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Making Risk Management Work

ABSTRACT

In the department of defense, risk management typically focuses on precisely defining a risk statement, evaluating its probability of occurrence and severity of consequence, and identifying and planning mitigation steps. This simplistic approach to risk management often becomes difficult to implement in a way that provides useful insight to the Program Manager. This paper will discuss the shortfalls of this approach to risk and will discuss issues such as the importance of understanding the impact of time (when a risk is realized) on the consequences, differentiating risks based on knowledge gaps from those on uncertainties, effective risk mitigation planning, incorporating the cost of risk in program cost estimates, the issues associated with rolling up multiple lower level risks into higher level risks, and the relationship between risk management and set-based design.

INTRODUCTION

Risk management has long been a responsibility of program managers. In the Department of Defense (DOD), guides such as (DOD 2017) have defined risks as

"… potential future events or conditions that may have a negative effect on achieving program objectives for cost, schedule, and performance. Risks are defined by (1) the probability (greater than 0, less than 1) of an undesired event or condition and (2) the consequence, impact, or severity of the undesired event, were it to occur."

Risks are often articulated with an "if-then" statement: "if (description of undesirable event or condition), then (description of the consequence, impact, or severity of the undesired event)

In risk analysis, each risk statement is evaluated using criteria such as those presented in Table *1* and Table *2* to assign levels for the severity of the consequences and the likelihood of the undesirable event or condition. Each risk is then typically plotted on a risk matrix (Figure *1*). Risks in the green area are considered low, yellow area medium, and red area high. Risks evaluated as high or even medium are managed closely and often resources are allocated to mitigate these risks.

Risk mitigation is the action a program takes to address a risk. Most risk mitigation actions take the form of one of the following (DOD 2017):

a. Accept the risk: do nothing, and be willing to accept the consequences should it occur.
b. Avoid the risk: take an alternate path where the evaluated risk is lower
c. Transfer the risk: assign responsibility for mitigating the risk to another organization. Note that this action does not change the risk – the risk still exists.
d. Control the risk: implement a strategy to reduce the likelihood of the event/condition and/or the severity of the event/condition.

If risks are controlled, a risk burn-down plan is typically developed to illustrate the systematic reduction of risk due to planned activities. Each activity is assigned a start and finish date and the target likelihood and consequence levels at the end of the activity. This risk burn-down plan, and progress towards completing the plan are typically depicted in a waterfall chart (Figure *2*.)

Risks are usually tracked in a risk register. Modifications to the risk register are typically controlled by a risk review board. A risk register can easily have over 50 individual risks identified in it. If the risk register grows beyond several hundred items, risks are often either grouped together, or the risk register is broken into several parts with each part managed by a different risk review board.

Issues and opportunities are related concepts (DOD 2017):

"Issues are events or conditions with negative effect that have occurred (such as realized risks) or are certain to occur (probability of 1) that should be addressed."

"Opportunities have potential future benefits to the program's cost, schedule, and/or performance baseline."

Table 1: Sample Consequence Criteria (DOD 2017)

Level	Cost	Schedule	Performance
5 Critical Impact	10% or greater increase over APB objective values for RDT&E, PAUC, or APUC Cost increase causes program to exceed affordability caps	Schedule slip will require a major schedule rebaselining Precludes program from meeting its APB schedule threshold dates	Degradation precludes system from meeting a KPP or key technical/supportability threshold; will jeopardize program success [2] Unable to meet mission objectives (defined in mission threads, ConOps, OMS/MP)
4 Significant Impact	5% - <10% increase over APB objective values for RDT&E, PAUC, or APUC Costs exceed life cycle ownership cost KSA	Schedule deviations will slip program to within 2 months of approved APB threshold schedule date Schedule slip puts funding at risk Fielding of capability to operational units delayed by more than 6 months[1]	Degradation impairs ability to meet a KSA.[2] Technical design or supportability margin exhausted in key areas Significant performance impact affecting System-of System interdependencies. Work-arounds required to meet mission objectives
3 Moderate Impact	1% - <5% increase over APB objective values for RDT&E, PAUC, or APUC Manageable with PEO or Service assistance	Can meet APB objective schedule dates, but other non-APB key events (e.g., SETRs or other Tier 1 Schedule events) may slip Schedule slip impacts synchronization with interdependent programs by greater than 2 months	Unable to meet lower tier attributes, TPMs, or CTPs Design or supportability margins reduced Minor performance impact affecting System-of System interdependencies. Work-arounds required to achieve mission tasks
2 Minor Impact	Costs that drive unit production cost (e.g., APUC) increase of <1% over budget Cost increase, but can be managed internally	Some schedule slip, but can meet APB objective dates and non-APB key event dates	Reduced technical performance or supportability; can be tolerated with little impact on program objectives Design margins reduced, within trade space [2]
1 Minimal Impact	Minimal impact. Costs expected to meet approved funding levels	Minimal schedule impact	Minimal consequences to meeting technical performance or supportability requirements. Design margins will be met; margin to planned tripwires

Notes:
[1] Consider fielding of capability to interdependent programs as well.
[2] Failure to meet TPMs or CTPs directly derived from KPPs or KSAs are indicators of potentially not meeting a KPP or KSA

APB: Acquisition Program Baseline; APUC: Average Procurement Unit Cost; ConOps: Concept of Operations; CTP: Critical Technical Parameter; PAUC: Program Acquisition Unit Cost; PEO: Program Executive Officer; KPP: Key Performance Parameter; KSA: Key System Attribute; OMS/MP: Operational Mode Summary/Mission Profile; RDT&E: Research, Development Test & Evaluation; TPM: Technical Performance Measure

Table 2: Typical Likelihood Criteria (DOD 2017)

Level	Likelihood	Probability of Occurrence
5	Near Certainty	> 80% to ≤ 99%
4	Highly Likely	> 60% to ≤ 80%
3	Likely	> 40% to ≤ 60%
2	Low Likelihood	> 20% to ≤ 40%
1	Not Likely	> 1% to ≤ 20%

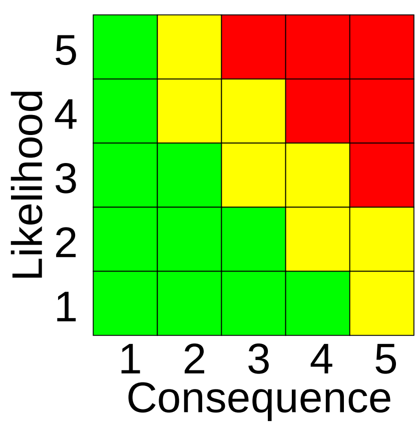

Figure 1: Risk Matrix

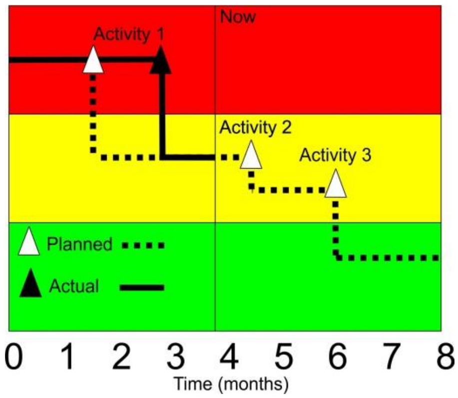

Figure 2: Waterfall Chart

While managing issues has much in common with managing risks, most program offices treat them very differently. As one would expect, issues are generally tracked in real time using tools such as action item trackers. Updates on progress is typically required on a weekly or even a daily basis. Risks on the other hand, are often tracked on a monthly or quarterly basis.

Many program offices do not have the resources, both in personnel and funding to actively manage more than a few opportunities. Because there are typically only a few, the management of opportunities tends to be ad hoc.

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RISK MANAGEMENT CHALLENGES

The risk management process described in the previous section appears straightforward. Unfortunately, once one actually attempts to apply the process to a real program, particularly one in early stages of product development, several challenges become apparent.

a. In early stage design, the risk statement often describes the discovery of a condition in the future rather than a future event. The severity of the consequences of this condition depends on when the uncertainty is resolved. If resolved early in the design process, the consequences could be minimal. If the condition is not resolved until the product is produced, changes can be very expensive. Capturing this time dependency in a risk statement is very challenging.
b. In evaluating the consequences, maintaining consistency in the basis of comparison can be challenging. A high cost risk for a subsystem when using its budget / objective values may be a low risk for the overall system.
c. Risk are accepted, but the appropriate contingency funds to correct the undesired event are not included in the program cost estimate or budget.
d. As indicated earlier, transferring a risk does not change the risk. Often organizations believe they no longer need to worry about a risk once it is transferred. Unfortunately, the potential negative outcome can still impact the original organization.
e. The waterfall charts are success oriented and misleading. If the risk could in fact be systematically reduced to a low level by accomplishing specific risk mitigation tasks, then simply incorporating those tasks into the project's Integrated Master Schedule (IMS) should cause the risk to be re-evaluated as low. Since most, if not all uncertainty will have been removed, there would be no need to further track the risk as part of a risk management program. The tasks become scheduled work as part of the normal development process.

KNOWLEDGE GAPS AND UNCERTAINTY

During the early stages of a project, many of the risks are typically due to a lack of knowledge (aka "knowledge gap") rather than an inherent uncertainty. The designers are not always familiar with the details of all the options open to them. Any potential solution that is unfamiliar is assigned risk, even though that potential solution may in fact be perfectly acceptable. Evaluating the likelihood of occurrence is difficult, because the uncertainty is not inherently due to the potential solution, but rather the uncertainty is due to our lack of understanding of that potential solution. In effect, evaluating the likelihood is akin to measuring one's own ignorance on the topic.

Furthermore, the evaluation of the consequences generally presumes a baseline concept already exists. Early on, many design decisions are still open, and the consequences may depend on what is eventually chosen for these design decisions. Employing design methods such as Set-Based Design (SBD) which delays decisions until knowledge gaps are resolved complicates the evaluation of these types of risks.

The knowledge gained through analyses and experiments can result in a re-evaluation of the likelihood of occurrence of a knowledge gap. In contrast to the typical waterfall chart, this re-evaluation may result in the likelihood increasing, event to the point of the risk becoming an issue.

Risks based on knowledge gaps are fundamentally different from risks that are based on inherent uncertainties. The root causes of inherent uncertainties can include:

- Risk is based on the unpredictable cost or availability of a material such as steel, lithium, crude oil, etc.
- Risk is based on the future capabilities of a potential adversary.
- Risk is based on the future availability of manufacturing assets. Will current companies stay in business and will they have capacity to take on the work?
- Risk is based on future environmental conditions. (i.e. weather)

While these risks can be bounded with adequate analysis or experimentation, they cannot be resolved during the design process. Once bounded, extra analyses or experiments will not markedly improve the estimates; controlling the risk to reduce the probability of occurrence is not possible. One of the other mitigation strategies must be employed.

a. Accept the risk: defer implementing a response until the risk is actually realized.
b. Avoid the risk: chose a different solution which is not impacted by the inherent uncertainty
c. Transfer the risk: buy a futures contract for materials, buy insurance, leave it to the in-service program manager to address.[1]
d. Control the risk: Make the design robust, or employ modularity and adaptability to affordably address the risk. (see Doerry 2012, Doerry & Koenig 2017)

Because the approach to mitigating risks based on knowledge gaps differs from those that are based on inherent uncertainties, the risk register should track which category each risk belongs to.

Because of the difficulties of evaluating the likelihood and consequence of knowledge gaps, it may be advantages to remove knowledge gaps from the risk register and managing them through a knowledge based design method such as SBD and/or Decision Oriented Systems Engineering (DOSE). SBD is discussed below; the relationship of SBD and filling knowledge gaps as part of Knowledge Based Development (KBD) is detailed by Kennedy et al. (2008). DOSE is described in U.S. Patent #7493298, Buckley & Stammnitz, (2004) and in Buckley & Womersley, (2007).

REQUIREMENTS RISKS

Requirements risks address the fundamental question as to whether a program is building the right product. Are the requirements provided by the customer likely to change? A requirements risk review is recommended to categorize the

[1] Leaving the risk for the in-service program manager is transferring risk from the perspective of the acquisition program manager. From the Navy corporate viewpoint it would likely be viewed as risk acceptance.

customer requirements into the following groups (based on Burrow et. al 2014):

a. Firm: Requirement is unlikely to change.
b. Short Term Flexible: Uncertainty in the requirement will be resolved prior to the start of product design.
c. Mid Term Flexible: Uncertainty in the requirement will be resolved prior to establishment of the product architecture.
d. Far Term Flexible: Uncertainty in the requirement will be resolved prior to production.
e. Robust or Modular-Adaptable: Uncertainty in the requirement will not be resolved prior to production.

The flexible groups enable deferring establishing requirement values until a specified time in the product development. The design should be capable of being affordably adaptable to a specified range of the requirement for the amount time associated with the flexible groups. This flexibility range is different from that bounded by threshold and objective values in that with the flexibility range, the customer will eventually specify the value. Often industry is left to establish the performance level between the threshold and objective values.

Keeping a design flexible for a specified period of time adds cost to the program, but reduces the consequences of the risk should a requirement require changing after design has started. Thus keeping a requirement open should not be justification for procrastination; the work to resolve the requirements uncertainty should be clearly defined, funded, and performed.

COST OF RISK

While DOD guidance (DOD 2017) discusses risk consequences in terms of cost, schedule, and performance, monetizing all risks has benefits:

a. Ensures the costs consequences of multiple risks are consistent and comparable.
b. Enables the expected value of the cost of the risk to be incorporated into cost estimates.
c. Enables return on investment calculations to be performed on risk mitigation activities.

In monetizing a risk, the consequence becomes the cost of addressing the risk event should it occur. Schedule delays are reflected in the cost of fixed expenses, opportunity costs, and the costs of keeping other systems in operation longer than desired. Performance impacts can be translated into costs needed to increase performance to the requirement, increased costs to other systems, opportunity costs, etc.

Monetizing risk also enables the cost of risk to be properly accounted for in cost estimates. To do this, the source of funding to address the risk event must be clearly identified. If cost estimates are not sensitive to the identified risks, the program manager may be tempted to cancel risk mitigation activities and assume risk because doing so will make the cost estimate decrease, although the actual program costs will likely increase. See Doerry 2009 for a more complete explanation.

Monetizing risks makes Return on Investment (ROI) calculations possible for risk mitigation activities. The reduction in the expected cost of a risk event (The expected cost of the risk event is the product of the probability of the risk event times the cost of addressing the risk event) can be compared to the cost of the risk mitigation activity. (DOD 2017) If a risk mitigation activity has a positive ROI, then its inclusion in the program plan should result in a decrease in the estimated cost of the program. Eliminated a risk mitigation activity with positive ROI from the program plan should result in program cost estimates increasing (Doerry 2009, Doerry and Sibley 2015).

When analyzing a risk, an estimate of the dollar cost of the risk event by funding source should be made and recorded in the risk register. After this estimate is made, it can be converted into the consequence level by comparing the estimate to a reference program cost and applying the consequence criteria. Since the reference program cost can change over time, recording the estimated cost of the risk event facilitates recalculation of the risk levels.

IMPACT OF TIME

The cost of a risk event depends on when during the product's life cycle, one concludes that the risk event has occurred. In general, the cost of implementing unplanned design changes increases exponentially with time. If one concludes that a risk is an issue early in conceptual design, the cost of design rework is usually orders of magnitude less than the cost of modifying an in-service ship. Hence the evaluation of the consequence of a risk depends on the assessment of when the risk is identified as an issue and corrective action is taken (Figure 3). This uncertainty of the risk consequence exists prior to the development of mitigation planning.

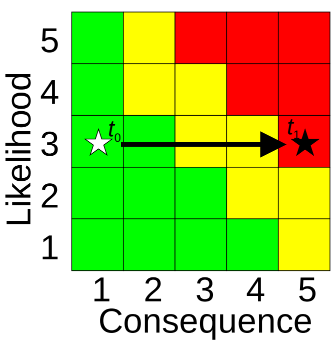

Figure 3: Impact of time of risk realization on consequence

As indicated earlier, inherently uncertain risks generally remain uncertain during the product development process; mitigation activities must concentrate on reducing the consequence should the risk event occur.

The estimate of the likelihood of the risk event for knowledge gaps can generally be greatly improved through analysis and experiments during the development process. While the conduct of experiments includes testing, the testing is very different from the verification testing conducted as part of the systems engineering process. Verification testing ensures components, sub-systems, and systems achieve their design objectives. Testing associated with eliminating knowledge gaps is used to inform design and the development of design objectives. In general, the greatest ROI is achieved by resolving knowledge gaps as early as possible.

In any case, when conducting a risk analysis, one needs to be very specific as to the assumptions or determination as to the likely time when the risk is resolved as either an issue or not. An evaluation of consequence usually only has meaning in the context of the assumed time of risk resolution.

EFFECTIVE RISK MITIGATION PLANNING

Doerry and Sibley (2015) recommend the risk mitigation activity approach depicted in Figure 4. This approach is comprised of the following elements for each risk mitigation activity:

a. Develop Plan: The plan specifies the test, the possible outcomes of the test, and the associated mitigation for each outcome.
b. Perform Test. A test is an analysis or experiment that can have *n* possible outcomes. The subject of the test can be a knowledge gap, a proposed change to the configuration, an assessment of the robustness of the current baseline to the risk event, etc.
c. Determine Outcome. The results of the test determine the outcome. Each outcome has an associated mitigation and updated risk likelihood and consequence.
d. Implement Mitigation. Mitigation is a change to the plan or design that usually impacts either (or both) the risk's likelihood or (and) consequence. One possible mitigation is to do nothing. Performing the test may by itself add additional information to refine the likelihood (either increasing or decreasing the likelihood) and the consequence. One outcome could be

confirmation that the baseline design path is acceptable and no further mitigation is needed.

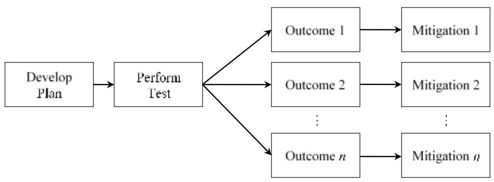

Figure 4: Risk Mitigation Activity Approach

For this recommended approach, Doerry and Sibley (2015) provide a quantitative method for calculating ROI and updated likelihood and consequences based on Bayes' Theorem.

The risk waterfall chart requires modification to reflect this recommended risk mitigation approach. Figure 5 is a modified waterfall chart depicting the multiple paths that can be taken based on the outcome and mitigation for multiple cascaded risk mitigation activities. Note that the plan may not result in each path ending with a green risk evaluation. The probability of a path occurring times the expected cost of that path may be low enough to warrant deferring additional planning until it is more certain the path could be taken.

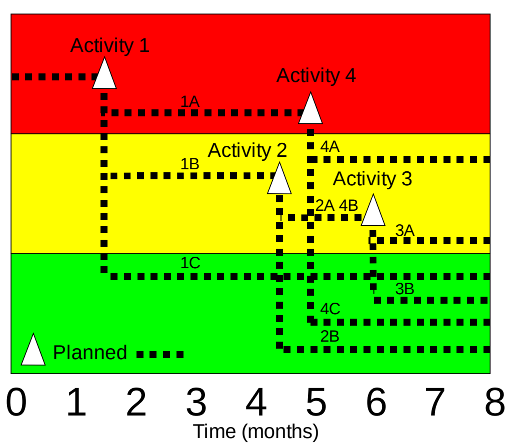

Figure 5: Risk Mitigation Plan

For example, if the results of Activity 1 indicate that path 1B is taken, the risk mitigation plan is trimmed to show only the remaining possible steps as depicted in Figure 6. Paths 1A, 1C and Activity 4 with its paths have all been eliminated due to the results of Activity 1. Note that because activity 4 has been eliminated, the plan for outcome 4B is now moot. Once Activity 2 is complete, it may be beneficial to plan additional mitigation activities for path 3A if path 2A is taken.

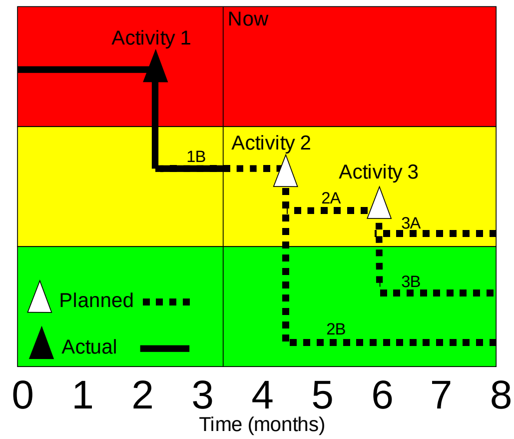

Figure 6: Updated Risk Mitigation Plan

An agile risk mitigation planning and execution process is needed to affordably execute the recommended approach. The majority of planning costs should not be incurred for an activity until there is a high likelihood that the activity will actually be conducted. Furthermore, each mitigation activity should not require a long lead time from the time of commitment to conduct the activity; the commitment will only occur once the predecessor activities indicate the likely path will lead to the activity.

RISK MANAGEMENT AND SET-BASED DESIGN

In contrast to many design methods, SBD arrives at a design solution by eliminating infeasible and highly dominated potential design solutions rather than iterating on the characteristics of one or a few design solutions. A feasible solution is evaluated to meet known hard design constraints, such as structural strength, stability, and validated minimum performance requirements. A highly dominated solution is a feasible solution with properties (typically cost) greatly inferior to another feasible solution; highly dominated solutions are not likely ever to be preferred solutions. See Singer et al. (2009) and Singer et al. (2017) for more information on SBD.

One of the key attributes of a SBD process is that decisions are not made until decision makers have sufficient knowledge and the remaining uncertainty is unlikely to result in the decision being modified in the future. SBD focuses on not revisiting decisions (via iteration for example) by making the right decision once. Hence a SBD process naturally focuses on identifying knowledge gaps, tying the knowledge gap to a future decision, and conducting analyses and experiments to gain the requisite knowledge before the decision needs to be made.

A feature of SBD is that opportunities are naturally incorporated into the decision-making process. In other design methods, opportunities are usually eliminated because they are viewed as "risky" primarily because of knowledge gaps. In SBD, the risk associated with the knowledge gap must be resolved before a decision can be made to eliminate the opportunity. Thus an opportunity is more likely to be incorporated into a design employing SBD than in other methods.

Because addressing knowledge gaps is a key element of SBD, and properly evaluating knowledge gaps as risks is difficult, a strong case is made for managing knowledge gaps within the SBD process and not within a traditional risk management process.

The risk register should still identify the knowledge gaps as risks, but it should then reference the SBD knowledge management process for managing these risks. In this manner, the number of risks that are actively tracked and managed by the risk management program is limited to those caused by inherent uncertainties.

ROLLING UP RISK METRICS

Since a risk register can contain many individual risks, program managers often would like to gain an understanding of the overall risk exposure of a program in a few metrics. Often this is desired in the form of a "rolled up" risk that aggregates many risks. Typically, there is a struggle to define the risk event or the consequence succinctly for this "rolled up" risk. One way to state the risk is:

"If one of the risks in this group of risks occurs, then there will be a negative consequence to the program."

While this risk statement is accurate, it is completely unsatisfying from a descriptive viewpoint. Still this risk statement has the advantage of being derived from the properties of the group of underlying the risks if the consequences are consistently evaluated. For example, the expected cost of the rolled up risk is the sum of the expected cost of all the risks in the group:

$$E_{Rolled} = \sum_{i=1}^{n} E(Z_i) = \sum_{i=1}^{n} P(Z_i)C\,(Z_i)$$

where

Z_i = risk event i

$P(Z)$ = Probability of risk event Z

$C(Z)$ = Cost of rectifying risk event Z

$E(Z)$ = Expected cost of risk event Z

The expected cost of the rolled up risk is the product of the probability of a risk event occurring and the "average" cost of rectifying that risk:

$$E_{Rolled} = P(Z_{rolled})C(Z_{rolled})$$

If one assumes all the risks are statistically independent of each other, then the probability of a risk occurring is given by:

$$P(Z_{rolled}) = 1 - \prod_{i=1}^{n}\left(1 - P(Z_i)\right)$$

The cost of rectifying the rolled up risk can be calculated by:

$$C(Z_{rolled}) = \frac{E_{Rolled}}{P(Z_{rolled})}$$

Often, only the levels for likelihood and consequences are assigned to individual risks.

Hence a representative probability for a given likelihood level and a representative cost for a given consequence level must be inferred. Note that the representative cost can be normalized if done consistently. Table 3 provides an example for converting levels to probabilities and costs for individual risks, as well as ranges for probability and cost to convert the rolled up values back to levels.

In examining the equations, the likelihood level will always be equal to greater than the highest likelihood level of any of the risks.

Table 3: Example level conversion for rolling up risks

Level (Likelihood or Consequence)	Probability (range)	Cost (range) {Normalized units}
1	0.10 (>.01 to ≤ .20)	0 (0 to <2)
2	0.30 (>.20 to ≤ .40)	5 (2 to < 10)
3	0.50 (>.40 to ≤ .60)	25 (10 to < 50)
4	0.70 (>.60 to ≤ .80)	75 (50 < 150)
5	0.90 (>.80 to ≤ 1.0)	225 (≥150)

Table 4 and Figure 7 illustrate the calculations and rolled up results for one set of five risks. Note that for this set of 3 green risks and 2 yellow risks, the rolled up risk is red.

As more risks are included into an aggregate, the probability of at least one of them being realized quickly becomes very high. This is illustrated in Table 5 and Figure 8 where five green risks combine into a rolled up red risk. Hence it is very appropriate to include the expected costs of risks into the cost estimates of a program. Programs that have more than a handful of risks will experience a near certainty of having one of their risks realized. Programs that do not include funding to cover the expected costs of their risks are under-funded. This key point cannot be over-emphasized; risk has a real cost that must be incorporated into program cost estimates.

Table 4: Risk Roll Up Example 1

Risk	Likelihood	Consequence	Probability	Cost to Rectify	Expected Cost
A	2	2	0.3	5	1.5
B	2	3	0.3	25	7.5
C	1	5	0.1	225	22.5
D	2	4	0.3	75	22.5
E	1	2	0.1	5	0.5
Roll up	**4**	**4**	**0.72**	**75.5**	54.5

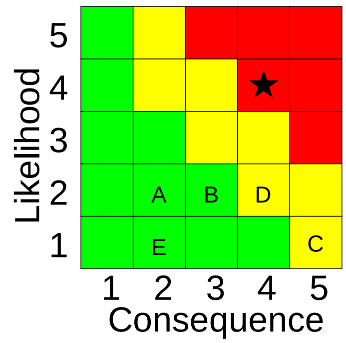

Figure 7: Risk Matrix Example 1

Table 5: Risk Roll Up Example 2

Risk	Likelihood	Consequence	Probability	Cost to Rectify	Expected Cost
A	2	3	0.3	25	7.5
B	2	3	0.3	25	7.5
C	2	2	0.3	5	1.5
D	2	2	0.3	5	1.5
E	2	2	0.3	5	1.5
Roll up	5	3	0.83	23.4	19.5

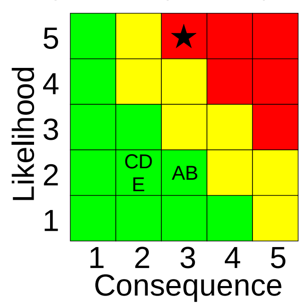

Figure 8: Risk Roll Up Example 2

RECOMMENDATIONS AND CONCLUSIONS

This paper has discussed many nuances in managing risk and makes the following specific recommendations:

a. Monetize the consequence of all risk events and identify the source of funding.

b. Explicitly state the reference program cost so that that the consequence levels of multiple risks are comparable.
c. Evaluate whether the risk is due to a knowledge gap or an inherent risk.
d. Manage knowledge gaps within the context of a knowledge based design method such as SBD
e. For each risk, explicitly state when during the system's life cycle the risk event is assumed to take place.
f. Use the risk mitigation activity approach proposed by Doerry and Sibley (2015)
g. If rolled up risk metrics are required, use the method provided.
h. Ensure program cost estimates incorporate the expected cost of risk and are sensitive to the impact of mitigation activities on the expected cost of risk.

Following these recommendations promises to improve the effectiveness of a risk management program and improve a program manger's insight into program risks.

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