An Improved Alternative to Heat Map Risk Matrices for Project Risk Prioritization

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Abstract: In a previous article we discussed the weaknesses of the popular heat map style risk matrix for project risk prioritization, and we proposed an alternative called the risk-adjusted loss (RAL) method. Although the RAL method demonstrated significant improvement, there were mechanical as well as interpretive issues associated with it. This paper describes improvements to the RAL method and experimentally demonstrates its superiority over the heat map style risk matrix for prioritizing project risks.

Keywords: Project Risk Management; Heat Map; Risk-Adjusted Loss

A. Introduction and Background

Heat Map Risk Matrices

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

In this paper, we assume that project risks have already been identified and assessed with respect to probability (or likelihood) and impact and we focus on Step 3 (Risk Prioritization) only. A common and logical approach for prioritizing risks is to calculate Expected Loss (EL) for each risk, where EL is the product of the risk's Probability P (typically expressed as a fraction between 0 and 1 or as a percentage between 0 and 100) and the risk's Impact I (typically expressed in dollars,) and then to prioritize the risks from the highest EL to the lowest (see equation 1.)

$$EL = P \times I \tag{1}$$

Heat Map Risk Matrices ("Heat Maps") were developed to exploit this logic and are commonly used to prioritize project risks (See **Figure 1**). The two axes of the matrix are Risk Probability and Risk Impact. The matrix's cells are then prioritized as green for low-priority, yellow and/or orange for intermediate priority, and red for high priority. (Instructions for using the Heat Map technique are included in **Appendix I**.) Unfortunately, Heat Maps do a poor job of prioritizing risks accurately because of inherent errors such as subjectivity, symmetry, category prioritization reversal, and a failure to account for Risk Aversion, which often dominates how individuals and companies feel about risk (see Monat and Doremus, 2018, for a detailed explanation of these errors.) The impact of erroneously prioritizing project risks can include common project setbacks, very large capital losses, and even loss of life.

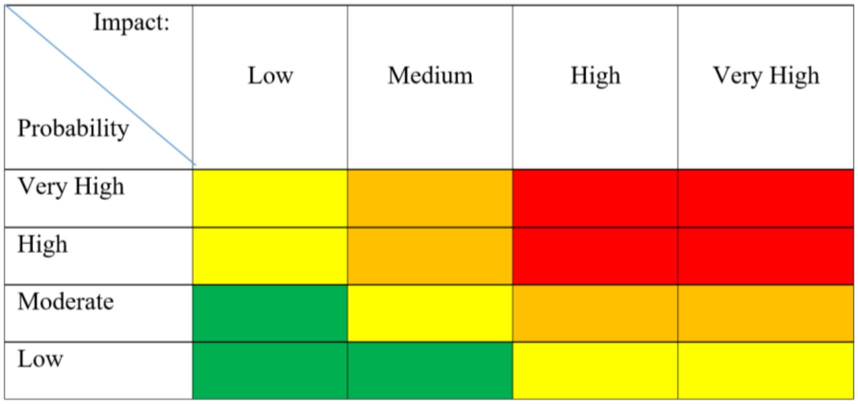

Figure 1. Typical Heat Map Risk Matrix

Why Heat Map Risk Matrices persist in business is unknown, although we suspect that this is because they are familiar, they are visually appealing, and they seem to be simple. However, project risk management is an economic exercise, and in an ideal world risks are prioritized correctly when those with the highest expected losses make the top of the list; this is not always the case for Heat Maps.

In this paper, we propose an alternative risk prioritization technique (the Risk-Adjusted Loss (RAL) method) that minimizes many of the errors inherent in the Heat Map project risk prioritization technique. Objectives are to convince practitioners of the superiority of the RAL method and to promote its use as a more reliable and less subjective method for prioritizing project risks.

<u>The Risk-Adjusted Loss (RAL) Method</u>

The RAL method is a way of prioritizing project risks by assigning a probability P and an impact I to each identified risk and then calculating a Risk-Adjusted Loss (RAL). The RAL technique minimizes the subjectivity and category prioritization reversal inherent in Heat Maps; it also incorporates risk aversion, which has been proven to dominate the way humans feel about taking risks (Kahneman & Tversky, 1979). Risk aversion can be modeled using a utility function, several of which have been developed. A few of the notable utility functions are the exponential function, the logarithmic function, and the mean-variance utility function. Each of these functions uses a term known as Risk Tolerance (RT). The RT parameter determines the shape of the decision-maker's utility function and in turn reflects the decision maker’s risk propensity (Clemen & Reilly, 2014). Because of its simplicity, we elected to use the mean-variance utility function in our development of the RAL method. Instructions for using the RAL method are included in Appendix II.

Three field studies were conducted to collect real-world data comparing the Heat Map technique with the RAL method.

B. Experiments

1. Approach

Subjects of the experiments were graduate students who were taking a course in Risk Management and Decision Analysis. The students were all working professional project managers progressing toward their master's degrees. Participants volunteered their time and expertise to prioritize a group of 5 risks for which both probability and impact were provided, using both the Heat Map and the RAL method.

2. The First Experiment

In the original experiment, we solicited the expertise of 25 professional project managers who were taking our classes in Risk Management during the Fall of 2017. All of these individuals were presented with five separate risks, each with varying probabilities and impacts (in USD), and after learning about the two different methods of prioritizing risks, they were asked to prioritize the five risks using both methods. They were then asked to assess the two methods.

3. Data and Results of the First Experiment

Sixty % of the individuals felt that the RAL method was *easier to use* than the heat-map method. A large majority (88%) felt that the RAL method also provided a *more accurate* prioritization. Finally, for the heat-map prioritization method, the prioritization *consistency* among managers was very poor: sixteen different prioritizations were provided by the 25 project managers. The RAL method yielded substantially better consistency in risk prioritization than the heat map method: all of the test subjects listed either Risk 2 or 3 as the highest priority and Risk 4 or 5 as the lowest. Thirty-six % 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. Twenty % of the test subjects made simple calculational or observational errors. The lack of perfect consistency in the RAL method was traced to misinterpretation of the formula that had been provided for the calculation of RAL (Risk-Adjusted Loss):

$$RAL = PI + \frac{PI^2(1-P)}{2\,(RT)} \qquad (2)$$

Where P = Probability of the risk occurring, I = Impact of the risk in dollars, and RT = the Risk Tolerance of the entity for whom the risk is being assessed. Those who obtained the “correct” prioritization (the prioritization that accrues when Equation 2 is applied correctly: Risks 2, 1, 3, 5, 4) interpreted Equation 2 as RAL=PI + PI^2(1-P)/[2(RT)]. Those who obtained the “incorrect” prioritization (3, 2, 1, 5, 4) misinterpreted Equation 2 as RAL=PI + $(PI)^2$(1-P)/[2(RT)] [note the parenthesis around the second PI term.] One aim of the current research was to see if equation 2 could be rewritten to minimize misinterpretation and to thereby substantially improve the prioritization consistency afforded by the RAL method.

4. The Second Experiment

The errors deriving from the RAL method were due to misinterpretation of the RAL equation (Equation 2): To obviate this problem, in the second set of experiments, we modified Equation 2 to be:

$$RAL = (P\ x\ I)\left[1 + \frac{I\,(1-P)}{2\,(RT)}\right] \qquad (3)$$

Where again P is a decimal fraction between 0 and 1.0 and I and RT are in \$. Note that the RAL should be > the EL for each risk. Equations 2 and 3 are functionally equivalent. However, it was hoped that the formulation of Equation 3 would result in fewer user errors.

Following our correction to the RAL equation, the second round of experiments was conducted in the fall of 2018, using Equation 3 in lieu of Equation 2. Again, working professional project managers taking graduate classes in a new cohort were solicited to participate in this experiment.

Thirty-one participants in the research study were provided a set of 5 risks along with each risk's probability and Impact. The participants were then asked to prioritize the risks, first using the Heat-Map technique and then using the RAL technique (details are provided in Appendix I.)

5. Data and Results of the Second Experiment

For this second set of experiments, 57 % of the individuals felt that the RAL method was *easier to use* than the heat-map method. *All* of the participants (100 %) felt that the RAL method provided a *more accurate* prioritization. Finally, for the heat-map prioritization method, the prioritization *consistency* among managers was very poor: 20 different prioritizations were provided by the 31 project managers. The RAL method yielded substantially better consistency in risk prioritization than the heat map method: all of the test subjects listed either Risk 2 or 3 as the highest priority and Risk 4 as the lowest. Twenty-three respondents (74.2 %) prioritized the risks (in order) as Risks 2, 1, 3, 5, 4 while 5 (16.1 %) determined the prioritization to be Risk 3 followed by Risks 2,1,5, and 4. Three (9.7 %) of the test subjects made simple calculations or observational errors. The systemic error by the 5 individuals who obtained a prioritization of 3, 2, 1, 5, 4 in the RAL method was traced to a miscalculation of the Risk Tolerance RT in Equation 2: while the correct equation is RT = 0.064 x Annual Sales, those 5 participants slipped a decimal point and calculated RT as RT = 0.64 x Annual Sales. The results of this trial again indicated the superiority of the RAL method and provided more consistent results than the first trial, but we felt that we could improve the technique further.

6. The Third Experiment - Autumn of 2019

A third trial was attempted to obviate the Risk Tolerance calculation error. Instead of using RT = 0.064 X Annual Sales, this time we provided the equation RT = (Annual Sales)/15.6; all other parameters and equations were the same as for the second trial.

7. Data and Results of Third Experiment

For the 3rd set of experiments, 78 % of the individuals felt that the RAL method was easier to use than the heat-map method while 94% of the participants felt that the RAL method provided a more accurate prioritization. For the heat-map prioritization method, the prioritization consistency among managers was very poor: 11 different prioritizations were provided by the 18 project managers. The RAL method yielded substantially better consistency in risk prioritization than the heat map method: Fifteen respondents (83.3 %) prioritized the risks (in order) as Risks 2, 1, 3, 5, 4. One respondent derived a different prioritization because he miscopied the impact of risk 1 as $1 million when it should have been $10 million. Two respondents derived erroneous prioritizations after correctly executing all calculations and simply transposing 2 risks. The results of this trial again indicated the superiority of the RAL method and provided more consistent results than the first and second trials. The mechanical errors suggest a need for careful checking of all calculations, perhaps by a second party.

C. Discussion

It is probably impossible to eliminate all subjectivity from project risk assessment and prioritization. However, whatever prioritization tools we use should not add to the subjectivity; the common heat map risk matrix approach does just that. The heat map approach is very popular despite its known deficiencies (Monat and Doremus, 2018; Hubbard, 2009; Ball & Watt, 2013; Cox, 2008, 2009; Duijm, 2015; Aven, 2017; Wall, 2011, Bahill and Smith, 2009; Oboni and Oboni, 2013; Pickering and Cowley, 2010; Thomas et al., 2014; Wijnia, 2012.) It is not clear why the heat map remains popular. However, it may be because it is well-known and familiar and therefore people are comfortable with it as a communication tool because the color coding is intuitively appealing (reminding us of red/yellow/green stoplights), or because the prima facie logic seems correct (high-probability, high-impact risks should take a higher priority than low-probability, low-impact risks.) The fact remains, however, that the heat map risk matrix technique frequently provides the wrong answer: that is, a risk prioritization that upon analysis, does not makes sense.

Relative to the heat map technique, the Risk-Adjusted Loss (RAL) method represents a substantial improvement. It is regarded by users as easier to use and more accurate. More importantly, it provides very high prioritization consistency among various users while the heat map technique does not. It minimizes subjectivity.

For present purposes, it is useful to define a *Consistency Metric* κ where $0 < \kappa < 1.0$ and κ is the fraction of identical prioritization responses in the largest group of identical prioritized responses. For example, if 30 subjects were asked to prioritize 5 risks and all of them reported a prioritization of 1, 3, 5, 2, 4, then κ would be 1.0. If, on the other hand, 20 of them reported a prioritization of 1, 3, 5, 2, 4 and the rest reported other prioritizations, then κ would be .667. If only 10 reported identical prioritizations then κ would be 0.333. Thus, the closer κ is to 1.0, the better the consistency. κ = 1.0 is ideal, indicating perfect consistency among respondents. κ was calculated for each trial; the results are presented in **Table I**.

Table I. Consistency Metric κ for the 3 Trials

	Trial I	**Trial II**	**Trial III**
Heat Map Technique:	.16	.19	.28
Risk-Adjusted Loss Technique:	.44	.74	.83
Ideal:	1.0	1.0	1.0

It is clear that the RAL technique yields substantially better consistency than the heat map technique. In the 3rd trial, the Consistency Metric κ was greater than 0.8, which represents very good consistency. The heat-map technique yields poor consistencies with κ~0.25. Despite its superiority, the RAL approach must be used with caution; we were surprised by the simple procedural or calculation errors made by several users.

The first type of error involved incorrect order of operations (parentheses before exponentiation.) The second error involved the slipping of a decimal point in the calculation of Risk Tolerance. The third type of error involved either misreading of the data or simple arithmetic errors. The fourth type of error involved transposition or transcription errors. Care must be taken in the technique formulation to avoid these errors. Although we have not been able to eliminate all errors, we have reformulated the RAL technique to yield a prioritization consistency metric of >0.8. (Contrast this with the Heat Map technique, which yields a prioritization consistency of <0.3.)

D. Conclusions and Summary

The popular heat map risk matrix approach for prioritizing project risks is fraught with errors including subjectivity, category prioritization reversal, and a failure to account for Risk Aversion, which often dominates how individuals and companies feel about risk. Because of this, it can lead to serious mis-prioritization and mismanagement of risks. We propose an alternative to the standard risk matrix (the Risk-Adjusted Loss or RAL technique) that accounts for these deficiencies and provides a significantly better risk prioritization tool. Three field trials were conducted to assess the alternative method for project managers. The field trials clearly demonstrated the superiority of the RAL technique in ease of use, accuracy, and prioritization consistency. We recommend that the RAL method be used instead of the Heat-Map technique for the prioritization of project risks.

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APPENDIX I. INSTRUCTIONS TO SURVEY PARTICIPANTS

EXTRA-CREDIT RESEARCH PROJECT

Professors Doremus and Monat are researching the best ways to ***prioritize project risks***. This is an opportunity for you to assist in their research. Participating is completely optional! But if you do an excellent job, you will earn 3 additional points on your OIE 541 course final grade. The entire project should take ~an hour or two.

*　　*　　*

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 fractional form between 0 and 1.0, where 0 means there is no probability of the risk occurring and 1.0 means it is a certainty) and impacts (in $$):

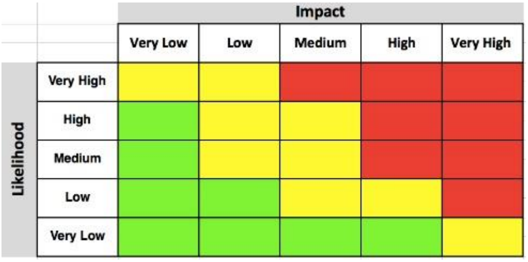
Risk	P, Probability	I, Impact ($)
1	.01	$10,000,000
2	.05	$5,000,000
3	.50	$1,000,000
4	.75	$50,000
5	.90	$80,000

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.



STEP 1. Establish and Color-Code the Matrix

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 (0-1.00) 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
.81-1.00	Very High

or

Probability Range	Category
0-.20	Low
.21-.80	Medium
.81-1.00	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
$500,001-1,000,000	Medium
$1,000,001-5,000,000	High
>$5,000,000	Very High

or

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

or

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 0.15 and an impact of $3,000,000, and if your category bounds are as follows:

Probability Range	Category
0-.20	Very Low
.21-.40	Low
.41-.60	Medium
.61-.80	High
.81-1.00	Very High

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

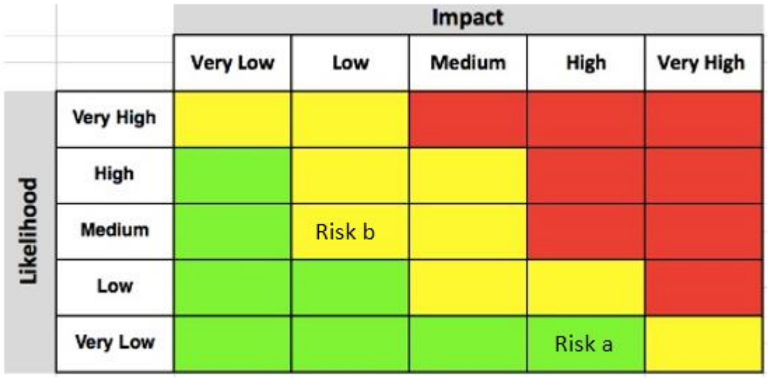
Then you would categorize this risk as "Very Low Probability, High Impact."

Similarly, a risk with a probability of 0.50 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:



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 the 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:

Risk	P, Probability	I, Impact ($)	EL, Expected Loss ($)	RAL, Risk-Adjusted Loss ($)	Priority
1	.01	$10,000,000			
2	.05	$5,000,000			
3	.50	$1,000,000			
4	.75	$50,000			
5	.90	$80,000			

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

- $\left\{\begin{array}{l} .064 \text{ x (annual sales)} \leftarrow \textit{used for Trial 2} \\ \text{(Annual Sales)/15.625} \leftarrow \textit{used for Trial 3} \end{array}\right\}$ or
- 1.24 x (net income) or
- .157 x (equity).

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

$$EL = P \times I$$

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:

$$\text{RAL} = (\text{P x I})\left[1 + \frac{\text{I}\,(1-\text{P})}{2\,(\text{RT})}\right] \quad \leftarrow \text{used for trials 2 and 3}$$

(This used to be (in 1st set of experiments): $RAL = PI + \frac{PI^2(1-P)}{2\,(RT)}$)

Where again P is a decimal fraction between 0 and 1.0 and The and RT are in $. 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 is *easier to use*, and why?

______Heat-Map Risk Matrix _________RAL _____________Neither

Explanation:

____
____
____
____

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

______Heat-Map Risk Matrix _________RAL _____________Neither

Why? (Please be specific):

____
____
____
____
____
____

* * *

Please ***save*** this completed document and either post the results to the Canvas website or e-mail it to Professor Monat at jmonat@wpi.edu.

Thank you for helping with this research!

APPENDIX II---THE RAL METHOD

STEP 1. Identify all relevant project risks, and determine the Probability P (between 0 and 1.00) and Impact I (in dollars) for each.

STEP 2. Determine RT, the Risk Tolerance of the entity for whom you are doing the analysis. You may use the following Rules of Thumb:

- RT= (annual sales)/15.6 or
- RT = 1.24 x (net income) or
- RT = .157 x (equity).

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

$$EL = P \times I$$

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

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

STEP 5. Prioritize the risks from highest RAL to lowest.

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Dr. Monat is a Professor of Practice within the Systems Engineering Program/ECE Department and the Foisie Business School at Worcester Polytechnic Institute, Worcester, MA, where he teaches (both online and face-to-face) and develops courses in Operations Risk Management, Project Management, System Optimization, Business Practices for Engineers, and Systems Thinking. Dr. Monat has both management and teaching experience in the business consulting, medical device, separations, food & beverage, and environmental industries, having served as President and founder of Business Growth Specialists, Inc., as President of Harvard Clinical Technology, as Sr. Vice-President of Pall Corporation, and in a variety of executive positions for Koch Membrane Systems, Inc. Dr. Monat's current research interests include applications of systems thinking, business applications of logistic regression, emergence and self-organization, project risk management, operations risk analysis, and competency-based education. He has a B.S. in Aerospace and Mechanical Sciences from Princeton, and an M.S. and Ph.D. in Civil Engineering from Stanford. He is a member of INCOSE and the Project Management Institute.

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