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INTRODUCTION
In 1970, the Medical Journal of Australia published an article titled “Accidents in Australia: the need for research”. The essence of the article was that “the commonsense approach (to injury prevention) and its associated folk activity can now be described as palpably ineffective and due for replacement.” The author was Eric W Wigglesworth (Wigglesworth, 1970).

In the same year, William Haddon Jr, MD, wrote an editorial introducing what was to become the single most important idea in the developing science of injury prevention. In an editorial “On the escape of tigers: an ecological note” (Haddon, 1970) Haddon outlined his famous argument that transfer of energy is the cause of injuries and thus the prevention of injuries is achieved through a data driven, systematic approach to minimising this transfer. From the third of his ten strategies for injury prevention (i.e. prevent the release of energy) he derived the title of his editorial.

As safety scientists and practitioners we took the idea of energy control and ran with it. It worked. It worked so well we did not take the time to read Haddon’s editorial properly to find its complete message. Now we are left somewhat surprised to find the energy control approach seems to have led us to a dead end. Despite strong support for the scientific approach to injury prevention, there is a clear gap in the translation of this scientific evidence to injury prevention practice.

While energy may be the cause of injury, it also maintains life and luxury. Energy is not limited to discrete hazards that can be confined to create risk free zones in which individuals are totally safe. All tigers cannot be caged. Understanding the mechanisms of energy control cannot be the whole solution.

Arguably there is less interest now in injury prevention than there has been in Australia at any time in the last 50 years. Is the answer to do more of what we are doing, but do it better? Or has our systematic consideration of energy transfer factors become the new commonsense approach so palpably ineffective that Wigglesworth would now be calling for us to entirely rethink our approach and replace it with a more systemic way forward?
Rethinking our approach to the problem of injury can be done in four steps. First, understand energy transfer as a part of an ecological model of causation. Second, recognise that the practice of injury prevention is an ecological activity. Third, acknowledge that ecological injury prevention is social change. Finally, appreciate that achieving social change requires a systemic not a systematic approach.

The four step shift in how we think about injury can be institutionalised by redefining injury, its causation and its control in terms consistent with a systemic rather than systematic approach. Injury should no longer be characterised in terms of a condition caused by individual level exposure to a release of energy; and injury prevention should no longer be characterised as the process of energy control. Instead injury prevention should be defined in the language of an ecological understanding of injury causation, and systemic approaches to societal change. The aims of this paper are to explain the four step shift in how we think about injury, and to suggest a new definition of injury prevention that allows us to close the gap between scientific evidence and injury prevention practice.

ENERGY TRANSFER AS A PART AN ECOLOGICAL MODEL OF CAUSATION

The contemporary definition of injury describes it as the consequence of transfer of energy to a tissue of the body where the magnitude of that energy is beyond the limits compatible with the tissue’s normal physiological function. Thus anything that affects the range of tolerance of the tissue or that extends the energy exposure beyond the tolerance range can be considered within this definition to be a component of the causal relationship between energy and consequent injury (McClure et al, 2011).

This definition is based on a disease model that operates at the individual level. The no-fault connotations of disease causation are overtly assumed by this injury definition, which is formulated in terms of the aetiology of the condition rather than any health-related outcome.

There is no material difference between these component causes of the energy transfer event and the underlying factors that comprise the context within which the event occurs. These “causes of the causes” together with characteristics of the energy transfer event have been previously described using metaphors such as the “chain of causation” or the “web of causation” or the “causal set”, or more specifically, the ecological model of injury causation (Susser and Susser, 1996a&b).

The ecological model of causation comprises the totality of factors in combination, that, had that totality not existed, the given injury would not have occurred. Typically the causal model for any injury involves a large number of known and unknown factors. The factors may be observable entities and/or abstract attributes and they operate at the individual, group and environmental levels (McClure et al, 2011).

The ecological model of injury causation can be exemplified by a hypothetical case of a head injury sustained by a driver of a commercial heavy vehicle during a single-vehicle road crash on an interstate highway in the early hours of the morning. In this hypothetical case the overweight driver, fatigued by combination of sleep apnoea, biological circadian rhythm and inappropriate driving schedules, drifts onto a soft shoulder of road while navigating a gentle curve at speed, over corrects, crosses back into the opposite side ditch, hits his head on the side pillar as his truck hits tree, and dies from extensive brain injury.

In this example, what is the cause of injury? Kinetic energy absorbed by the brain at point of impact greater than the limits compatible with the brain’s normal physiological function? The absence of a side impact airbag? The lack of a wire rope ropes barriers lining the highway? The speed of the vehicle? The clay shoulder on the inside curve of the road? Inappropriate company practices related to driving/payment schedules and lack of fatigue monitoring? Or is it the myriad of upstream factors related to distribution of goods and services and the industry, government and
community priorities that explain why effective sleep apnoea screening, treatment protocols, and road safety programs were not operational at the time of the crash? Energy transfer was certainly involved, but it was the ecology of circumstances that better reflects the true cause of death.

THE PRACTICE OF INJURY PREVENTION IS AN ECOLOGICAL ACTIVITY
The concept of injury prevention is implicit in the concept of injury causation. If you could remove that particular arrangement of factors that constitutes the cause of a specific injury, then you necessarily have prevented the injury. The traditional approach to the prevention of injury focuses on those factors directly related to energy exchange. Within this paradigm, research methods are systematically used to isolate energy transfer components of injury events from the context in which these components operate. Using Haddon’s ten principles of prevention, countermeasures are then generated to minimise the opportunity for the energy in such circumstances to do harm (Haddon, 1970). If found to be efficacious under research conditions, these countermeasures are recommended for widespread implementation.

There are three major problems with the traditional systematic approach to injury prevention. The first of these is that energy is ubiquitous and all objects can in certain circumstances be elements of the injury causal set. Thus the number of potential energy transfer events is almost infinite. Any attempt to develop an injury prevention process that requires the facts of every single injury event to be systematically analysed and pre-emptively addressed through energy control design is prohibitively onerous.

The second problem is that the context in which injury events occur tends to maintain the balance of event factors in ecological equilibrium. This equilibrium ensures the large scale drivers that have created the circumstances for the event will continue to drive towards the creation of these circumstances, in opposition to the smaller scale efforts of individual practitioners working on preventing specific events.

Finally, while the systematic approach has proved particularly successful in relation to problem description, energy transfer identification, and efficacious countermeasure development, it provides no answers to the issue of how you take “what works” in the lab, and “make it work” in practice. The essence of this issue is that the first three steps are undertaken in the research domain, but necessarily the final step of making injury prevention work in practice needs to be undertaken in the public domain. The systemic approach to energy control thus entails a “research-to-practice” translation that occurs between the countermeasure development and the program implementation phases. The extent of the disjunct that requires a “translation” process to make it work clearly has major potential to block effectiveness.

The ecological approach provides the solutions to each of the problems that beset the traditional systematic energy control approach. First it provides the means of making operational prevention activities sufficiently “upstream” to be common across a substantial proportion of targeted conditions and relevant situations. This overcomes the need to design preventive solutions for the almost infinite number of situations in which injury occurs. Instead focus can be on the underlying generic contexts of which the energy transfer events are peripheral manifestations. By focusing on only a few critical factors, this approach will allow us to not only simplify our efforts, but also simplify our message, and thus allow us to have far greater impact. The ecological approach provides a “unifying theory” that will overcome the fragmentation (and thus invisibility) of contemporary injury prevention and allow us to have a much higher profile in addressing injury as a single issue.

Second, in contrast to the energy control approach, ecological interventions set out specifically to change the ecological equilibrium. Ecological injury prevention works by implementing structural change
that in turn changes population-level social policies and modification to ecological environments that underpin the context in which the potential injury events occur. This encourages widespread adoption of processes and practices that operate at each of the multiple levels of the ecological determinations of injury. The effect of this forces a change in individual exposure to harmful transfer of energy. This circumvents the problem of trying to work against the resistance of existing structures.

Finally, because ecological injury prevention is conceived and conducted as a societal activity, it is entirely existent within the public domain. There is no issue (as there is with the systematic approach) of needing to “translate” across the science to practice divide. In contradistinction to the research centred “push” prescribed by the expert-driven, systematic approach to injury prevention, an ecological approach requires practitioners and policy makers from across all areas in society to “pull” evidence and information from a variety of sources, as required to achieve their goals (Bugeja et al, 2011).

The intuitive appeal of the ecological approach is exemplified by the problem of injury in children 0-5 years of age. Considered in terms of an energy exchange model, this is an extremely complicated problem. Are risk factors for intentional injury different from unintentional injury? Can we really map in advance all those situations where children get themselves into trouble and pre-emptively implement energy control interventions? Can the rights of children to be protected from injury be disentangled from their rights to freedom, and adult support? Is it indeed possible to tease out child injury from child health? How do you improve the safety in households where 60 percent of child injuries occur but to which practitioners have little access? How can the new science of injury prevention be made relevant to parents who are juggling the existing burdens of young families? Considered in terms of childhood injury being an ecological issue, these questions become unimportant. All we need instead are the two questions, “What do we need to put in place as a society to optimise the wellbeing of children?”, and “How do we optimise the function of that aspect of society over which we have influence to ensure children are not at risk?”.

ECOLOGICAL INJURY PREVENTION IS SOCIAL CHANGE

Injury prevention as an ecological concept considers the totality of causes in context and involves managing the combined arrangement of factors. This cannot be achieved by examining some aspects of the problem in isolation from other aspects. If the causation and prevention of injury is understood as an ecological issue then it is the whole of society that is the target of the intervention process. The expectation would be that in addressing the whole of society, changes will occur in such a way as to minimise the prevalence of injury causal sets and the consequent incidence of injury. Thus, ecological injury prevention is the process of achieving change to societal entities and relationships to enable improvement in the injury-related health and wellbeing of its citizens. This perspective is in marked contrast to the classic approach that aims to achieve population level reductions in injury by accumulating the benefits of systematic efforts to control energy transfer at the level of potential injury events.

The basis of the systematic approach to injury prevention is that countermeasures proven to be efficacious in the research setting can be scaled up by policy makers and practitioners for use at the population level. The logic flaw in this approach is that a population level intervention is not the same as a scaled up research study. Population level injury prevention is not simply a matter of hoping for widespread implementation of results of research studies of countermeasure efficacy. In fact it is the reliance on this hope that is the reason for an enormous backlog of injury prevention evidence not yet implemented.

Countermeasure efficacy studies are highly circumscribed activities, in which willing participants are supported to undertake
certain processes prescribed at the individual level. Injury prevention programs on the other hand, are complex social policy interventions, delivered to non-consenting members of the public using existing social infrastructures, designed to achieve ecological sustainable change. The nature of a scaled up research-based program cannot have components that exist at the societal level. If changing societal structures is the essence of an ecological approach to injury prevention, then scaled up programs necessarily fail to contain the elements required for its success. If they are to have the requisite characteristics to be effective, social change initiatives need to be designed from the ground up using society rather than the laboratory as the operational dynamic.

This limitation is well demonstrated in the area of natural disasters. Comparisons between communities experiencing natural disasters of similar a type and scale have shown that for any given disaster, resilient communities suffer less injury-related harm than non-resilient communities. The goal of disaster-related injury prevention is to increase community disaster resilience by encouraging increased disaster preparedness, management, response and recovery. Community disaster resilience is a community-level attribute not something that is quantified by summing the resilience of individual community members.

As has been shown by a review of recent Australian bushfires (Goode et al, 2012), disaster preparedness, management, response and recovery are all inextricably linked in a complex sociotechnical system. The government component of the response alone has six organisational levels including policy and budgeting; regulatory bodies; local area government planning and budgeting (including governance, technical and operational management; physical processes and actor activities; and equipment and surroundings). The biggest breakdowns in bushfire disaster response in Australia were not associated with the capacities of individual parts of the system but how the parts worked together as a single system under crisis conditions.

**SOCIAL CHANGE REQUIRES A SYSTEMIC NOT A SYSTEMATIC APPROACH**

If ecological injury prevention is to increase the injury-related health and wellbeing of citizens, then the challenge faced by all interested parties is how this desired change can be achieved. Change is especially difficult given that it needs to be made at the societal level rather than hope ecological change can be achieved through an accumulation of systematic changes.

Society is a complex system and as such contains large networks of interacting entities or agents (Paperin et al, 2011). These networks and their components are often poorly understood. Shifts in connections within the system, or shifts between states of fragmentation and connection may be extremely abrupt and behaviours within the networks often labile, varied and unpredictable. The size of complex systems can provide for substantial inertia in the context of negative feedback loops. However, there may be “tipping points” where positive feedback loops produce massive escalating effects. Connectivity and feedback loops can result in rapid phase shifts from locally driven global influence to globally driven local response (Paperin et al, 2011).

**REDEFINING INJURY, ITS CAUSATION AND ITS CONTROL SO THAT WE SHIFT FROM THE SYSTEMATIC TO THE SYSTEMIC APPROACH**

Even when we have done the rethinking, the challenge for us is to apply this thinking to prevention practice. Let us start with defining injury, its causation and its control, in such a way as to institutionalise the shift in perspective from the systematic to the systemic. In order to be an essentially systemic societal approach, the definition of injury, its causation and its control needs to be grounded in the societal purpose of a sustainable future. As a foundational truth, McMichael & Bulter (2006) explain this as, “…ultimately about optimizing human experience, especially well-being, health and...
survival... The central task is to promote sustainable environmental and social conditions that confer enduring and equitable gains in population health.” (McMichael & Bulter, 2006, p22-23)

On the basis of this premise, a suggested definition of injury prevention is, the optimal governance and functioning of individuals within their social and physical environments in circumstances where human wellbeing is an essential performance requirement expected of all institutions, organisations and citizens.

This definition implies the categorical imperative that those responsible for a given attribute of an individual or environment are also accountable for the extent to which this attribute puts human wellbeing at risk.

In contrast to the energy transfer definition of injury based on a disease model, made operational at the individual level and overtly avoiding notions of accountability and outcome, the proposed new definition is systems-focused, outcomes-driven, grounded in accountability, and ubiquitously applicable.

Human wellbeing, safety and survival is not a byproduct of societal function, it is the reason for it. Lost lives and destroyed families are not inevitable losses on which progress is built; they are indicators of failed progress.

THE PARAMETERS OF THE WAY FORWARD

By defining injury in terms of core societal purpose, it is no longer an isolated issue but part of core societal function, and injury prevention a component of core social development. While injury is seen as an add-on, it will always be an afterthought, and always poorly addressed. If it can be centralised so that it is considered a part of a society’s core business, then injury prevention will have universal support. By championing integrated social policy for the improvement of society, those advocating for injury prevention will use the core social drivers to achieve injury prevention more dramatically and sustainably than could be achieved using a scattered approach of systematic situational energy control.

Injury prevention is not primarily done by injury prevention researchers. The researcher’s main role is to provide evidence that can be drawn on by society when needed. Nor is injury prevention done primarily by injury prevention practitioners. Practitioners work towards sustaining the strength and focus of societal engagement on the injury issue. The practitioner’s main role is to encourage a public domain convergence of problem recognition, political will and evidenced-based solutions and thus create opportunities to galvanise policy action.

Injury prevention is primarily achieved by society in its collective development of integrated individual, government and industry policy that is aimed at promoting “sustainable environmental and social conditions that confer enduring and equitable gains in population health” (McMichael & Bulter, 2006, p22-23). Such integrated policy will ensure that in all areas where injury occurs human wellbeing is recognised as an essential performance requirement and that all those responsible for a given attribute of an individual or environment will hold themselves accountable for the extent to which this attribute puts human wellbeing at risk.

So what can we do as researchers, practitioners and policy makers? Has the “everything is connected to everything” approach completely disempowered us as individuals to move forward on anything? By shifting from a systematic approach that has been shown to be so successful within specified limits, to a systemic approach where individuals appear to have so little control, have I prescribed a recipe for disempowered inactivity? I do not think so.

Society is a complex system. Have we given up on trying to improve society because there is so little one person can do? Of course not. Do we sit around saying it is too complex and we do not have the levers to achieve change? Of course not. Societies do change. Sophisticated societies have the levers for complex ecological development built into their structure. Accountability at all levels of governance, transparency of
process, informed citizenry and robust public debate ensure that the voice of the citizenry can be heard in decision-making processes. These are the levers which drive societal development and are just the levers that need to be used to achieve effective injury prevention. If societal goals are defined in terms of sustainable wellbeing and if injury is recognised within the accepted scope of that, then our role is to facilitate collective activity by providing the expertise needed to support the right collective decisions at the right times and right places.

The way forward for injury prevention is to do the homework, to do the research, to do the planning so we are ready with the answers. However, unless these answers address the needs of integrated policy development, they will be unheeded. We need to do more than simply have the right answers; we need to encourage the right questions and be around the tables with the societal opinion leaders and decision makers when these are being asked.

CONCLUSION
The ideas in this paper are not new. They are simply the ideas Haddon outlined in his seminal article all those years ago (Haddon, 1970). Haddon titled his editorial, “an ecological note”. He described his ideas as instruction “for all concerned with environment, ecology, and the public health”. Haddon’s thesis all along was that the science of injury prevention is energy control in context. This paper simply suggests we revisit Haddon’s seminal text and read it more carefully. As researchers, policy makers and practitioners we have tended to emphasise the energy control aspect of Haddon’s solution. Now perhaps is the time to start working on ways to put injury prevention back into context.

REFERENCES
Work Health and Safety Act “due diligence”: Will our current safety systems be compliant?

SUSANNE BAHN

ABSTRACT

The harmonisation of work health and safety legislation began to come into effect in Australia in January 2012 and is part of the Council of Australian Governments (COAG 2008) National Reform Agenda. This paper reviews the meaning of and adherence to the due diligence requirements of Section 27 and the definition of consultation in sections 48 and 49 of legislation enacting the Model Work Health and Safety Act 2011 (WHS Act) to determine whether off the shelf safety systems are compliant under the new legislation. These requirements include provision of safe systems of work (Section 19(1)) that is the result of consultation with all workers. Some businesses in Australia purchase off the shelf safety systems with completed safe work procedures and operational manuals. Little or no consultation occurs with workers as to whether these documents are a correct account of their daily work tasks. Communication is limited to tool box and safety meetings. The paper questions whether pre-developed safety systems that have limited consultation and development between staff and management comply with Sections 27(5) and 47-49 of the WHS Act.

INTRODUCTION

This paper examines specific sections of the Model Work Health and Safety Act (WHS Act) which has been enacted as law in NSW, Queensland, the Northern Territory, the ACT and the Commonwealth from January 2012 (Tooma, 2012). Section 27 of the WHS Act requires, officers of PCBUs1 that are legal entities (rather than just individuals) to exercise due diligence. PCBUs have duties (section 19) and if the PCBU is anything other than a sole trader or partnership, then officers of that PCBU also have obligations (section 27) to ensure the PCBU complies with its obligations. Sections 47 to 49 establish specific obligations of PCBUs in relation to consultation, and officers will need to ensure the PCBU complies with these. Workers have duties to exercise reasonable care. Exercising due diligence includes taking the steps set out in section 27(5) which include: having up-to-date knowledge of work health and safety matters, applying these to the nature of the operating business, ensuring appropriate resources and processes are in place to minimise risk and that these are complied with and ensuring all persons in the workplace receive information regarding incidents, hazards and risks (Safe Work Australia, 2011).

Sections 47 to 49 outline the obligations of the PCBU relating to consultation with workers in the development of safe work processes. These obligations include: ensuring that work processes accurately reflect workers’ tasks, that workers have the opportunity to express their views about health and safety risks, that they can contribute to the decision-making processes relating to work tasks and that they are advised of

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outcomes in a timely manner (Safe Work Australia, 2011). In this paper, the relevant sections of the WHS Act are presented and discussed with implications for those firms who purchase off the shelf safety systems that do not include consultation with workers. New South Wales court cases (under the previous state Act at the time of the ruling) are cited that focus on a requirement of the judges for proof of worker consultation. The issue in these cases was that simply using paper based systems that sat on shelves gathering dust did not deem compliance for the prosecuted companies. Although evidence of worker consultation has not yet been examined in legal proceedings under any of the harmonised WHS Acts, it is likely that the requirement for consultation with workers and the use of pre-developed safety systems will be an issue that is considered in the future in determining compliance. The paper concludes with a recommendation that businesses large and small, across all sectors and jurisdictions should be examining their current safety systems to determine if they are compliant under the new WHS Acts. The recommendation for those firms who have purchased off the shelf safety systems with pre-developed documentation is to examine their consultation processes with their workers and formally record these events as evidence of compliance.

DUE DILIGENCE AND CONSULTATION IN RELATION TO THE WHS ACT
The PCBU duty in section 19 of the WHS Act establishes the PCBU’s responsibilities in relation to the health and safety of a range of workers. A PCBU is described as a person conducting the business alone (self-employed) or with others, having health and safety responsibility as far as is reasonably practicable for all workers providing services including those contracted and hired through labour hire organisations (WHS Act section 19). In addition “officers” may be directors of a company and others such as CEOs who make or participate in making decisions about the whole or a substantial part of the company , but are not necessarily involved in the day-to-day running of the company, must exercise due diligence to ensure that the PCBU complies with the Act. It should be noted that with this is a new duty and in the event that an officer is found to be in breach of the WHS Act the penalties can be severe.

A key development in the WHS Act (in section 19) is a clear statement of the responsibilities of PCBUs, as employers or otherwise, for the health and safety of workers performing work for the PCBU in any capacity (section 7). These issues come to the fore when businesses use workers that they do not directly employ such as labour hire and sub-contractors. In the literature, for example, Mayhew and Quinlan (1997); Underhill (2002); Johnstone and Quinlan (2006); and James, Johnstone, Quinlan and Walters (2007) write about the devolving of health and safety responsibility for contracted labour by the host organisation. Their research indicated several cases of host organisations attempting to shift the management and supervision of contracted labour back to the third party firm rather than take on that role themselves. Further, Johnstone and Quinlan (2006) discuss the blurring of work health and safety responsibilities, employment conditions and the transfer of human resource management functions to labour agencies (Connell & Burgess, 2002). James, et al (2007) explain that there is difficulty distinguishing between self-employed workers and in-house workers, when determining health and safety responsibilities, which is exacerbated when some staff are employed on fixed term contracts. The new PCBU duty in the WHS Act addresses these issues relating to devolving responsibility by preventing PCBUs from evading responsibility by outsourcing or contracting out labour.

In order to improve conditions, Deakin (2004) called for more ‘reflexive’ forms of regulation that were less prescriptive allowing for employer flexibility and the sharing of employer duties between employment agencies and host organisations. Finally, Johnstone, Mayhew and Quinlan (2005) also
argue that WHS regulation of contracted or outsourced labour is difficult. They maintain that the use of such forms of labour “increases the likelihood of multi-employer worksites, corner-cutting, and dangerous forms of work disorganisation, as well as situations where the legal responsibilities of employers are more ambiguous and attenuated” (Johnstone, et al 2005:391). The harmonised WHS Acts address these concerns by extending the PCBU’s’ responsibilities to a wide range of workers, and requiring officers of PCBUs to exercise due diligence to ensure the PCBU complies with their obligations and does not evade responsibility. However, given that officers of PCBUs may be those who are removed from the practical running of the company and may not have direct access to health and safety practices within organisations, the onus on the individual to meet the due diligence requirements of the Act is considerable. The due diligence requirement within the WHS Acts includes taking ‘reasonable steps’:

a) To acquire and keep up-to-date knowledge of work health and safety matters; and

b) To gain an understanding of the nature of the operations of the business or undertaking of the person conducting the business or undertaking and generally of the hazards and risks associated with those operations; and

c) To ensure that the person conducting the business or undertaking has available use, and uses, appropriate resources and processes to eliminate or minimise risks to health and safety from work carried out as part of the conduct of the business or undertaking; and

d) To ensure that the person conducting the business or undertaking has appropriate processes for receiving and considering information regarding incidents, hazards and risks and responding in a timely way to that information; and

e) To ensure that the person conducting the business or undertaking has, and implements, processes for complying with any duty or obligation of the person conducting the business or undertaking under this Act; and

f) To verify the provision and use of resources and processes referred to in paragraphs (c) to (e). (Safe Work Australia, 2011:29-30).

Access Economics (2011:18) reports in their analysis of the impact of implementing the WHS Act that “for the most part, neither substantial changes, nor large costs or benefits are expected”. However, the interpretation of sections 19, 27 (5), and 47 to 49 in relation to ‘ensuring health and safety, so far as is reasonably practicable’ (the PCBU duty) and exercising ‘due diligence’ (the officer duty) and ‘consultation’ with workers has far reaching implications (Tooma, 2010). The WHS Act under the due diligence clause places personal liability for workplace safety on officers who include company directors, financial officers and persons who make or participate in making decisions that affect the whole or a substantial part of a business or undertaking (eg members of boards). The responsibility of company officers (Directors, CEOs, and so on) is clearly spelt out in the WHS Act as a positive duty where officers can be deemed personally liable for breaches of their duty (Foster, 2012). Section 27 of the WHS Act describes where this duty applies:

1. That there is a corporate “PCBU” which has a duty or obligation under the WHSA;
2. That the accused individual is an “officer” of that PCBU;
3. That the accused has failed to exercise “due diligence” to ensure that the PCBU complies with that duty or obligation (Safe Work Australia, 2011).

In recent years this standard has been considered under the previous state legislation by the New South Wales courts in proceedings in 2006, 2007 and 2009 (NSWIRComm 323; 170 & 163). For example in the Inspector Kumar vs David Aylmer Ritchie case (NSWIRComm 323, 2006) the judge specified due diligence requirements.
that included a safety system was not merely a paper scheme that “paid lip service to the Act”. Foster (2009) noted the issues of non-compliance arising from safety systems that are only established on paper as due diligence requires that these systems are also implemented in the workplace in consultation with workers and that these systems are regularly monitored so that specific safety issues are responded to in a timely manner.

Safety systems compliance or not?

Organisations in Australia should be questioning whether the safety management systems they have in place will ensure they are compliant upon the introduction of the WHS Act in 2012. Of particular concern is the requirement to consult with workers as is detailed in Section 48 (1) requiring:

(a) that relevant information about the matter is shared with workers; and
(b) that workers be given a reasonable opportunity:
   (i) to express their views and to raise work health or safety issues in relation to the matter; and
   (ii) to contribute to the decision-making process relating to the matter; and
(c) that the views of workers are taken into account by the person conducting the business or undertaking; and
(d) that the workers consulted are advised of the outcome of the consultation in a timely manner.

(2) If the workers are represented by a health and safety representative, the consultation must involve that representative.

Examples of off-the-shelf products include pre-filled, generic job safety analyses, safe work procedures, policies and training manuals. These documents cover a wide range of processes including the operation of plant, emergency drills, working at heights, working in confined space, etc. The accessibility to these generic documents may seem an easier and simpler method of compliance; however it is the requirement to genuinely consult with workers that appears to be missing. The practice of supplying such systems is big business in Australia with a number of consultancies developing generic safe work procedures and job safety analyses that can be purchased by organisations. In these instances the system is installed, the company logo attached, with no communication or consultation with workers whatsoever. As the WHS Act requires that workers have an opportunity to express their views and contribute to decision making, pre-prepared documents in off the shelf management systems will need to be the subject of consultation with workers in order to ensure workers views are taken into account. Section 49 of the WHS Act (Safe Work Australia 2011:45-46) determines the consultation that is required:

(a) when identifying hazards and assessing risks to health and safety arising from the work carried out or to be carried out by the business or undertaking;
(b) when making decisions about ways to eliminate or minimise those risks;
(c) when making decisions about the adequacy of facilities for the welfare of workers;
(d) when proposing changes that may affect the health or safety of workers;
(e) when making decisions about the procedures for:
   (i) consulting with workers; or
   (ii) resolving work health or safety issues at the workplace; or
   (iii) monitoring the health of workers; or
   (iv) monitoring the conditions at any workplace under the management or control of the person conducting the business or undertaking; or
   (v) providing information and training for workers; or
(f) when carrying out any other activity prescribed by the regulations for the purposes of this section.

This section of the WHS Act clearly states
the requirement to consult with workers when developing and implementing safety systems. However, it is not unusual to find documents that have been shared or borrowed from other organisations and the original logos still in place on safe work procedures, job safety analysis and operating manuals. Examples of this can be found in the resources sector and particularly on green field mining sites. Therefore even the big end of town should take a closer look at whether their current safety systems are compliant with the WHS Act due diligence requirements. Furthermore the impact on smaller business is of concern in that these organisations may not have a safety system in place at all and have no dedicated safety professionals they can call upon to carry out the due diligence requirements of the WHS Act. Eakin, Champoux and MacEachen (2010) in their Canadian study found that documentation of risk was problematic, particularly for smaller firms. Other research has shown that individual, organisational, social, cultural and economic factors influence workplace safety policies, processes and practices (Baldock James, Smallbone & Vickers, 2006; Frick & Walters, 1998; Vickers, James, Smallbone & Baldock, 2005). Finally, safety consultancies providing generic safety documentation need to address the consultation requirements of the WHS Act when their client organisations introduce them into their work practices.

CONCLUSION
This paper has highlighted the relevant sections of the WHS Act that relate to due diligence and consultation requirements and their significance for safety systems in organisations. The obligations of PCBUs and of officers require appropriate processes to be established and implemented, and central to these are processes for consulting workers. This consultation includes the ability of the worker to have input to the working practices of their organisation and to raise health and safety issues. Evidence that direct consultation has occurred with workers is important in the event of legal proceedings against firms, as demonstrated in the case of Kumar v Ritchie (NSWIRComm 323, 2006). Businesses large and small, across all sectors and jurisdictions should be examining their current safety systems to determine if they are compliant under the WHS Act 2011. A particular focus should be on those organisations that have purchased off the shelf safety systems with pre-developed documentation. In reviewing their systems, in the light of the recent NSW Industrial Relations court proceedings, organisations would do well to place the lens on their consultation processes with their workers and document that these interactions have occurred.
REFERENCES


INTRODUCTION

Long term exposure to whole body vibration (WBV) is a known risk factor for the development of back pain (Bernard, 1997; Bovenzi & Hulshof, 1998). Many operators of earth-moving equipment used in mining are exposed to significant WBV for relatively long periods (Cann et al., 2003; Kumar, 2004; Smets et al., 2010).

The Model Work Health and Safety Act 2010 places an obligation on designers, manufacturers, importers and suppliers of plant to ensure, so far as is reasonably practicable, that plant such as earth-moving equipment is without risks to the health of persons who operate the plant. The obligation holders must ensure that appropriate evaluations are conducted to ensure this obligation is met, and are required to communicate the results of these evaluations to purchasers.

ISO2631.1 is ambiguous regarding which measures should be utilised and its application is problematic. Task-dependent variability in vibration measurements was noted. The implication for equipment manufacturers is that measurements must be taken in the range of realistic operating conditions. The implication for mine operators is that systematic measurement of whole body vibration correlated with information such as the activity being undertaken has potential to assist in the identification of appropriate control measures.

ABSTRACT

Exposure to whole body vibration (WBV) is a hazard for operators of earth-moving equipment. ISO2631.1 “Evaluation of human exposure to whole-body vibration. Part 1 - General Requirements” is referred to within guidance provided to obligation holders such as mine operators and equipment manufacturers. Measurements gathered from dozers in operation at a surface coal mine are examined to both gain insight into the vibration to which operators of this plant are exposed, and to illustrate issues related to the application of ISO 2631.1.

Twenty-six measurements were gathered from ten dozers undertaking a range of activities at a surface coal mine. Unlike most equipment types, the WBV exposure associated with dozers is characterised by vibration in the fore-aft (X) direction which is frequently greater than that measured in the vertical direction (Z). If Z direction vibration expressed as r.m.s. only is considered, the vibration exposure of the dozer operators lies within or below the “Health Guidance Caution Zone” (HGCZ) proposed by ISO2631.1 for an 8 hour exposure to the 26 situations measured. A similar conclusion would be drawn from consideration of the X direction acceleration values. However, if X direction accelerations are multiplied by 1.4 as suggested by ISO2631.1, half of the measurements exceed the HGCZ. If the accelerations in different directions are combined into a Vibration Total Value as defined in ISO2631.1, all except four of the measurements exceeded the HGCZ.

ISO2631.1 is ambiguous regarding which measures should be utilised and its application is problematic. Task-dependent variability in vibration measurements was noted. The implication for equipment manufacturers is that measurements must be taken in the range of realistic operating conditions. The implication for mine operators is that systematic measurement of whole body vibration correlated with information such as the activity being undertaken has potential to assist in the identification of appropriate control measures.
Australian Standard AS2670.1-2001 duplicates ISO2631.1-1997 “Evaluation of human exposure to whole-body vibration. Part 1 - General Requirements” (International Standards Organisation, 1997). While ISO 2631.1 defines methods for the quantification of whole body vibration, as explicitly noted in the introduction, it “does not contain vibration exposure limits”. Guidance is provided in clauses 7, 8, and 9, and confusingly, additional guidance is located in “informative” annexes B, C & D regarding the evaluation of possible effects of vibration on health, comfort and perception, and motion sickness, respectively.

The application of the guidance is not straightforward. Several ambiguities and anomalies have been noted in the application of ISO2631 to the evaluation of WBV. For example, Griffin (2004) noted ambiguity regarding the axes to be evaluated for the evaluation of health effects. Griffin (ibid) also noted the anomalous use of a multiplying factor of 1.4 for X and Y-axes when guidance is provided regarding the evaluation of health effects of WBV, but not for the evaluation of the effects of WBV on comfort. For these, and other reasons, obligation holders may encounter difficulties in the use of ISO2631.1.

ISO 2631.1
ISO 2631.1 begins by defining symbols and coordinate systems and nominates acceleration as the primary quantity by which vibration is to be expressed. Instructions are then provided regarding: direction of measurements; the locations for measurements; signal conditioning; and duration of measurements (i.e., “sufficient to ensure reasonable statistic precision and to ensure that the vibration is typical of the exposures which are being assessed” p. 5).

Frequency weightings to be applied to the accelerations measured for the evaluation of health effects in the seated position are provided i.e., \(W_k\) for the Z direction (approximately vertically through the seated operator), and \(W_k\) for the X (forward-backward) and Y (lateral) direction. The peak weighting for the X & Y directions is in the vicinity of 1/2 to 1/4 Hz, decreasing to a minimum weight at 4 Hz. A broader spectrum of frequencies is weighted more highly for the Z direction, with weighting given to frequencies between 1/2 and about 60 Hz, and the maximum weighting of frequencies between 4 and 10 Hz.

ISO 2631.1 clause 6.1 defines the “basic evaluation method” as the calculation of the frequency weighted root-mean-square (r.m.s.) acceleration (ISO 2631.1 equation 1, units m/s^2). ISO 2631.1 clause 6.2 defines a “crest factor” as the ratio of the maximum instantaneous peak value of the frequency-weighted acceleration signal to its r.m.s. value over the period of measurement. It is suggested that if the crest factor is below or equal to 9, then the r.m.s. acceleration values are “normally sufficient” measures of severity for the evaluation of human vibration effects.

Two additional measures of vibration amplitude are described in ISO 2631.1 clause 6.3. These additional measures are suggested for use when high crest factors, or the presence of occasional shocks, mean the basic evaluation method may underestimate vibration effects. The running r.m.s. method defined in ISO2631.1 equation 2 provides a maximum transient vibration value (MTVV) (units = m/s^2) which is sensitive to occasional shocks. The second alternative described in clause 6.3 is the fourth power vibration dose method which uses the fourth power of the acceleration time history and provides a vibration dose value (VDV, units m/s^{1.75}) which is sensitive to acceleration peaks.

In addition to the “crest factor” criterion for the use of alternative methods, ISO 2631.1 clause 6.3.3 suggests two additional thresholds for the use of alternative methods for evaluating health or comfort effects of vibration. MTVV is suggested for use if the ratio of the MTVV value to the r.m.s. value exceeds 1.5; VDV is suggested when the ratio of the VDV to the product of the r.m.s. value and the fourth root of the time period of the measurement exceeds 1.75.

A vibration total value (VTV) is defined in clause 6.5 which provides a value of the combined X, Y & Z r.m.s. accelerations (being the square root of the sum of the squared accelerations - weighted by subsequently defined multiplying factors \(k_x\), \(k_y\) and \(k_z\)). ISO 2631.1 clause 6.5 suggests that the use of the VTV is recommended for assessing comfort, and a note further suggests that VTV has “been proposed for evaluation with respect to health and safety if no dominant axis of vibration exists” (p. 13).
Clause 7 provides guidance regarding the evaluation of health effects. It is proposed that: the frequency weighted r.m.s. shall be determined for each axis (clause 7.2.1); the assessment shall be made independently for each axis, and that the assessment shall be made considering the highest frequency-weighted acceleration determined in any axis (clause 7.2.2); although it is noted the "vector sum" (i.e., VTV) is "sometimes used to estimate health risk" when vibration in two or more axes is comparable. Clause 7.2.3 states "The frequency weightings shall be applied for seated persons as follows with the multiplying factors indicated", defining the multiplying factors (k) as 1.4 for X and Y-axes, and 1 for acceleration in the Z direction.

Further guidance regarding evaluation of the health effects of whole body vibration are provided in Annex B of ISO2631.1. A note in the introduction of this Annex suggests that the guidance is based on the response of seated human to vibration in the Z direction, and that "there is only limited experience in applying the part of ISO2631 to other directions or postures.

In ISO 2631.1 clause B.3.1, Figure B.1 defines two versions of a "health guidance caution zone" (HGCZ) for weighted r.m.s. accelerations of different durations. The different versions are congruent for durations between 4 and 8 hours. For exposures below the HGCZ, it is suggested that no health effects have been clearly documented. For exposures within the HGCZ “caution with respect to potential health risks is indicated” and for acceleration exposures greater than the HGCZ it is suggested that “health risks are likely”.

Ambiguity exists in that the “multiplying factors” (k) are not referred to, nor included in the equations in Annex B. Indeed the only equation in ISO 2631.1 in which the “multiplying factors” appear explicitly in relation to health effects is in the definition of VTV, and “k” is not defined in clause 4 “Symbols and subscripts”.

While no numerical values are provided by ISO 2631.1 (other than by reference to Figure B.1), the lower and upper bounds of the HGCZ for an 8 hour exposure have been quoted as 0.47 m/s^2 and 0.93 m/s^2 respectively (McPhee et al., 2009).

ISO 2631.1 clause B.3.1 Note 2 suggests that an estimated value for VDV (eVDV) can be inferred from the r.m.s. value (the product of 1.4 times the weighted acceleration and the fourth root of the duration of the measurement) and suggests that eVDV values of 8.5 m/s^1.75 and 17 m/s^1.75 correspond to the upper and lower bounds of the HGCZ respectively.

The final clause of ISO 2631.1 Annex 3 is titled “Method of assessment when the basic evaluation method is not sufficient”. However, the clause provides no more information than earlier sections, merely referring the reader to earlier clauses (6.2.1, 6.3.1, 6.3.2, and 6.3.3). No guidance regarding the evaluation of MTVV with respect to the HGCZ is provided. No indication is provided regarding whether multiplying factors (k) should be applied to X and Y directions for MTVV evaluation.

Indeed, no explicit guidance is provided in ISO 2631.1 regarding the evaluation of VDV, although it has been generally inferred that the values referred to for eVDV in note 2 of clause B.3.1 may be utilised (Paddan & Griffin, 2002). No indication is provided regarding whether multiplying factors (k) should be applied to X & Y directions for VDV evaluation.

**EU DIRECTIVE 2002/44/EC**

The European union directive 2002/44/EC (European Parliament, 2002) sets an exposure action value (EAV), above which it requires employers to control the whole-body vibration risks of their workforce and an exposure limit value (ELV) above which workers must not be exposed. Annex B to the directive provides an interpretation of the application of ISO 2631.1 to measure vibration exposure against these values viz:

The assessment of the level of exposure to vibration is based on the calculation of daily exposure A(8) expressed as equivalent continuous acceleration over an eight-hour period, calculated as the highest (rms) value, or the highest vibration dose value (VDV) of the frequency-weighted accelerations, determined on three orthogonal axes (1,4awx, 1,4awy, awz for a seated or standing worker) in accordance with Chapters 5, 6 and 7, Annex A and Annex B to ISO standard 2631-1(1997).

The r.m.s. and VDV threshold values provided for the EAV and ELV are higher than those implicitly provided in ISO 2631.1 Annex B. EU
Directive 2002/44/EC provides EAV thresholds of 0.5 m/s² (r.m.s.) or 9.1 m/s¹.⁷⁵ (VDV); and ELV thresholds of 1.15 m/s² (r.m.s.) or 21 m/s¹.⁷⁵ (VDV) respectively. The upper ELV values “above which workers must not be exposed” in particular are significantly less protective that the upper HGCZ values implied within ISO2631.1.

The aim of this paper is to evaluate a sample of 26 WBV measurements from dozers in operation at a surface coal mine to both gain insight into the vibration to which operators of this plant is exposed and to illustrate issues related to the application of ISO 2631.1 to such a situation.

METHODO
Twenty-six measurements were gathered over a 6 month period from ten dozers (9 x Caterpillar D11R, 1 x Caterpillar D10) undertaking a range of activities at a surface coal mine (Table 1). The dozers were operated by 18 different drivers. The A triaxial DeltaTron (seat pad) accelerometer was secured with tape to the seat of each dozer to measure vibration at the seat-buttock interface in the fore-aft (X), lateral (Y) and vertical (Z) dimensions. A DeltaTron uniaxial accelerometer was secured with beeswax to the floor adjacent to the seat to simultaneously measure vibration at the floor in the vertical (Z) direction only. Calibration of the accelerometers was conducted prior to each testing session. The measurement durations ranged from 16 min to 70 min.

A Bruel & Kjaer Human Vibration Analyser Type 447 was applied the frequency weightings defined by ISO2631.1 for health effects in the seated position and calculated r.m.s., MTVV and VDV measurements in the X, Y and Z directions for the seat pad accelerometer, and in the vertical direction for the floor accelerometer. VDV does not provide an average measure of acceleration during the time period measured, but rather this measure increases with measurement duration. Consequently the VDV values are expressed as an 8 hour exposure value [VDV(8)] to allow comparison between measurements of different durations.

The ratio of the accelerations in the Z direction measured at the seat to accelerations in the Z direction measured at the floor provides

<table>
<thead>
<tr>
<th>ID</th>
<th>Dozer</th>
<th>Driver</th>
<th>Activity</th>
<th>Time</th>
<th>X RMS (m/s²)</th>
<th>Y RMS (m/s²)</th>
<th>Z RMS (m/s²)</th>
<th>X VDV(8) (m/s¹.⁷⁵)</th>
<th>Y VDV(8) (m/s¹.⁷⁵)</th>
<th>Z VDV(8) (m/s¹.⁷⁵)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>1</td>
<td>Roads, building ramps, soft dirt</td>
<td>16:07</td>
<td>0.482</td>
<td>0.342</td>
<td>0.446</td>
<td>12.5</td>
<td>8.98</td>
<td>13.9</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>2</td>
<td>Building ramps, soft dirt</td>
<td>31:44</td>
<td>0.604</td>
<td>0.452</td>
<td>0.645</td>
<td>13.6</td>
<td>9.61</td>
<td>13.5</td>
</tr>
<tr>
<td>3</td>
<td>A</td>
<td>2</td>
<td>Building ramps, soft dirt</td>
<td>23:14</td>
<td>0.506</td>
<td>0.392</td>
<td>0.744</td>
<td>12.3</td>
<td>7.99</td>
<td>19.1</td>
</tr>
<tr>
<td>4</td>
<td>B</td>
<td>3</td>
<td>Bulk pushing shale</td>
<td>28:35</td>
<td>0.602</td>
<td>0.555</td>
<td>0.581</td>
<td>12.7</td>
<td>11.5</td>
<td>10.9</td>
</tr>
<tr>
<td>5</td>
<td>C</td>
<td>4</td>
<td>Bulk pushing shale</td>
<td>31:57</td>
<td>0.559</td>
<td>0.548</td>
<td>0.557</td>
<td>12.0</td>
<td>11.8</td>
<td>10.9</td>
</tr>
<tr>
<td>6</td>
<td>C</td>
<td>3</td>
<td>Bulk pushing shale</td>
<td>38:47</td>
<td>0.549</td>
<td>0.526</td>
<td>0.671</td>
<td>12.6</td>
<td>11.9</td>
<td>12.3</td>
</tr>
<tr>
<td>7</td>
<td>D</td>
<td>5</td>
<td>Dragline dozer, including ripping</td>
<td>32:47</td>
<td>0.821</td>
<td>0.710</td>
<td>0.684</td>
<td>16.8</td>
<td>14.2</td>
<td>13.2</td>
</tr>
<tr>
<td>8</td>
<td>E</td>
<td>6</td>
<td>Pushing, building ramps, spoil</td>
<td>31:53</td>
<td>0.588</td>
<td>0.435</td>
<td>0.416</td>
<td>13.1</td>
<td>9.13</td>
<td>7.84</td>
</tr>
<tr>
<td>9</td>
<td>C</td>
<td>7</td>
<td>Pushing, building ramps, spoil</td>
<td>20:25</td>
<td>0.524</td>
<td>0.431</td>
<td>0.503</td>
<td>12.4</td>
<td>8.78</td>
<td>9.18</td>
</tr>
<tr>
<td>10</td>
<td>B</td>
<td>8</td>
<td>Pushing, building ramps, spoil</td>
<td>21:08</td>
<td>0.519</td>
<td>0.371</td>
<td>0.374</td>
<td>12.1</td>
<td>7.50</td>
<td>7.63</td>
</tr>
<tr>
<td>11</td>
<td>F</td>
<td>9</td>
<td>Pushing, building ramps, spoil</td>
<td>22:46</td>
<td>0.476</td>
<td>0.349</td>
<td>0.772</td>
<td>11.4</td>
<td>7.41</td>
<td>14.9</td>
</tr>
<tr>
<td>12</td>
<td>G</td>
<td>10</td>
<td>Drill benching</td>
<td>29:05</td>
<td>0.624</td>
<td>0.569</td>
<td>0.513</td>
<td>13.8</td>
<td>14.21</td>
<td>9.88</td>
</tr>
<tr>
<td>13</td>
<td>B</td>
<td>11</td>
<td>Pushing</td>
<td>24:03</td>
<td>0.861</td>
<td>0.771</td>
<td>0.684</td>
<td>17.4</td>
<td>16.4</td>
<td>13.5</td>
</tr>
<tr>
<td>14</td>
<td>D</td>
<td>12</td>
<td>Cutting highwall, pushing to rill</td>
<td>32:49</td>
<td>0.705</td>
<td>0.610</td>
<td>0.527</td>
<td>14.8</td>
<td>12.2</td>
<td>12.5</td>
</tr>
<tr>
<td>15</td>
<td>G</td>
<td>13</td>
<td>Ripping, benching</td>
<td>22:20</td>
<td>0.566</td>
<td>0.506</td>
<td>0.492</td>
<td>12.3</td>
<td>10.9</td>
<td>9.06</td>
</tr>
<tr>
<td>16</td>
<td>H</td>
<td>14</td>
<td>Pushing, cleaning floor</td>
<td>27:46</td>
<td>0.876</td>
<td>0.802</td>
<td>0.672</td>
<td>17.6</td>
<td>16.5</td>
<td>13.0</td>
</tr>
<tr>
<td>17</td>
<td>D</td>
<td>12</td>
<td>Pushing, cutting the key</td>
<td>60:18</td>
<td>0.704</td>
<td>0.584</td>
<td>0.504</td>
<td>15.1</td>
<td>12.0</td>
<td>9.36</td>
</tr>
<tr>
<td>18</td>
<td>A</td>
<td>1</td>
<td>Pushing</td>
<td>27:08</td>
<td>0.708</td>
<td>0.608</td>
<td>0.541</td>
<td>14.9</td>
<td>12.9</td>
<td>10.3</td>
</tr>
<tr>
<td>19</td>
<td>I</td>
<td>15</td>
<td>Pushing and ripping, digger clean up</td>
<td>46:12</td>
<td>0.781</td>
<td>0.698</td>
<td>0.823</td>
<td>15.7</td>
<td>14.3</td>
<td>16.1</td>
</tr>
<tr>
<td>20</td>
<td>A</td>
<td>16</td>
<td>Pushing</td>
<td>25:39</td>
<td>0.754</td>
<td>0.588</td>
<td>0.545</td>
<td>15.9</td>
<td>12.1</td>
<td>10.4</td>
</tr>
<tr>
<td>21</td>
<td>J</td>
<td>11</td>
<td>Pushing - some ripping</td>
<td>30:18</td>
<td>0.931</td>
<td>0.826</td>
<td>0.714</td>
<td>18.5</td>
<td>16.4</td>
<td>12.5</td>
</tr>
<tr>
<td>22</td>
<td>A</td>
<td>1</td>
<td>Pushing - no ripping</td>
<td>28:09</td>
<td>0.773</td>
<td>0.677</td>
<td>0.521</td>
<td>16.6</td>
<td>14.3</td>
<td>9.40</td>
</tr>
<tr>
<td>23</td>
<td>C</td>
<td>4</td>
<td>Rippling and at an angle</td>
<td>32:06</td>
<td>0.680</td>
<td>0.673</td>
<td>0.495</td>
<td>14.3</td>
<td>14.5</td>
<td>10.1</td>
</tr>
<tr>
<td>24</td>
<td>D</td>
<td>17</td>
<td>Cutting highwall, clean dragline pad</td>
<td>70:15</td>
<td>0.729</td>
<td>0.586</td>
<td>0.583</td>
<td>16.6</td>
<td>13.4</td>
<td>12.2</td>
</tr>
<tr>
<td>25</td>
<td>J</td>
<td>18</td>
<td>Ripping and pushing</td>
<td>23:00</td>
<td>0.748</td>
<td>0.720</td>
<td>0.720</td>
<td>15.8</td>
<td>17.2</td>
<td>13.4</td>
</tr>
<tr>
<td>26</td>
<td>G</td>
<td>13</td>
<td>Ripping</td>
<td>23:44</td>
<td>0.626</td>
<td>0.596</td>
<td>0.574</td>
<td>14.6</td>
<td>14.9</td>
<td>11.4</td>
</tr>
</tbody>
</table>
an indication of the effectiveness of the seat in attenuating vibration. Measurement of this Seat Effective Amplitude Transmissibility (SEAT) value was undertaken for both r.m.s. and VDV measures of acceleration.

RESULTS & DISCUSSION

Basic evaluation method

Figure 1 presents the distributions of the basic evaluation method (r.m.s.) for the 26 measurements. The HGCZ for an eight hour exposure as defined in ISO 2631.1 Annex B is indicated. The Z direction r.m.s. acceleration values at the seat were considerable less than the r.m.s. values measured at the floor, and r.m.s. SEAT values ranged from 0.42 to 0.88. The majority of Z direction r.m.s. acceleration values lay within the eight hour HGCZ, with only 3 of 26 measurements falling below the zone. Based on these Z direction measurements “caution with respect to potential health risks is indicated” for 8 hour exposures. For 21 of the tests, however, the highest r.m.s. values were in the X (forward-backward) direction. When these values were multiplied by 1.4 as required by ISO 2631.1 clause 7.2.3, half of the measurements exceeded the eight hour HGCZ.

Given the relatively similar magnitudes of r.m.s. values for X, Y and Z directions illustrated in Figure 1, it might well be considered that “no dominant axis of vibration” was evident and consequently, as noted in clause 6.5 of ISO 2631.1, the combined accelerations in all directions (VTV) “has been proposed” for the evaluation of health effects. When the VTV was calculated as defined in clause 6.5, all but four of the 26 measurements of dozer operators exceeded the eight hour HGCZ. According to this measure it would be inferred that “health risks are likely” for eight hour exposures in these situations. The ambiguity in whether VTV should be used for the evaluation of health effects is consequently problematic.

Criteria for considering alternative measures

Crest factors for the Z direction calculated ranged from 6.2 to 35.4 (median = 11.5), and 19 of the 26 measurements were greater than 9 (the cut-off suggested by ISO 2631.1 as indicating alternative measures of vibration measurement should be considered).

The crest factor is sensitive to the duration of measurement, in that the longer the measurement duration, the greater the probability of a higher peak value, and consequently its validity as a criterion for the use of alternative measures might be questioned.

The ratio of MTVV to r.m.s. for the Z direction ranged from 2.4 to 5.9 (median = 3.0), and all measurements in all directions exceeded the threshold of 1.5 nominated as the criteria for use of MTVV. The use of this criterion would suggest that MTVV should be utilised in the evaluation of the dozer measurements, although as noted earlier, no guidance is provided regarding how these values should be evaluated.

In contrast, only 3 of the 26 measurements exceeded the VDV threshold criteria of the ratio of the VDV to the product of the r.m.s. value and the fourth root of the time period of the measurement in the Z direction (measurements 1, 3 & 14). Use of this criterion would suggest that the basic evaluation method was sufficient for all other measurements.
Alternate methods
Figure 2 describes the distributions of MTVV calculated as described in ISO2631.1 equation 2. Again the greatest values for the dozer accelerations are consistently in the fore-aft direction. As noted above, interpretation of these data is difficult because no guidance is provided within ISO 2631.1 regarding the evaluation of MTVV values. It is clear than measurement 3 provided an exceptionally high MTVV value in the Z direction, and might logically be highlighted for further investigation. However, in the absence of evaluation criteria, the utility of the MTVV measure is limited to providing an alternative means of describing different measurements.

Figure 3 describes the distributions of VDV [expressed as 8 hour equivalent VDV (8)] for the floor accelerometer and the three dimensions at the seat. The VDV(8) values are consistent with r.m.s. values in that the X-axis was the greatest value in the majority of trials. Almost all VDV(8) values (without the application of the k multiplier to X and Y directions) were within the HGCZ. If the X and Y directions are increased by 40% (k = 1.4), all except four measurements lie beyond the HGCZ. ISO 2631.1 does not make it clear whether this is an appropriate procedure, however.

As for the r.m.s. values, VDV values at the floor are far greater than those in the Z direction experienced by the dozer operator at the seat.

Utility of ISO 2631.1
While ISO 2631.1 provides a method for describing whole body vibration, given the explicit introductory statement that the standard “does not contain vibration exposure limits”, the ambiguities and anomalies noted by Griffin (2004) and illustrated here, and the caveats contained within the standard (particularly that related to the acknowledged lack of evidence for the evaluation of vibration in the X & Y directions) it is difficult to know how to utilise the standard most appropriately.

The Z-axis is the dominant vibration axis for most equipment types. For example, Cann et al (2003) tested 14 different types of construction equipment and reported that the Z-axis was dominant for all except dozers, excavators, crawler loaders and compactors (where, as here, the X-axis dominated). Where the Z direction is dominant, consideration of the r.m.s. and VDV(8) values is relatively straightforward. In the absence of evidence suggesting otherwise, it seems prudent to utilise the more conservative HGCZ zone values rather than those provided by the EU regulation. Even where the Z-axis is not dominant, it seems prudent to evaluate these values given the potential implication in the development of back pain, in addition to considering the X or Y-axes.

Consideration of vibration in X and Y-axes is complicated by the anomalous “k” factor

The VDV SEAT values ranged from 0.16 to 0.86 quantifying the effectiveness of the seat in attenuating accelerations in the Z direction.

Figure 4 (A-C) illustrates the relationship between VDV(8) and r.m.s. measurements for the X, Y and Z directions. The HGCZ for 8 hour exposures to both r.m.s. and VDV are indicated. Measurements which lie in the shaded regions are those for which there was agreement between evaluation methods. A generally high correspondence was evident, the exceptions being measurements 1 and 3, for which an evaluation of the VDV measure in the Z direction suggests a higher risk than r.m.s. This is consistent with the VDV criterion for the use of alternative methods which highlighted these trials (and one other) as trials for which the basic evaluation method may in insufficient.
introduced by ISO2631.1. No rationale for the inclusion of the multiplier is provided, nor any explanation why lateral vibration is weighted more highly when evaluating VTV for health effects rather than comfort. Indeed, evidence exists which suggests that lateral vibrations are reported to be significantly less comfortable than vertical vibrations (Dickey et al., 2002; Griefahn et al., 1999) suggesting that, if anything, the weighting for X & Y directions should be greater for evaluating comfort.

Influence of task
Six of the 26 measurements, including trials 1 and 3, were taken from one Dozer (A). Figure 5 illustrates the range of acceleration magnitudes measured [VDV(8) measurement range from 19.4 to 19 m/s\(^1.75\)]. The highest VDV values were measured whilst the dozer was engaged in “building ramps”, while the lower three measurements were associated with “pushing” tasks. Differences in operator technique may also influence vibration amplitudes. Investigation of the situations in which the highest vibration levels were measured may reveal opportunities for reducing the vibration exposure of operators.

These data highlight the important observation that, as well as vehicle design aspects such as suspension and seating, the vibration amplitudes to which earth moving operators are exposed are also a function of a range of other factors such as roadway conditions and vehicle speed and, perhaps particularly in the case of dozers, the operations being performed. The implication for designers, manufacturers, importers and suppliers of plant aiming to meet their obligations to ensure that appropriate evaluations are conducted is that vibration assessments must be conducted while the equipment is performing the range of tasks and operations for which the equipment might reasonably be anticipated to be used; and under the range of conditions which might reasonably be anticipated to be encountered.

The implication for persons conducting a business or obligation holders in control of a workplace where earth moving equipment is used is that short duration measurements taken at irregular intervals are unlikely to provide a reliable indication of the magnitudes of vibrations to which earth moving equipment operators are exposed, and consequently not provide the information required by employers to meet their obligations to, so far as is reasonably practicable, eliminate or minimise risks to health and safety. More systematic measurements at frequent intervals, correlated
with other information such as the activities being undertaken and detailed assessment of other risk factors such as posture, has potential to assist in the identification of appropriate control measures - be they improving shot firing standards; more frequent maintenance of suspension, seating, or roadways; changes to cab design or seating; operator training; or more effective controls such as remote operation or automation.

CONCLUSION
ISO2631.1 is ambiguous and anomalous in a number of respects and its application is consequently problematic. Task-dependent variability in vibration measurements was noted. The implication for equipment manufacturers is that measurements must be taken in the range of realistic operating conditions in order to accurately characterise vibration exposure for design purposes. The implication for mine operators is that systematic measurement of whole body vibration correlated with information such as the activity being undertaken has potential to assist in the identification of appropriate control measures.

ACKNOWLEDGEMENT
Permission from Anglo American Callide mine to publish these data is gratefully acknowledged. The data were collected by Kate Maslen.

REFERENCES


A Brief Review of Fluid Power System Safety in Australia

JEFF MARLEY

ABSTRACT
In Australia there is a significant and increasing reliance on pressurised (pneumatic and in particular hydraulic) fluid as an energy transfer medium. While there has been some discussion of the fatalities associated with fluid power, little attention has been paid to the incidence and pattern of injuries and incidents associated with interaction with these systems. The majority of the statutory authorities in Australia have responded only superficially to specific risks posed by this technology across all industry sectors. While high pressure fluid power installations in Australia are subject to few mandatory engineering standards and prescriptive training requirements, they continue to be widely employed across all industry sectors. Efforts are needed to further reduce the workplace risk associated with fluid power systems including the development of effective all-industry sector safety guidelines and training regimes in order to reduce the incidence of fatalities, injuries and incidents associated with this technology.

INTRODUCTION
Electrical and fluid (hydraulic and to a lesser extent pneumatic) energy sources and internal combustion engines are the primary sources used to provide motive power to Australian industry. The national electricity grid relies on coal-fired power stations using high pressure and temperature steam for electricity generation. Electricity derived from the national grid or from diesel generators and fluid power from electrical/diesel powered pumps are used extensively to provide usable power to an extensive range of plant and equipment in the manufacturing, construction, agriculture, resource extraction (mining) and transport sectors.

Working in the proximity of the various fluid power systems involves exposure to risk (Tichon & Burgess-Limerick, 2011; Thomas & Buckmaster, 2003). It is the risk that is directly associated with the installation, use and maintenance of fluid power systems that is the primary topic of this paper.

In the construction, manufacturing, agriculture, mining and transport sectors, operations and maintenance personnel can come in contact with fluid under pressure in a range of applications including: hydraulic control systems installed in a range of fixed plant including production lines; conveyors and long-wall mining systems; fuel injection, hydraulic braking and hydraulic control systems installed in mobile plant including excavators, cranes, front-end loaders, tractors, haul trucks, drilling, roof & rib-bolting machinery, continuous miners, loaders, shuttle cars; and miscellaneous applications such as high pressure steam-lines, grease-lines, grease guns and spray painting equipment, etc.

As Australia continues to ride the wave of the resources and to a lesser extent the construction and manufacturing boom there will be an increasing prevalence of fluid power integrated into the range of fixed and mobile plant across all industry sectors. This will, without the application
of appropriate safe systems of work, increase the exposure of operations and maintenance personnel to risk associated with these systems. The importation of second hand plant from overseas or from within Australia, undertaken to minimise capital costs and reduce delivery delays can also result in an increase in the level of risk associated with the installation, use and maintenance of such plant.

FATALITIES, INJURIES AND ‘INCIDENTS’ ASSOCIATED WITH FLUID POWER SYSTEMS  
OPERATION AND MAINTENANCE

Significant numbers of fatalities and injuries have been associated with mechanics, heavy equipment operators and those who work with or along side high pressure fluid systems (NOHSC, 2000; NSW Department of Primary Industries Mine Safety Reports; Queensland Government Mines Inspectorate Safety Bulletins).

These have included; the death of an operator who interacted with high pressure hydraulic fluid escaping as a result of a hose ‘staple’ failure while taking fluid samples on long-wall mine equipment (NSW Department of Primary Industries, 2006); the death of a maintenance engineer who was working on a long-wall shield cylinder that was under ‘hydraulic intensification’ when they pushed on a leg in an attempt to position a restraining pin causing high pressure hydraulic fluid to escape (NSW Department of Primary Industries, 1994); the death of an operator as a result of the release of high pressure hydraulic following the failure of a fitting on the accumulator start circuit of diesel engine (NSW Department of Primary Industries, 2007); and the death of a field service mechanic during testing of a diesel engine, when diesel oil under pressure was injected through his eye (US Mine Safety & Health Administration, 2008).

Fatalities have also resulted from fire that has been fueled by a sudden release of hydraulic fluid in the presence of a source of ignition (SafeWork South Australia, 2012; WorkCover Authority of NSW -v- Shortland Electricity 1995; US Occupational Safety & Health Administration, 1991; US Mine Safety & Health Administration, 2004); and being struck by a solid object propelled by hydraulic kinetic energy (WA Department of Mines & Petroleum, 2008).


In 2011 the NSW Government undertook a review of “escape of fluid” incidents, reportable under the NSW Coal Mine Health & Safety Regulation 2006 (NSW Department of Industry & Investment, 2011). This review documented 1,186 “escape of fluid” incidents reported between 2007 and 2010. In this 4 year period 152 people were exposed to near misses or injury across 42 (of a total of 86) NSW Coal mines. Referring to Table 1 below, 5 of those 152 persons sustained fluid injection injuries, representing 3.3% of all persons reporting such incidents, a proportion that is twice as high as the incident rate predicted by Bird’s widely recognised ‘Accident Ratio’ of 10 minor injuries for each 600 incident occurrences (Bird, 1979). Against the background of a generally accepted conservative reporting rate for all work sectors, the implication is that the use of fluid power in the mining sector is associated with significant and uncontrolled risk.
The range of reportable “escape of fluid” incidents associated with long-wall mining operations in NSW is especially significant. Eight (8) years of “escape of fluid” incidents or injury data associated with long-wall operations (to 2007) was analysed (NSW Department of Industry & Investment, 2007) and is represented in the following Table 2:

<table>
<thead>
<tr>
<th>Incidents</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-wall face</td>
<td>618</td>
<td>52%</td>
</tr>
<tr>
<td>Development units</td>
<td>387</td>
<td>33%</td>
</tr>
<tr>
<td>Outbye</td>
<td>151</td>
<td>13%</td>
</tr>
<tr>
<td>Surface</td>
<td>18</td>
<td>1.5%</td>
</tr>
<tr>
<td>Open cut</td>
<td>12</td>
<td>1%</td>
</tr>
<tr>
<td>Total</td>
<td>1,186</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 2: Mechanisms of NSW Long-wall ‘Escape of fluid’ incidents. (NSW Department of Industry & Investment, 2007).

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hose failures</td>
<td>105</td>
<td>41%</td>
</tr>
<tr>
<td>Unsafe isolation</td>
<td>50</td>
<td>20%</td>
</tr>
<tr>
<td>Fitting failures</td>
<td>41</td>
<td>16%</td>
</tr>
<tr>
<td>Unplanned movement</td>
<td>23</td>
<td>9%</td>
</tr>
<tr>
<td>Other incidents</td>
<td>23</td>
<td>9%</td>
</tr>
<tr>
<td>Either hose or fitting failures</td>
<td>13</td>
<td>5%</td>
</tr>
<tr>
<td>Total</td>
<td>255</td>
<td>100%</td>
</tr>
</tbody>
</table>

Of the tabulated total of 255 incidents, 42% (107) near misses or injury involved maintenance operators working on pressurised fluid systems and 58% (148) near misses or injury involved “bystanders”. Critically, the most number of incidents are associated with hose failures, followed by unsafe isolation practices then failure of plant fittings.

While these and the remaining mechanisms may seem initially disparate, analysis of the various statutory investigating authorities’ findings suggests there are commonalities. Regardless of whether it concerned a fatality, injury or ‘incident’, it can be seen that in almost every case, a significant latent condition identified as contributing to these incidents was the underpinning failure to apply effective risk management and training regimes.

Many of these incidents, injuries and fatalities are associated with the resource (mining) sector. However there is widespread anecdotal evidence that significant numbers of similar incidents associated with fluid power systems occur in other sectors where the reporting of near misses, while mandated by statutory prescription, are not as rigorously enforced as in the mining sector.

HAZARDS ASSOCIATED WITH FLUID POWER SYSTEMS

Under normal operation fluid power systems are ‘closed’ systems, therefore exposure to escaping pressurised fluid is usually a result of a system or component failure (Thomas et al, 2003). The incidence of fatalities and injuries associated with the use of fluid power systems especially documented within the Australian resource extraction (mining) sector has led to the development of Mine Design Guideline (MDG) 41 ‘Guideline for Fluid Power System Safety at Mines’ (NSW Department of Industry & Investment, 2010).

This guideline, based in part upon provisions in the Australian Standard AS 2671 (Standards Australia, 2002) has been recommended for use by statutory authorities in NSW and Queensland as a standard to be achieved at mining operations (NSW Department of Industry & Investment, 2010; Queensland Department of Mines & Energy, 2001, 2011).

The stated aim of the MDG-41 guideline is to ‘assist in formulating a management system approach for the safe use of fluid power systems in mines, …[to provide] a good industry benchmark for engineering standards and fit for purpose equipment…[and to be considered as] good industry practice for mitigating and controlling the risks associated with the use of fluid power systems in mines at this time’ (NSW Department of Industry & Investment, 2010 p i).

HIGH RISK FLUID POWER SYSTEMS

MDG-41 defines ‘High risk’ work on fluid power systems to include that undertaken ‘where fluid pressure exceeds 5MPa or the pressurised fluid exceeds 60°C in temperature and where a hose, fitting, adaptor or connection could break, burst or fail and expose people in the vicinity of the area to the pressurised and/or hot fluid’.

Referring to MDG-41 Section 2.3.1 (NSW
Department of Primary Industries, 2010) in the context of the fatalities, injuries and incidents highlighted above, the range of hazards involving pressurised fluid that persons can be exposed to include: failure of pressurised system components resulting in contact with whipping hoses, air borne shrapnel and unplanned mechanical movement of equipment such as actuators, motors, pumps, steering or brakes, etc; uncontrolled release of pressurised fluid resulting in catastrophic destruction of and/or fluid injection into, skin & tissues; uncontrolled release of hazardous or toxic fluids and/or vapours leading to chemical burns, inhalation of toxic vapours, skin irritation and the onset of diseases such as dermatitis, etc; uncontrolled release of heated fluid or steam resulting in thermal burns; fires and/or explosions through contact of escaping ‘atomised’ spray / mist with hot surfaces, etc; and failure of protection controls resulting in electric shock or static electric discharge initiated fire or explosion.

**HIGHER SYSTEM PRESSURE LEADS TO MORE SIGNIFICANT INJURIES**

As with electrical energy where, if direct contact is made with a critical level of primary energy, there is a potential for personnel to suffer injury or death.

Table 3 below provides a comparison of typical gauge pressures in various commonplace, construction and resource sector pressurised systems in context with skin injection thresholds. It should be noted that the threshold potential for fluid injection injuries associated with normal (undamaged) skin is 750 psi (5,200 Kpa or 52 Bar) and with pre-existing compromised skin (cuts and lesions still healing from previous injury) is 600 psi (4,100 Kpa or 41 Bar).

It can be seen from the table 3 that closed fluid power systems on haul trucks, excavators, long-wall systems, steam reticulation systems, air greasers and diesel engine injectors contain significantly increased pressures when

<table>
<thead>
<tr>
<th>Pressurised System</th>
<th>psi</th>
<th>kPa</th>
<th>Bar</th>
</tr>
</thead>
<tbody>
<tr>
<td>General air pressure (sea level)</td>
<td>14.5</td>
<td>100</td>
<td>1.0</td>
</tr>
<tr>
<td>Automobile pneumatic tyre</td>
<td>32</td>
<td>220</td>
<td>2.2</td>
</tr>
<tr>
<td>Bicycle pneumatic tire</td>
<td>65</td>
<td>450</td>
<td>4.5</td>
</tr>
<tr>
<td>Workshop (compressed air) pneumatic tools</td>
<td>90</td>
<td>620</td>
<td>6.2</td>
</tr>
<tr>
<td>Drill rig (compressed air) pneumatic power</td>
<td>250</td>
<td>1720</td>
<td>17.2</td>
</tr>
<tr>
<td>Threshold potential for fluid injection injuries associated with pre-existing compromised skin (cuts and lesions still healing from previous injury)</td>
<td>600</td>
<td>4100</td>
<td>41</td>
</tr>
<tr>
<td>Threshold potential for fluid injection injuries associated with normal (undamaged) skin. Threshold pressure for MDG-41 ‘High Risk’ Fluid Power System</td>
<td>750</td>
<td>5200</td>
<td>52</td>
</tr>
<tr>
<td>Haul truck disc brake hydraulic pressure / crawler track drive</td>
<td>2500</td>
<td>17200</td>
<td>172</td>
</tr>
<tr>
<td>9020 Dragline Dump Block Assembly / Excavator/wheel loader bucket</td>
<td>4000</td>
<td>27500</td>
<td>275</td>
</tr>
<tr>
<td>Long wall – hydraulic pressure</td>
<td>5000</td>
<td>35000</td>
<td>350</td>
</tr>
<tr>
<td>Hydraulic tools / torque wrench / hydraulic pump</td>
<td>9400</td>
<td>64800</td>
<td>648</td>
</tr>
<tr>
<td>Air greaser (‘Grease Gun’) pressure</td>
<td>10100</td>
<td>70000</td>
<td>700</td>
</tr>
<tr>
<td>Diesel engine injector systems</td>
<td>12000</td>
<td>82740</td>
<td>827.4</td>
</tr>
<tr>
<td>Low power water- jet cutter</td>
<td>40000</td>
<td>276000</td>
<td>2760</td>
</tr>
<tr>
<td>Underground mine roof jack</td>
<td>50000</td>
<td>344000</td>
<td>3440</td>
</tr>
</tbody>
</table>

i. Mrvos, Dean & Krenzelok, 1987. Other studies have suggested that the compromised skin injection threshold could be as low as 100psi (Hart, Smith & Haq, 2006; Neal & Burke, 1999; Scott, 1983).
iii. Pressure stated represents abnormal operating pressure (‘Pressure Intensification’) potentially associated with this type of equipment.
considered in context with threshold (skin) fluid injection pressures. These higher system pressures relate to increased consequence (and hence risk) upon system failure and it is important to note that many of these items of plant can also be found across other working sectors outside of the mineral resources (mining) sector.

‘Pin-hole’ leaks are a common occurrence in fluid power systems. Fluid (‘jets’) escaping under pressure from a ‘pin- hole’ can reach velocities in excess of 660 Kph from a 3000 psi pressurised hose (Vasilevski, Noorbergen, Depierreux & Lafontaine, 2000; Neal & Burke, 1999) and with increased pressure, pin hole jet velocities up to 2500 Kph have been documented (Smith, 2005). Such pin-hole leaks contacting unprotected flesh will result in knife-like incisions in skin, tissue and bone and injection of pressurised fluids through the skin potentially leading to extensive penetration into underlying tissues and blood stream.

On the continuum of physical injuries, a ‘pin-hole’ leak of 1000psi from a hydraulic hose is sufficient to result in a minor injury (NSW Department of Primary Industries, 1998, 2000, 2004) while a higher pressure stream (~3000 - 50,000 psi) can result in massive organ damage and even instantaneous death (NSW Department of Primary Industries, 1994, 2006, 2006; NOHSC, 2000).

A possible consequence of a seemingly minor incident of fluid injection from a hose ‘pin hole’ leak, is limb amputation, especially if the fluid injection injury is not appropriately treated in a timely fashion. Prolonged internal contaminant contact can result in necrosis of underlying tissue (Hart, Smith & Haq, 2006; Smith, 2005; Thomas & Buckmaster, 2003;Vasilevski, Noorbergen, Depierreux & Lafontaine, 2000; Neal & Burke, 1999; Lewis, Clarke, Kneafsey & Brennen, 1998; Mrvos, Dean & Krenzelok, 1987; Ramos, Posch & Lie, 1970; Kaufman, 1970). Some areas of the body such as the eyes are more susceptible than others to damage from high pressure fluid (NSW Department of Primary Industries, 2004, 2004; Mrvos, Dean & Krenzelok, 1987). Other factors contributing to the severity of injury include the volume, viscosity, toxicity and temperature of the injected fluid (Smith, 2005).

Additionally, under conditions of low light or dusty atmospheres, fluid escaping from such a ‘pin hole’ may not be easily seen – compounding efforts directed at controlling the risk associated with this hazard. The occurrence of pin holes are not limited to the ‘in service’ failure of hose, hose fittings or components containing pressure can also be a result of poor installation or testing practices.

**FLUID POWER SYSTEM USE IN CONSTRUCTION, MANUFACTURING, AGRICULTURE AND TRANSPORT**

Fixed and mobile plant using fluid power is used in the construction sector. Fluid power systems are an integral part of a wide range of construction plant including conveyors, earth moving machinery, excavators, front-end loaders, under-road borers, asphalt milling and pavers, drilling platforms, cranes, road registered haul / dump trucks and pressurised fluid powered ‘hand’ tools etc. Also plant is installed in facilities being constructed, including pre-operational manufacturing and mine facilities and commercial infrastructure.

Fluid power is also used in the manufacturing sector in a wide range of fixed and mobile plant including conveyors, power (stamping) presses, power shears, high pressure grease pipe line and guns, industrial (forklift) trucks and material hoists etc. Pressurised steam lines are also used in manufacturing facilities associated with the production of alcoholic beverages and processed and packaged foods.

Fluid power in the agricultural sector is used in mainly mobile plant including tractors (including independent hydraulic attachments), front-end loaders, grain harvesters, cotton ginning machinery and a small amount of fixed plant such as conveyors, etc. Fluid power in the transport sector is used within commercial freighters / cargo ships, port unloading facilities such as container handling cranes, industrial lift trucks, conveyors and unloading facilities,
freight trains and road registered trucks including semi-trailers and B-doubles, etc.

SAFETY GUIDELINES
As discussed previously, many of the fluid power associated incidents, injuries and fatalities involve equipment failures, unsafe work & isolation/energy dissipation practices, underpinned by the failure to implement a safe, effective and proactive fluid power operation and maintenance management and training system. As an initial step towards addressing this, safety guidelines need to be developed and disseminated within all manufacturing, construction, agriculture and transport sectors employing high pressure fluid power systems. While the MDG-41 guideline (NSW Department of Primary Industries, 2010) was originally designed to address issues associated with fluid power in the resources (mining) sector (An example of a MDG-41 aligned Plan is the 'Gujarat Nre Minerals Limited Fluid Power Systems Safety Management Plan', 2009), the manufacturing, construction, agriculture and transport sectors will benefit from the adoption of the relevant provisions within MDG-41 and the Australian Standard AS 2671 (Standards Australia, 2002).

A further recommendation of this paper is that all persons conducting a business or undertaking (PCBU) employing high pressure fluid power systems (conforming to MDG-41 'high risk' criteria) should review and revise their Health and Safety Management Systems (HSMS) to achieve greater alignment with Australian Standard AS/NZS 4801 (Standards Australia, 2001).

The HSMS should document; the responsibilities of fluid power operators, maintainers and where applicable, designers, manufacturers, installers and testers; the legislative standards applying to the health and safety aspects of fluid power management; system (technical) standards including non-mandatory standards such as Australian Standards and ISO Standards applying to the installation, operations and maintenance of the fluid power system (including inspection and testing regimes of critical parts such as relief valves, sensors, hoses and fittings, etc); design standards including non-mandatory standards such as Australian Standards and ISO Standards applying to the design of the fluid power system (where applicable); safe work procedures (SWP) incorporating isolation & lockout and defect management standards used in operations and maintenance of fluid power systems and where applicable, installation and decommissioning of the system; the methodology employed for effective communication and consultation at the workplace; the methodology employed for effective risk management at the workplace; emergency provisions for incidents involving fluid power systems, including fluid injection protocols; the training & competency requirements for operators and maintainers of fluid power systems; and a listing of the range of fluid power system documentation required to be maintained.

Ultimately the Commonwealth and various states' statutory authorities need to collaborate to develop a code of practice to adequately meet the 'fluid power' safety needs of all industry sectors. The range of legislation, regulation and codes of practice released under the recent harmonization process fails to account for specific risks encountered across many industry sectors that are associated with working fluid power systems.

TRAINING IN FLUID POWER SYSTEMS
As outlined above, a vast majority of the incidents, injuries and fatalities discussed within this paper are associated with hose or fitting failures, followed by unsafe isolation practices. The resulting statutory authority investigation of these incidents have in almost every case identified a lack of awareness and/or specific operational training as significant contributors to the occurrence of these events.

Under the national harmonised legislation, workers and other persons should be provided with any information, training, instruction or supervision that is necessary to provide all persons present at the worksite with the highest level of protection against harm from hazards and risks arising from work.

Unlike the field of electrical technology,
training and qualifications for persons to undertake high risk work in fluid power systems are not mandated under statute. According to anecdotal and trade journal evidence, there continues to be reliance on in-house fluid power systems training and supporting documentation often sourced from private organisations that supply hose and fittings to the industry sector (Gates Corporation, 2009; Martin, 2011).

While web-searches for fluid power / hydraulic training and in particular nationally recognised training yielded some results in terms of accredited course modules and units of competency, the availability and range of training providers offering these modules is very limited when compared with those offering electrical technology courses and qualifications. In short while some accredited courses are available to augment the learning of trade apprentices and trainee engineers, there is lack of evidence that these course options are widely embraced within any industry sector.

The general benefits of in-house workplace training are well documented and understood. However, while in-house training offers an opportunity to promote and enhance a deeper understanding of work practices, processes and technology existing on site, a lack of a widely recognized cross-sector training framework (with either endorsed or non-endorsed ‘fluid power system’ components) potentially undermines the establishment of minimum standards of knowledge and skills and the transferability of those skills across worksites and across industry sectors.

To address these issues, this paper advocates that all worksites incorporating high risk fluid power systems conforming to the MDG-41 criteria should include fluid power system core training in the employee training program. This should require the completion of relevant nationally accredited course units in fluid power systems (Refer to Table 4 below) for all personnel required to undertake critical tasks on such systems as well as the undertaking of extensive in-house workplace training sessions conducted by a Registered Training Organisation (RTO).

CONCLUSION

High risk fluid power systems are widely employed and continue to be used in growing numbers of installations of fixed and also mobile plant deployed across the various industry sectors. Unlike electrical technology, high risk fluid power installations in Australia are subject to few mandatory engineering standards and few prescriptive training requirements. Without efforts to further reduce the risk associated with this technology, to develop effective safety guidelines applicable to all industry sectors and address the various unresolved training issues, it is likely the incidence of fatalities, injuries and incidents associated with the use of this energy transfer mechanism observed over the last decade will continue unabated.

<table>
<thead>
<tr>
<th>Table 4: Examples of nationally recognized ‘Fluid Power’ training ‘Units of Competency’ available within Australia (training.gov.au.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit of Competency</td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>LMTCG3003A</td>
</tr>
<tr>
<td>MEM234007A</td>
</tr>
<tr>
<td>MSAPMOPS405A</td>
</tr>
<tr>
<td>MEM18022B</td>
</tr>
<tr>
<td>UEPMN405A</td>
</tr>
<tr>
<td>MEM18052B</td>
</tr>
<tr>
<td>MEM234032A</td>
</tr>
<tr>
<td>AURT309140A</td>
</tr>
<tr>
<td>MEM18053B</td>
</tr>
<tr>
<td>MEM18023B</td>
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