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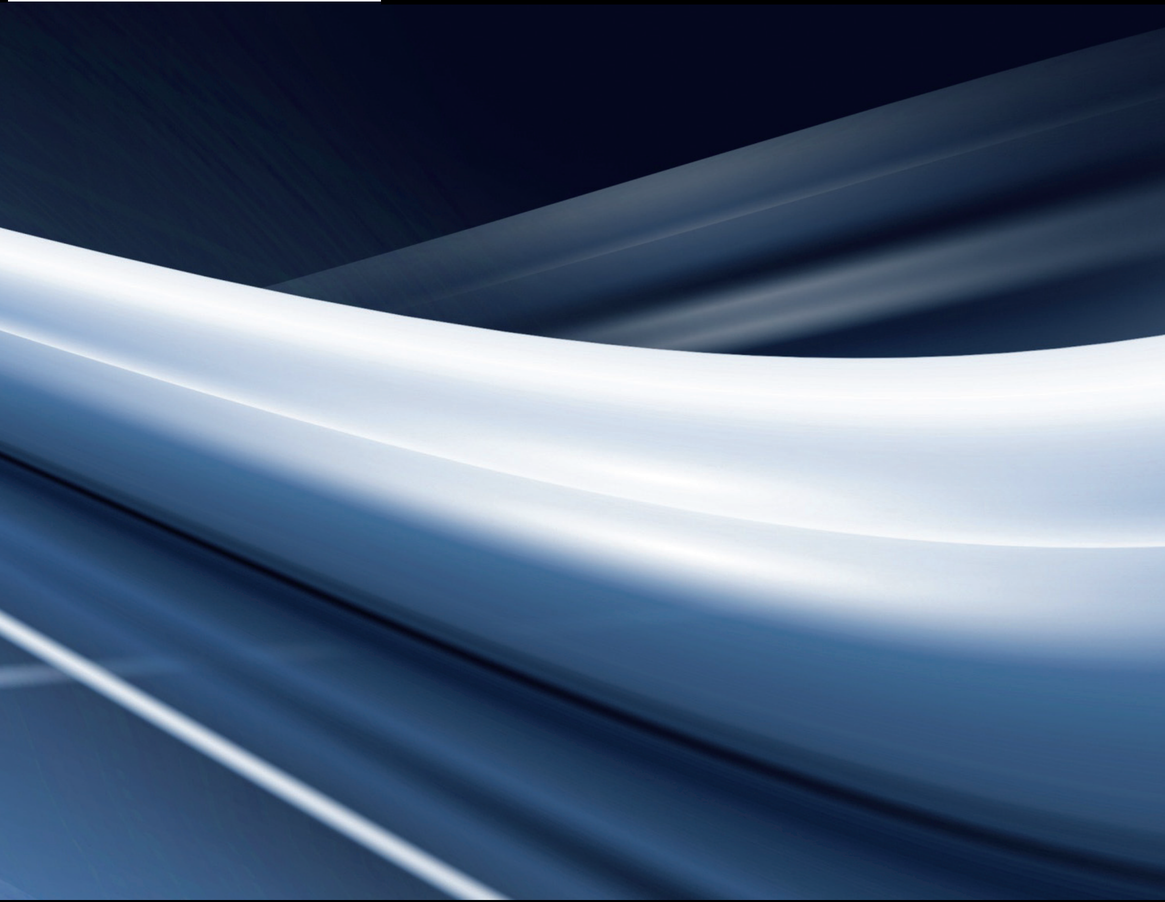

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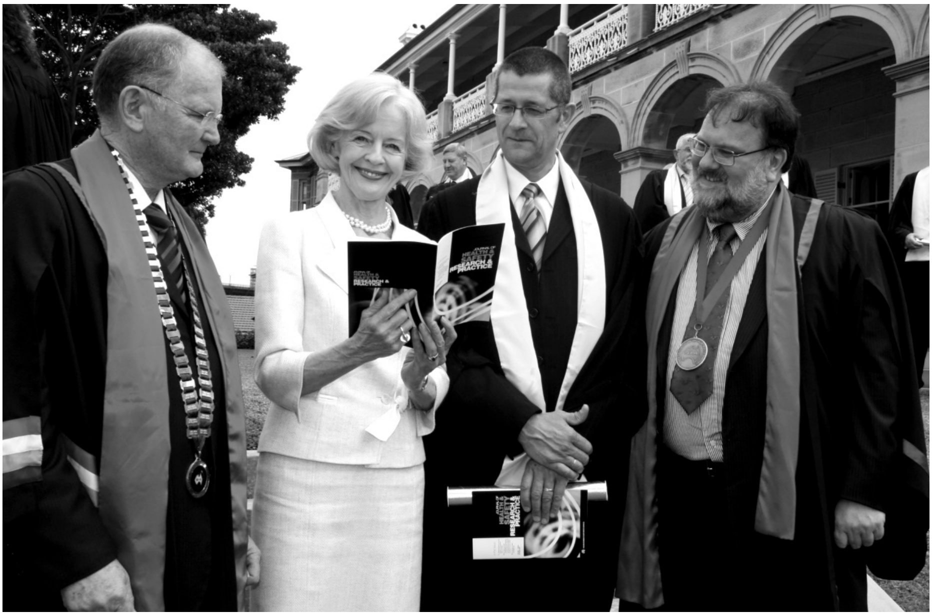
Editorial

Since the publication of the first issue of the Journal of Health and Safety Research and Practice and its launch by our patron The Governor General, Her Excellency Ms Quentin Bryce AC, the editorial office has received a very pleasing number of manuscripts for review. This indicates that there is a high level of interest in a journal of this nature as well as preparedness by safety professionals and researchers alike to share knowledge and ideas and subject those to rigorous peer-review. Interest in subscriptions by libraries and individuals is growing.

One measure of success of the journal is the number of citations that articles receive in other journals. This requires widespread distribution of the journal and its articles; distribution beyond the Safety Institute of Australia (SIA) membership. Following a 6-month period of SIA member and subscriber-only access, the release of the



The Governor General, Her Excellency Ms Quentin Bryce AC launches the JHSRP at Admiralty House, with the National President Mr Barry Silburn(left), Editor in Chief Dr Steve Cowley and (then) Dean of the College of Fellows Dr Geoff Dell (right)

in this issue:

first issue into the public domain via the internet (www.sia.org.au) is assisting this. There is evidence that a relationship exists between open access and increased citation rates (Open Citation project 2009) and the redesign of the Journal web pages that facilitate access by web crawlers has been important. Summaries of both embargoed and open-source articles are now presented to an international audience of health and safety professionals; allied professionals; researchers; and students via Google Scholar and other bibliographic database search engines.

A limitation on any journal of this nature is the availability of qualified individuals who are willing to freely give their time to undertake reviews, provide constructive criticism to authors and then review subsequent drafts. The JHSRP Editorial Board is assisting with the growth of a database of reviewers and the assistance of both board members and reviewers is very much appreciated.

In this issue we publish three quite discrete articles. Hayes presents the findings of research into the decision making processes that personnel employ in major hazard facilities and how those processes sit with the context of a safety case regime that has set operating limits. Pickering & Cowley review the validity of the widely used risk assessment matrix; they question the usefulness of such tools given the limited knowledge of the underlying principles of their construction and the highly subjective nature of risk perception and thus allocation of values to operators used in the matrix. Stuckey provides a data set that will inform research into health and safety issues surrounding light vehicle use in Australia. The documentation of such data sets is very important for further research.

In Australia, researchers' access to data sets that may be used for meaningful assessment of risk is often limited. In particular, access to useful data from the state and commonwealth workers' compensation databases is hampered by, among other things, differences in database structure, differences in field coding and differences in fundamental definitions of terms. There is also reluctance by some workers' compensation agencies to either de-identify data such that it may be released to researchers or, alternatively, make release conditional to preserve anonymity. Further, the relatively small size of the databases limits their usefulness in quantifying risk associated with, for example, particular activities or items of equipment. Aggregated sets of consistently coded data are required to provide statistical power. Perhaps, as the Australian jurisdictions work more closely together through harmonised legislation, harmonised approaches to data collection and reporting will emerge and more useful data will become available to researchers.

DR STEVE COWLEY, FSIA
EDITOR IN CHIEF, JHSRP

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Safety Decision Making – Drawing a Line in the Sand

JAN HAYES[1]

ABSTRACT

Operational personnel in complex process plant such as major hazard facilities are regularly called upon to make decisions that balance the production and safety requirements of their organisation. Hazardous facilities that operate under safety case-style regulatory regimes typically have in place a set of operating limits. These limits normally cover both restrictions on process parameters and required minimum safety equipment availability, apparently removing the need for in-the-moment judgements. Focussing solely on compliance with a pre-defined operating envelope underestimates the direct contribution to safety from the operating team based on their professional judgement. In practice, there are many possible system conditions that do not contravene the defined operating limits and yet are not safe. This does not mean that the procedure writers are wrong, it is simply a reflection that not every possible state of a complex dynamic system can be identified in advance. Research has identified a line in the sand approach taken by experienced operating crews when abnormal situations arise. This approach could form the basis of a process rule (similar to job safety analysis or permit to work) to assist operational crews in making better decisions.

INTRODUCTION

Organisations that operate complex plant such as major hazard facilities and nuclear power stations face special challenges. Their activities have the potential to cause significant numbers of deaths if things go wrong, so they need to operate conservatively. On the other hand, they also face normal commercial pressures to reduce costs and maximise production. The accident literature abounds with cases where organisations failed to achieve this balance, for example, Texas City (Hopkins, 2008; US Chemical Safety and Hazard Investigation Board, 2007), Buncefield (HSE Major Incident Investigation Board, 2008), Longford (Dawson and Brooks, 1999; Hopkins, 2000), Beaconsfield (Melick, 2007), Gretley (Hopkins, 2007) and Piper Alpha (Cullen, 1990) to name just a few.

Achieving the appropriate balance between these two priorities requires a multi-facetted approach from design and engineering, through to maintenance and operations. A key aspect of the role of operations personnel is to make decisions that balance organisational goals and take appropriate action. Researchers of high reliability theory have focussed on the need for mindfulness from operational personnel (Weick and Sutcliffe, 2001), whereas more recently, researchers of resilience engineering have focussed on sacrifice decisions, i.e. in the moment sacrificing of long term production targets

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Decision making, major hazard facilities, operating limits

in order to take action on short term safety imperatives (Woods, 2006). The emerging analysis of the circumstances surrounding the Deepwater Horizon incident is also emphasising the importance of operational safety decision making (US Department of the Interior, 2010).

This paper describes some of the results of a broader case study-based research project investigating how operational managers in high hazard industries make safety decisions (Hayes, 2009). It is a "normal operations" study (Bourrier, 2002) which looks at day-to-day decisions and attempts to draw lessons from cases where things have gone mostly according to plan in contrast to studies that review past accidents to determine what went wrong.

The research showed that, in making sense of situations, and taking action, operational managers act from two different occupational identities. As employees, operational managers take direction from their organisational superiors by way of rules and cultural norms. In addition to their identity as employees the operational managers also have a strong professional identity which drives their decision making by valuing such qualities as dedication to the job, public trust, loyalty to peers and in-depth technical knowledge. Their experience also gives them a deep understanding of the system, its inherent complexity, and the potential for serious consequences if things go wrong. These aspects of professional and organisational identity are complementary to the use of rules and the role of compliance discussed below.

METHOD

The research was conducted using ethnographic techniques based on interview, observation and document review. The work is founded in a case study tradition of social science inquiry (Flyvbjerg, 2001). The aim is to improve our practical understanding of safety performance by collecting stories which provide a rich picture of decision making by operational managers managing safety and production goals. The results are both descriptive and explanatory of the organisational situations studied.

Overall, three organisations participated in the broader research. They were chosen based on their having similar organisational goals and environments (despite differing technologies). This paper draws on interview data collected from operational managers at two organisations; a UK nuclear power station and a chemical plant in Victoria, Australia[1]. The nuclear power station operates under the UK Nuclear Installations Act (1965). The chemical plant holds a Major Hazard Facilities Licence under the Occupational Health and Safety (Major Hazard Facilities) Regulations (State of Victoria, 2000).[1]

The interviewees (n=22) were selected on the basis of their organisational roles. Most interviewees were operational managers. They were the most senior individuals on shift and their job was to supervise the operating crew and ultimately to decide if a production interruption is required for safety reasons. A few interviewees were chosen because operational managers sought their advice in making decisions. Even in a large organisation, there is only a small group of people who hold these roles. Eleven people were interviewed in each organisation. They were asked to describe some specific situations in which they had to make a decision balancing safety and system efficiency/operations/production. Twenty six stories were collected in total (of which four are described below) along with rich contextual information about how individuals conceptualise safety and how they choose a course of action in any specific case.

Information obtained from interviews was supplemented by documentation such as procedures and position descriptions.

Approval for this work was obtained from the Australian National University Faculty of Arts Ethics Committee.

COMPLIANCE WITH OPERATING LIMITS

The idea of defining an operating envelope or a set of operating limits for complex process plant has wide acceptance in both industry standards[2] and safety regulation. Such limits provide a fixed boundary of acceptability for specific system parameters that impact safety. Examples of these are; maximum and/or minimum values of measurable system properties such as pressure, composition, or number of operators; and specific minimum requirements for equipment such as always having one pump running and one on-line spare and must not run without gas detection in place. [2]

Ensuring that operations stay within the operating envelope at all times is an overriding factor in decision making in the face of equipment breakdown or abnormal operating conditions.

Turning to how these limits are used in practice, at the nuclear power station the defined operating limits were treated by all involved as a set of firm and fixed boundaries never to be crossed. One operational manager said:

"…we will comply with them absolutely, where we can, and if not we will flag it up to the world. If we do deviate we know that we will be held personally responsible and it can be a career threatening type of thing…it's something we take very seriously because it's the safety envelope of the plant. If we go outside of that we are threatening safety."

Story 1 is a typical example of action taken as a result of the limits defined in the operating instructions.

Activities at the chemical plant were managed in a similar way as illustrated in Story 2.

Compliance with the defined operating envelope is often a regulatory requirement. In the case of this research, each site operates under a safety case-style regulatory regime that treats operational limits in a similar way. Setting operating limits is largely an engineering exercise. Limits are based on risk analysis and engineering design considerations with input from operations personnel to ensure that issues such as the

YOU NEED TO BUTTON YOUR REACTORS AND BUTTON YOUR TURBINES.

Shift Manager Interviewee 2 was out in the plant when the sudden loud noise and visual impact of high flow in the venting and relief system made him aware that a plant trip had started. Returning to the control room, he discovered that a full reactor and turbine trip had been initiated by the control room staff. A failure had occurred in the low voltage power system, which meant that the technicians had lost access to the data presentation system that allows them to monitor the plant and would not be able to 'see' what was happening from inside the Control Room. Operating instructions call for an immediate trip in these circumstances.

Tripping the reactors and turbines initiates a period of very high workload for the entire shift to shut down and isolate all equipment and perform all necessary external notifications (since power generation has ceased).

In this case, control functions were not impacted by the failure, so, in theory, operations could have continued without monitoring until the data presentation system was restarted (estimated to take 20-25 minutes). The staff members on duty were well aware that operating instructions require an immediate trip if monitoring is lost, even if there are no signs that the reactors and plant are not operating normally. This was the action that they took.

Story 1

MINIMUM MANNING LEVELS

Shift Manager Interviewee 1 recounted the story of an occasion where, through illness and lack of availability of a replacement technician, there were only five technicians available to work a shift in the plant instead of the usual six. It is possible to run in the short term with only five technicians but there is insufficient capacity to manage any maintenance work or attend to developing plant issues. Interviewee 1 said that he chose to shut down one section of the plant that is relatively simple and hence safest to restart. He described the decision in practical terms based on the tasks that needed to be done for the plant to run safely. The safety case specifies that the minimum number of people necessary to safely run the plant is six. This limit was set when the Safety Case was prepared based on analysis of previous operating experiences.

Story 2:

necessary response time have been taken into account.

The two stories recounted above and many others in the research data show that these types of limits are commonly respected in practice. This may be what regulators, engineers and senior managers expect to see, but this is far from a complete picture, as described below.

LINE IN THE SAND

Operational managers described other occasions when they had chosen to interrupt operations, even though the state of the plant was not close to the boundary of the operating envelope. This is an important point. Operating outside the defined envelope is unsafe, but operation within the envelope is not automatically seen as safe just because none of the individual stated parameters is in danger of being breached. Ironically the complete set of operating limits is sometimes called the Safe Operating Envelope (or SOE) for the plant but experienced operations people know that it is possible for the system to be inside the SOE and yet not safe.

Sometimes the process system may present unusual modes of operation or failures not foreseen by the engineers who wrote the procedures and set system limits. This may be seen as a failure on the part of those who wrote the procedures. In a perfect world all hazardous operating modes could be defined and proscribed. In fact the real-world operation of complex ageing technology, often in a changing environment, means that there will always be the potential for system behaviours that have not been predicted in advance. A recent study of the California electricity system (Roe and Schulman, 2008) found that the grid transmission control room staff operated in performance modes covered by routine procedures only 10% of the time. The system was under so much pressure (due to fluctuating power demands from customers and fluctuating power availability from generators) that control room staff spent almost their entire working time balancing transmission system integrity (safety) and delivery reliability (production) in ways that the system designers had not foreseen.

The performance of the systems at the nuclear power station and the chemical plant was much more stable. Nevertheless, at both sites there were occasional deviations that designers had not foreseen. In such cases, the operational managers at the nuclear power station moved into a mode that they called conservative decision making. Under this approach, as an abnormal situation develops, the manager fixes a limit beyond which attempts to continue running will be curtailed and the facility will be moved to a safe state (usually shut down). This is similar to a limit imposed by a formal operating instruction, but it is specific to the particular situation at hand and is developed at the time by the crew based on the available information about the state of the system. Within this self-imposed limit, personnel continue to monitor the situation and attempt to solve the problem. If the situation is not resolved before the limit is reached, then the plant is shut down. Story 3 below describes a specific case where a limit like this was developed and used.

WE SET BOUNDARIES AND WORK WITHIN THOSE

One of the Shift Managers (Interviewee 1) recounted the story of restarting a nuclear reactor after a planned outage. Part of the way through the start up sequence, the control room technician found that there was a problem with moving the control rods (one of the key devices used to control the reactor power level). The technician's initial response (shouted out to Interviewee 1, who was in his office adjacent to the control room at the time) was to plan to shut the reactor down again immediately.

Further investigation (over a few minutes) showed that it was possible to manually decrease the power of the reactor but not increase it. Interviewee 1 described this as "partial control". It was also established that, whilst there is a minimum power level specified in the operating instructions, they were well above that figure. Before continuing, they set themselves a limit.

"We gave ourselves a bound of power level whereby if it went down so far towards the automatic trip, then we would have tripped it anyway… so, we set boundaries and worked within those."

Within two to three minutes they had solved the problem with the control rods and were back to power raising.

Story 3

What would have happened in this case if the power level had continued to fall? Would they really have acted to shut down the reactor, or would they have simply continued in their efforts to fix the problem? The research data includes several cases where facilities were shut down in accordance with the agreed criteria.

Several of the stories told by operational managers at the chemical plant followed a similar pattern. In one case, the manager was involved in temporary repairs to a leaking cooling water system. Since the plant was still running, he had set the control room technician the task of monitoring a plant parameter with instructions to shut equipment down if a specific limit was reached. However, at the chemical plant there were also several stories told where the limit that formed part of the operational manager's thinking in the first instance was then ignored as repairs were delayed for a range of practical reasons. Story 4 is a case in point.

This story shows our tendency to revise our original view that the activity or operation was undesirable based on our very short-term experience. This can lead to acceptance of continuing operation with decreased safety margins.

In her study of the Challenger disaster, Vaughan (1996) found that, over a period of years, NASA technical staff came to accept observed damage to solid rocket booster seals as normal, even though it was initially seen as a problem. Eventually the seals were so damaged on one launch that they failed and the shuttle was lost. She calls this shift in what is normal or accepted practice "the normalisation of deviance". The research with operational managers indicates that such normalisation can occur very quickly in cases where the self-imposed limit is not strongly articulated and recorded.

FALSE ECONOMY

Shift Manager Interviewee 10 told the story of a fault in a valve in the plant water system that developed late one Monday afternoon. This meant that, instead of levels being managed automatically, the technicians had to manually check the water level in the system and ensure that sufficient water was in each tank. Maintenance advised that the necessary part would be delivered and installed on Tuesday. The water is used to cool each reactor vessel i.e. as a key process safety system. Interviewee 10 considered leaving the affected reactor offline until the valve was repaired, but was convinced without much difficulty by the departing day Shift Manager that they could manage to run the plant overnight by adjusting the water levels manually.

Interviewee 10 came back on shift on Tuesday evening to discover that the wrong part had been delivered during the day, so the system was still on line with levels being adjusted manually. He continued with this approach but *"2 o'clock in the morning that decision bit us in the bum because the cold tank had dropped to a level where we lost suction to the pump that supplies the chiller units, which were no longer supplying chilled water to the tank, which meant that the autoclaves that needed chilled water weren't getting it and we had to [manually dump] two batches."*

This has both production and safety implications. Initiating a manual dump of the contents of the reactor indicates that the reaction is not under full control and that urgent action is required. If the contents are not manually dumped and the pressure continues to rise, then the automatic relief system will initiate a dump to atmosphere, the "last resort" in reaction control. Dumping the partially reacted product is also a production issue as that batch of product is lost and it takes some hours to get the plant back to a normal running state.

"So that's probably a really good example where in hindsight, the decision, what I said to [other senior operations staff] on Monday night, just leave it off until we get a new valve, would have been the best one."

Story 4

These examples show that this aspect of decision making is of similar importance to compliance with the plant operating envelope, yet it is largely invisible to regulators and staff outside the immediate operational areas of most high technology organisations.

APPLYING EXPERIENCE

The line in the sand approach implies that the person setting the line has sufficient experience to make a reasonable judgement. The parameter chosen is often a time limit (as in Story 4) but it is sometimes another plant parameter such as pressure, temperature or flow. The research suggests that in setting such limits, operational managers consider two things: (i) in considering the danger associated with an abnormal operating state or activity, operational managers do not use the concept of risk (in the sense of likelihood and consequence). Instead, they assume that normal operations are safe and loss of any safety barriers is of serious concern to them. They become very uncomfortable if safety systems or devices are unavailable, or likely to be impaired or ineffective for any reason. Their focus is on repairing/ reinstating, or providing temporary replacements and they will rapidly interrupt production if these options are not possible; (ii) past experiences that had frightened them greatly and given them a vivid appreciation of the potential danger posed by the system. These stories are sometimes accidents involving injuries or deaths of colleagues, but more often they are seemingly more trivial occasions that nevertheless have left a strong impression that the facilities are dangerous and at times unpredictable. Keeping the danger under control is a priority for which they are actively responsible.

It seems likely that the line in the sand approach has been adopted because it supports the cognitive processes that the operational managers naturally use as experienced decision makers (Dreyfus and Dreyfus, 1986; Klein, 2003) based on intuition rather than analysis and with a strong commitment to the required outcome. This approach does not dictate how best to come to a conclusion about the safety or otherwise of the system. Rather, it specifies a way of helping an operational manager stick to his judgement once he has drawn initial conclusions (unless the situation changes).

CONCLUSIONS

Organisations rely critically on the experience and expertise of engineers in designing safe plant, and recording the limitations of the design in the form of a well-defined set of operating limits. Compliance with such limits is clearly a key aspect of ensuring safe operations, but much less attention has been paid to the role of experience and expertise of senior operations personnel.

Comments from senior managers about the broader research project from which this work is taken (Hayes, 2009) often revealed the view that their operational managers had relatively little freedom and that their job was limited to application of concrete rules. In fact, the research has highlighted decisions being made largely outside existing rules and procedures. The line in the sand approach could be formalised into a procedure for decision making focussing on the circumstances in which to create a line in the sand, plus development, monitoring, recording etc. This type of procedure is an example of a process rule (Hale and Swuste, 1998). The idea behind using process rules for safety assurance is that, if the series of steps that a skilled individual is required to perform is specified, then the individual will come to the best possible decision. Other examples of process-based rules commonly used in manufacturing and process industries are permit to work systems and job safety analysis.

Putting in place a procedure for operational safety decision making based on the line in the sand concept would make these safety practices more visible and hence able to be drawn in to normal management system practices such as training, review and audit. In a political environment where operational decisions are likely to come under increasing levels of scrutiny, this must be a good thing for safety outcomes and for reputation management.

[1] *The third participating organisation was an air navigation service provider.*

[2] *See for example Center for Chemical Process Safety (2007) and International Atomic Energy Agency (2000)*

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Risk Matrices: implied accuracy and false assumptions

ALEXANDER PICKERING[1]
STEPHEN P COWLEY[1]

ABSTRACT

Risk matrices are used during hazard identification and risk assessment processes and provide a construct for people needing to display the two variable relationship between likelihood and consequence that are considered to be the elements of risk. The purpose of a matrix is to reduce the continuum of risk into ranges or bands such as high, medium or low. These bands are often allocated colours such as red for the highest risks to green for the lowest. Sometimes each band in a matrix is allocated a numerical value or range. The multiplication of likelihood and consequence implies a quantitative basis although it may not be widely understood. The multiplication operator produces lines of equal risk that a matrix cannot model accurately and thereby introduces risk reversal errors. Weaknesses in matrices are further compounded by subjectivity and bias introduced by users and the value of such tools is brought into doubt. A shift of emphasis from the risk assessment stage to the risk control stage of a hazard management process may lead to better and more timely decision making and better use of resources.

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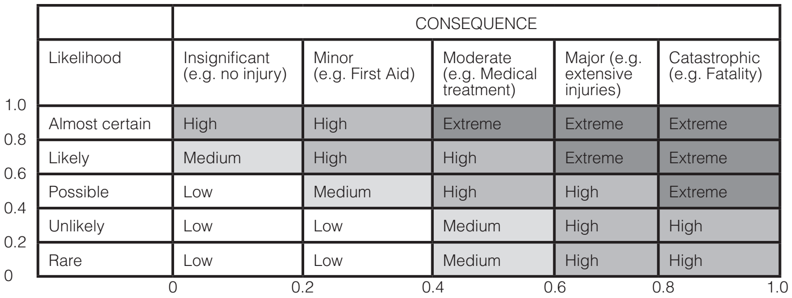
KEY WORDS
Matrix, risk, likelihood, consequence, estimation, bias

INTRODUCTION

Risk matrices are very commonly used during hazard identification and risk assessment processes (Cook 2008). They are used to: articulate the level of risk associated with an identified hazard; to rank risks and thereby propose actions; to justify a proposal or action; and to re-assess risk to demonstrate the effectiveness of a control (residual risk) (Cook 2008; Cox 2008; Smith, Siefert and Drain 2008). Risk matrices provide a construct for people needing to display the two variable relationship between likelihood and consequence that are considered to be the elements of risk (Standards Australia 2004).

A Risk Matrix is a tool used to allocate a level of risk to a hazard from a pre-defined set. An example is shown in Figure 1. Two dimensional matrices are most common but not exclusive (Hewett, Quinn, Whitehead and Flynn 2004) and are lauded as “simple, effective approaches to risk management” (Cox 2008). They are used in many countries (Papadakis and Chalkidou 2008) and promoted through international standards (Standards Australia 2004; Cook 2008).



	CONSEQUENCE				
Likelihood	Insignificant (e.g. no injury)	Minor (e.g. First Aid)	Moderate (e.g. Medical treatment)	Major (e.g. extensive injuries)	Catastrophic (e.g. Fatality)
Almost certain	High	High	Extreme	Extreme	Extreme
Likely	Medium	High	High	Extreme	Extreme
Possible	Low	Medium	High	High	Extreme
Unlikely	Low	Low	Medium	High	High
Rare	Low	Low	Medium	High	High

Figure 1 Example Risk Matrix

Risk Matrices are common within, and specific to, many different industries and business sectors including; medicine (McIlwain 2006); construction (Bender 2004); aerospace (Moses and Malone); major facilities (Filippin and Dreher 2004; Iannacchione, Varley and Brady 2008); railways (Kennedy 1997); agriculture (Hewett, Quinn et al. 2004); mining (Stoklosa 1999; Md-Nor, Kecojevic, Komljenovic and Groves 2008). Some matrices have been developed for specific applications within the occupational health and safety (OHS) domain (Cook 2008). Some organisations use one matrix for assessment of risk associated with business risk and a different matrix to assess risk associated with exposure to work place hazards. These may be mis-matched in their allocation of descriptors of likelihood and consequence values and thus cause confusion.

Risk assessment is a highly subjective process and individuals are prone to systematically misperceive risk (Hubbard 2009) and there is limited scientific study to show if risk matrices improve risk making decisions (Cox 2008). This paper focuses on the use of risk matrices used in the assessment of risks associated with workplace health and safety and questions the basis of the reliance upon them as a tool for risk-based decision making.

THE BASIS OF RISK MATRICES

Risk matrices are tools that allow the categorisation of risk using, for example, "high", "medium" or "low". The definition of risk in the OHS discipline is not universally agreed and this, in itself, presents difficulties in the communication of the outcomes of risk assessment (Cowley and Borys 2003; Viner 2003). However, a widely accepted definition in Australia is the "effect of uncertainty on objectives" (Standards Australia 2009 p1). A further definition that is of particular use with regard to work place safety is that of Rowe (1988) who defines risk as the "potential for the realisation of the unwanted, negative consequences of an event." Risk is generally considered to be derived from an estimate of probability or likelihood and consequence or severity (Cagno, Di Giulio and Trucco 2000; Health and Safety Executive 2001; Middleton and Franks 2001; Bender 2004; Cox 2008). Viner (1996) proposes that risk is a function of frequency (probability x exposure) and consequence (the unwanted negative or adverse result of the event). Herein risk will be considered to be the generally accepted function of likelihood and consequence (Donoghue 2001; Cox 2008; Smith, Siefert et al. 2008) i.e. $R = f(L,C)$, where L and C can be quantified on ratio scales making the multiplication operator meaningful (Martin and Pierce 2002; Standards Australia 2004).

Thus, most matrices employ likelihood and consequence as their x and y axes and therefore it is generally accepted that Risk = Likelihood x Consequence (R=LxC) (Donoghue 2001; Standards Australia 2004; Cox 2009). The purpose of the matrix is to reduce the continuum of risk into ranges or bands of equal risk e.g. high, medium or low risk. These bands are often allocated colours: red for the highest risks to green for the lowest giving rise to the term 'Heat Map'.

Each band in a matrix and the allocated risk level is sometimes given a numerical value or range. However, quantifiable data is often unavailable and so semi-quantifiable or qualified arguments are used (Clemens and Pfitzer 2006). Whether or not numerical scales are used the qualitative risk scale implies the existence (at least in principle) of an underlying quantitative risk scale that it maps to (Cox 2009). Knowledge about hazards and their effects is required for effective estimates of risk based on qualitative parameters (Donoghue, 2001, p. 121).

MATRIX DESIGN

Matrices are typically an array of cells presented as squares or rectangles in rows and columns representing risk categories or levels. The number of risk categories within a matrix is determined by the organisational requirement for specific actions with respect to the risk category (Smith et al., 2008, p. 2). For example, within a matrix having three categories of risk, the organisation may dictate that work must cease when a hazard is categorised as high-risk but proceed when categorised as low-risk. Some predetermined actions may be required if the risk is categorised as “moderate”. Within a 5 x 5 matrix having five risk levels (for example, low, moderate, high, very high and extreme) a range of additional actions may be included. Risk matrices with too few categories may suffer ‘range compression’, where risks with significant variation in likelihood and or consequence might become grouped into the same category (Cox, 2009, p. 101) (Hubbard, 2009, p.130).

The parameters applied to the x and y axes also vary and some matrices illustrate risk increasing from left to right and bottom to top. Others represent the reverse with increasing risk towards the left or top down (Alp, 2004, p. 36).

Some matrices are purely qualitative and use words to express likelihood and consequence (Bender, 2004, p. 2) (Standards Australia 2004). Qualitative analysis is used when quantitative data is not available or when the more onerous quantitative methods are impractical. (Standards Australia 2004).

Semi-quantitative and quantitative risk matrices incorporate in the likelihood or consequence arguments, data derived from injury statistics or epidemiological studies, for example. Use of historic data may however be problematic as incident rates vary over time and data collection may be biased (Donoghue 2001; Gadd, Keeley and Balmforth 2004; Hopkins 2004; Hopkins 2005; Smith, Siefert et al. 2008). The number of incidents and injuries within organisations is usually too low to provide a basis for quantification of risk (Health and Safety Executive 2001).

If the numerical value of both likelihood and consequence are known, then the quantitative measure of risk is also known based on R = L x C. In this case, a Risk Matrix is not required to rank hazards as this will be self evident.

Consequence values in quantitative matrices are often represented by ranges because they are dependent on conditional factors. This lack of ‘point value’ is considered to be a weakness (Smith, Siefert et al. 2008). Establishing this ‘point value’ through accuracy in the estimation of likelihood and consequence is impractical in most cases. Despite it representing objectivity, the expense in time and resources for investigation, testing and analysis exceeds the capability of the organisation and the time frame of the project (Smith, Siefert et al. 2008).

MATRIX USE AND INTERPRETATION

The cell at the intersection of a row and a column that respectively represent the chosen likelihood and consequence values signifies a discrete risk category or score and therefore the boundaries between the cells imply that each cell is categorical rather than a position on a risk continuum. However, if R = L x C (Donoghue 2001; Standards Australia 2004; Cox 2008; Smith, Siefert et al. 2008) then points of equal risk plotted on a matrix form curved lines of the form y=R/x. Figure 2 shows lines of equal risk for arbitrary and dimensionless values of risk (R) increasing at 0.1 intervals between 0.1 and 0.9, superimposed onto a 5 x 5 matrix. Figure 2 shows the non-linearity of points of equal risk, that they do not align themselves with the cells or their boundaries and they bisect the cells asymmetrically. Thus the equal risk curves divide risk categories and render the plot of the likelihood and consequence estimations ambiguous. Changing the position of grid lines or number of rows/columns does not eliminate the problem (Cox 2008).

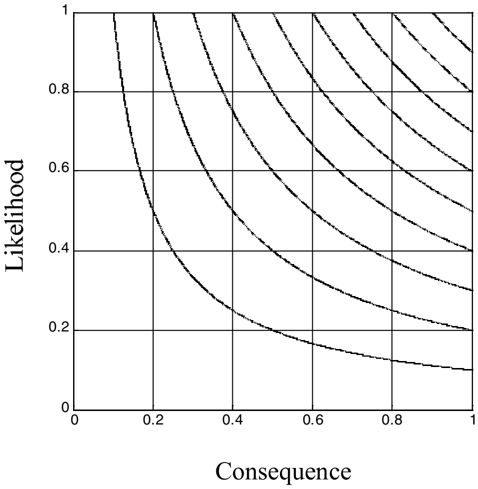


Figure 2 Risk matrix showing lines of equal risk conforming to y=1/x

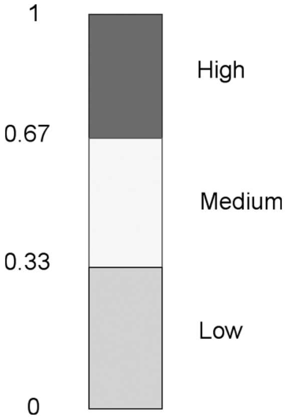


Figure 3 Equal distribution of risk categories

In practice very few users will be aware of this division of cells and thus the risk categorisation that results from an assessment may over or under-estimate risk relative to that anticipated or expected category, i.e. if the user errs to a higher level of protection where cells contain more than one risk category, then “rounding up” will result in fewer risks being categorised “low”.

Designers of matrices do not seem to evenly space risk levels and values are decided by placement on the matrix rather than being mathematically derived. If, for example, likelihood and consequence are normalised and the descriptors “low”, “medium” and “high” are evenly distributed between zero (lowest) and one (maximum) the distribution would appear as shown in Figure 3. When mapped onto a typical 5x5 matrix, the high risk values between 0.67 and 1.0 inhabit the three top left cells only whereas the values between 0 and 0.33 are in nineteen cells as shown in Figure 4.

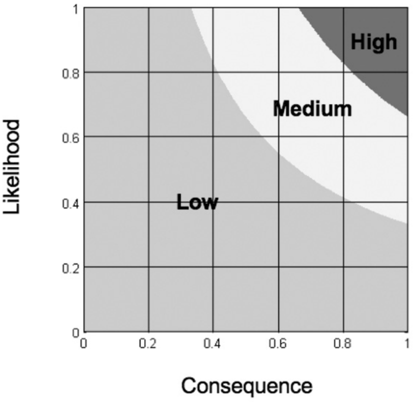


Figure 4 Risk matrix showing equal distribution of risk categories

Changing where we define the boundaries between high, medium and low, has a dramatic effect on where the levels lie on a matrix. For example, by changing the boundaries between low and medium risk to 0.1 and medium and high to 0.4 as shown in Figure 5, the matrix shown in Figure 6 is produced. The areas are distributed more evenly despite all risk above 0.4 being defined as high.

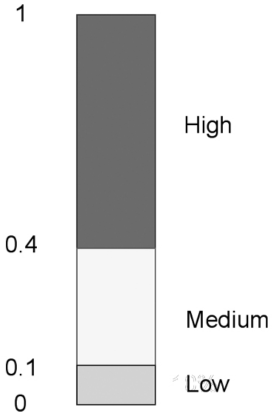


Figure 5 Adjusted distribution of risk categories

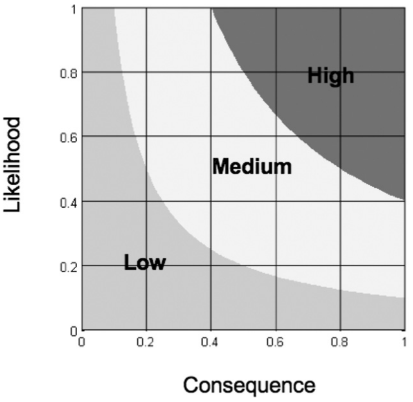
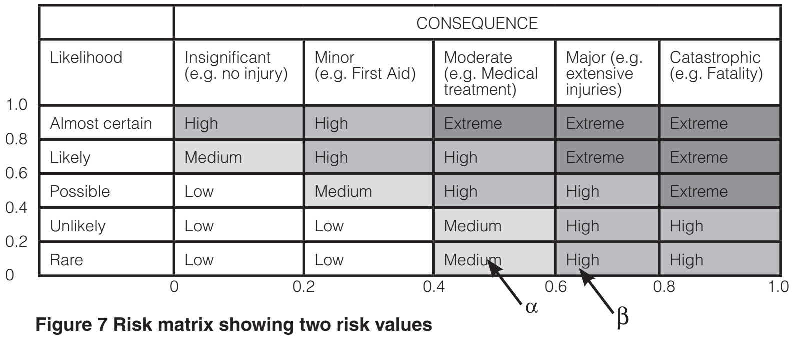


Figure 6 Risk matrix showing arbitrarily adjusted distribution of risk categories

Rounding the entire cell up to the highest value contained therein seems reasonable when considering the highest level of risk, e.g. it would be prudent for a cell containing some ‘high’ area to be categorised as high. However, this ‘rounding up’ is less useful when considering the lowest row and column which always contain some ‘low’ data points no matter what level is chosen. This can lead to the over estimation events of very low likelihood and high consequence. For example the consequence of being struck by a meteorite is predictably catastrophic, however, even with a negligible likelihood of being struck by a meteorite, many risk matrices will indicate something greater than low risk and thereby prescribe some preventive action. Cox states that the lowest row and column should all be ‘low’ (Cox 2008 p 504)

The ability to rank risks (and by extension any corrective actions) in order of priority is one of the fundamental purposes of risk matrices. Unfortunately, this can not be guaranteed. For example, let us consider two points α and β in figure 7 with point likelihood and consequence values of (0.1,0.5) and (0.05,0.65) respectively. α’s risk value is categorised as “Medium” and β “High” despite the risk value at α being 0.05 and the risk value at β being 0.03. Thus, the user might reasonably assume that the lower risk should be addressed first.

Risks that have been assessed to be of high likelihood but low consequence and therefore “low” risk, should not suffer organisational malaise. The sum of many low impact incidents can lead to a ‘no real harm done’ culture (Standards Australia 2004; McIlwain 2006).



	CONSEQUENCE				
Likelihood	Insignificant (e.g. no injury)	Minor (e.g. First Aid)	Moderate (e.g. Medical treatment)	Major (e.g. extensive injuries)	Catastrophic (e.g. Fatality)
Almost certain	High	High	Extreme	Extreme	Extreme
Likely	Medium	High	High	Extreme	Extreme
Possible	Low	Medium	High	High	Extreme
Unlikely	Low	Low	Medium	High	High
Rare	Low	Low	Medium	High	High

Figure 7 Risk matrix showing two risk values

Cox (2008) suggests that for risk matrices to be logical the points in a 'High' risk category should have values greater than those in the 'Low' category and that small increases in likelihood or severity should not cause a jump in category from Low to High without going through an intermediate category. Furthermore, equal quantitative risks should have the same qualitative risk rating. This is impossible to achieve for all risk values because the matrix grid lines do not follow the equal risk contours. It is, however, possible to ensure equal rating for 'High' and 'Low' categories, while accepting some inconsistency in intermediate categories.

The practical implications of the three axioms (above) for risk matrices are that all cells in the left column and bottom row represent the lowest risk category and that all cells in the second column from the left and second row from the bottom do not represent the highest risk category (see for example Figure 8). For the matrix shown in Figure 8 Cox (2009) states that the probability of two randomly selected pairs of points being correctly rank ordered is 3/25 x 17/25 = 0.082. The matrix is therefore unable to correctly rank two risks over 90% of the time. This does not promote accurate resource allocation and some uses of 5x5 matrices "…do not match well with observed reality." (Hubbard 2009).

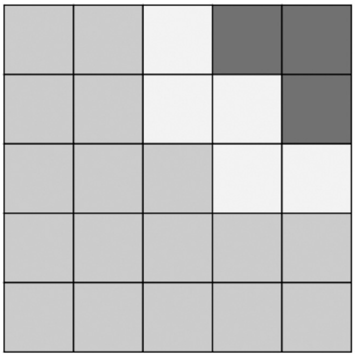


Figure 8 Five by five matrix
(Adapted from Cox, 2009, p. 114)

SUBJECTIVE FACTORS

The use of Risk Matrices involves "subjective and arbitrary judgements" making any absolute risk determination questionable (Bluff and Johnstone 2004). Many factors will influence a subjective assessment including experience, proximity to perceived benefits from the activity (Botterill and Mazur 2004), how well the risk is understood, how the risk is distributed (equity), an individual's control of the risk, social, ethical and cultural factors, and voluntary assumption of the risk (Health and Safety Executive 2001). People also have a tendency to overestimate small probabilities and underestimate large ones (Tversky and Kahneman 1992; Smith, Siefert et al. 2008) and there is a general tendency by people to move selections away from the lowest and highest measures of likelihood and populate cells towards the middle of the likelihood scale. (Payne 1951). In general there will be an exaggeration of loss, particularly by people with a personal interest in the outcome. This effect is likely to influence the selection of risk cells toward a higher consequence.

Harvey (2002) noted the potential for inconsistent results by risk matrices when comparing risk estimation tools. Risk Matrices may promote reverse engineering: the modification of likelihood or consequence levels to achieve a desired risk score (Gadd, Keeley et al. 2004).

Given the biases associated with risk assessment processes the accuracy of the matrix should be questioned. In the UK, the Health and Safety Executive has published guidance materials that bypass the risk assessment stage of hazard management by identifying hazards and then simply deciding what to do about them. Similar guidance was published for Health and Safety Representatives in Sweden in the 1980's and encouraged detailed risk assessment only when a risk control measure was not immediately apparent or when an exploratory investigation did not suffice (Swedish Work Environment Fund (ASF) 1988; Cowley 1990). Perhaps it is now timely to question the current emphasis on risk assessments using tools such as risk matrices and instead shift the focus to risk control.

CONCLUSION

Risk Matrices are used to categorise and prioritise risks. However, there appears to be little scientific analysis of their value in improving risk related outcomes.

The lack of specifications for Risk Matrix design may cause confusion through the variations in the number of rows and columns, the values on the x and y axes and the direction of risk scaling within the matrix.

A widely used definition of risk involves the multiplication of likelihood and consequence. This implies a quantitative basis although it may not be widely understood. The multiplication operator implies lines of equal risk that a matrix cannot model accurately and thereby introduces risk reversal errors. Weaknesses in matrices are further compounded by human bias and the value of such tool is therefore brought into doubt.

A shift of emphasis from the risk assessment stage to the risk control stage of a hazard management process may lead to better and more timely decision making and better use of resources.

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Occupational Light Vehicle Use: Characterising the at-risk population.

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DEBORAH C. GLASS[1] MALCOLM R SIM[1]

ABSTRACT

Previous occupational light vehicle research has concentrated on employees using cars. The aim of this study was to identify and characterise the total occupational light vehicle-user population and compare it with the privately-used light vehicle population. Occupational light vehicle and private light vehicle populations were identified through use-related 2003 registration categories from New South Wales Roads and Traffic Authority data. Key groups of occupational light vehicle registration variables were comparatively assessed as potential determinants of occupational light vehicle-user risks. These comparisons were expressed as odds ratios with 95% Confidence Intervals. The occupational light vehicle population vehicles (n=646,201) comprised 18% of all light vehicle registrations. A number of statistical differences emerge between the two populations. For instance, 86% of occupational light vehicle registrants were male versus 65% of private registrants, and 56% of the occupational users registered load shape vehicles versus 20% of the private registrants. Occupational light vehicles registered for farming or taxi use were more than six times more likely to belong to sole-traders than organisations. Sole-traders were nearly twice as likely to register light-trucks, and twice as likely to register older vehicles, than organisations. This study demonstrates that the occupational light vehicle user population is larger and more diverse than previously shown with characteristics likely to increase the relative risks of motor vehicle crashes. More occupational light vehicles were load shapes and therefore likely to have poorer crashworthiness ratings than cars. Occupational light vehicles are frequently used by sole-traders for activities with increased OHS risks including farming and taxi use. Further exploration of occupational light vehicle-user crash risks should include all vehicle types, work arrangements and small 'fleets'.

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Key words: occupational light vehicles;
work driving; work arrangements.

OCCUPATIONAL LIGHT VEHICLE USE: CHARACTERISING THE AT-RISK POPULATION.

INTRODUCTION

Occupational light vehicles are light-vehicles of all types used by working drivers and passengers, regardless of work activity or arrangements. Occupational light vehicles include cars, utilities, 4-wheel drives, panel-vans, tray-trucks, and goods-carrying vans.

Motor vehicle crashes are the most common cause of work-related trauma, and absence from work in most western countries and are estimated to cost US employers up to $60 billion annually (Pratt, 2003). Despite a well-documented literature of etiological and intervention research into heavy vehicle occupational health and safety, little research has focused on occupational light vehicle-users who comprise an increasing proportion of the working population (Stuckey & LaMontagne, 2005). Occupational light vehicle-users are unusual in that they can work in traditional or precarious work arrangements, on the public road system, thereby operating within both road safety and occupational health and safety policy contexts. Most previous occupational light vehicle research has studied crash outcomes within company owned car-shaped passenger fleets and does not appear to have included studies of entire working populations (Haworth, Tingvall & Kowadlo, 2000). A comprehensive description of the particular characteristics of the at-risk occupational light vehicles, and the user population, is necessary to provide the appropriate context for identification of occupational health and safety risks factors and public policy.

A number of British studies examining risk factors for large groups of company car drivers have hypothesised a 'fleet driver effect' as the reason fleet drivers have up to 50% more accidents than other drivers (Dimmer & Parker, 1999; Grayson, 1999; Lynn & Lockwood, 1998). This 'effect' is reported as a combination of factors including the use of new and large vehicles and employer-vehicle ownership (Grayson, 1999).

Occupational light vehicle-user is not a job title and frequently the road-based work activity is irregular and incidental to a designated occupation (Stuckey & LaMontagne, 2005). Occupational light vehicle-users work in many industries and include couriers, taxi-drivers, salespersons, tradespersons, and other workers moving between locations. Occupational light vehicle-users drive for work purposes thus differing from private light vehicle road users.

This paper presents a population-based characterisation of the whole occupational light vehicle-user population in the most populous Australian state, New South Wales (NSW). This study aimed to estimate the size of the occupational light vehicle population, describe its characteristics related to users, vehicles, environment, and work arrangements, and to compare these with private light vehicle population characteristics.

METHODS

Study Population

Data was obtained from the NSW Roads and Traffic Authority (RTA) registration data base, the government agency responsible for road safety, driver licensing and vehicle registration. This RTA data included details for all NSW registered light vehicles (n=3,529,761) for the year ending June 2003. Light vehicles are defined by the RTA as vehicles with a gross vehicle mass less than 4.5 tonnes (Roads and Traffic Authority, 2001). Registration is compulsory annually for all new and existing NSW vehicles used on public roads. The June 2003 data were the most recent, comprehensive data available for registered light vehicles. NSW was the only Australian jurisdiction with work-registration categories which could be used as a proxy for work-relatedness. Business registration is mandatory for work-use vehicles and costs around one-third more than registration for private use (Roads & Traffic Authority, 2007). This business registration provides tax and work-related advantages for vehicles used for work, and concessions for vocational groups such as primary producers, who declare their vehicle use to be solely or principally for primary-production.

For the purposes of this study occupational light vehicle registrations were defined as light vehicles registered "substantially for a work purpose" and registered between 1st July, 2002 and 30th June 2003. The occupational light vehicle population (n=646,201) was identified from total light vehicle registrations by removing vehicles weighing more than 4.5 ton; those with a seating capacity of more than 12 persons, and those unlikely to be used on public roads (e.g., forklifts), or with a non-work-related or private usage. (Figure 1). The private light vehicle population (n=2,440,269) was defined as light vehicles registered "substantially for social, pleasure or domestic-use purposes" in the same time period (Roads and Traffic Authority, 2001).

Registration variables were extracted from the RTA data and are presented in four key groups, users, vehicles, environment and work arrangements. These groups were derived using a systems model of potential determinants of occupational light vehicle crashes, which integrates both work- and road-related perspectives (Stuckey, LaMontagne & Sim, 2007). This systems model places the vehicle user at the centre of work- and road-related settings. It recognises that while driving, the OLV-user's workplace is their vehicle, functioning within varied work arrangements and within both the road and OHS legislative environments.

MEASURES

Registrant variables: Age and gender data were extracted from sole-trader first registrants or single vehicle company registrations, where the occupational light vehicle-user could be assumed to be the registrant. This data was therefore available for only around a third of all registrations, the others being company registrants with more than one registration.

Vehicle variables: Vehicle age, type, fuel-type, gear-type, primary color, weight, make and model were extracted. Vehicles were divided into cars, (sedans, coupes, station wagons); or load vehicles (van derivations; utilities; light-trucks). Engine capacity, cylinder numbers and weight were used to describe power and weight.

Road environment: Registered occupational light vehicle location was used to indicate the predominant vehicle-use area and dichotomised into the Sydney metropolitan area versus rural and regional NSW.

Work arrangements: Occupational light vehicles from the "registered operator type" variable were divided into those registered to organisations or those registered to private persons, for their business use. These private-person business-use registrants were those of unincorporated-organisations, for the purpose of this paper referred to as 'sole-traders'. These included a sub-set of occupational light vehicles registered by a company representative, such as a vehicle leasing company, on behalf of and for the use of sole-traders. Usage and customer categories were used to describe users' driving purpose for all occupational light vehicles. 'Fleet size' was defined as the total number of vehicles registered to each registrant.

Statistical Analysis

Data analysis was conducted using Intercooled STATA, version 9.1. Percentages and ranges were calculated for categorical variables. Means and standard deviations were calculated for continuous variables, as well as dividing them into categories. Descriptive variable distributions were compared between occupational light vehicle and private light vehicle registrations. To further explore these effect sizes, odds ratios (ORs) and 95% Confidence Intervals (CIs) were calculated using logistic regression to compare the characteristics in the two groups, e.g. the proportion of males to females in the

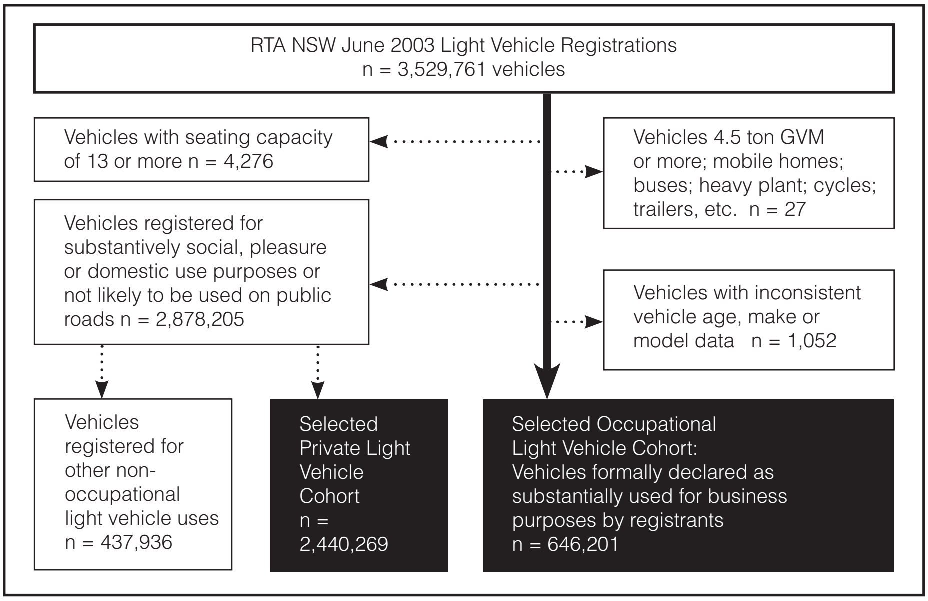

Figure 1: Population Selection Process

Model Level	Characteristic descriptor	Category	OLV Registrants n=646,201	PLV registrants n=2,440,269
Drivers & Passengers	Age of vehicle registrant at time of registration*	16-29 years	6%	17%
		30-44 years	37%	36%
		45-60 years	42%	37%
		60+ years	15%	10%
	Gender of OLV users*	Male	86%	65%
		Female	14%	35%
	Age by gender of OLV users*	16-29 years	Male/Female	Male/Female
		30-44 years	6% / 7%	16/ 20%
		45-60 years	36/ 40%	36/ 37%
		60+ years	42/ 42%	36/ 35%
Work Environment	Type and shape of OLV	Car shape	44%	80%
		4W (SUV)	11%	9%
		Light Truck	44%	10%
		Small Bus	1%	1%
		Sedan,	34%	71%
		Wagon	10%	10%
		Utility (pick-up)	15%	5%
		Van, cab & chassis or table-top.	38%	13%
		Other (bus, animal/furniture carrier, etc)	3%	1%
	Vehicle age	<5 years old	64%	21%
		5-10 years old	21%	32%
		10+ years old	15%	47%
	Vehicle colour	White	50%	31%
		Silver	13%	14%
		Blue	10%	15%
		Yellow, Grey or Red	10%	18%
		Green, Brown or Black	10%	14%
		Sign-writing	<1%	<1
		Other colours	7%	12%
	Type of fuel used in OLV	Petrol	78%	93%
		Diesel	19%	4%
		LPG or Petrol/LPG combination	2%	1%
		Other	1%	2%
	Vehicle power	<2001cc	20%	49%
		>2000cc	80%	51%
		<4 cylinders	45%	70%
		>4 cylinders	55%	30%
	Vehicle weight	1999kg	90%	98%
		2000 - 4500kg	10%	2%
	Gear type of OLV	Automatic	58%	60%
		Manual	42%	40%
	Vehicle Make Market Share	Toyota	25%	21%
		Holden (GM)	20%	18%
		Ford	17%	16%
		Other Makes (n=146)	38%	45%

Table 1: User and Vehicle Characteristics for Occupational Light Vehicles (OLV) versus Private Light Vehicles (PLV): Frequencies

Model Level	Characteristic descriptor	Category	OLV Registrants n=646,201	PLV registrants n=2,440,269
Road Environment	OLV registration location	Sydney region Rural & Regional NSW	65% 35%	63% 37%
Organisational Environment	Nature of registrants work activity	Business General Primary Producers Taxis Others (charity; ambulance, fire, etc.)	85% 12% 1% 2%	100% - - -
	Work arrangements of OLV users	Organisation On behalf of Sole-traders Sole trader (non-incorporated) Non-work purpose	62% 10% 28% -	- - - 100%
	Registrant's industry category – public/private.	State or Federal Government Federal Govt Municipal Bodies State services (police, elect etc.) General Public Other (consular,trusts, etc.)	2% <1% 1% 1% 94% 2%	- - - - - 100%
	Fleet size – number of OLV registered by each registrant	1 vehicle fleet 2-5 vehicles 6-10 vehicles 10+ vehicles	26% 43% 8% 23%	58% 41% 1% <1%
	Govt fleets	<500 vehicles 500- 1500 vehicles >1500 vehicles	7% 85% 15%	<1% n/a n/a

***excludes data from vehicles registered to an organisation with more than 1 vehicle registered.**

occupational light vehicle group compared to the proportion of males to females in the private light vehicle group.

This study was approved by the Monash University Standing Committee on Ethics in Research Involving Humans (SCERH #2003/562)

RESULTS

Occupational Light Vehicle & Private Light Vehicle User and Vehicle Characteristics

While a third of private light vehicles were registered by females, 86% of occupational light vehicle registrants were male (Table 1). Private light vehicle-users were younger than the occupational light vehicle group, 53% being under 45 years of age compared to 43% of occupational users.

Private light vehicles were predominantly car shapes while occupational light vehicle comprised about half and half load and car shapes. Fifty-three percent of all light trucks were occupational light vehicle rather than private light vehicles. Occupational light vehicles were newer compared to the private light vehicles, nearly half the private light vehicles being older than 10 years.

Sydney metropolitan region was the registered location for the majority of all NSW light vehicles, 61% of occupational light vehicles being in the outer Sydney region. Rural or regional registered occupational light vehicles included around 95% of primary producers and half the load vehicles. More than 80% of taxis, 70% of general business and 65% of government registrations were in the Sydney metropolitan region.

More than 98% of private light vehicles were registered in fleets of 5 or fewer e.g. family registrations. A quarter of all occupational light vehicles were in single vehicle fleets. The two largest government-registered fleets were both around 1,800 vehicles.

Comparing characteristics between occupational light vehicle and private light vehicle groups.

The proportion of males to females in the occupational light vehicle population was around three times that in the private light vehicle group, as was the proportion of users more than 30 years of age (Table 2). Around five times as many occupational light vehicle were diesel-fuelled than those in the private light vehicle group. There was little difference between the ratio of occupational light vehicle registered in the Sydney region and that of private light vehicle registrations.

Occupational Light Vehicle Type Characteristics

As occupational light vehicle users register a wide range of vehicle types with known differences in crashworthiness further analysis of the characteristics of the different occupational light vehicle types

Variables	OLV		PLV		OR (95%CI)
	n	%	n	%	
Drivers/Passengers					
Less than 30 years age	25,123	7.6	412,105	17.3	1
30 or more years age	311,650	92.5	1,976,028	82.7	2.6 (2.5-2.6)
Male	205,414	86.05	1,552,573	64.54	1
Female	33,298	13.95	853,129	35.46	3.4 (3.3-3.4)
Vehicle Environment					
Car shape	283,876	43.9	1,953,186	80.0	1
Load shape	362,321	56.1	487,083	19.9	5.1 (5.0-5.15)
Vehicle ≥5 years old	343,495	53.2	1,938,673	79.5	1
Vehicle <5 years old	302,101	46.8	498,983	20.5	3.4 (3.4-3.4)
Other colour	324,893	50.3	1,685,530	69.1	1
White colour	321,308	49.7	754,739	30.9	2.2 (2.1-2.2)
Petrol fuel	506,105	80.8	2,278,313	95.8	1
Diesel fuel	120,374	19.2	101,087	4.2	5.3 (5.3-5.4)
<2001cc engine	129,758	20.2	1,166,646	48.3	1
>2000cc engine	513,415	79.8	1,251,212	51.7	3.6 (3.6-3.7)
≤4 cylinder engine	349,757	54.2	1,697,474	69.6	1
>4 cylinder engine	296,140	45.8	741,307	30.4	1.9 (1.9-1.9)
≤1999kg weight	567,693	88.3	2,382,332	97.7	1
≥2000-4500kg weight	74,861	11.7	55,090	2.3	5.7 (5.6-5.7)
Manual gear	304,318	57.7	975,266	59.6	1
Automatic gear	223,272	42.3	661,979	40.4	1.1 (1.0-1.1)
Road Environment					
Rural/Regional NSW	228,760	35.4	907,472	37.2	1
Sydney region	417,441	64.6	1,532,797	62.8	1.0 (1.0-1.1)

Table 2: User and Vehicle Characteristics for Occupational Light Vehicles (OLV) versus Private Light Vehicles (PLV): Odds Ratios and 95% Confidence Intervals

Registrant Work Arrangement Type	Organisation	Registered on behalf of a sole trader or non-incorporated company	Sole Trader or non-incorporated company	All OLV Registrations n=646201
% Of total OLV registrations	62%	10%	28%	100%
Cars shapes Light Truck shapes 4-Wheel drive	51% 38% 11%	26% 64% 10%	26% 64% 10%	44% 45% 11%
≤4 cylinders 5-6 cylinders >6 cylinders	47% 48% 5%	60% 36% 4%	54% 40% 6%	49% 46% 5%
Vehicle <5 years old Vehicle 5-10 years old Vehicle >10 years old	72% 18% 10%	50% 26% 24%	50% 27% 23%	64% 21% 15%
Registered in the Sydney Region Registered in Rural or Regional NSW	72% 28%	49% 51%	54% 46%	65% 35%
General Business use Primary Producer use Taxi use Other use	91% 6% <1% 2%	77% 23% <1% <1%	70% 27% 2% 1%	85% 12% 1% 2%
1 vehicle fleet 2-10 vehicle fleet 11-500 vehicle fleet 500+ vehicle fleet	21% 42% 25% 11%	31% 67% 2% <1%	34% 55% 1% 0%	26% 51% 16% 7%
1 vehicle fleet - Car shapes - Light truck shapes	 10% 7%	 10% 18%	 16% 14%	 12% 10%
500+ vehicles - Car shapes - Light truck shapes	 7% 3%	 <1% <1%	 0% 0%	 4% 2%

Table 4: Selected Occupational Light Vehicle (OLV) Characteristics By Registrant Work Arrangements

was undertaken (Table 3). Nearly 80% of primary-producer and 44% of general business occupational light vehicle were load vehicles. These load vehicles were more likely to be heavier (OR=5.70, 95% CI 5.65-5.77) but have a lesser engine capacity than that of cars (OR=4.69, 95% CI 3.67-3.71). Half the load shapes were five or more years old in contrast to the car-shapes, of which 74% were less than five years old. Half the occupational light vehicle fleet was colored white, including nearly 80% of load-shaped vehicles.

Occupational Light Vehicle Characteristics By Registrant Work Arrangements

Including the 10% of vehicles leased to sole-traders, 38% of all occupational light vehicles were registered for use by a sole-trader not an organisation. Most were registered for use in general business or primary production work. As work arrangement type may influence occupational health and safety risks, (Quinlan, Mayhew & Bohle, 2001) further analysis was undertaken of occupational light vehicle characteristics across employer and sole-trader work arrangements. (Table 4). Organisations were more likely than sole-traders to register

Occupational Light Vehicle Types (n=646,201)	Cars (sedan, coupe, convertible, station-wagon) n= 283,876	4-wheel drive vehicles (off-road vehicles) n=73,261	Load vehicles (utility, small bus, van, tray truck, cab & chassis, etc.) n=289,064
Of Total OLV registrations	44%	11%	45%
≤ 4 cylinders	35%	35%	69%
5-6 cylinders	69%	57%	28%
≥6 cylinders	6%	8%	3%
≤1999kg weight	99%	65%	86%
≥2000-4500kg weight	<1%	35%	14%
White color	27%	29%	78%
Silver color	20%	20%	4%
Blue color	12%	15%	5%
Other color	41%	36%	13%
Petrol fuel	97%	79%	36%
Diesel fuel	>1%	20%	60%
LPG/LPG+ petrol or diesel fuel	3%	1%	2%
Other fuel	.	.	2%
Automatic transmission	85%	66%	23%
Manual transmission	15%	34%	77%
Vehicle <5 years old	74%	80%	50%
Vehicle 5-10 years old	18%	16%	26%
Vehicle >10 years old	8%	4%	24%
Registered Sydney Region	78%	65%	52%
Registered Rural or Regional NSW	22%	35%	48%
Employer registered	78%	70%	67%
Sole trader registered	22%	30%	33%
General Business use	93%	89%	77%
Primary Producer use	3%	11%	21%
Taxi use	2%	-	<1%
Other	2%	-	<2%
1 vehicle fleet	27%	31%	23%
2-10 vehicle fleet	42%	54%	59%
11-500 vehicle fleet	21%	10%	13%
500+ vehicle fleet	10%	5%	5%

Table 3: Selected Characteristics By Occupational Light Vehicle Types

occupational light vehicle car shapes, less than five years old, in the Sydney area for general business use.

Around half the regionally located vehicles were registered by sole-traders for primary production. Farming or taxi use registered vehicles were more likely to belong to sole-traders than organisations (OR 6.25, CI 6.13-6.35; OR 6.7, CI 6.3-7.1, respectively).

Sole-traders are more likely to register light trucks (OR 1.83, CI 1.80-1.85) than organisations, (OR 2.26, CI 2.23-2.28). Ninety-nine percent of all sole-trader occupational light vehicles were in fleets of ten or fewer registrations.

Load vehicles were more likely to be registered in small fleets (five or fewer vehicles), (OR 1.62, CI 1.60-1.64). Only two occupational light vehicle fleets had more than 5,000 registrations, the larger of these being a fleet of vehicles registered for lease to sole traders for general business use. The majority of these were light trucks, such as those used by couriers, maintenance or trades workers.

DISCUSSION

There has been relatively little research into occupational light vehicle-use and most previous studies have described only a selected sub-set of the occupational light vehicle population. The study findings suggest a substantially larger and more diverse population of occupational light vehicle-users, many with load-shaped vehicles and the majority in small fleets of fewer than five registrations.

The study identified a large group of self-employed and small fleet users of occupational light vehicles, most of whom are male but older than those in the previous British studies.

Little has previously been known of the number or driving patterns of occupational light vehicle-users. Occupational light vehicles may be used in a variety of ways, including daily by a single occupant such as a sales-person, or repeatedly by a series of occupants in the case of a taxi. The identified occupational light vehicle population included only vehicles formally declared in the registration database as substantially used for business purposes. Previous studies have described the blurring between private and work use of light vehicles; Stradling (2001), for example, found nearly 20% of English motorists drove their own cars to do employers' work at least weekly (Stradling, 2001). No published estimates of the number of occupational light vehicle-users in the working population or the road-user population were found in the peer reviewed literature. Considering the likelihood of a private light vehicle being used at least occasionally for work-use and our conservative occupational light vehicle selection process, the 18% of NSW 2003 light vehicle registrations identified as occupational light vehicle is likely to be an underestimate. Regardless, occupational light vehicle-users appear to comprise a substantial sub-set of the labour force and road-users.

Vehicles

While most previous occupational light vehicle research has focused on company-owned car-shapes, Anderson (2001) found 23% of Canadian pick-up (utility) drivers used their vehicles for work, and Lyn and Lockwood (1998) found 9% of UK company drivers used vans (Lynn & Lockwood, 1998; Anderson, Winn & Agran, 1999). In 2003 company registered cars comprised 10.3% of all cars licensed in Great Britain (Broughton et al, 2003). Our study found occupational light vehicles comprise a substantial proportion of all LV registrations including both a greater proportion of all registered cars and more than 50% of all light trucks and other load shapes.

The finding that the majority of NSW occupational light vehicles are load-shaped further underscores the need to include this group in any work-related vehicle studies, particularly as vehicle shape significantly impacts MVC outcomes. Australian crashworthiness studies (1993-2000) rate small cars and commercial vehicles' crashworthiness poorly, with slight improvement for large or medium cars and 4-wheel-drive vehicles (Newstead et al, 2003). Light commercial vans rate 'average' to 'significantly worse than average' for nearly all models and years (Australian Transport Safety Bureau, 2007). Load vehicles are generally not fitted with safety options common to car shapes such as air-bags and ABS braking (Haworth, Tingvall & Kowadlo, 2000; Grayson, 1999; Lyn & Lockwood, 1998; Australian Transport Safety Bureau, 2007). The fact that only three vehicle manufacturers hold 62% of the occupational light vehicle market-share in Australia presents opportunities to influence future safe-vehicle design.

Road Environment

The majority of all light vehicles are registered in the Sydney area, reflecting the general NSW population distribution. Registration location provides information as to the home-base or starting point of work activity for occupational light vehicle users, particularly for sole-traders. Symmons and Haworth (2005) describe crash locations of NSW work vehicles across all vehicle-types as more frequent and serious outside the Sydney metropolitan region (Symmons & Haworth, 2005). Load-shaped occupational light vehicles are more likely to be registered outside the metropolitan areas than car shapes and this combined with their poorer crashworthiness rating suggests an increased crash-injury risk.

Work Arrangements

Work design and arrangements both impact occupational light vehicle-user health and safety. Many workers use vehicles as a mobile office, undertaking work tasks such as phone-calls while driving. Self employed workers and others working in non-traditional workplaces including vehicles, are more vulnerable to both OHS and general health-related risks and are usually not covered or recorded by workers' compensation insurance schemes (Quinlan, Mayhew & Bohle,2001; Lewin-Epstein &Yuchtman-Yaar, 1991). The occupational light vehicle population appeared to mirror Australian contemporary employment trends with up to a third being in non-traditional work arrangements, however males appeared to be over-represented in this group (Australian Bureau of Statistics, 2007). There has been a steady increase in Australian casual employment from 18.9% of the workforce in 1988 to 27.3% in 2003. In NSW in January 2004, 12% of the workforce were sole-traders or own-account workers, and a further 20% were employees without paid leave entitlements (Quinlan, Mayhew & Bohle, 2001, Australian Bureau of Statistics, 2003).

Company-car users have been described as working in managerial, administrative or skilled manual occupations undertaking construction, sales, marketing, trades, courier or farm work (Downs et al, 1999; Salminen & Lahdeniemi, 2002; Australian Transport Safety Bureau, 2001). The conservative selection of work-purpose categories in our study removed potential occupational light vehicle-users such as workers using rental vehicles and the many casual users of their own private light vehicle for work. While most occupational light vehicle-users were in the general business use category, around half of these used load-shapes suggesting cargo or trades activities - their vehicle being both a tool of trade and a means of conveyance.

Study Strengths and Limitations

The RTA collects extensive information about registrants and vehicles, some of which was not available for research purposes because of privacy legislation (i.e., data potentially identifying registrants). Registration data provides useful information about occupational light vehicles but its characterisation of users is limited as the registrants may or may not be the actual users. While nearly 30% of occupational light vehicle were in single fleet registrations (suggesting user-owners) this may not apply to larger and organisation-owned fleets, therefore the number of registrations with information on driver demographics was limited to those of single fleet registrations and sole-operators. No data describing actual numbers of occupational light vehicle-users were available, a particular problem for multiple-user or multiple-use vehicles such as taxis and pool vehicles.

Data for annual kilometers traveled was available for only 3% (n=20,367) of the occupational light vehicle population, insufficient for characterizing road use exposures. Previous occupational light vehicle estimates of annual kilometers have included 4,000 to 40,000 for UK company car drivers; 17,000 for Canadian occupational light vehicles; and 26,800 and 39,800 respectively for Finnish construction-workers and salespersons (Lyn & Lockwood, 1998; Salminen & Lahdeniemi, 2002; Road Transport Canada, 2000; Adams-Guppy & Guppy, 1995; Department for Transport, 2004). ABS motor vehicle use data for October 2002-2003 shows that cars average 11,200 and commercial vehicles 20,300 annual 'business' kilometers, respectively (Australian Bureau of Statistics, 2003). The data which was available suggests annual occupational light vehicle road exposures were considerably more varied than those previously described, with a small group of occupational light vehicles averaging well over 100,000 kilometers annually, particularly taxis. For future studies it would be useful to have kilometres travelled data relating to work purpose and arrangements.

The occupational light vehicle population numbers are likely to be conservative as many private light vehicles are used on an ad-hoc basis for business purposes are not registered as occupational light vehicle. Business registration related advantages for vehicles substantively used for work, does not apply to vehicles only occasionally for business purposes.

The study has some unique strengths as it provides the first available description of a total occupational light vehicle-user population in a large jurisdiction, rather than a sample of a particular user group or company fleet. NSW has the largest Australian vehicle fleet, representing over a quarter of all light vehicles in the country and therefore suggesting these occupational light vehicle population characteristics could be generalized to all Australian occupational light vehicle-users (Australian Bureau of Statistics, 2003). Furthermore, as participation and work arrangement characteristics in the Australian labour force including, gender distribution and employment within industry sectors are similar to those in the USA, Canada, and the United Kingdom, the at-risk occupational light vehicle-user populations of these and other western countries are likely to share many of the characteristics described in this study (Raynor, 2007; Quinlan, Mayhew & Bohle, 2001). This occupational light vehicle population description differs significantly from previous fleet based studies which excluded groups of sole-operators, the self-employed, and load vehicle users (Haworth, Tingvall & Kowadlo, 2000; Grayson, 1999; Lyn & Lockwood, 1998).

CONCLUSIONS

Our study has demonstrated that occupational light vehicle-users are clearly a substantial population within the workforce. User, vehicle, environment and work arrangement characteristics suggest a more diverse mix than previously described in the occupational light vehicle-crash literature with features such as the greater number of load-shaped vehicles which increase the crash likelihood of an occupational light vehicle compared to a private light vehicle. The worker's vehicle is their workplace when used on public roads while working, and the workplace should be safe regardless of the work arrangement, vehicle type or journey purpose (Stuckey & LaMontagne, 2005). To date, there has been minimal application of OHS policy to the occupational light vehicle as a workplace. Addressing identified risk factors for occupational light vehicle motor vehicle crashes could help reduce occupational light vehicle trauma as well as the general road toll.

In future studies linked light vehicle crash data and occupational light vehicle population data would enable the extrication of work-road crashes from general motor vehicle crashes, improve data capture and facilitate detailed exploration of occupational health and safety-risk factors across all occupational light vehicle-users. This could underpin the development of essential occupational light vehicle-related OHS policy and practice (e.g. the provision of safer commercial vehicles), thereby assisting to reduce the impact of occupational light vehicle crashes as a serious contemporary occupational health problem.

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