one of the aforementioned levels of 'design-relatedness'. Subsequently, the newly-developed definition would need to be validated by providing case vignettes of work-related incidents to the experts, using both familiar and non-familiar situations. This process would assist to substantiate that the operational definition can be successfully and reliably implemented in practice to identify 'design-relatedness' from text descriptions. It would also provoke more thought about how to clarify the meaning of 'design-relatedness' for research purposes.

On this basis we propose use of an extension of the method described above to derive and validate a definition of 'design-related' occupational injury that may enable indicative reporting of design-related occupational injury based on existing data, chiefly workers' compensation and Coroner records.

Operational definitions could be based on various sources, including:

> legal definitions
> standards or other formal conventions
> norms or opinions of relevant professionals, or
> evidence derived from analytic studies of design-related risk.

The project proposed here is based on norms and opinions of relevant professionals. This approach has been chosen because of the very limited relevant information content of one of the main relevant data sources (workers' compensation), and the lack of well-formulated explicit definitions of design-related injury of the other three types listed.

The proposed project to develop and test an operational definition of 'design-related' occupational injury has the following main steps:

1. Develop a definition of 'design-related' occupational injury in terms that are generally acceptable to a reference group of OHS professionals. We suggest using as a starting point the definition in Appendix 1 of the first report of this project.
2. Specify a range of types of circumstances of injury, including some which appear to fit within the scope of the definition, others that do not and others whose status is ambiguous.
3. Prepare a set of brief descriptions ('vignettes') of hypothetical, but realistic, cases of work-related injury corresponding to the circumstances specified in step 2. Vignettes are to be framed, as far as is feasible, in terms of concepts and categories in the TOOCS system. Seek confirmation by the reference group that vignettes intended to fit the agreed definition are seen as doing so, and modify vignettes and/or definition if necessary. Record a consolidated reference group assignment of 'design-relatedness' of each vignette (the 'gold standard' assignment). The number of vignettes required in the set will depend on the number of types of injury circumstance to be assessed for 'design-relatedness'. It will be desirable to limit the number to about one hundred, for reasons of practicality.
4. Develop an instrument to enable observers to record whether they think that a vignette meets the stated definition of 'design-related' occupational injury, and to rate the confidence with which they make each assignment.
5. Invite a sample of OHS professionals to assess the 'design-relatedness' of the vignettes, in terms of the study definition and by means of the instrument. Participants should also be invited to comment upon and rate their satisfaction with the definition.
6. Analyse results in terms of:

a. congruence between 'gold standard' assignment 'design-relatedness' by the reference group and assignments by other subjects

b. extent of inter-rater agreement on 'design-relatedness' of vignettes, overall and for the set of vignettes intended to represent each distinct type of design-related circumstance of injury, and

c. subjects' satisfaction with the study definition of 'design-relatedness'.

Broad agreement with the study definition would indicate that it coincides reasonably well with tacit views and knowledge of OHS professionals similar to the subjects. This can be described as content validity. If the study does not reveal broad agreement with the definition, it may well enable an assessment of the nature of disagreement, which would be informative.

Good inter-rater agreement (i.e. well in excess of chance) in the assignment of work-relatedness to a group of vignettes representing a case-type will provide evidence that cases of that type can be recognised reasonably reliably. These case types are candidates for inclusion in an operational definition of design-related occupational injury, specified in terms of groups of cases having a particular pattern of TOOCS codes.

Pilot project to develop and test a definition of 'design-relatedness'

The information used in the first report of this project came from the NCIS for the examination of fatality data and from the workers' compensation data for the examination of non-fatal injuries. These data sources are useful for examining occupational injuries. However, limitations with each data source inhibit their current utility for allowing the classification of cases as design-related. These limitations are largely attributable to neither system being developed with the intention of collecting data for this purpose. The NCIS system generally provided fairly extensive detail about individual cases, although specific information concerning 'design-relatedness' is not often provided. The workers' compensation data generally provided little information, often containing no descriptions explaining the circumstances associated with the injury, or minimal ones.

A practical question was whether a sub-set of records in these existing sources could be identified as 'design-related', despite limited case data. In the absence of a well-stated operational definition we opted to test whether multiple raters would draw similar conclusions as to which cases met the study definition (and with what degree of certainty).

As described in Appendix 1 of the first report of this project, the test involved using these text descriptions as the basis for assessing cases of occupational injury as 'Definitely', 'Probably', 'Possibly', 'Unknown' or 'Not' design-related. Rating was based on a qualitative definition of 'design-relatedness', also stated in the appendix.

Analysis of the NCIS data used in the first report included assessments of 'design-relatedness' by three coders who separately allocated cases to one of the five categories outlined above. Each coder was blind to the responses of the other coders until after analysis. One coder coded each of the 210 cases and all cases were coded by at least two coders, with 95 cases being coded by all three coders. A more detailed description of this procedure is presented in Section 2.2.2 of the first report.

An analysis of inter-rater reliability was conducted by a fourth investigator to examine the statistical congruence between the individual raters. Considering 200 cases (ten practice cases were not examined) and all five assignment categories, an average level of inter-rater reliability was found (61% agreement between cases, k=0.40). When the five categories were collapsed into two more distinct categories ('Definite/Probable' compared to 'Possible/Unknown/Not'), the inter-rater reliability improved (83% agreement, k=0.63). Considering the 84 cases where all three coders rated the cases, a lower level of inter-rater reliability was found when five categories were used (49% agreement, k=0.35), but the agreement at the two category level was similar (80% agreement, k=0.56).

We concluded that this approach provided useful information, though the limited source information can be expected to adversely affect both sensitivity and specificity and the method is likely to result in misclassification of many cases (in comparison with classification based on richer case information). The net effect of misclassification might be either underestimation or overestimation of the incidence of design-related workplace fatalities and injuries, by an uncertain degree. Validity is likely to be improved by discussion of cases that are initially categorised differently, and the assignment of an agreed final code.

5.3.2 Use of an attributable fractions method to improve monitoring of design-related occupational injury using existing or enhanced case data

Poor design is likely to be a factor in some, but not all, of many types of occupational injury. In some instances, it may be possible and meaningful to assign a particular case as being design-related. An example is a death in which a clearly identified design defect of a piece of equipment was obviously and crucially involved.

In other situations, it may be much less meaningful, or less possible, to categorise individual cases of a particular type as being design-related. For example, it is likely that the design of knives influences the likelihood of a user sustaining a laceration, but so do other factors, and the contribution of each factor will differ from case to case.

As another example, the provision of travelling sales personnel with vehicles whose design provides best available occupant protection would be likely to reduce serious or fatal work-related road injury in this group, but probably not to zero. This is because other factors contribute to risk, such as speed, seatbelt use, and road and traffic conditions. (Another factor is that the best available vehicle occupant protection is less than perfect.)

This raises the question of how one could assess the contribution of knife design to the burden of this type of injury if the only information available is a file of workers' compensation cases in which 'knife' is recorded as being involved, and 'laceration' is recorded as the type of injury.

A similar problem confronted efforts in another study to measure the extent of death and disease attributable to alcohol consumption. A method found to be useful in that context (and others) might help with assessing the burden of design-related occupational injury. Therefore, the approach is considered in more detail here.

Alcohol is a factor in all cases of certain conditions, such as acute alcohol poisoning and alcoholic liver cirrhosis. However, alcohol is a factor in only some cases of other conditions, such as oropharyngeal cancer and injuries resulting from motor vehicle traffic incidents, and information available in relevant case data sources does not usually enable particular cases to be reliably identified as alcohol-related.

A review of other evidence about the association between alcohol and such conditions can provide the basis for an estimate of the proportion of each type of condition that can be attributed to alcohol (an 'attributable fraction'). Preferably, the estimate is based on analytic studies of the effect of particular levels of alcohol consumption on risk of a disease of interest, combined with survey data on alcohol consumption in the population of interest. However, data from descriptive studies is used when suitable analytic studies are not available. Several reviews of this type have been undertaken in Australia since about 1990, covering diseases attributable to alcohol (tobacco and other drugs have also been considered in the same context). Provided that the conditions for which attributable fractions are estimated can be identified in a data source, such as records of hospital admissions, it is a simple matter to apply the fractions to the information in the data source in order to derive an estimate of the count (or rate) of cases attributable to alcohol. Where available evidence is sufficient, separate attributable fractions are often estimated for males and females, and for broad age groups.

In summary, attributable fractions have been used to assess the burden of disease due to alcohol and other drugs by combining information derived from reviewing scientific literature on a topic with suitable administrative data. A similar method might be capable of enabling surveillance of 'design-related' occupational injury.


However, our assessment of literature on the influence of design on the risk of occupational injury suggests that analytic evidence is rare, and even descriptive studies are quite limited.

In conclusion, an attributable fractions approach has potential to improve assessment of the burden of design-related occupational injury, particularly for types of case in which it is not meaningful, or it is impracticable, to assign 'design-relatedness' at the level of individual cases. Implementation of the method will, at present, be seriously impeded by lack of good quality evidence on which to base estimates of fractions of cases attributable to design.

5.3.3 Enhancement of occupational injury data sources to improve identification of design-related cases

The third element in this suite of methods proposed to enable better measurement of design-related occupational injury is to enhance the information content of currently available data sources by including additional information.

Two aspects to this were distinguished:

1. altering or increasing information collected on all cases in a source, and
2. obtaining additional information on cases of certain types.

Altering or increasing information collected on all cases in a source

As noted above, the main current data sources lack information sufficient to allow reliable assessment of whether cases are design-related. This problem could be reduced by the addition of suitable categories to classifications of data items currently collected, and by the collection of suitable new data items. Items relevant to design might focus on whether machinery involved in an injury conforms to Australian safety standards, with particular focus on aspects such as guarding.

The specific variables to be included should be identified on the basis of findings of the first two elements of the proposed program. It may be necessary to supplement this information by conducting a study to ascertain which questions would provide the maximum amount of information in relation to whether a specific situation was design-related. Again, the expertise of OHS professionals should be used.

Whilst this approach is complex and would involve greater costs associated with expansion of data collection, it has the potential to greatly improve the validity and reliability with which cases can be identified as design-related.

Certain minor changes that could be made at relatively low cost might result in useful improvements in information. For example, revision and review of inclusion criteria for certain TOOCS categories could be undertaken.

Obtaining additional information on cases of certain important types.

The second aspect of this element of the proposals is that certain types of work-related injury cases could be specified as being 'Priority Safe Design Issues', and that relevant additional data should be collected on these types of cases. Designation of a case type as a priority could be reviewed periodically, and supplementary data collection could stop when a case type ceased to have priority status.

'Priority Safe Design Issues' would be specified so as to be identifiable in terms of existing information (i.e. in terms of TOOCS categories), and would be chosen because they are prominent among severe or frequent injury, and are events in which design is likely to play an important role.

Additional information would be required on cases of these types. The increased burden of collection would be relatively easily justified, especially if the designated case types are widely recognised as being unacceptable, and if they are not numerous.

A plausible example is injuries in which amputation or severe laceration results from contact with any machine that, according to OHS law or other requirements, should be guarded. Requirements for guarding are intended to prevent such injuries. Every case of this type is an instance in which that aim has not been achieved. While factors other than design might be involved in these events, an implicit question is whether differently designed guarding or other characteristics of tools, equipment, work-space, work process, et cetera would have prevented them.

Additional information sought would differ between Priority Safe Design Issues. Considering the example of amputation due to contact with machinery, additional data might include the brand and model of the machine producing the injury (preferably also serial number), information on whether that machine had been modified in any way, a summary description of the circumstances leading to the event, and reference information enabling linkage to the report of any internal or external investigation of the event.

Much of the value of this approach would flow from the potential to link case data to other sources. The value of brand and model data comes from the potential it provides to link cases with detailed design information, which should be obtainable from manufacturers or importers of the product. Comparable linkage is possible in some other safety-related contexts, such as vehicle identification numbers, registers of certain medical implants (e.g. prosthetic hip and knee joints) and part identification and tracing in the aircraft industry.

5.3.4 Novel methods for understanding and preventing design-related occupational injury

The final part of the suite of proposals in this section is intended to encourage efforts to identify innovative concepts and methods that have potential to enable advances in the complex area of obtaining better and more useful information for measuring and preventing design-related occupational injury.

One such novel method is introduced here. It is already being developed with the aim of improving consumer safety through a novel combination of methods to obtain, process and disseminate information about the influence of design on the safety of users of specific products. While non-trivial differences exist between the context in which consumers and workers are exposed to injury risk, there are enough similarities to warrant consideration of this approach, though direct and literal transfer from one sector to the other might not be possible.

In the following section a literature review of the background relevant to the approach is provided, followed by a specific recommendation for future research.

A large volume of OHS research has concentrated on identifying design-related work injuries and fatalities and subsequently modifying and improving the design of personal protective clothing, machinery and tools utilised in the workplace with the intention of reducing injuries. However, even in occupational settings where adequate safety protection devices are implemented, injury commonly results at least partly from workers bypassing existing safety devices or from failing to properly utilise the safety equipment.[9, 77] It is therefore important that safety device designers incorporate an understanding of the role of human factors in workplace injuries into their designs.

Motivation for the risky behaviours which can result in injury are diverse and can include: internal drivers, such as lack of confidence to seek appropriate training in the use of safety devices, or the removal of personal protective equipment to increase personal comfort; and external drivers, such as eliminating safety devices which inhibit production proficiency or workplace culture.[78, 79] However, even in the presence of internal and external drivers, not all workers equally engage in risky behaviours. According to the Behaviour Motivation Hypothesis, engaging in risky behaviours is largely driven by risk perception,[80] which relates to an individual's appraisal of the potential negative or positive consequences of an action and the given likelihood of this consequence[81].

Previous research attempts to understand the role of human factors and risky behaviour in workplace injuries has led to the use of a nomothetic research design, which involves applying a generalised group level analysis. Such applications of this research has involved examining the accuracy of worker's risk perceptions by relating them to injury events,[82] by identifying correlates of risk factors, such as experience and physical work conditions,[83] and by retrospectively examining group data sets on workplace injuries, as was done in the first report of this project. Whilst this design is beneficial for identifying work-related injuries, it does not identify individuals' risk perceptions and other factors that lead to injuries.

An alternative to this approach is the use of an ideographic research design that incorporates the use of individual descriptions of situations. The use of an individualistic approach provides a better understanding of risk perceptions and of how risk perceptions are translated into risky behaviours. Use of this research design in an OHS context would provide an understanding of individual behavioural patterns in response to specific risk-related situations, which may be overlooked in traditional group level analysis.[74]

Although this research design has not previously been employed in OHS research, this approach has been successfully applied in the area of consumer product usage.[72, 75] Van Duijne[74] examined the role of human factors in product use by using naturalistic observations of consumers utilising novel and familiar products in conjunction with open-ended interviewing to identify the perception of risk and other factors that led to risky behaviours. Knowledge of the actual use of these products by consumers, and factors which result in injuries, were reported to design engineers to enable them to incorporate human factors information into the design process to mitigate future injuries.

There is potential for improving prevention-orientated information on design-related occupational injury in an approach that combines detailed, product-specific (or, possibly design issue-specific) linked appraisal of design factors, risk perceptions and risky behaviours, in situations as close to real-world work as can be achieved. Integral to the approach is sophisticated analysis and communication of findings to designers. (In the occupational context, 'designers' should be taken to refer to people responsible for design of work settings and systems, as well as designers of specific machines or tools.)

Such work will be complex and challenging, but the insights derived from even a small number of carefully documented investigations could contribute enormously to understanding how design influences safety in relation to work.

A specific example of a study design could involve situations where fatalities or injuries are known to occur as a result of inadequate or inappropriately used guarding, which was identified in the first report as a major design issue. If this study followed the model of Van Duijne, a small number of workers would (with their knowledge and consent) be video recorded whist performing work tasks operating the machinery in question, in a real (or realistically simulated) work setting. Soon afterwards, workers would view the recordings and inform the observer why they performed certain actions and what they were thinking during the process. In a variation of the method for an occupational setting, subsequent comparison of the though processes and risk perceptions involved in variations of task performance thought to be more or less risky would be compared and analysed. The findings would then be related, in suitable form to users, mangers and designers of equipment and work settings, as a precursor to moderated collaborative review of the interacting elements of design, human factors and operational issues, with a view to identifying alterations likely to reduce risk. The information obtained in the course of this process would also be assessed for insights to guide the interpretation of existing administrative data on injuries of the types that result from the risk under study, and for insights into how collected data could be modified to provide more meaningful information on design-related occupational injury.

5.4 DISCUSSION AND CONCLUSIONS

The principle, 'eliminate hazards at the design stage' is appealing, implying a focus on primary prevention of occupational injury by means that do not place an unrealistic or unreasonable burden of care on workers or managers in the day-to-day use of materials, tools, systems, and other designed elements of work environments.

However, integration of this principle into contemporary OHS information systems is challenging. The concept 'design-related' injury is abstract, and does not have well-recognised operational definitions. 'Design-relatedness' has not been a prominent consideration during selection of the data items and development of the classifications used in most OHS information systems.

Moreover, the influence of design (however defined) on injury risk is, in many circumstances, to modify the probability of injury, rather than to be a more or less sufficient single cause. As such, simply 'counting the cases' is not an adequate basis for measuring the burden of injury attributable to design.

Finally, while the general concept of 'designing for safety' is well-recognised, several considerations suggest that there is potential to improve implementation of the concept. These are the continuing occurrence of certain types of occupational injury which are the subject of design-based prevention; the small body of published analytic research on the topic; and the existence of new approaches to design-based safety which have yet to be tried in the context of occupational safety.

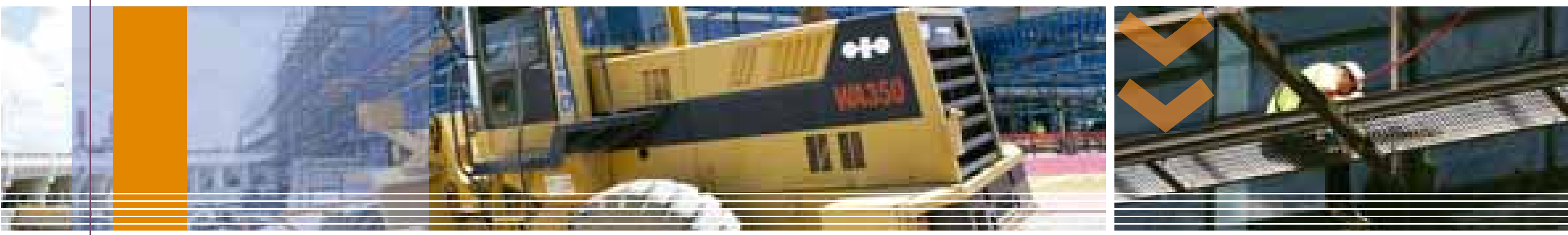
A suite of four ways to improve information on design-related occupational injury in Australia have been proposed. Table 3 provides an overview of the program.

The proposed program is strongly influenced by the scope of this project, which focuses on design as a factor involved in the occurrence and prevention of occupational injury. Design is, of course, only one of several important factors influencing safety, though it often interacts with others. Many facets of design interact with human factors — perceptual, cognitive, physical and behavioural. Design also interacts with environmental factors, such as climate. Design in workplaces operates within the broader contexts of social, economic, legal and industrial relations theory, practice, norms and requirements.

The focus of these proposals on design should not be seen as downplaying the importance of other factors to occupational safety, or as being an alternative to them. Rather, the point is to ensure that the contribution of design to occupational safety becomes reasonably well understood, and to improve the likelihood that situations in which poor design is an important threat to safety will be recognised and corrected.

Table 3: Overview of proposed program of information development to support surveillance and prevention of design-related occupational injury

	1. Operational definition	2. Attributable fractions	3. Enhanced data	4. Information to enable safer design
Outline	Derive operational case definition of 'design-related' from field survey and apply it to existing data to enable indicative monitoring.	Develop attributable fractions for 'design-relatedness' and apply them to existing or enhanced case data to enable more valid monitoring.	Selectively enhance case data in existing sources to enable more valid and reliable monitoring.	Achieve safer design through detailed investigation of how design influences risk, focusing on selected severe, frequent or intractable hazards.
Research and development required	Survey a sample of OHS professionals to derive an operational definition of design-related occupational injury suitable for use with existing workers' compensation data.	Review literature and, if necessary, OHS professional opinion, to produce attributable fractions ('design-relatedness') for categories in relevant classifications (notably TOOCS 3).	Periodically review the specifications of routine occupational injury data collections in light of information on design-related injury, to identify changes to items and classifications that would enable better monitoring of design-related injury.	
Implications for routine data collection	None.	Could proceed with existing data, though likely to benefit from enhancements arising from project 3.	Implications could be minor (e.g. tightening definitions of existing categories) to substantial (e.g. adding an item that would require collection of unfamiliar information).	Likely to provide insights that could be translated into improved content of routine data collections.
Strengths	Relatively quick and cheap.	Enables account to be taken of probabilistic influences of design on occupational injury	Evidence-based enhancement of existing data sources. Findings of projects 1, 2 and 4 would be key sources.	Focus on discovering how design influences risk in specific and important settings, and communicating this to enable safer design
Weaknesses	Will, at best, provide indicative monitoring, due to limitations of existing data.	OHS literature is lacking on many relevant risk relationships.	Restricted to types of information that can be obtained through existing data systems.	Methods developed for consumer product safety may require modification for use in occupational setting.
Indicative cost and duration	Develop definition and apply it to existing workers' compensation data: order of one year and $\$10^5$	Develop attributable fractions based on review of existing literature, and apply to existing workers' compensation data: order of one year and $\$10^5$ (Note: Many important gaps in knowledge are likely to be identified during the review. Filling these would be much more costly and time-consuming.)	Low marginal cost for enhancement of classifications if made part of next revision of TOOCS and NCIS. Likely increase in data acquisition burden. Database of designed objects reported under a Priority Safe Design Issues program could be based on existing information held by manufacturers and importers.	Uncertain, and likely to vary considerably between instances. Recommend pilot application, selecting several (at least two) potentially fruitful examples, such as injury by powered saws and injury associated with the use of ladders



6 SUMMARY AND CONCLUSIONS

Design issues are rarely considered comprehensively in OHS research. This report presents a detailed consideration of the role of design issues in fatal work-related injury in Australia, with emphasis on recurrent circumstances and key industries. The analysis has shown that:

> similar design problems are involved in many fatal incidents

> design is an important contributor to fatal injury in many industries, and

> solutions already exist for most of the identified design problems.

There is little information on factors that influence the extent to which design issues are considered in equipment and machinery procurement decisions.

There are several information barriers that adversely affect the measurement and monitoring of design-related occupational injury. This report proposes potential solutions to these barriers.

Design issues make an important contribution to the occurrence of fatal and serious non-fatal work-related injury in Australia. Measurement and monitoring of the extent and nature of the contribution of design issues should be able to be improved through:

> the development of an agreed definition or set of definition

> improvement of current data sources and/or introduction of new data sources, and

> the use of new research approaches.

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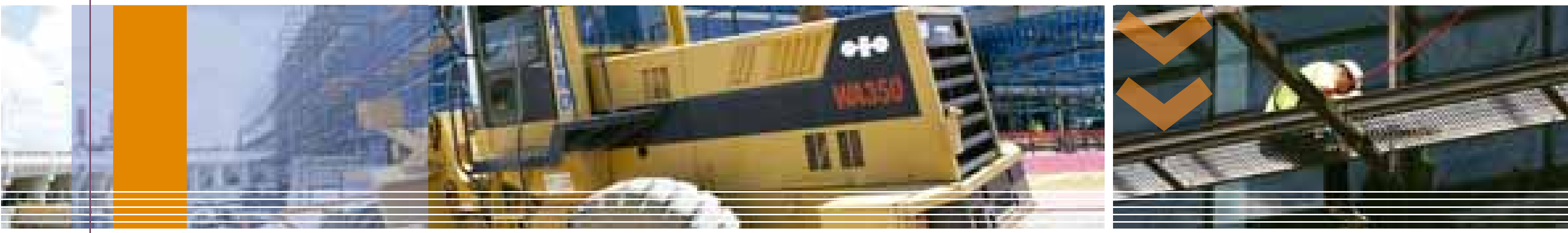

APPENDIXES

APPENDIX 1 CORONIAL RECOMMENDATIONS AND COMMENTS

design-related recommendations or comments made by a coroner and arising from the 77 fatal incidents considered in Section 3 are presented here. A brief case scenario is provided (in italics) at the beginning of each case. The coroner's recommendations and/or comments are placed in quotation marks.

Case 1

An avionics technician working underneath an electronic equipment bench was electrocuted when he grabbed hold of the pins on a three-pin extension cord. At some time previously the flow of current in the circuit had been reversed, causing the pins in the plug to be live. There was no residual current device protecting the circuit.

"In matters of public health and safety connected with this death I adopt the recommendations of the Work Health Investigators contained in their report. These are:

1. {The employer of the fatally injured worker } implements a safety management system that meets the requirements of the Work Health Act, 1996 and the Work Health (OHS) Regulations, 1996 including but not limited to:

> Introduces active processes of hazard identification, risk assessment and control.

> Ensuring any work requiring a license be conducted only by those people holding the appropriate license. This work must include rewiring of the facility by a licensed electrician to comply with the Australian New Zealand Standard – Wiring Rules (ANZS 3000).

> The provision of Residual Current Devices to protect:

- workbenches; and
- power outlets likely to be used as supply for portable electrical devices.
- Ongoing system review including internal audit to ensure the integrity of the safety management system employed.

The Department of Industries and Business commence an awareness program notifying all Northern Territory employers and residents that electrical installations must be installed, maintained and repaired by competent licensed electricians.

This sad and untimely death, and these recommendations, bears similarity to a death at a tyre repair centre in Darwin in 1997 and subsequent recommendations. In that death Residual Current Devices would have also saved the life of the deceased."

Case 2

A farmer climbed to the top of a truck trailer in an attempt to secure a tarpaulin in high winds and was blown off, falling six metres. Although the primary design issue in this incident probably related to the need for a ground-based tarping system, a fall protection system would have been appropriate if a ground-based tarping system was not used.

"The death of ... was preventable by appropriate systems of work that avoided climbing on to the top of the load to secure the tarpaulin. The farming, transport and tarpaulin manufacturing industries need to work together to solve the problems associated with the system of work and related product design. Assistance from Monash University

Engineering School and the Accident Research Centre may also be helpful in providing further research and potential design solutions.

These comments are a sensible start to countermeasures. It is essential that the information on how this incident occurred be widely disseminated via the WorkCover Authority to the relevant farming and transport industry groups. It is also essential that the case information be distributed to the tarpaulin manufacturers.

It is important that the transport industry, farming groups and tarpaulin manufacturers work together to improve the design and tolerances of tarping systems too in order to avoid or reduce instances of farmers and truck drivers having to climb on top of loads to secure the tarpaulin. Systems of work and appropriate guidelines also need to be disseminated throughout the farming and transport industries."

The Coroner also recommended:

> That the Farming, Transport and tarpaulin manufacturing industries be encouraged to work together to devise, design and trial practical solutions that reduce the risk of the need for farmers and transport workers to climb on top of loads to secure tarpaulins ;

> The WorkCover Authority should consider assisting by facilitating this work (perhaps also the Transport Safety Group could also be involved)

> Further study needs to be undertaken to determine the effects of wind on ground operated tarp systems

> The results from such a study need to be passed onto users of such systems (including both existing users and potential future users). This could be facilitated by relevant Agricultural and Transport industry bodies

> Manufacturers of ground operated tarp systems should be encouraged to devise safer systems that can be used in high wind situations, and

> Companies enforcing policies regarding ground operated tarping systems should also be made aware of the problems windy conditions might cause to existing systems, and ideally, become involved in determining safer systems.

Case 3

A miner was crushed in a roof fall whilst moving hoses on a continuous miner. The design of the machine required the operator to move into an area that did not have adequate overhead protection to undertake some tasks.

"The fall of the mudstone in the roof has occurred as a result of an occurrence commonly referred to as a 'rib spall'. The location of the service manifold on the continuous miner has put the deceased in a position where he was susceptible to the effects of a 'rib spall'. I note that following this tragic accident, the manifold location was modified so it can be accessed from the front of the machine."

Case 4

A foreman was struck by a falling metal jig that had come loose from the stands that were holding it up. The jig was used to hold items prior to the jig and items being taken for galvanising. The jig had to be put in place using a forklift, taking care to position the jig securely in the housing on top of a stand at either end of the jig. Workers were required to check that the jig was securely in place prior to performing work under the jig. This work method was standard industry practice at the time. Unfortunately, the stands were not aligned properly, meaning the jig was not housed properly. The jig fell when the worker was underneath, causing fatal injuries.

"This type of accident was not heard of before and can therefore be described as rare. Following this accident, a detailed safety review was conducted which resulted in the legs of the stands being fixed in concrete with the heads of the stands incorporating a re-designed housing that was raised, deepened and proceeded the full depth of the stand, that is the full length of the 'T' arms of the jig. Any deficiency in the safety of the original design and any element of human error which may have contributed to this accident, has been further minimised."

Case 5

A removalist was crushed as he tried to connect a trailer to the back of a truck. The stand used to support the draw bar while the trailer was attached was rigid and required the worker to be exposed to a high-risk situation as he stood between the trailer and the truck.

"As a result of their investigations {the OHS expert} recommended that the trailer draw bar be fitted with a wind down leg as opposed to the rigid leg stand, in order to prevent operator injury whilst coupling the trailer drawbar to the truck ring feeder coupling. This ensures the two couplings are the same height even in undulating ground surfaces.... The {Work Cover Investigator} attended the premises of {the employer of the fatally injured worker} and viewed the trailer that was involved in this accident. He stated that since the accident, the trailer has been fitted with such a wind down leg as recommended by {the OHS expert}, ensuring this does not happen again."

Case 6

A cartage contractor was electrocuted when the crane he was operating to move a demountable building came into close proximity with high voltage overhead wires. The operator was aware of the wires and appeared to knowingly operate the crane at a short distance from the wires, but the crane did not have an over luffing device present that would have prevented the crane being operated in such a hazardous situation.

"I find that the death of the deceased was primarily the result of a tragic error of judgement on the part of the deceased in that he continued to operate the crane when he ought to have been aware that its operation was clearly dangerous when the boom was so close to the overhead power lines.

I find that the fact that the power lines were not at the prescribed height above the road surface did not cause or significantly contribute to the death of the deceased. However, they may have posed a hazard to other legitimate traffic movements on the roadway. I would recommend that the appropriate authority conduct an inspection of its installations to ensure that the prescribed clearances are being complied with."