

RISK MATRIX

KEYWORDS

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# An Alternative to HEAT MAP RISK MATRICES for Project Risk Prioritization

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• ABSTRACT •

Heat map risk matrices are widely used to prioritize risks. They are Standard Operating Tools for risk management as prescribed by the Project Management Institute (PMI), International Council on Systems Engineering (INCOSE), and many other organizations. They are widely used in projects and programs structured for product development, business, construction, R & D, medicine, and politics. However, they suffer from several weaknesses, notably subjectivity, symmetry, category prioritization reversal, and a failure to account for Risk Aversion, which often dominates how individuals and companies feel about risk. Because of this, they can lead to serious mis-prioritization and mismanagement of risks. We propose an alternative to the standard risk matrix that accounts for these deficiencies and provides a significantly better risk prioritization tool. Two field trials were conducted to demonstrate the benefits of the alternative method for project managers.

INTRODUCTION

Project Risk Management typically involves 5 steps (Wijnia (2012), Systems Engineering Process Office (2002), Microsoft (2017), Project Management Institute (2008)):

1. Risk Identification
2. Risk Assessment/Analysis
3. Risk Prioritization
4. Risk Response Planning
5. Risk Monitoring

Each step is challenging, but all are important in the proper management of project risks. This paper addresses Step 3 (Risk Prioritization) only, assuming that project risks have already been identified and assessed with respect to probability (or likelihood) and impact.

Risk matrices (also known as “probability and impact matrices” or “Risk Heat Maps”) are two-dimensional arrays that typically list risk impact on the abscissa and risk probability on the ordinate (Project Management Institute, 2008; Cox, 2008; INCOSE, 2011; Alleman, 2010). They are often used to prioritize risks. A typical risk matrix is depicted in Figure 1.

Impact: Probability	Low	Medium	High	Very High
Very High	Yellow	Orange	Red	Red
High	Yellow	Orange	Red	Red
Moderate	Green	Yellow	Orange	Orange
Low	Green	Green	Yellow	Yellow

FIGURE 01. Typical risk matrix.

Heat map-type risk matrices are implicitly based on the expected value theory of risk, in which expected loss (EL) is the product of risk probability and risk impact:

$$EL = P \times I$$

where EL = expected loss

P = Probability of the risk occurring (between 0 and 1.0)

I = Impact of the risk (often expressed in dollars)

For example, if an individual believes that there is a 70% chance of losing \$100,000, then the expected loss is \$70,000 according to Expected Value Theory. Using this principal, the risks are color-coded, typically using red to indicate risks having high probability and high impact; or orange or yellow to indicate risks with intermediate combinations of impact and probability; and green to indicate risks having either low impact or low probability or both. Red risks take the highest priority, yellow and orange intermediate, and green the lowest priority. Once risks are prioritized, organizations typically apply most resources and urgency to their highest-priority risks; lower priority risks are de-emphasized and may be eliminated entirely from further risk management. Improper risk prioritization can waste resources, cause projects to fail, and in extreme cases cost lives.

Risk matrices suffer from serious flaws:

1. They are qualitative and subjective, and definitions of “high”, “medium,” and “low” may mean different things to different people.
2. They are typically presented as symmetric about the diagonal, which is often invalid.
3. They do not account for risk aversion, which is manifested by almost every entity in making decisions.
4. The breadth of the categories may result in serious prioritization errors.

These flaws have been demonstrated and well-documented. Many researchers (Hubbard, 2009; Ball & Watt, 2013; Cox, 2008; Duijm, 2015; Aven, 2017; Wall, 2011) note the subjectivity associated with assigning both probabilities and impacts. Hubbard (2009) calls the use of risk matrices “borderline or worthless” and Cox (2009) calls it “worse than useless.” Wall says that “their theoretical basis is superficial and the validity of the qualitative information they employ is highly suspect.” Duijm agrees with Cox but makes several recommendations for Risk Matrix use and design because “attempting to curtail their use will be futile.” Ball and Watt also agree with Cox in that “there simply may be no right way to fill in these matrices” and go on to state that they belie a spurious simplicity. Bahill and Smith (2009) list 9 flaws associated with Risk Matrices. Oboni and Oboni (2013) claim that “[Risk Matrices] can be misleading, and expose organizations to potential litigation,” and also that they “have a number of staggering intrinsic conceptual errors, with potentially dramatic negative consequences on their users.” Pickering and Cowley (2010) note that on a plot of Probability vs Impact, iso-risk lines should be hyperbolic and thus the rectangular categorizations of a risk matrix are conceptually wrong, yielding over- and under-prioritization of risks. They further state that “...there appears to be little scientific analysis of their value in improving risk related outcomes.” Thomas et al. (2014) note that “Risk Matrices produce arbitrary decisions and risk-management actions. These problems cannot be overcome because they are inherent in the structure of the Risk Matrices.” Wijnia (2012) argues that “The problems and criticisms [associated with risk matrices] concentrate on 3 points: (i) the risk matrix does not prioritize distinguishable risks, (ii) the risk matrix prioritizes risks incorrectly, and (iii) the risk matrix results in incorrect decisions on mitigations.”

Despite these known issues, heat-map risk matrices are still widely used and, in fact, are recommended by prestigious organizations such as the Project Management Institute, the International Council on Systems Engineering, and the U. S. Department of Defense, possibly because the flaws are not well-understood or because the alternatives are perceived to be too complex. In this paper, we attempt to simplify some of the arcane technical explanations of the weaknesses and present a simplified, practical, alternative approach to Project Risk Prioritization.

THE PROBLEMS

--- A. Subjectivity ---

All risk assessment involves some subjectivity in assessing both the probability and impact of risks, but risk assessment matrices seem to magnify this issue. Common verbal descriptors for probability include "Very High," "High," "Medium," "Low," "Almost Certain," "Highly Likely," "Possible," and "Unlikely." Common descriptors for impact include "Low," "Medium," "High," "Very High," "Minimal," "Major," and "Catastrophic;" there are many others. The descriptors are wholly subjective and different people might have very different quantitative figures in mind for a probability that corresponds to "High" or an impact described as "Medium." The imprecision of the verbal descriptors can lead to prioritization errors. Although subjectivity cannot be eliminated from risk management, the tools that are used should certainly not add to the inherent subjectivity.

--- B. The Error of Symmetry ---

Most risk matrices are symmetric or near-symmetric about the diagonal (University of Sydney, 2016; Department of Defense, 2006; INCOSE, 2015; Project Management Institute, 2008.) That is, they treat a High Probability-Very High Impact (H-VH) risk with the same priority as a Very High Probability-High Impact (VH-H) risk. This is fundamentally wrong and can lead to huge errors in risk prioritization. Consider the risk matrix shown above in Figure 1, which is symmetric about the diagonal. A Very-High Probability-High Impact (VH-H) risk is designated red, as is a High Probability-Very High Impact (H-VH) risk; thus they are both treated with the same priority. But let's assign quantitative values to the axis descriptors:

Probability Descriptor	Probability
Very High	.9
High	.75
Moderate	.5
Low	.25

Impact Descriptor	\$\$ Impact
Low	\$10,000
Medium	\$100,000
High	\$300,000
Very High	\$1,000,000

TABLE 01. Quantified Probability Descriptors

TABLE 02. Quantified Impact Descriptors

[As noted above, the descriptors are subjective and may mean different things to different people; another individual might assign entirely different values to the descriptors in Tables 1 and 2, and this might change the resulting risk prioritization significantly. In addition, each verbal descriptor probably relates to a range of values; for simplicity, range mid-point values are used here.] If one replaces the verbal descriptors in Figure 1 with the quantitative values of Tables 1 and 2, one obtains Table 3:

Impact:	Low	Medium	High	Very High
Probability	\$10,000	\$100,000	\$300,000	\$1,000,000
Very High 0.9	\$9,000	\$90,000	\$270,000	\$900,000
High 0.75	\$7,500	\$75,000	\$225,000	\$750,000
Moderate 0.5	\$5,000	\$50,000	\$150,000	\$500,000
Low 0.25	\$2,500	\$25,000	\$75,000	\$250,000

TABLE 03. Quantitative Risk Matrix

In Table 3, the cell values have been calculated by cross multiplying the Impact by the Probability, per Expected Value theory, which states that EL (Expected Loss) = Probability x Impact. The color-coding in Table 3 has been adjusted so that cells

are colored red if the product of Impact and Probability exceeds \$500,000; orange if the product is between \$100,001 and \$500,000; yellow if the product is between \$10,001 and \$100,000; and green if the product is less than \$10,000.

These thresholds are arbitrary and may be adjusted by the user; this is easily accomplished using conditional cell formatting in MSExcel. The distribution of cell colors in Table 3 is very different than that in Figure 1 and therefore the risk prioritization is different.

In addition, Table 3 is not symmetric about the diagonal. For example, the Very High Probability-Medium Impact (VH-M) value of \$90,000 is less than 20% of the Moderate Probability-Very High Impact (M-VH) value of \$500,000; yet the conventional heat map risk matrix would have categorized these two risks with equal priority. The one with the larger dollar impact is much more concerning. Similarly, the VH-H risk of \$270,000 is only 36% of the H-VH risk of \$750,000 and requires different prioritization, but the conventional risk matrix of Figure 1 classified them both as red.

Clearly, using undefined subjective verbal descriptors and symmetric tables does not yield good risk prioritization or subsequent decision making.

--- C. Risk Aversion ---

Unfortunately, the problem gets worse. Under expected value theory (where EL = P x I) a risk with high P and low I can have the same expected loss as one with low P and high I. For example, if an individual believes that there is a 10% chance of losing \$100,000, then the expected loss is \$10,000 according to Expected Value Theory. Similarly, a 1% chance of losing \$1,000,000 would also have an expected loss of \$10,000. Therefore, these two risks would be treated equally and would garner the same prioritization color on a risk matrix. But most people (and companies) feel differently about those two risks: they are much more concerned with the second risk than the first because of risk aversion, and would assign the second risk a much higher priority. While probabilities are bounded by 0 and 1.00, potential financial impacts are unbounded: the maximum probability one could see is 1.00 but the maximum dollar impact could be in the millions, billions, or higher. People tend to focus on the potential dollar loss more than on the probability. Risk aversion is exhibited by individuals, organizations, teams, and companies, most of whom are highly risk averse when dealing with large potential dollar losses (Taylor & Weerapana, 2010; Binswanger, 1981).

One may account for risk aversion by inferring a utility function for the decision-maker (Clemen and Reilly, 2014). The utility function quantitatively describes the entity's risk aversion and may be used to correct the Expected Loss (EL) calculated using expected value theory to a Risk-Adjusted Loss (RAL). The RAL may be calculated in several ways. One of the simplest methods is to use the Mean Variance Utility Function (MVUT) (Pratt, 1964; McNamee & Celona, 1987), which calculates the RAL as:

$$RAL = PI + \sigma^2/[2(RT)] \quad (1)$$

In equation 1 RT is the Risk Tolerance of the organization or individual for whom the project is being conducted<sup>1</sup> and  $\sigma^2$  is the variance. The variance  $\sigma^2$  is an indicator of the uncertainty associated with the risk and may be calculated from the equation

$$\sigma^2 = (PI)^2(1-P) + (PI-I)^2 \times P \quad (2)$$

which simplifies to

$$\sigma^2 = PI^2(1-P). \quad (3)$$

Substituting this expression into equation 1 yields

$$RAL = PI [1 + (1-P)/2 RT] \quad (4)$$

Risk Tolerance RT is the capability of an entity to absorb risk. It is a dollar amount, and the larger, the greater the ability to absorb risk. Corporations typically have much greater RTs than individuals. For relatively risk-averse companies, a rule-of thumb is RT= .064 x (annual sales) or 1.24 x (net income) or .157 x (equity) (Howard, 1988). Typically, individuals have RTs in the tens of thousands or hundreds of thousands whereas companies have RTs in the millions, tens of millions, or hundreds of millions.

If one applies equation 4 to the 2 risks described at the beginning of this section using a RT=\$500,000, the Risk-Adjusted Loss is \$10,900 for the first risk (P=.10 and I = \$100,000) but RAL = \$19,900 for the second risk (P=.01 and I = \$1,000,000), as shown in Table 4. (Recall that the Expected Loss for both risks was \$10,000 and they were assigned equal priority according to expected value theory.)

Risk	Expected Loss Using Expected Value Theory EL=P x I	Risk-Adjusted Loss Incorporating Risk-Aversion with RT=\$500,000 RAL = PI [1 + (1-P)/(2RT)]
Risk 1 (P=0.1, I=\$100,000)	\$10,000	\$10,900
Risk 2 (P=0.01, I=\$1,000,000)	\$10,000	\$19,900

TABLE 04. Comparison of Expected Losses with Risk-Adjusted Losses

Taking into account risk aversion effectively doubles the expected loss of the second risk, which is consistent with how the individual actually feels. The second risk must take a higher priority.

One may now apply equation 4 to the values in the cells of Table 3 to calculate Risk-Adjusted Losses, for various values of Risk Tolerance RT. For a RT=\$500,000 the results are depicted in Table 5:

Impact:		\$10,000	\$100,000	\$300,000	\$1,000,000
Probability	Low	Medium	High	Very High	
0.9	Very High	\$9,009	\$90,900	\$278,100	\$990,000
0.75	High	\$7,519	\$76,875	\$241,875	\$937,500
0.5	Moderate	\$5,025	\$52,500	\$172,500	\$750,000
0.25	Low	\$2,519	\$26,875	\$91,875	\$437,500

TABLE 05. Risk-Adjusted Losses

The thresholds for the various colors in Table 5 are identical to those used in Table 3. Note that the distribution of cell colors in Table 5 is different than that in Table 3 and much different than that in Figure 1. In some cases, Risk-Adjusted values are nearly double what they were without risk aversion. For example the Low Probability-Very High Impact risk was color-coded yellow in Figure 1 (indicating low-moderate priority) while in Table 3 it was calculated to be \$250,000 (orange or high priority) but in Table 5, which is corrected for risk aversion, this risk has a risk-adjusted value of \$437,500. Similarly, the Moderate Probability-Very High Impact risk was coded as orange in Figure 1 and Table 3 but red (highest prior-

1. The Mean Variance Utility function is an approximation and is valid only when RT>0.4 x I. Other utility functions (such as exponential and logarithmic) provide more accurate results for all values of RT, but are more complicated to use.

ity) in Table 5 due to Risk Aversion, which increased its calculated value from \$500,000 to \$750,000. The risk-adjusted values are almost always greater than non risk-adjusted values due to risk aversion; they provide a much better indication of how people and companies feel about risk.

--- D. Category Prioritization Reversal ---

Unfortunately, the situation gets even worse. Consider 2 risks as shown in Table 6:

Risk	Expected Loss Using Expected Value Theory EL=P x I	Risk-Adjusted Loss Incorporating Risk-Aversion with RT=\$768,000 RAL = PI [1 + (1-P)/(2RT)]
Risk 1 (P=0.29, I=\$499,000)	\$144,710	\$178,088
Risk 2 (P=0.005, I=\$501,000)	\$2,505	\$3,318

TABLE 06. Comparison of Two Risks

Using either Expected Value Theory or risk-adjusted losses, Risk 1 has ~2 orders of magnitude greater expected loss than Risk 2 and should take a higher priority. But imagine a matrix categorization scheme in which probabilities between 0 and 0.30 are categorized as "Low"; impacts between \$100,000 and \$500,000 are categorized as "high"; and impacts greater than \$500,000 are categorized as "very high" (see Figure 2). In such a scheme Risk 1 would be Low Probability-High Impact while Risk 2 would be Low Probability-Very High Impact and Risk 2 would take a higher priority than Risk 1, which is clearly dramatically wrong. The error occurs because a probability of .005 is lumped into the same category as a probability of 0.29 and because impacts of \$499,000 and \$501,000 (which differ by less than half a percent) are placed in different impact categories. The arbitrariness of category breadth definition has led to a serious prioritization error.

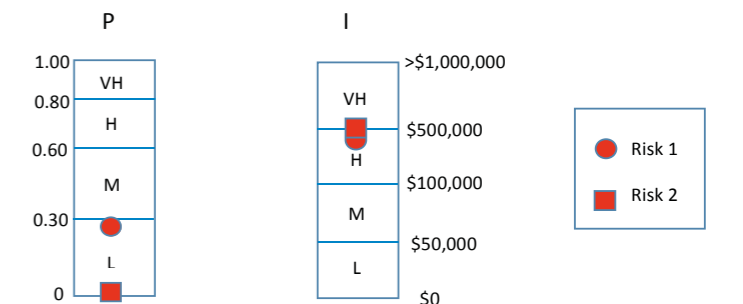


FIGURE 02. Category Prioritization reversal

Thus, significant prioritization errors accrue when quantitative values for probability and impact are not used, when risk aversion is not accounted for, and due to the arbitrary nature of defining category breadths. The conventional heat map risk matrix mis-prioritizes risks, sometimes very significantly.

PROPOSED ALTERNATIVE

Although it is not possible to eliminate all subjectivity from risk prioritization, we can at least avoid errors introduced by the risk management tools themselves. A good solution to the category prioritization reversal, symmetry, and lack of accounting for risk aversion in risk matrices is the Enhanced Risk Assessment Matrix (Monat, 2013). A simplified version of this is easy to apply and

provides accurate risk prioritization:

1. Identify the risks.
2. Assign quantitative values for probability and dollar impact to each (subjective).
3. Estimate the organization's or individual's Risk Tolerance RT using a rule-of-thumb.
4. Apply Equation 4 to calculate Risk-Adjusted Losses (RALs).
5. Prioritize the risks from highest RAL to lowest.

This approach requires few machinations and calculations, and is very straightforward. For graphic appeal, color-coding can be added if desired.

**PRACTICAL EXAMPLE**

The SideLobe Company (\$12M annual sales) designs and develops surface and air search radars for various industrial sectors including commercial, state, and federal organizations. SideLobe has decided to embark on a risky air search radar project for the Navy. The radar is risky because it takes advan-

Probability Descriptor	Impact Descriptor
Very High (VH)	Very High (VH)
High (H)	High (H)
Moderate (M)	Medium (M)
Low (L)	Low (L)

TABLE 07. SideLobe's Verbal Descriptors

ID	Risk	Probability	Impact
1	Desired technology and functionality is not achievable.	M	VH
2	L band radar subcontractor cannot deliver required functionality on time.	M	H
3	Required staffing levels cannot be met.	H	H
4	Design maturity cannot meet radar stability requirements.	L	M
5	Targets are misidentified and subsequently engaged.	L	VH

TABLE 08. Most Significant Project Risks

tage of newly developed software algorithms that automatically detect, track, identify, engage, and destroy air targets. Typical radars of this type normally require human intervention to assess threats and engage them with the appropriate weapon system. The SideLobe Robotic Acquisition System (RAS) automates this entire process without human intervention.

At the outset of the project SideLobe consulted various references (including the Project Management Body of Knowledge (PMBOK)), and established the probability and impact verbal descriptors shown in Table 7 for use in the risk assessment.

SideLobe then developed a list of project risks, of which the 5 most significant are shown in Table 8.

Using the typical Heat Map Risk Matrix as prescribed by the PMI and INCOSE, SideLobe then depicted the risks as shown in Table 9 in which the numbers in the 5 cells correspond to the 5 risks:

Impact: \ Probability	Low	Medium	High	Very High
Very High				
High			3	
Moderate			2	1
Low		4		5

TABLE 09. SideLobe's Heat-Map Risk Matrix

At this point, SideLobe feels they have done their job regarding risk management and, based upon this rudimentary assessment, are now going to focus on risk 3 as the highest priority, followed by risks 1 and 2 as the next highest. Yet, for some reason the senior managers at SideLobe are not comfortable with this crude analysis and (fortunately) don't feel that these risks are actionable without more information.

SideLobe decides that they must quantify the probabilities and impacts of the 5 risks identified in Table 8. Although they find it difficult to ascribe numerical values to their subjective feelings, they persevere using a team-oriented brainstorming session and develop Table 10, in which they articulate exactly what they mean by "high," "medium," "low," etc.

ID	Risk	Probability	Impact
1	Desired technology and functionality is not achievable.	M (0.5)	VH (\$2,000,000)
2	X band radar subcontractor cannot deliver required functionality on time.	M (0.6)	H (\$800,000)
3	Required staffing levels cannot be met.	H (0.90)	H (\$600,000)
4	Design maturity cannot meet radar stability requirements.	L (0.30)	M (\$400,000)
5	Targets are misidentified and subsequently engaged.	L (0.005)	VH (\$2,000,000)

TABLE 10. Risks with Quantitative Probabilities and Impacts

At this point SideLobe feels much more comfortable with how they are handling their risks because they can prioritize the risks based upon their quantified probabilities and impacts. However, in a side discussion with a business partner, they learn about risk aversion and how it often dominates how companies feel about risks. Thus, SideLobe reworks their assessment to include risk aversion using the Risk Tolerance rule-of-thumb for moderately risk averse firms. Using a corporate heuristic for Risk Tolerance of 0.064 x annual sales, SideLobe's Risk Tolerance RT would be 0.064 x \$12,000,000 = \$768,000. Using the Mean Variance Utility Function they calculate the Risk Adjusted Loss for each risk of Table 10 using equation 4:  $RAL = PI[1+(1-P)I/2(RT)]$ , and re-tabulate the risks in order from highest RAL to lowest, obtaining Table 11.

Table 11 shows the risks prioritized by Risk-Adjusted Loss (RAL). In table 11 the cells are colored red if the Risk-Adjusted Loss exceeds \$1,000,000; orange if the RAL is between \$500,001 and \$1,000,000; yellow if the RAL is between \$100,001 and \$500,000; and green if the RAL is less than \$100,000. Note that the priorities depicted in Table 11 are different from those depicted in Table 9: Risk 1 is now the highest priority, followed (in order) by risks 2, 3, 4, and 5 (the previous prioritization was Risk 3, 1, 2, 5, 4). Inasmuch as Risk 3 has only 1/3 the RAL of Risk 1, classifying Risk 3 as the highest priority could yield a substantial waste of resources.

**BENEFITS FOR THE PROJECT MANAGER - FIELD VALIDATION**

Determining a project risk's probability and potential impact are steps 1 and 2 of the Project Risk Management approach described in the Introduction. This study, however, assumes that the impact and probability have been determined for each project risk, and focuses on the correct prioritization of the risks once they have been characterized. To demonstrate the value to the project manager of the Risk-Adjusted Loss method of project risk prioritization, 2 field studies were conducted. In the first, 5 WPI Systems Engineering professors (all of whom were familiar with heat-map type risk matrices for risk prioritization) were asked to prioritize 5 given risks whose probabilities and \$ impacts were provided (see Table 12) using a heat-map risk matrix.

The 5 professors (identified as A, B, C, D, and E) came up with 4 different prioritizations, as shown in Table 13.

The prioritizations are significantly different for 4 of the 5 professors. The same 5 professors were then asked to prioritize the same 5 risks using the Risk Adjusted Loss method. This time, 4 of the 5 professors developed identical prioritizations: Risk 3 followed (in order) by risks 2, 1, 5, and 4; the 5th professor obtained a prioritization of Risk 3 followed by risks 2, 4, 1, and 5. This shows that the heat-map style risk matrix cannot be relied

ID	Risk	Probability P	Impact I	Expected Loss (P x I)	Risk-Adjusted Loss (per equation 4)
1	Desired technology and functionality is not achievable.	M (0.5)	VH (\$2,000,000)	\$1,000,000	\$1,651,042
2	X band radar subcontractor cannot deliver required functionality on time.	M (0.6)	H (\$800,000)	\$480,000	\$580,000
3	Required staffing levels cannot be met.	H (0.90)	H (\$600,000)	\$540,000	\$561,094
4	Design maturity cannot meet radar stability requirements.	L (0.30)	M (\$400,000)	\$120,000	\$141,875
5	Targets are misidentified and subsequently engaged.	L (0.005)	VH (\$2,000,000)	\$10,000	\$22,956

TABLE 11. Risk-Adjusted Losses for Each Risk

upon to provide consistent results, even when used by highly intelligent people who are familiar with its application; while the RAL method provides much better prioritization consistency. These results also suggest that the heat map introduces subjectivity while the RAL method does not.

In the 2nd field study, 25 past or current project managers (who also happened to be graduate students in 2 WPI Operations Risk Management courses) were provided 5 theoretical project risks along with their probabilities and potential impacts. The project managers were asked to prioritize the risks using a) a heat-map risk matrix and b) Risk-Adjusted Loss. Specific instructions that were given are provided in Appendix I.

The results are interesting and somewhat surprising (data are summarized in Appendix II.) Sixty % of the individuals felt that the RAL method was easier to use than the heat-map method. Typical comments for those who preferred the RAL method included, "I believe the RAL method is much easier to read and interpret because it quantifies the risk. It's a better visual representation of the data, and it better informs decision makers with clear and concise evidence" and "The RAL method was easier because it didn't really involve any creativity, critical thinking or brain power. We have the formulas and tables, so literally all I did was plug it all into Excel and let it do the math. The Risk Matrix method involved thinking about the different categories and

Risk	P(%)	I(\$)
1	1	10,000,000
2	5	5,000,000
3	50	1,000,000
4	75	50,000
5	90	80,000

TABLE 12. The 5 Risks Presented for Prioritization

	Professor A	Professor B	Professor C	Professor D	Professor E
Highest Priority	Risks 2 and 3	Risks 2 and 3	Risk 3	Risk 5	Risk 3
↑	Risks 1 and 5	Risks 1 and 4	Risks 1 and 2	Risks 1, 2, 3, and 4	Risks 1 and 2
	Risk 4	Risk 5	Risk 5		Risk 5
Lowest Priority			Risk 4		Risk 4

TABLE 13. Professor Risk Prioritizations Using Risk Matrix



their bands, doing some internal reflection on what I thought they should be grouped as, and looking at the results once I prioritized the risks to make sure they made sense. Neither method was really hard to use, but the Risk Matrix method took longer and was more effort.”

Typical comments from those who felt the Heat-Map method was easier included, “I believe the Heat-Map Matrix would be considered easier to use only in that there is no math involved and it might be less intimidating to some people. But that is not to say the RAL isn’t easy, in fact, it’s pretty straight forward and easy enough to use” and “Since I am, as well as many of the Sponsors I encounter each day, very familiar with the Heat Map Risk Matrix, that gives it a leg up on ease. Also, since many of these same Sponsors are non-technical with even simple equations and numbers hurting their heads, I would say that the Heat Map Risk Matrix method will continue to be easier accepted, as they would “understand” simple probabilities and impacts much easier than Expected Loss, Risk Tolerance, and Risk Adjusted Loss. That said, the use of a Heat Map Risk Matrix always has and always will be more “qualitative” than “quantitative” in both how the probability ranges are determined and defined (why 0%-20%, why not 0% to 10%??), and most certainly how impact ranges are categorized (Minor, Moderate, Major) and assessed. Thus, I would say that the Heat Map Risk Matrix is “easier” to use.”

The general consensus seemed to be that for those who are not intimidated by numbers and calculations, the RAL method is easier to develop, but less familiar than the heat map, which is well-known and therefore may be easier to use as a risk communication tool.

A large majority (88%) felt that the RAL method provided a more accurate prioritization. Typical comments from those individuals included, “Hands down the RAL provides a better prioritization. In fact I would go so far to say that the heat map does not really prioritize the risks. If you do not take expected value into account, how can you compare. Specifically if someone is ranking the order I am not really sure by what basis you do this. In practice, the only real use I have seen of the colors was a way to form a basis to ignore an issue that has no practical solution. Every other time the colors just track who is monitoring the steps to fix the risk” and “The heat map limits you to bucketing risks into 3 categories (well one can do more colors) and the bucketing does not do a good job of handling prioritization by combining impact and probability. The RAL uses a straightforward calculation to prioritize the risks which includes the effects of risk aversion. Heat map does not cover risk aversion.” Of the few respondents who felt that the Heat-Map approach provided more accurate prioritization, comments included, “A better visual aid in how to explain why a risk is more important to the project than other. It can be used for your own use, it can be easily recognized by others without formal training, and can be manipulated as needed to reflect an ever changing risk landscape” and “Heat-map matrices are a very good visual to show the impact of something that could be more than just monetary significance. If a risk has a lower monetary value but longer outage time than another risk, that impact could be included in a heat-map matrix, where that wouldn’t necessarily show up in an RAL.”

The clear consensus was that the RAL approach is more quantitative while the heat map is qualitative; that the RAL technique reduces prioritization errors, and that the RAL technique is superior because it allows for risk aversion.

The bottom line in assessing the 2 techniques, however, is the consistency with which different project managers prioritize the given risks. For the heat-map prioritization method, the consistency among managers was very poor. Sixteen different prioritizations were provided by the 25 project managers, only one of which (Risks 1, 3, and 5 as top priority and Risk 2 and 4 as lowest priority) was provided by more than 2 individuals. Seventeen individuals rated Risk 1 as the top priority while 5 rated it the lowest. Seventeen rated Risk 3 the top priority while 5 rated it the lowest. This great inconsistency demonstrates the weakness of the heat-map approach in prioritizing risks. With exactly the same data on risk probability and impact, there is great variation in the resulting priorities deriving from the heat-map approach.

The RAL method yielded substantially better (but not perfect) consistency in risk prioritization. 100% of the respondents listed either Risk 2 or 3 as the highest priority and Risk 4 or 5 as the lowest. Twenty project managers (80%) came up with a prioritization of either Risks 3, 2, 1, 5, and 4 (in order) or Risks 2, 1, 3, 5, 4. Of those 20 project managers, 9 (36%) prioritized the risks (in order) as Risks 3, 2, 1, 5, and 4 while 11 (44%) determined the prioritization to be Risk 2 followed by Risks 1, 3, 5, and 4. The reason for this bifurcation in prioritization is interesting and surprising: those who obtained the “correct” prioritization (the prioritization that accrues when Equation 4 is applied correctly: Risks 2, 1, 3, 5, 4) interpreted Equation 4 as  $RAL = PI + PI^2(1-P)/[2(RT)]$ . Those who obtained the “incorrect” prioritization (3, 2, 1, 5, 4) misinterpreted Equation 4 as  $RAL = PI + (PI)^2(1-P)/[2(RT)]$  [note the parenthesis around the second PI term.] This surprising error underscores the need to be extremely clear in the expressions used for equations, even when following notation conventions, when administering the RAL technique to prioritize risks.

The 5 project managers who developed neither of the 2 most common prioritizations typically made simple calculational or observational errors. For example, two rated Risk 4 as a higher priority than Risk 5 even though they had calculated a higher RAL for Risk 5. One dropped a zero in the RAL calculation and 1 did not use the correct equation, dropping the (1-P) term in Equation 4. These errors underscore the need to check calculations carefully (perhaps by another analyst) when using the RAL method.

Despite the calculational and observational errors and those caused by misinterpretation of Equation 4, the prioritization consistency derived from the RAL method is substantially better than that deriving from the heat-map method. Addressing those errors via checking calculations with a 2nd analyst and clarifying the interpretation of Equation 4 should dramatically improve the consistency of the RAL method. The better consistency afforded by the RAL method indicates that the RAL method is a better tool for risk prioritization than the heat-map and thus provides substantial value to project managers.

## CONCLUSION

Heat map style risk matrices are poor risk prioritization tools. They suffer from subjectivity, lack of consideration of psychological factors important in decision-making, and categorization errors, all of which can yield significant risk mis-prioritization. The result can be wasted resources, failed projects,

and in extreme cases loss of life. This paper describes a risk prioritization approach based on Risk-Adjusted Loss that obviates these weaknesses. All of the techniques demonstrated herein are easily implemented in spreadsheet programs such as MS Excel using standard equation operators, utility functions, and conditional formatting. These techniques will yield better risk prioritization and hence fewer wasted resources, more successful project outcomes, and in extreme cases may even save lives. ♦

## • APPENDIX •

Pretend that you are a risk analyst for a small, moderately risk-averse engineering company that has annual sales of \$10 million and \$4 million in equity. Your company is executing an important, big project involving city infrastructure. Your team has identified the following 5 project risks, along with their probabilities (in %) and impacts (in \$):

Risk	P, Probability (%)	I, Impact (\$)
1	1	\$10,000,000
2	5	\$5,000,000
3	50	\$1,000,000
4	75	\$50,000
5	90	\$80,000

We want to prioritize these risks to determine which are most important to address first, which are less important, and which risks may not require any action at all. We’d like to compare 2 different techniques for prioritizing these project risks:

1. The common heat-map type risk matrix
2. Prioritization based on Risk-Adjusted Loss (RAL)

A good prioritization method would properly distinguish the most important from the least important risks. To compare these 2 different prioritization approaches, please follow the step-by-step instructions below:

### --- Part I. USING A HEAT-MAP STYLE RISK MATRIX TO PRIORITIZE RISKS. ---

		Impact				
		Very Low	Low	Medium	High	Very High
Likelihood	Very High					
	High					
	Medium					
	Low					
	Very Low					

#### STEP 01. Establish and Color-Code the Matrix

A good prioritization method would properly distinguish the most important from the least important risks. To compare these 2 different prioritization approaches, please follow the step-by-step instructions below:

1. Will this be a 3 x 3, 4 x 4, 5 x 5, or other matrix? Note that it need not have the same number of rows (for likelihood or probability) as columns (for impact), so it could be a 4 x 5 matrix, for example.

2. Color in the cells: red for the most significant risks, green for the least significant, and yellow and orange for intermediate risks. (You may use only 2 colors (e.g. red and green), 3 colors (red, yellow, green), 4 colors (red, orange, yellow, green) or any other scheme that you like.

#### STEP 2. Establish Probability Categories and Bounds

1. For the probability (or “likelihood”) you will have as many probability categories as the number of rows you decided upon in Step 1. Now you need to name them e.g. “Low,” “Medium,” “High,” (if you have 3 categories) or “Very Low,” “Low,” “Medium,” “High,” “Very High” (if you have 5 categories). You may use any names you like (e.g. “inconsequential” instead of “very low”).

2. Now you need to establish the bounds for each probability category; that is, you must break the probability scale (0-100%) up quantitatively. You may use any scale you like: linear, logarithmic, some combination, or any other scale. Examples might be:

Probability Range (%)	Category
0-20%	Very Low
21-40%	Low
41-60%	Medium
61-80%	High
81-100%	Very High

OR

Probability Range (%)	Category
0-20%	Low
21-80%	Medium
81-100%	High

#### STEP 3. Establish Impact Categories and Bounds

1. For the impact you will also have as many impact categories as the number of columns you decided upon in Step 1. Now you need to name them e.g. “Low,” “Medium,” “High,” (if you have 3 categories) or “Very Low,” “Low,” “Medium,” “High,” “Very High” (if you have 5 categories). You may use any names you like (e.g. “inconsequential” instead of “very low”).

2. Now you need to establish the bounds for each impact category; that is, you must break the impact dollar scale (\$0-\$X) up quantitatively. You may use any scale you like: linear, logarithmic, some combination, or any other scale. Examples might be:

Impact Range (\$)	Category	
\$0-100,000	Very Low	
\$100,001-500,000	Low	OR
\$500,001-1,000,000	Medium	
\$1,000,001-5,000,000	High	
>\$5,000,000	Very High	

Impact Range (\$)	Category	
\$0-300,000	Very Low	
\$300,001-600,000	Low	OR
\$600,001-900,000	Medium	
\$900,001-1,200,000	High	
>\$1,200,000	Very High	

Impact Range (\$)	Category
\$0-1,000,000	Low
\$1,000,001-5,000,000	Medium
>\$5,000,000	High

#### STEP 4. Categorize each Risk by Probability P and Impact I

1. For each of the 5 risks that you have been given, you must categorize both their probability and impact using the scales that you developed in steps 2 and 3 above. For example, if a given risk (“Risk a”) has a probability of 15% and an impact of \$3,000,000, and if your category bounds are as follows:

• APPENDIX •

Probability Range (%)	Category	Impact Range (\$)	Category
0-20%	Very Low	\$0-100,000	Very Low
21-40%	Low	\$100,001-500,000	Low
41-60%	Medium	\$500,001-1,000,000	Medium
61-80%	High	\$1,000,001-5,000,000	High
81-100%	Very High	>\$5,000,000	Very High

Then you would categorize this risk as “Very Low Probability, High Impact.”

Similarly, a risk with a probability of 50% and an impact of \$280,000 (“Risk b”) would be categorized as “Medium probability, Low Impact.”

Categorize all 5 given risks in this manner.

**STEP 5. Locate Each Risk on the Matrix**

The 2 risks described above (Risk a: Very Low Probability, High Impact; and Risk b: Medium Probability, Low Impact) would be placed as shown below on this particular risk matrix:

		Impact				
		Very Low	Low	Medium	High	Very High
Likelihood	Very High					
	High					
	Medium		Risk b			
	Low					
	Very Low				Risk a	

Clearly, Risk a’s priority is green and Risk b’s is Yellow.

Place all 5 given risks on your chosen risk matrix in this manner.

**STEP 6. Read Off the Matrix Prioritization**

Red risks are highest priority, orange (if you used orange) next highest, yellow next, and green lowest priority. Note: it is entirely possible that you will have multiple risks at the same priority, and that you may therefore have fewer than 4 different priorities. Please complete the table below listing the priority of each of the 5 given risks.

- Priority 1 (Red): \_\_\_\_\_
- Priority 2 (Orange—if used): \_\_\_\_\_
- Priority 3 (Yellow): \_\_\_\_\_
- Priority 4 (Green): \_\_\_\_\_

--- Part II. USING RISK-ADJUSTED LOSS TO PRIORITIZE RISKS ---

Now, please repeat the risk prioritization using the Risk-Adjusted Loss method:

**STEP 1. Use the table shown here with the given Probabilities P and Impacts I for each risk**

STEP 2. Determine RT, the Risk Tolerance of the entity for whom you are doing

Risk	P, Probability (%)	I, Impact (\$)	EL, Expected Loss (P x I)	RAL, Risk-Adjusted Loss*	Priority
1	1	\$10,000,000			
2	5	\$5,000,000			
3	50	\$1,000,000			
4	75	\$50,000			
5	90	\$80,000			

$$* RAL = PI \left[ 1 + \frac{I(1-P/100)}{2(RT)} \right]$$

the analysis (your fictional engineering company--remember, the annual sales and equity are provided in the 2nd paragraph on page 1). You may use the following Rules of Thumb:

- RT= .064 x (annual sales) or
- 1.24 x (net income) or
- .157 x (equity).

**STEP 3. Calculate EL, the expected Loss, of each risk, using the following equation-**

$$EL = PI$$

And fill in the EL values in the table provided in STEP 1 above.

**STEP 4. Calculate RAL, the Risk-Adjusted Loss, of each risk, using the following equation-**

$$RAL = PI \left[ 1 + \frac{I(1-P/100)}{2(RT)} \right]$$

Note that the RAL should be > the EL for each risk.

**STEP 5. Fill in the table provided in STEP 1 above.**

**STEP 6. Prioritize the risks from highest RAL to lowest and fill in the following table-**

- Priority 1: \_\_\_\_\_
- Priority 2: \_\_\_\_\_
- Priority 3: \_\_\_\_\_
- Priority 4: \_\_\_\_\_
- Priority 5: \_\_\_\_\_

--- Part III. GENERAL INFORMATION ---

Name: \_\_\_\_\_

Title: \_\_\_\_\_

Have you ever served on a project team?:  Yes  No

Are you serving on a project team now?  Yes  No

Have you ever managed a project?  Yes  No

Are you managing any projects currently?  Yes  No

Which, of the 2 methods above, do you believe provides a better risk prioritization?

Heat-Map Risk Matrix  RAL  Neither

Why? (Please be specific): \_\_\_\_\_

\_\_\_\_\_

APPENDIX II

Summarized Field Study Data

Respondent:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Heat-Map Technique																									
Top Priority		1,2,3																							
2nd Priority		4,5	3		5		3	1,2		3				5			1						1,5		
Middle Priority			1,3,5					2,5					1												
4th Priority																									
Last Priority																									
RAL Technique																									
Top Priority	3	2	3	2	3	2	2	2	2	3	3	2	2	2	3	3	2	3	3	2	3	3	2	2	2
2nd Priority	2	1	2	3	2	1	1	3	1	2	2	1	1	1	2	2	1	2	1	2	1	2	1	1	1
Middle Priority	1	3	1	1	1	3	3	1	3	1	1	3	3	3	1	1	3	1	2	1	3	1	3	3	3
4th Priority	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Last Priority	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

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