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The Role of Design Issues in Work-Related Fatal Injury in Australia

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Abstract

Problem: This study aimed to provide an assessment of the contribution of design to the occurrence of fatal work-related injuries in Australia. *Methods:* The Australian National Coroners' Information System was the data source for fatal injuries. Deaths resulting from workplace injuries on or between 1 July 2000 and 30 June 2002 were included. *Results:* Seventy seven (37%) of the 210 identified workplace fatalities definitely or probably had design-related issues involved. In another 29 (14%), the circumstances were suggestive that design issues were involved. The most common scenarios involved problems with rollover protective structures 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. *Summary:* Design is a significant contributor to work-related fatal injury in Australia. There is considerable scope for preventing serious work-related injury through improving design of plant, equipment, and vehicles used for work-related purposes.

Keywords: Death; Coroner; Occupation; Design; Injury

1. Problem

There are many potential contributing factors to any work-related incident that results in injury. These include aspects or characteristics of the systems of work, the equipment and materials used, the environment, and the worker. For most potential incidents, the use of passive safety measures, those that function without the need for input by workers, is preferred as a means of control. Passive safety measures can be designed to decrease the likelihood of an incident occurring (e.g., guarding on machinery), decrease the likelihood or severity of an injury resulting from an incident (e.g., Roll-Over Protective Structures on mobile equipment; residual current devices), or even to decrease the consequences of an injury that has occurred (e.g., a safety alarm system allowing early localization and treatment of an injured person). These are preferred because they do not require the actions or cooperation of workers, and function regardless of whether unforeseen events occur or workers or others are using the equipment as intended.

Most passive safety measures work because they are designed into the equipment, building, or system of work. For this reason, in recent years there has been increasing interest in and focus on the contribution of design to occupational health and safety (OHS; National Occupational Health and Safety Commission, 2000; National Occupational Health and Safety Commission, 2002; Toft, Howard, & Jorgensen, 2003). Little is known about the extent to which design issues contribute to work-related injury, but the few studies that describe the proportions of injuries caused by poorly designed or malfunctioning equipment in the workplace clearly show that poorly designed machinery, safety measures, and/or workplaces play a significant role in elevating the overall risk of occupational injury (Gardner, Cross, Fonteyn et al., 1999; Sorock, Lombardi, Courtney et al., 2001; Batra & Ioannides, 2002; Trethewy & Atkinson, 2003). In addition, the general occupational health and safety literature contains many case reports of specific design failures and potential solutions. These include design issues related to tractors (Bernhardt & Langley, 1999; Powers, Harris, Etherton et al., 2001), construction machinery (Pratt, Kisner, & Moore, 1997), computer mice (Ullman, Kangas, Ullman et al., 2003), forklifts (Collins, Landen, Kisner et al., 1999; Collins, Smith, Baker et al., 1999; Janicak & Deal, 1999; National Institute for Occupational Safety and Health [NIOSH], 2001), tractors, augers (Ingram, Crowe, Wassermann et al., 2003), and needles (Bryce, Ford, Chase et al., 1999; NIOSH, 1999).

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This study aimed to provide an assessment of the contribution of design to the occurrence of fatal work-related injuries in Australia. The detailed project reports arising from this study, and related work, are available elsewhere (National Occupational Health and Safety Commission, 2004; Driscoll, Harrison, Bradley et al., 2005; Australian Safety and Compensation Council, 2006).

2. Methods

2.1. Work-relatedness

Only work-related cases were considered in this study. The definition of "work-related" was that adopted by the National Coroners Information System (NCIS) (described below). A work-related case was defined as *"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."* (The full definition of work-relatedness can be found at Monash University National Centre for Coronial Information, 2001.) 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 hospitalized after major injury.)

2.2. Design-related

For this study, 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 (i.e., the incident or the fatal injury would not have occurred if the design issue had not been present); and it was realistic to expect that this factor could have been modified to avoid the incident or the subsequent fatal injury.

Persons injured as a result of motor-vehicle incidents involving road vehicles on public roads, aircraft crashes, train crashes, or medical misadventure were excluded. This was because relevant design issues were already addressed by specific authorities and did not fall within the scope of occupational health and safety design as envisaged for this project; and/or because the available data sources were unlikely to contain information regarding design issues for these types of cases.

2.2.1. Source of information

The primary source of information on 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. Essentially all injury deaths are reported to a coroner, and all such reported deaths are entered into the NCIS. The NCIS was important for the current project because it is the only source that covers all work-related fatal incidents, 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 NCIS information on these cases was not available to researchers at the time this study was conducted.

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.

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; if someone was electrocuted by domestic current on a circuit without an earth leakage device; if a tractor or bulldozer operator was killed if 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 if 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 argued that a design-related prevention approach might have been possible.

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 one other coder. 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 here, '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 agreement at the two-category level, prior to discussion of discrepant cases, was 83% (kappa = 0.63).

For those cases identified as definitely, probably, or possibly being related to design, the main apparent design problems were recorded. Examples of how this coding approach was applied to a range of case descriptions are available elsewhere (National Occupational Health and Safety Commission, 2004; Driscoll et al., 2005).

3. Results

Four hundred and eighty four work-related cases were identified for the two-year period ending June 30, 2002. Of these, 274 (57%) were excluded because they involved medical

Table 1
Agency group identified for working persons and bystanders fatally injured in workplace incidents

Industry	Definite/Probable design-related		Total fatalities	
	Number	% design-related	Number	% of all deaths
Crushing, pressing, rolling machinery	4	100.0	4	
Conveyors and lifting plant	12	92.3	13	
Electrical installation	6	85.7	7	
Other plant and equipment	2	66.7	3	
Machinery and (mainly) fixed plant	**24**	**88.9**	**27**	**12.9**
Self-propelled plant	11	64.7	17	
Semi-portable plant	1	100.0	1	
Other mobile plant	14	60.9	23	
Road transport	11	44.0	26	
Rail transport	0	..	2	
Water transport	0	..	10	
Mobile plant and transport	**37**	**47.4**	**78**	**37.1**
Workshop and worksite tools and equipment	2	100.0	2	
Kitchen and domestic equipment	1	100.0	1	
Office and electronic equipment	1	100.0	1	
Garden and outdoor powered equipment *(includes weapons)*	0	..	7	
Other powered equipment, tools and appliances	1	100.0	1	
Powered equipment, tools and appliances	**5**	**41.7**	**12**	**5.7**
Handtools, non-powered, edged *(includes knives)*	0	..	8	
Other handtools	0	..	1	
Fastening, packing and packaging equipment	1	50.0	2	
Furniture and fittings	0	..	1	
Ladders, mobile ramps and stairways, and scaffolding	2	20.0	10	
Other non-powered equipment	2	25.0	8	
Non-powered handtools, appliances and equipment	**5**	**16.7**	**30**	**14.3**
Chemicals and chemical products	**0**	**..**	**1**	**0.5**
Materials and substances	**2**	**16.7**	**12**	**5.7**
Outdoor environment	3	10.0	30	
Indoor environment	1	100.0	1	
Underground environment	0	..	1	
Environmental agencies	4	**12.5**	**32**	**15.2**
Live four-legged animals	0	..	6	
Other live animals	0	..	4	
Human agencies	0	..	3	
Animal, human and biological agencies	**0**	**..**	**13**	**6.2**
Other and unspecified agencies	**0**	**..**	**5**	
TOTAL	**77**	**36.7**	**210**	**100.0**

By design-related involvement. Australia (excluding Queensland), 2000–01 and 2001–02. Number and per cent.

misadventure, motor-vehicle incidents, or plane incidents. This left 210 work-related deaths within the scope of the current study, virtually all of which had occurred in some type of formal workplace.

Seventy seven (37%) of the 210 workplace deaths definitely or probably had design-related issues involved. One of these fatalities was a bystander death. In another 29 (14%), the circumstances were suggestive that design issues were involved, but there was not enough information to conclude that design was definitely or probably involved. For 43 deaths (20%), it was not possible to determine if design issues were or were not involved, due to little or no information available in police description or Coroner's Findings (41 deaths) or because it was difficult to decide for theoretical reasons if the circumstances met the definition of design-related (two deaths). For the remaining 61 deaths (29%), design issues were unlikely to have been involved.

3.1. Agency of injury

The most commonly involved agencies were mobile plant and transport, environmental agencies and machinery and fixed plant. Design-related issues were most prominent for machinery and fixed plant and mobile plant and transport, but varied considerably between different specific agency types (Table 1).

3.2. Types of design issues

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 rollover 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 2).

Table 2
Design-related problems in fatal workplace incidents

Category	Definite/probably design-related	
	Number	%
ROPS/seat belts	13	16.9
Guarding	11	14.3
Residual current device	9	11.7
Fall protection	6	7.8
Hydraulics	6	7.8
Overhead protection (cabin, etc)	5	6.5
Roof material	2	2.6
Brakes	2	2.6
All-terrain vehicles	2	2.6
Building construction	2	2.6
Safety systems	2	2.6
Vehicle blind spots	1	1.3
Stacking	1	1.3
Over-luffing	1	1.3
Controls	1	1.3
Lighting	1	1.3
Other	12	15.6
Total	**77**	**100.0**

Australia (excluding Queensland), 1 July 2000 to 30 June 2002. Number and per cent.

3.2.1. Problems with rollover protective structures (ROPS) and/or associated seat belts

Typical problems involving ROPS and/or seat belts involved persons falling out of tractors, often when the tractor rolled over, and being struck by the tractor. In some instances there were no ROPS, and in some the ROPS appeared to be present but the person was still struck by the tractor or received fatal injuries when they were thrown out. Seat belts were rarely mentioned. This meant that, although seat belts were obviously not being worn at the time of the incident, it was not clear whether they were fitted and not used, or not fitted.

3.2.2. Inadequate guarding

Guarding was a major design issue, usually because guarding was absent or inadequate. Three of the incidents involved clothing being caught in an auger, and others involved contact with moving parts in fixed equipment (e.g., a water pump conveyor; a potato bin tipper). In some cases it was hard to separate the guarding issue from the broader design issue of in-built safety processes, such as safety inter-locks and fail-safe systems. Three incidents involved the deceased person being caught in inadequately protected presses or crushers, and another involved being caught by parts of an automated dairy.

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 3).

Table 3
Industry identified for working persons fatally injured in workplace incidents

Industry	Definite/Probable design-related		Total fatalities	
	Number	% design-related	Number	% of all deaths
Agriculture, Forestry and Fishing	28	38.4	73	34.8
Agriculture	*25*	*52.1*	*48*	22.9
Other agriculture [1]	*3*	*12.0*	*25*	11.9
Construction	18	43.9	41	19.5
Transport and Storage	8	40.0	20	9.5
Manufacturing	7	43.8	16	7.6
Wholesale Trade / Retail Trade	7	50.0	14	6.7
Mining	4	57.1	7	3.3
Cultural and Recreational Services	2	14.3	14	6.7
Health and Community Services	1	20.0	5	2.4
Accommodation, Cafes and Restaurants	0	-	4	1.9
Finance and Insurance / Property and Business Services	1	25.0	4	1.9
Government Administration and Defence	0	-	1	0.5
Not known	0	-	4	1.9
Bystander	1	14.3	7	3.3
TOTAL	77	36.7	210	100.0

Australia (excluding Queensland), 2000–01 and 2001–02. Number and per cent.
[1] Services to Agriculture; Hunting and Trapping / Forestry and Logging / Commercial Fishing.

4. Discussion

'Design' can be interpreted narrowly or broadly, as can the question of whether some particular aspect of design can be considered to be 'related' to a particular event or type of injury case. A narrow interpretation would focus on types of cases in which design contributed strongly and directly to the outcome, in ways that are likely to be detectable with reasonable assurance on a case-by-case basis. A broad interpretation could extend beyond this to include the contributions of design to work-related injury and fatalities in contexts in which this cannot be assessed on a case-by-case basis; that is, considering design as a risk factor for injury, determined by means of population studies and summarized in terms of attributable risk. It could also extend to consider aspects of design, and the relationship of design to injury, which are more abstract and less direct, such as comfort and aesthetics as factors amenable to design and which can influence matters such as the usage of personal protective equipment; design as a factor influencing the likelihood of human errors of particular types; and the design of safety training programs. The primary advantage of a narrow interpretation is easier identification of the main physical design aspects of an incident. The main disadvantage is that this will encompass a smaller part of the total scope of 'design-related' work-related injury than might prove to be achievable by a broader, but less certain approach. The approach adopted in this analysis was the narrower interpretation.

Few publications consider in detail the role of design issues in work-related incidents, although some have included design issues as a small component of a broader analysis of the contributing factors in work-related injury. As a result, there were no approaches identified that could be adopted. For this study, a pragmatic approach to the identification of design issues was adopted. The task involved using the available data, which had not been collected or recorded with the aim of describing aspects of design that may have been important to the occurrence of the incident. The approach used was in part impeded by the data limitations. It involved including cases if aspects of the design of machinery, plant, equipment, or structures had clearly contributed to the occurrence of the fatal incident and/or to the sustaining of fatal injuries as a result of the incident, and where such aspects could reasonably be expected to be preventable with current technology.

For many circumstances, deciding whether design issues were involved, and identifying the type of issue, was straightforward. However, this was not always the case. The main cause of this difficulty was the lack of detailed information about the incident circumstances. For example, there have been many instances of workers being hit by forklift trucks where issues of line of sight, warning lights, alarms, or environmental lighting have been found to be important. All of these factors can be considered design problems. However, if the only relevant available part of a description is that "a pedestrian worker was hit by a forklift truck," there is not enough information to be confident that design played a role. In a small number of cases, there was adequate information about the circumstances, but difficulties arose because of uncertainty regarding whether design should have been considered to play an important part in

the incident. Even where design issues were considered to have contributed, the identification of the relevant design issue was not always straightforward. A classification scheme was developed during this project, but was sometimes difficult to apply because a number of different design approaches might have prevented the problem. Only the apparent primary design issue was identified, although in some instances it was likely that more than one design issue contributed. Finally, when interpreting the results of this study, the nature and source of the raw data must be kept in mind. The NCIS data were not collected primarily for prevention purposes in general, nor to consider design issues in particular. The NCIS information was provided by police officers, OHS officers, and/or coroners. The available information may be expected to under or over emphasize factors related to design in some incidents, although underestimation seems more likely. Adding this to the problem that "design-relatedness" is inherently an imprecise concept, the results of the analysis can only be considered indicative. They clearly indicate that design is an important contributing factor in work-related fatal injury, and the study provides a best estimate of the extent of involvement, but the precise contribution is not known.

The main design issues identified for fatal work-related incidents were problems with rollover protective structures and/or associated seat belts; inadequate guarding; lack of residual current devices; inadequate fall protection; failed hydraulic lifting systems; and inadequate protection mechanisms (such as enclosed cabins) on mobile plant and vehicles. Most of the main design problems are old issues, with guarding the most prominent example. These appear to provide a lot of scope and opportunity for prevention activities. Incidents involving all-terrain vehicles showed the intersection between design and usage. All-terrain vehicles on farms are commonly used in purposes for which they were not specifically designed. This gap between design and use sometimes contributes to the incident occurring, and it could be argued that it is reasonable to expect that the designers and manufacturers anticipate such use.

The identification of design issues in work-related incidents leading to fatal injury in this study cannot be expected to include the full range of circumstances in which design contributes to such incidents. For most fatal incidents involving issues with the physical design of machinery, plant, and equipment, reasonably detailed descriptions by the police and/or coroner should provide the type of information necessary to assess the role of design. However, even detailed information may not allow the identification or assessment of the role of the design of systems, process, and buildings unless it is collected with these issues in mind. Nevertheless, the design of systems, process, and buildings can be expected to contribute to some incidents resulting in work-related injury. Limitations in the available data sources meant that these potential design factors were beyond the scope of the current analysis. This is another reason why the estimates of design-relatedness presented here must be considered to be underestimates of the true situation.

The methodological approach taken in this study falls between an amalgamated case series and a population-based study. There was commonly sufficient information to confidently conclude that design did (or did not) make a meaningful contribution to the death. This does not necessarily mean design was the only such contributing factor, nor even that it was the most important factor. Indeed, in most work-related injury deaths there are several important factors involved. However, cases were only classified as design-related if the available information strongly suggested that the incident would not have occurred, or would not have had its fatal outcome, if the design issue had not been present. An important part of the definition focused on whether "…it was realistic to expect that this factor could have been modified to avoid the incident or the subsequent fatal injury." It was not feasible in the study to assess the tractability, cost, or risk trade-offs relevant to determining the most appropriate prevention approaches to use for each identified incident. It may be that in some circumstances the required design change will never be implemented because of the need to take these factors into account. However, the vast majority of incidents involved obvious design issues that appeared to have straight-forward design solutions, and it is reasonable to expect that focus on the design aspects would be the most appropriate prevention approach for such incidents. Therefore, the information presented in this paper does not prove that tackling design issues is always the most cost-effective prevention approach for such incidents as those presented here (although the arguments were presented earlier as to why it might be). What it does show is that design is an important contributing factor to fatal work-related injury in Australia.

5. Summary

This paper presents a consideration of the role of design issues in fatal work-related injury. The concept of design-relatedness is not well conceptualized or practically applied in the literature and therefore there were no existing definitions or approaches that could be adopted. The main finding from the study is that design is a significant contributor to fatal injury in Australia. This is the case with a wide variety of machinery, plant, and equipment, although the extent of involvement varies between them. Limitations of the data sources mean that the percentage involvement identified in this analysis are likely to be underestimates.

Impact on Industry

Problems with the design of machinery, plant, and equipment make a significant contribution to the occurrence of serious work-related injury.

There is considerable scope for preventing serious work-related injury through improving design of plant, equipment, and vehicles used for work-related purposes. Many of the problems are not new and should be readily amenable to correction.

Safety issues related to design should be considered whenever machinery, plant, or equipment are being purchased.

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Competing Interests

TD and JH have conducted consultancy projects commissioned by NOHSC and the ASCC.

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