Risk Matrices: implied accuracy and false assumptions

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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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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)
1.0 – 0.8	Almost certain	High	High	Extreme	Extreme	Extreme
0.8 – 0.6	Likely	Medium	High	High	Extreme	Extreme
0.6 – 0.4	Possible	Low	Medium	High	High	Extreme
0.4 – 0.2	Unlikely	Low	Low	Medium	High	High
0.2 – 0	Rare	Low	Low	Medium	High	High
		0 – 0.2	0.2 – 0.4	0.4 – 0.6	0.6 – 0.8	0.8 – 1.0

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).

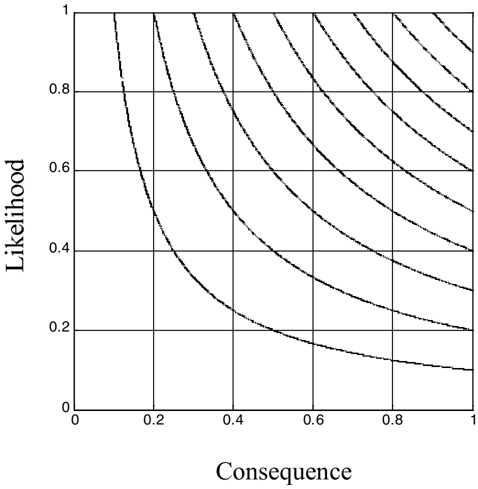

Figure 2 Risk matrix showing lines of equal risk conforming to y=1/x

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.

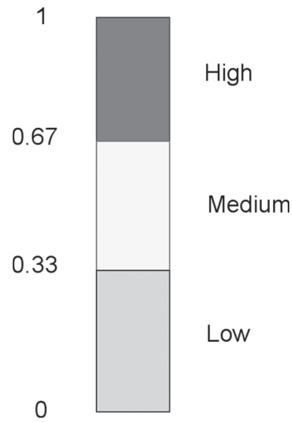

Figure 3 Equal distribution of risk categories

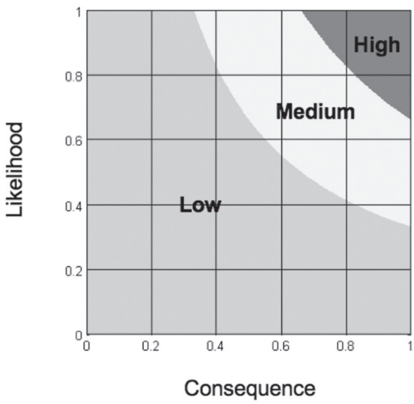

Figure 4 Risk matrix showing equal distribution of risk categories

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.

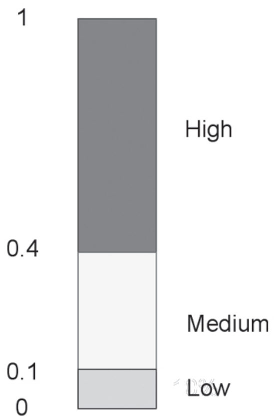

Figure 5 Adjusted distribution of risk categories

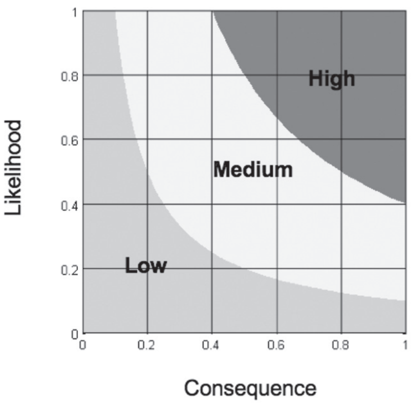

Figure 6 Risk matrix showing arbitrarily adjusted distribution of risk categories

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

Likelihood axis: 1.0, 0.8, 0.6, 0.4, 0.2, 0; consequence axis: 0, 0.2, 0.4, 0.6, 0.8, 1.0; points α, β

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).

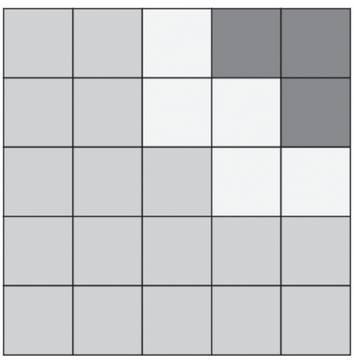

Figure 8 Five by five matrix (Adapted from Cox, 2009, p. 114)

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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