Seven Attributes of RISK ASSESSMENT

By Roger C. Jensen

IN THE OSH FIELD, risk assessment matrixes (RAMs) have become a widely used tool because of their usefulness (Baybutt, 2018; Main, 2020). These practical tools provide a means for characterizing the risk level of identified hazards and foreseeable hazardous scenarios. Risk level serves as valued inputs for several management processes.

Four management processes stand out as using risk level information. One is for use in making decisions about allocating resources. Another is for measuring progress in continual improvement processes. A third is measuring risk level prior to and after a safety-related activity, and a fourth is supporting decisions about acceptability of residual risks (Ale et al., 2015; Baybutt, 2018; Main, 2020). All four uses of risk level information have developed out of a need for risk measurement.

Although RAMs provide a practical, measurement-like tool for risk assessments, their simple appearance hides their underlying complexity. RAMs actually provide a means for obtaining indicators, not measures, of the level of risk of particular hazardous scenarios. The risk indicators (RIs) provided in RAMs are used in domains including protection of people, environment, property and business (Lyon et al., 2022). For this article, however, the focus is on RIs for the occupational hazards faced by employees (ANSI/ASSP/ISO, 2022; Cox, 2008; Duijm, 2015; Jensen, 2006, 2019; Nolan, 2017).

RAMs are most commonly in grid format with columns for severity categories, rows for likelihood categories and cells for RIs (Ball & Watt, 2013; Jensen et al., 2022; Main, 2004; Modarres, 2006; Pons, 2019). But there are many other options for the matrix rows and columns as well as other attributes of RAMs (Clemens et al., 2005).

The rationale for RAMs is based on the idea that future risk ($Risk_B$) of a hazardous occurrence (B) may be estimated by multiplying foreseeable severity (S) given that B occurs (S|B) times probability of occurrence (P_B) or likelihood of occurrence (L_B) as in Equations 1a and 1b (Modarres, 2006; Rausand, 2011).

KEY TAKEAWAYS
- **Risk assessment matrixes provide a measurement-like tool for characterizing hazard risk by accounting for severity and likelihood. The best matrix format depends on the needs of the organization.**
- **The many differences between risk matrixes are due to seven attributes: fundamental elements, orientation, size, axes scales, row and column header terms, risk indicators, and cell colors.**
- **This article focuses on the two-factor model of risk as a function of severity and likelihood. It was developed with the aim of sharing with the occupational safety community an appreciation for risk assessment matrixes beyond what is typically found in books and articles.**

Equation 1a:

$$Risk_B = (S|B) \cdot P_B$$

Equation 1b:

$$Risk_B = (S|B) \cdot L_B$$

Equations 1a and 1b apply if both terms are quantitative, like the S variable in terms of monetary loss, and the P and L variables being expressions of chance. If severity is not quantitative (thus qualitative), then risk indicators in the cells must be alternatives to the simple multiplications in Equations 1a and 1b. This article focuses on the two-factor model of risk as a function of severity and likelihood. Readers interested in more thoughts on defining risk may appreciate discussions in Kaplan (1997) and Rausand (2011).

In high-risk industries such as nuclear power, aviation, space travel, deep-sea exploration and many industrial plants processing highly hazardous chemicals, Equation 1a is used. Because of the importance of having accurate probability values, these are sometimes referred to as probabilistic risk assessments (Bahr, 2015; Modarres, 2006). However, for a large portion of ordinary-hazard industries, less mathematical approaches are desirable to help achieve visual appeal, ease of use and better communicate results of a teams' risk assessment to decision-makers (Duijm, 2015; Jensen, 2019; Jensen et al., 2022; Lyon et al., 2022; Pons, 2019).

This article was developed with the aim of sharing with the occupational safety community an appreciation for risk assessment matrixes beyond what is typically found in books and articles. For readers seeking more background on risk assessment matrixes, recommended articles include Baybutt (2018), Duijm (2015) and Clemens et al. (2005). From these and many other articles on RAMs, the author has identified seven attributes that contribute to the diverse variations in RAMs. This discussion focuses on seven RAM attributes: elements of RAMS, orientation of axes, size of the matrix, scaling the axes, terms for row and column headers, risk indicators in the cells, and assigning colors to cells.

Seven Attributes of RAMS

1) Elements of RAMs

Two-factor RAMs consist of three elements in a table—columns, rows and cells as depicted in Figure 1a. The example in Figure 1b has columns for severity of foreseeable harm and rows for likelihood. An alternative is to put likelihood in the columns and severity in the rows. Most recent articles in peer-reviewed journals use the row/column arrangement in Figure 1b, and that is generally followed in this article (Baybutt, 2018; Cox, 2008; Duijm, 2015; Jensen et al., 2022; Leveson, 2019; Main, 2004; Pons, 2019).

MATRIXES

For the chance of a harmful occurrence, the terms "probability" and "likelihood" are used in the literature. The term "likelihood" is used in this article to mean chance of something harmful happening. This is consistent with risk management vocabulary adopted for ANSI/ASSP/ISO 31000, Risk Management.

The cells within the chessboard-like table—the risk space—contain some sort of RI, based conceptually on Equations 1a and 1b. Equation 1a applies in the special case where severity categories are numerical (e.g., monetary), the rows are values of probability, and their product, when entered into applicable cells, will be quantitative based on monetary units. In practice, these values are crude estimates of what might occur in the future (Leveson, 2019). If the rows and columns are ordered categorical variables, the RIs will be qualitative categories such as those in Figure 2. Matrixes incorporating aspects of both quantitative and qualitative are discussed in another section.

2) Orientation of Axes

Orientation is an attribute of RAMs best explained using the Cartesian coordinate system depicted in Figure 3a (p. 28), with quadrants identified by Roman numerals. The placement of a RAM in one of these quadrants determines the positive and negative direction of each axis. To illustrate this, Figure 3b (p. 28) depicts a RAM in each quadrant. Red is used for the cells with the greatest risk and green for the lowest risk. Thus, the RAM orientation in quadrant I has both axes positive. In quadrant II, the rows are positive and the columns are negative. The literature on risk has numerous matrixes in quadrants I and II, none in quadrant III, and few in quadrant IV. Examples of quadrant II RAMs are found in Rausand (2011), Piampiano and Rizzo (2012), U.S. Department of Defense (2012), and Ruan et al. (2015). Clemens et al. (2005) provide examples of matrixes in both quadrants I and II. Their preference (which they referred to as Approach B) corresponds to the matrix in quadrant I of Figure 3b.

The four pictograms in Figure 3b have five rows and five columns making 25 total cells. Having an equal number of rows and columns is common, but unnecessary. A more important attribute is the size of the RAM.

3) Matrix Size

The RAM size may be described by the number of rows and columns or by the number of cells. The four-by-four RAM in Figure 2 has 16 cells. Organizations have options for adopting differently sized RAMs. Options may be based on their industry or a requirement of their customer, or may be tailored to their unique needs (Main, 2004, 2020). Organizations that

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FIGURE 1
ELEMENTS OF RAMs

Figure 1a shows a generic two-factor RAM consisting of columns, rows and cells in a table format. In Figure 1b, the axis factors are labeled.

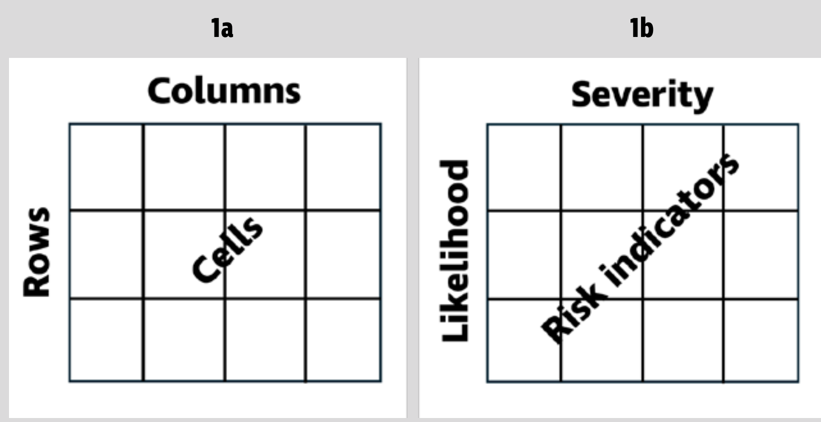


FIGURE 2
QUALITATIVE RAM

Example of a RAM with columns for severity categories and rows for likelihood categories. Three qualitative RIs are in the risk space.

Likelihood	Severity: *Negligible*	*Marginal*	*Serious*	*Catastrophic*
Highly likely	Low	Medium	High	High
Somewhat likely	Low	Medium	High	High
Somewhat unlikely	Low	Low	Medium	Medium
Highly unlikely	Low	Low	Low	Low

FIGURE 3
RAM ORIENTATION

Options for orientation of a RAM: Cartesian coordinate system (Figure 3a); four optional orientations for a RAM (Figure 3b). Corners with greatest risk are colored red and least risk colored green.

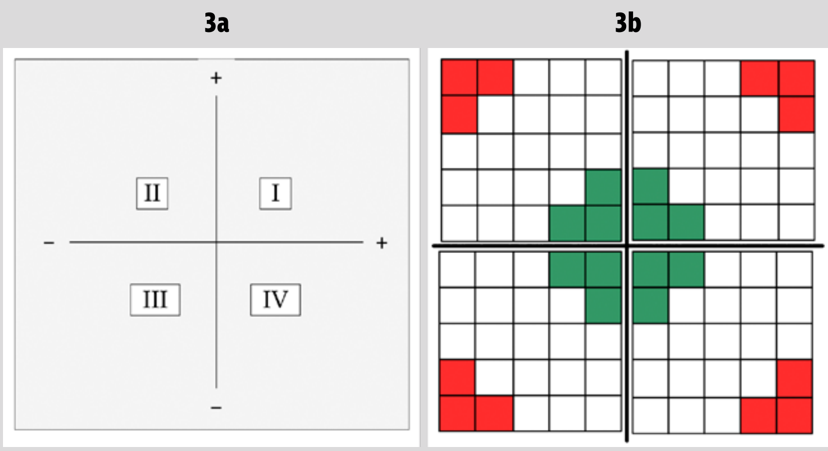


FIGURE 4
QUADRANT II RAM

Example of a quadrant II RAM from the U. S. Department of Defense.

	Catastrophic	Critical	Marginal	Negligible
Frequent	High	High	Serious	Medium
Probable	High	High	Serious	Medium
Occasional	High	Serious	Medium	Low
Remote	Serious	Medium	Medium	Low
Improbable	Medium	Medium	Medium	Low
Eliminated	Eliminated			

Note. From "Standard Practice for System Safety (MIL-STD-882E)," by U. S. Department of Defense, 2012 (https://bit.ly/3QAODyN).

sell products to the U.S. Department of Defense may feel compelled to use a matrix specified in the procurement materials such as the one for system safety programs in Figure 4. It illustrates a 20-cell RAM with four risk levels plus one for eliminated hazards. This widely recognized RAM is an example of a quadrant II RAM.

Two core considerations for selecting the size of a RAM are user capabilities and resolution. In choosing the size of a RAM, the initial consideration is the capabilities of those who will be using it. Relatively simple RAMs with four or six cells are better suited for less advanced users. Intermediate users may consider RAMs with nine, 12 or 16 cells. Larger RAMs with 20, 25, 30, 36 or more are for more advanced users.

The second consideration in choosing RAM size is resolution. This concerns a matrix with more cells and more risk categories compared to a lower-resolution matrix. If estimates of severity and likelihood are rather crude, there is no sense expecting people to reliably distinguish adjacent cells having small differences in their row and column categories. On the other hand, using a RAM with too few cells may be insufficient to get full value from the risk indicators. Figure 5 provides two RAMs to contrast matrix size. Figure 5a is a nine-cell matrix with lower resolution that is easier to use compared to the 30-cell matrix of Figure 5b, which has higher resolution but is more challenging to use. A team's choice of categories is based on information and judgment. Particularly in a large matrix (Figure 5b), the team's assignment of a specific cell in the RAM should be regarded as an approximation. Goerlandt and Reniers (2016) propose several ways a team may include in its report a display communicating the uncertainty of the chosen cell.

4) Scaling the Axes

Several respected authors have proposed ways to assign numbers to the axes of RAMs with the aim of using those numbers to create numerical RIs in the cells. Three common ways are numbering, exponential or logarithmic scales, and normalized linear scales.

Order Numbers

Axes sorted into ascending groups provide a natural order for the categories. The 16-cell matrix in Figure 6a (p. 30) and the 20-cell matrix in Figure 6b (p. 30) illustrate the order-number approach. In both examples, order provides the numbering for both row and column categories. The RIs in the cells are the product of the applicable order numbers of the cell's row and column. Strengths of this approach are simplicity, transparency and ease of communicating with decision-makers. A weakness of this approach is the use of multiplication based on ordered-category numbers that could just as easily be assigned letters instead of numbers. Thus, the risk indicators computed by multiplying order numbers provide an option for roughly sorting cells into higher and lower risk levels (Duijm, 2015), but RIs in the cells should not be used for any computations (Leveson, 2019). For example, it may be tempting to use RI numbers to calculate the percentage of risk reduction if a new risk-reduction tactic were to be implemented. Such a calculation will be influenced by the number of rows and columns. It would be better for an organization to adopt a RAM with RIs being independent of the number of rows and columns. For example, the four-by-four matrix in Figure 6a has a range of 1 to 16, while the four-by-five matrix in Figure 6b has a range of 1 to 20.

Exponential or Logarithmic Scaled RAMs

RAMs used for probabilistic risk assessments label the axes using exponents of 10 (or $\log_{10}$). The rationale is that a RAM using exponential numbering makes each category 10 times greater than the next lower category. This applies to both axes (Baybutt, 2018). The belief is that a team of people assigning probability and severity to a particular hazard can make an estimate no finer than that. For example, the probability categories for a four-category probability axis could be, from maximum probability to the least probable, 1.0, 0.1, 0.01 and 0.001. Similarly, for severity categories based on monetary units, the columns may be, from most to least severe, 10^5, 10^4, 10^3, 10^2 and 10^1. That would achieve the desirable attribute by making the most severe category (i.e., catastrophic) much greater than the least severe category (i.e., negligible or no harm). In order to help risk-assessment teams assign a specified hazard scenario to the most appropriate categories of severity and probability or likelihood, RAMs need a key with well-defined descriptions and examples of each category.

It is not technically necessary to divide the risk space into rectangular cells. Figure 7 (p. 31) shows an example of using continuous scales instead of rectangular cells to assign red, green and yellow colors to areas of similar risk according to Equations 1a or 1b. The green region in Figure 7 includes space for RIs no greater than the 0.1 line, and the red space includes areas for RIs greater than the risk line 10.

Normalized Linear Scales

A third method for labeling the horizontal and vertical axes of RAMs is to use the same scale for both and assign numbers using a normalized 10-based scale (0 to 1, 0 to 10, or 0 to 100). For the likelihood axis, a zero value represents a not credible occurrence, and a value of 10 represents certain to occur. For the severity axis, a zero value represents no harm and a value of 10 represents harm resulting from a worst credible incident. Cox (2008) provided the mathematical justification for using normalized linear axis scales to fill the gap between the probabilistic risk matrixes and the categorical risk matrixes used by many OSH practitioners. Cox proposed to scale each axis 0 to 1, resulting in a graphical risk space of value 1.0. Because using axes scaled 0 to 1 yields decimal points for every number in the risk space, this author recommends scales of 0 to 10 for both axes. This makes the risk space consist of 100 square units. The risk space has a natural zero on the lower left corner and a 100 value in the upper right corner. With ordered values and equal spacing throughout the range 0 to 10, each axis will be a continuous linear ratio scale variable suitable for basic mathematics similar to applying mathematical operators using a percentage variable with a scale ranging from 0% to 100%. One computation with potential value would be quantifying the risk reduction expected by a particular risk-reduction tactic.

Equation 2:

$$Percent\ reduction = 100 \cdot \left(\frac{RI\ before - RI\ after}{RI\ before}\right)$$

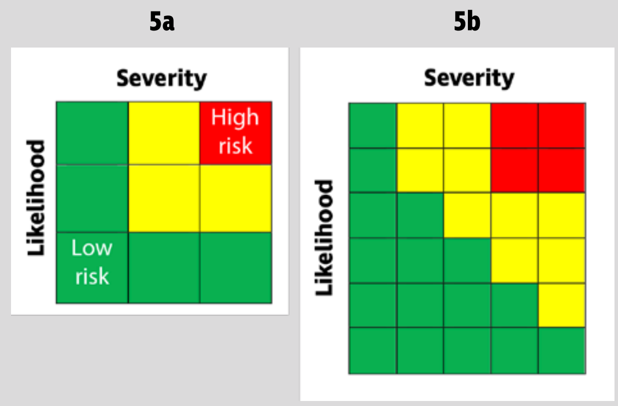
Equation 2 may be used for normalized linear scales, but not for order-based RIs, like in Figure 6 (p. 30). As Leveson (2019) notes, "the use of two ordinal scales makes it impossible to do sophisticated calculation with the entries."

The 10-based method provides RIs based on multiplying numbers in the cells' row and column. Multiplication is permitted under the following assumptions: the numbers are ordered, spacing between numbers are equal and continuous, and each scale ranges from none to all (e.g., 0 to 10 or 0 to 100). Furthermore, the underlying scale numbers are based on assumptions that the normalized scales are a reasonable alternative to the true exponential values because the RIs computed using Equation 1b will be in consistent order as the corresponding RIs computed by the exponential axes. The arguments provided by Cox (2008) have been written about with approval by several risk experts (Ball & Watt, 2013; Bao et al., 2017; Baybutt, 2018; Duijm, 2015; Goerlandt & Reniers, 2016; Ji et al., 2021; Ruan et al., 2015).

FIGURE 5

RESOLUTION

Contrast between RAMs of lower (Figure 5a) and higher (Figure 5b) resolution.



5) Terms for Row & Column Headers

The terms used for row and column headers can help risk analyzers select the most fitting option for severity and likelihood, provided the category terms are ordered and clearly separated (Burlet-Vienney et al., 2016). Historically, committees selected header terms without empirical research to support the chosen terms (Clemens et al., 2005). Researchers with Montana Technological University undertook two studies to address this knowledge gap. The first study was an on-campus survey of undergraduates majoring in engineering or OSH (Jensen & Hansen, 2020). Using 100-point rating scales, 84 participants rated terms presented in a traditional paper format. Mean ratings for each term were used to identify best sets of terms for different numbers of rows and columns. A follow-up study surveyed graduate students enrolled in a distance-learning industrial hygiene program, resulting in 37 completed surveys (Jensen et al., 2022). These participants had 2 or more years of work experience in a position related to industrial hygiene. The aim of the second survey was to confirm or modify findings from the first survey. Results from the second survey confirmed those of the first survey with one exception. For the term "somewhat likely," median ratings by the undergraduate students (60) were higher than the median ratings by the experienced online students (40). Recommendations based on the two studies applied to terms for severity, likelihood, probability and exposure. The criteria guiding set selection were that terms should be clearly distinguished from terms below and above each other, spacing between terms should be approximately equal, and mean ratings from the two surveys should be approximately consistent.

For severity, the recommended set for a matrix with three categories was severe, moderate and minor. For a matrix with four categories, the recommended set was catastrophic, serious, marginal and negligible (see Figure 2, p. 27). For a matrix with five severity categories, the two recommended sets were 1) catastrophic, severe, moderate, marginal and insignificant; and 2) catastrophic, serious, moderate, marginal and insignificant.

For likelihood, the recommended set for a matrix with three categories was highly likely, somewhat likely and very unlikely. For a matrix with four categories, the recommended set was highly likely, somewhat likely, somewhat unlikely and highly unlikely (see Figure 2, p. 27). For a matrix with five likelihood categories, the recommended set was certain, highly likely, somewhat likely, somewhat unlikely and highly unlikely. For a matrix with six likelihood categories, the recommended set was highly likely, likely, somewhat likely, somewhat unlikely, unlikely and highly unlikely. Some options to consider for likelihood are noted in Jensen et al.'s (2022) research paper, as are two other sets of terms sometimes used in RAMs: probability and exposure duration. After a risk-assessment team has decided on the appropriate categories for likelihood and severity, the RIs in the intersecting cells are used as input to the next step: determining cell coloring.

6) Risk Indicators in the Cells

The RIs in the cells are based on the intersection of chosen row and column values. RIs are intended to indicate the risk reflecting both severity and likelihood. These indicators may be as simple as high, medium and low, or red, yellow and green. It is apparent from the attention given to RAMs in the literature that many organizations prefer having numerical risk values in cells. Different organizations have their own uses for the RIs.

According to Cox (2008), an elementary rule (axiom) is that the axis labeling must use a continuous linear equal-interval ratio scale to multiply the numbers on the two axes of a RAM to obtain RI values using Equation 1b (p. 26). Another rule for both severity and likelihood is that each category must be clearly different from the categories below and above it. Defining bands of similar risk starts by establishing iso-risk lines. Figure 8 has five examples of iso-risk lines suitable for applying colors to groups of cells with similar RIs. The lines may be used to define risk bands in the 10-by-10 graphical risk space.

To complete the process of designing a RAM, the rectangular cells are drawn on the same risk space as the iso-risk lines and used as input to the next step: determining cell coloring.

7) Assigning Color to Cells

The matrixes in Figures 4 and 5 (pp. 28-29) use colors to show cells having similar RIs. The colored groups can be used to inform decisions on allocation of resources for risk reduction and decisions on acceptability of residual risks. Thus, accurate RIs contribute to informed OSH-related decisions and more effective OSH programs. To make the color grouping rational, a method is needed to scale the horizontal and vertical axes.

An advantage of a matrix having both axes scaled 0 to 10 is that it provides a basis for rational decisions on assigning colors to cells of similar risk (Bao et al., 2017; Cox, 2008; Jensen et al., 2022). The coloring decisions begin by drawing one or more lines of equal risk, such as depicted in Figure 8. The process is to decide on a value of RI, compute the likelihood value (L) for each value of severity (S) using L = RI/S, plot the point-pairs as dots and connect them as illustrated in Figure 8. For example, the lowest line in Figure 8 is for an RI of 20 and the highest line is for an RI of 60. These lines have the advantage of being independent of the number of rows, columns and cells. Another advantage of a 10-by-10 matrix is defining the width of each row and column. A conventional RAM has equal-width rows and equal-width columns. If, for example, one wants four categories of likelihood, draw horizontal lines at 2.5, 5.0 and 7.5. If one wants five categories of severity, draw vertical lines at 2.0, 4.0, 6.0 and 8.0. Discussions for different width rows and columns are provided by Pons (2019) and Clemens (2005).

For a three-color matrix, two iso-risk lines are needed. Cox (2008) recommends using three bands of similar risk colored red, yellow and green. The two iso-risk lines should be spaced enough to separate the red space from green space with a yellow belt of cells. If, for example, the iso-risk lines are 20 and 60, there will be a large green area in the lower-left space, a smaller red area in the upper-right space, and a wide belt of yellow in the middle. Then, depending on the size of the RAM, one may start the process of assigning colors to cells.

Iso-risk lines provide a rational basis for choosing appropriate colors for the cells, in contrast to using individual judgments. An example of what happens when RAM designers use the individual judgment approach comes from the British National Healthcare Service. Kaya et al. (2019) requested that hospitals in a region of England send a copy of their RAM. Of the 99 hospitals that responded, all used a five-by-five matrix. The most interesting finding was that there were 28 different RAMs. This is mentioned to observe that an unstructured approach to RAM coloring can be far from scientific.

In Figure 9 (p. 32), the two iso-risk lines (20 and 40) divide the risk space into the three risk areas shown in each of the three RAMs. If one wants to have more than three areas, the process is the same except that more iso-risk lines are used. Procedurally, the cells in the upper-right area are to be colored red as in Figure 9a. This red band includes all cells with RIs above 40. For cells bifurcated by an iso-risk line, there are two opinions. Cox (2008) proposes assigning cells to red only if all corners of the cell are above the iso-risk line. Bao et al. (2017) presents a rationale for assigning cell colors based on the larger area of the bifurcated cell. The color assignments in Figure 9 are based on the latter position. For example, the cells with RI values of 45 and 49 belong with the red group because the largest part of these cells is on the right side of the iso-risk line 40. The two iso-risk lines in

FIGURE 6

ORDER-NUMBER APPROACH

Two examples of scaling the axes with order numbers.

6a

Likelihood				
4	4	8	12	16
3	3	6	9	12
2	2	4	6	8
1	1	2	3	4
	1	2	3	4
	Severity			

6b

Likelihood					
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5
	1	2	3	4	5
	Severity				

Figure 9 are at 20 and 40. Severity axis numbers 1, 3, 5, 7 and 9 are midpoints of columns. Likelihood axis numbers 1, 3, 5, 7 and 9 are midpoints of rows. Numbers in cells are the product of row midpoints and column midpoints.

The second step is to color green the cells with RIs under the lower iso-risk line in Figure 9b (p. 32). The third step is to color yellow the remaining cells in Figure 9c (p. 32). The last procedure is to check results to make sure no green cells share a border with a red cell. That can happen if the two iso-risk lines are inadequately separated. The red cells and the green cells should be clearly separated so there is a belt of yellow cells between them. If the yellow belt seems larger than desired, options include replacing the lower iso-risk line with one a bit higher, replacing the upper iso-risk line with one a bit lower or introducing a fourth color (orange) for a few of the yellow cells bordering on the red band.

Discussion

The aim of this article is to share with the occupational safety community an appreciation for RAMs beyond what is typically found in books and articles. An important part of this involves RAM-relevant concepts and terms. Taken together, concepts and terms help advance the OSH field and facilitate communication. Relevant concepts discussed are the use of science for voluntary standards of practice, the deviation theory of accidents, and the question of what distinguishes quantitative matrixes from qualitative and semi-quantitative matrixes. RAM-relevant terms discussed are options for describing ways to reduce risk, and terms used in RAMs.

RAM-Relevant Concepts

A concern with many RAMs is that the row and column categories were chosen without the benefit of research. This is a concern because the choice of category determines the risk indicator. Accurate values of risk support sound decisions about safety-related actions. Two studies referred to in this article address this knowledge gap by providing evidence-based sets of terms for naming categories of each axis in two-dimensional RAMs (Jensen & Hansen, 2020; Jensen et al., 2022).

The second topic of this discussion is the deviation control theory of industrial operations (Kjellén & Albrechtsen, 2017). In work environments, managers and employees generally start each day with an expectation that everything will work as planned, although experienced personnel recognize that deviations from normal may occur. To detect safety-related deviations from progressing, resilient organizations have various engineering and administrative barriers in place to detect and correct each deviation to restore the normal functioning of the system (Lyon & Popov, 2020). The term "hazardous scenario" would apply if a deviation from normal occurs and the safety barriers are challenged to prevent further progression of unwanted events that may lead to a harmful conclusion. The harmful conclusion could be harm to employees or damage to equipment, environment or product. A RAM provides a measurement-like tool for assessing the risk level of a hazard before and after considering or establishing a safety-related barrier. This change in risk may provide valuable input information to managers who need to make decisions about priorities for safety project proposals and for decisions about risk acceptance.

The third RAM-related concept addresses an often-asked question as to whether RAMs should be classified as qualitative, quantitative or semi-quantitative. Bao et al. (2017) state that "Quantitative risk matrixes refer to those matrices whose inputs of risk matrices are described by continuous axes." Thus, using this definition, a 10-by-10 matrix, as described in this article, is a quantitative matrix. In contrast, qualitative risk matrixes, such as in Figure 4 (p. 28), label axes with categorical variables. Semiquantitative RAMs use order numbers on one or both axes.

FIGURE 7
SCALED RAM

A risk space sorted into three risk levels indicated by color. Both axes are scaled with an exponential scale.

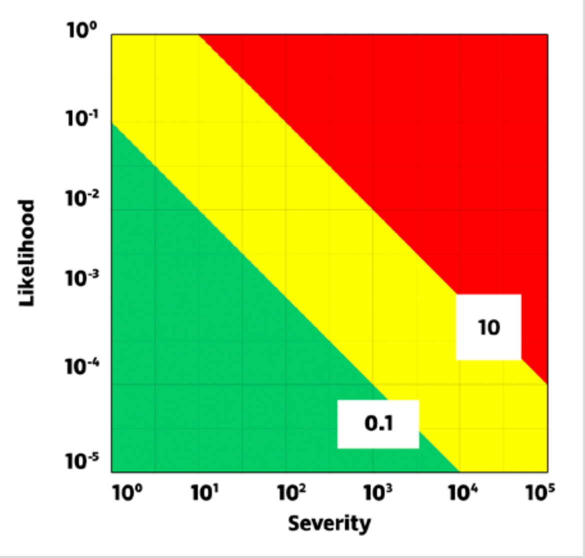


FIGURE 8
ISO-RISK LINES

Five iso-risk lines plotted in a 10-by-10 graphical risk space.

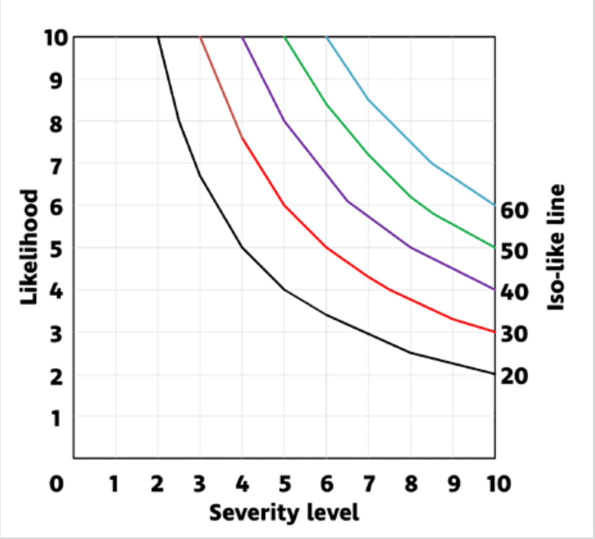
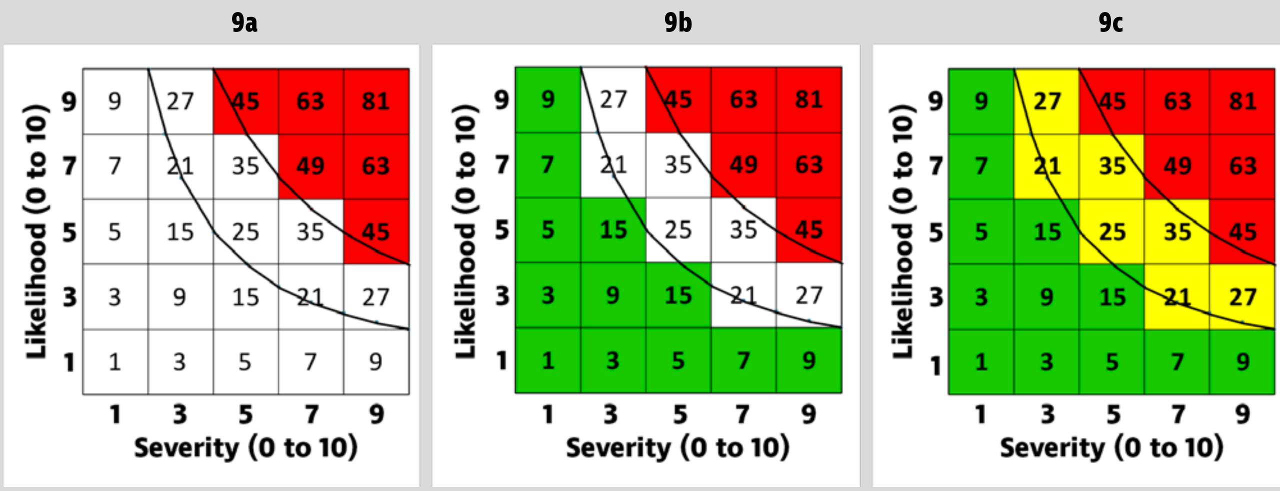


FIGURE 9
ASSIGNING COLOR

Three steps for assigning colors to cells in left to right order.



RAM-Related Terms

RAM-relevant terms discussed here include "risk," "risk reduction," "frequency," "likelihood" and "probability." RAMs are about risk and yet the most fundamental word—"risk"—has multiple meanings. A one-factor approach used in epidemiology may report results from a prospective cohort study by stating only the probability of a specified disease developing over a specified time. In contrast, for OSH, the two-factor approach, like in Equations 1b, is more practical. The author recommends using likelihood in RAMs for reasons explained in the "Elements of RAM" section. This is an example of a word commonly used in OSH having multiple meanings. For deeper discussion of words used in RAMs, see Kaplan (1997) or Rausand (2011).

Common terms for the rows of RAMs are "frequency," "likelihood" and "probability." The term "frequency" is used in the process industries (Baybutt, 2018; Nolan, 2017), typically expressed as a specific hazardous scenario occurring once in *N* years (e.g., once in 100 years). Thus, the frequency variable is a ratio with once (or more) in the numerator and a variable denominator based on estimates of the future. For example, a frequency of once per 1,000 years is lower risk than a frequency of once per 100 years. Frequency may be expressed as a probability by dividing the ratio. Another use of frequency is typical of worker exposure to a hazard such as a hazardous stairway in a workplace. One may speak of exposure as how often the stairway is used by employees. Greater frequency of use means greater exposure.

"Likelihood" has been emerging as the preferred RAM-related term for chance of occurrence because it is more flexible than the term "probability" and better suited for use with the crude estimates of future events used for occupational hazard analyses. A concise explanation in ANSI/ASSP/ISO 31073-2022 expresses a preference for the term "likelihood," and several authors agree that "likelihood" is more suitable than "probability" for occupational RAMs (Duijm, 2015; Jensen et al., 2022; Leveson, 2019).

An important terminology matter relevant to risk matrixes concerns measures to reduce risk of occupational hazards including mitigation, treatment and risk reduction. The term "treatment" is used in harmonized standards on management systems (e.g., ANSI/ASSP/ISO 31073-2022) to serve as an umbrella term for ways to reduce risk or otherwise deal with risks. Some types of treatments involve insurance and financial decisions, while others focus on hazards and prevention of employee injury, death and illness. A highly regarded innovator in the injury field, William Haddon Jr. (1973, 1980), identified 10 strategies for hazards of all kinds. Later, Jensen (2006, 2019) proposed nine strategies and "risk-reduction strategies" as a term for reducing an occupational risk by means including:

- eliminate or reduce the chance of a hazardous occurrence,
- moderate the harm if a hazardous event occurs, and
- respond, repair and rehabilitate the harm that occurred.

The word "strategy" coincides with the military distinction between strategies (the big picture) and tactics (more specific actions). Because strategies are quite broad, Jensen (2019) includes subcategories for each of nine strategies called risk-reduction tactics.

Conclusions

The author's conclusions are based on reviewing numerous peer-reviewed articles on RAMs. One important conclusion is that there is no one-size-fits-all risk matrix. However, comment is warranted on the author's opinions of some of the RAMs discussed in this article. Figure 2 (p. 27) illustrates a four-by-four qualitative RAM with three risk levels (high, medium and low). The words inside the matrix are suitable as-is, but coloring the cell backgrounds would enhance the usability. Figure 4 (p. 28) mirrors the U. S. Department of Defense (2012). Taken as-is, the author cannot recommend it because of the header terms. The author's primary criticism is the use of terms for the five rows of probability. From the top down, the row headers are frequent, probable, occasional, remote and improbable. Regarding the terms for rows five and four, ratings by students on a 100-point scale indicate that these two terms had essentially the same meaning—the mean ratings for probability and frequency were 68 and 72, respectively (Jensen & Hansen, 2020). Looking further down the header terms, the two lowest rows—remote and improbable—had essentially the same meaning on a 100-point rating scale; the mean ratings for remote and improbable 20 and 18, respectively. A second criticism is the header terms in MIL-STD-882E do not come from the same scales. "Probable" and "improbable" belong in a probability scale, while "frequent" belongs in a frequency scale.

Regarding Figure 5 (p. 29), although lacking row and column headers, Figures 5a and 5b show appropriate cell colors for a three-by-three and a five-by-six matrix. The author can recommend the five-by-five matrix in Figure 9c. It has both row and column categories ordered and clearly separated, and uses a 0-to-10 scale for each axis. The category midpoint values are shown and used to compute the RI numbers in the 25 cells in the risk space.

It is the author's hope that this article achieves the aim of sharing with the OSH community a deeper appreciation for RAMs. **PSJ**

Acknowledgments

Support for this project was provided in part by Montana Technological University's Training Project Grant (T03 OH008630) from NIOSH. The contents of this publication are solely the responsibility of the author and do not represent the official views of the CDC, NIOSH or the Department of Health and Human Services.

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Cite this article

Jensen, R.C. (2024, June). Seven attributes of risk assessment matrixes. *Professional Safety, 69*(6), 26-33.