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Transitioning Workplace Risk Assessments From Qualitative to Quantitative

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ABSTRACT

This article compares qualitative and quantitative approaches for assessing the risks of occupational hazards. Both approaches need a means for comparing the risk of a process with an indicator of acceptability based on two components—severity of foreseeable hazardous scenarios and likelihood of occurrence. These two components are presented in a 2-dimensional grid, or matrix, with axes for severity and likelihood. The common design of risk matrices uses categories for row and column axes with their intersection being the point for defining risk into categories. This paper presents an innovative pathway for transitioning risk matrices from being categorical to being quantitative. This involves making the axes continuous variables and making their product serve as a risk indicator. The author describes how employers may use quantitative risk assessments as tools to complement traditional rule-based approaches to make employment safer.

Keywords: Risk assessment, Risk rating, Risk measurement, Psychometric scales, Safety

INTRODUCTION

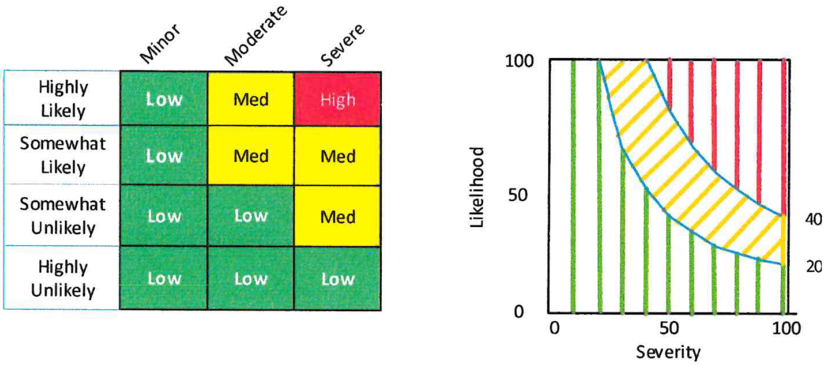
The risk-assessment approach grew out of a need for a feasible means to compare risks of a workplace system with an organization's level of risk acceptability.

Background

For a recognized hazard in a workplace, risk is commonly determined by considering two factors: one is severity of a hazardous event or exposure, the other is likelihood of the event or exposure. These are the factors used in this article. Similar factors used by some authors and organization refer to consequence and probability (Clemens et al., 2005; Nolan, 2011; Bahr, 2015; Duijm, 2015; Jensen, 2024). The format is typically presented as a chessboard-like rectangle with one axis for severity and the other for likelihood. In the rectangular area defined by severity and likelihood are indicators marking zones of similar risk commonly distinguished by the colours red, yellow, and green. Two fundamentally different ways of separating these zones are based on qualitative and quantitative axis scales. Examples in Figure 1 facilitate comparison of the two approaches.

Qualitative Approach

The qualitative approach uses a table structure as depicted in Figure 1(a) in which columns are labeled using ordered terms for severity and the rows are labeled using ordered terms for likelihood. Where rows and columns intersect to form rectangular cells, like in a spreadsheet, are risk indicators (RI) using words, colours, or both.



(a). Qualitative Matrix (b). Quantitative Matrix

Figure 1: Examples of risk-assessment matrices. The qualitative matrix on the left has 12 cells. The quantitative matrix on the right has both axes of 100 units, and shows iso-risk lines with values of 20 and 40 according to Risk = 0.01 x Likelihood x Severity.

Qualitative matrices use categorical scales for one or both axes. The 12 cells making up the risk area in Figure 1(a) use words and colors to indicate risk categories. Risk matrices with one categorical axis and one quantitative axis are considered qualitative or hybrid. The axis categories are intended to be ordered with clearly distinct categories. Traditionally, terms used as row and column headers are selected by the matrix designer or committee with little or no science. An example of how this approach is problematic was revealed by results of the survey of university students reported by Jensen and Hansen in 2020. They found the terms for row categories used in a well-known risk matrix includes categories that fail the goal of having clearly distinguishing adjacent categories.

A fundamental weakness of the qualitative (or categorical) approach is obtaining a numerical risk indicator to put into the cells. A common approach to creating numbers for the cells is to assign order numbers to both severity and likelihood axes, then inserting a numeric into each cell based on multiplying the row and column order numbers. Although multiplying order numbers makes no sense mathematically, the RIs resulting from this approach provide an easy means for separating zones of similar risk indicators (Lyon & Popov, 2020; Allen & Mahoney, 2025).

Quantitative Approach

The quantitative approach also uses a rectangular area but without being filled with rectangular cells; instead, areas of similar risk are separated by curved iso-risk lines formed by the equation: Risk = 0.01 × Likelihood × Severity.

As shown in Figure 1(b), both independent variables use a continuous line ranging from zero to 100. Quantitative approaches have a means for computing a numerical RI value for any point on the risk area. Although the risk area is not a true matrix, it is referred to as a matrix for this article. The system safety community has been using this approach for high-risk hazards like aviation crashes, nuclear power generation, and highly-hazardous chemical processes (e.g., Rausand, 2011). The occupational safety community has recognized the mathematical validity of this approach, but not embraced it. This could be due to a combination of the higher level of mathematics required and a sense the effort involved in finding more accurate RI values for common workplace hazards would exceed the utility of having more accurate estimates of risk.

METHODS

In Figure 1(b), both axes use a novel, mathematically justifiable, and accurate approach to create a valid risk-assessment matrix built on a foundation of the prior research described here. It involves establishing each axis as a 0–100 scale with points in the risk area computed by the product of severity (S) and likelihood (L). Lines of iso-risk can be drawn on the risk area and used to separate areas of similar risk. Typically, risk in the green and red areas indicate acceptable and unacceptable risk, respectively. Risk in the yellow area may be tolerable, depending on other factors such as financial considerations and assurance the risk has been reduced to as low as reasonably practicable (Marhavilas & Koulouriotis, 2021). This requires establishing continuous scaled axes.

Establishing Rating Scales

In order to bring more science to occupational safety, an investigation into terms used for row and column headers of risk-assessment matrices was undertaken. The plan was to learn what terms are fitting for levels of severity and likelihood, and what numerical values each term means to users. The choice of a rating scale appropriate for this aim borrowed on an extensive body of knowledge on measurement used in risk perception studies. Three forms of response scales were found in the risk perception studies identified by the author of this paper as being relevant to employment risks. One form uses Likert-style responses to a hazardous scenario; two examples are Xia, Wang, Griffin, Wu, & Liu (2017), and Álvarez-Chávez et al. (2019). The second form used a rating scale with eleven numbers (0 through 10), for example Lin et al. (2025). The third form used a bi-polar rating line with only end points labelled, for example, overall risk of working in a college chemistry laboratory used end points "very small risk" to "very high risk" (Álvarez-Chávez et al., 2019). End point examples for a severity scale were "not at all severe" and "extremely severe" (Man, Chan, & Alabdulkarim, 2019). The third form of rating scale was also used by the author and students in two surveys (Jensen & Hansen, 2020; Jensen, Bird, & Nichols, 2022). Both studies were intended to identify terms in use relevant to *severity, likelihood,* and *probability*. The first study had 84 undergraduate students taking senior-level courses in engineering or occupational safety and health (Jensen & Hansen, 2020). Participants were given a paper survey notebook part of which contained pages for ratings. Each page contained a term and an appropriate rating scale for the participant to mark the location where that term belongs on a 100-length line with only end-points labelled. All terms came from books and journal papers discussing risk assessment matrices. Half the terms were found on one or more scales for severity while the other half were found on matrices using likelihood or probability axes. Rating line end points for severity were worst harm and no harm, and for likelihood certain and no chance. Based on the survey findings, we began analyses by discarding terms to not recommend because of ambiguity or large variability in responses. The remaining terms were further searched looking for sets potentially suitable for recommending as headers for rows and columns in qualitative matrices. Because risk-assessment matrices come in different sizes, sets of terms were chosen to fit three, four, five, and six rows for likelihood as well as three, four, and five columns for severity.

The second survey by Jensen et al. (2022) used Qualtrics survey software (Provo Utah USA) for online participants to respond directly. Using a 100-length rating line, participants were able to mark any point on the rating line thereby removing any influence of having markers between the end points. The terms recommended by the first study authors were followed up with the aim of confirming or improving the recommended terms by using graduate students enrolled in an industrial hygiene online program. Each student had at least two years of work experience in industrial hygiene, safety, or other related field. Some additional terms were added as candidates to fill parts of the axes not well covered by terms tested in the first study. All but one of the terms recommended from the first study were confirmed in the second study (Jensen et al.). The exception was the term "somewhat likely" which had medians of 60 and 40 and means of 53.4 and 45.5 in the first and second survey, respectively. In an effort to find a different term for the middle range of likelihood, the term "moderately likely" was added to the second survey resulting in median and mean values of 55 and 57, considered by the authors as suitable for recommending.

Innovating

Two years after publishing the first and second studies on terms used in risk matrices, the author recognized the potential for using the ratings and terms for a different purpose—to serve a critical role in transitioning from qualitative matrices to quantitative matrices. The idea was to use applicable rating scales for the respective axes in quantitative matrices. Two rating lines are shown in the two panels in Figure 2, for severity and likelihood, respectively. Each line uses a 0–100 scale line with guide terms selected from results of the earlier surveys (Jensen & Hansen, 2020; Jensen et al., 2022).

Another attribute of this method for determining hazard-specific RIs lies in the distinction between subjective and objective data. As envisioned by the author, each RI of a defined system begins by having every member of the risk assessment team provide their ratings of severity and likelihood using the rating scales on Figure 2. Although these individual ratings are subjective, the computed average ratings of multiple individuals are objectively determined by equation. For example, for a specific hazard, each of the team members contributes a numerical rating of severity (S_n) and another for likelihood (L_n). The whole team's mean RI for that hazard will then be computed from Equation 1 by multiplying 1/100 × Mean S × Mean L:

$$Mean\ RI \ = \ 0.01 \times \frac{1}{n}\sum_{1}^{n} S_n \times \frac{1}{n}\sum_{1}^{n} L_n. \tag{1}$$

A similar approach, except the judgments of team members are in the form of ranks instead of values on a continuous scale, was reported by Bejinariu, Darabont, Burduhos-Nergis, Cazac, and Chiriac-Moruzzi (2023).

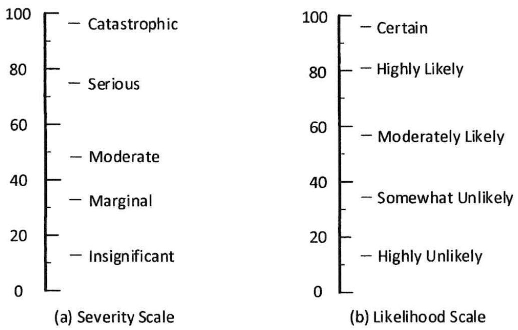


Figure 2: The two rating scales being recommended for (a) severity and (b) likelihood as pathways for obtaining ratings by members of a risk assessment team based on their knowledge and understanding of the residual risks of a particular hazard.

RESULTS

The key property of the axis scales is making each axis use a 0–100 range with guide words marking values as depicted in Figure 2. Guide word numerical values are the median values found in the earlier studies (Jensen, 2020 and Jensen et al., 2022). These rating lines are presented as the critical links for transitioning from the categorical to quantitative risk-assessment matrices. Figures 3 shows the guide words in order with bars indicating mean rating.

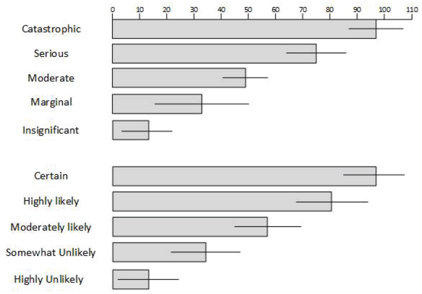


Figure 3: Bar Charts showing mean ratings and ± one standard deviations. Severity terms in upper panel, likelihood terms in lower panel.

DISCUSSION

Implications for Occupational Safety Management

Implementing a risk-assessment approach includes deciding on levels of risk acceptance, risk tolerance, and unacceptable risk. In the examples of quantitative approaches in Figures 1 and 3, iso-risk lines of 20 and 40 are displayed. These are for illustration only. Each organization needs to establish their own lines. Marhavilas and Koulouriotis (2021) provide guidance for establishing organization-specific risk acceptance criteria.

A vision of increasing use of risk-assessment approaches to complement traditional rule-based approaches will achieve safer employment in four ways.

First, risk-assessment approaches provide an alternative for managing hazards not adequately covered by required rules, regulations, and standards. Examples in the United States include hazards of manual lifting, repeated exertions, heat exposure, workplace violence, terrorism, and worker exposure to live-traffic in roadway work zones.

Second, RA teams following the approach described here avoid the shortcut of assigning RIs to hazards without first thinking through each of the two factors, severity and likelihood. An example might be a worksite with three hazards (H1, H2, H3) identified. By having each of the RA team members independently assign a value of S_n and L_n for each hazard, the average S and L value is used to compute the team's average RI. Examples of hypothetical RI locations are plotted in Figure 3. The RIs plotted in the risk area provide a visual means for evaluating and prioritizing how each hazard compares to the employer's risk tolerance according to the iso-risk lines 20 and 40. These three examples illustrate locations with low severity and low likelihood (H1), low severity and high likelihood, (H2), and mid-levels of both severity and likelihood (H3).

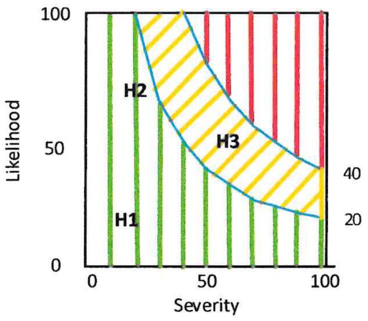


Figure 4: Quantitative risk matrix with risk indicators for three hazards plotted at their respective location.

Third, the process presented here also provides a means to quantify each factor, and their combined consideration, to arrive at an RI supported by justifiable considerations. An RI will never be perfect because it depends on estimating the future, but for purposes of risk management, the method of averaging judgments of multiple informed individuals should yield more objective risk estimates than more subjective means.

Fourth, this approach will be feasible to implement while yielding more accurate values of risk than the qualitative approach.

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