U.S. AEROSPACE INDUSTRY COST RISK ANALYSIS SURVEY

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Abstract

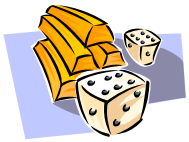
The purpose of this research paper is to summarize how the U.S. Aerospace Industry (Government and contractor) develops and applies cost risk analysis to aid business decisions. This paper is based on a survey provided to 2400 SCEA and SSCAG members in early 2008. It summarizes current risk assessment methods and tools, and the benefits to business decisions.

Survey responses (105) were received from 32 parent organizations, many with multiple sites. Organizations included 5 U.S. Government agencies, 12 major corporations, 13 support contractors, and 2 European agencies (Ministry of Defense and European Space Agency).

Tabulated results offer a "maturity metric" of prevailing practices, and depict positive trends versus the original 1998 survey. The 2008 survey contains four times as much information as the 1998 survey, with 12 new questions, expansion of old questions, and 60% more responses. New questions provide insight into decision benefits, $-thresholds, data sources, training, hurdles, and target confidence levels.

Aerospace program cost overruns and schedule slides have created considerable angst, funding issues, and negative headlines. As a result, DoD and NASA increasingly emphasize the importance of cost risk management and "cost realism" (i.e., "data-driven" estimates). Accordingly, the objectives of this survey and research paper are to …

- Assess current cost risk analysis practices and benefit to business decisions
- Identify preferred tools and methods
- Depict trends in methods and tools from 1998 to 2008
- Encourage analysts to be more proactive in assessing cost risk



Cost risk analysis supports business decisions in several important ways:

- Evaluate program strategies (e.g., bid/no-bid, make/buy, design trades)
- Avoid cost overruns and resist unwarranted cost reductions
- Manage and mitigate program risks

Several positive trends have surfaced during the past ten years:

- Historical actuals, as the basis of cost uncertainty, are used twice as often (37%)
- Finance Estimating is much more responsible for cost risk analysis (53%)
- Cost risk analysis is seen as less specialized (48%)
- Training has been dramatically improved

The survey finds several continuing concerns among cost risk managers and analysts:

- Cost risk analysis seen as "difficult" to do well
- Key hurdles include lack of data and weak management support
- Programs appear less pro-active, and more "wait-and-see" in resolving risk issues

On the whole, steady progress has been made since 1998, due to initiatives by government agencies, contractors, tool providers, and professional associations. Professional conferences (e.g., SCEA, ISPA, SSCAG) offer excellent training in techniques and tools to quantify and manage cost risk.

This research paper strives to advance the state of the art, promote risk analysis, and thereby support sound business decisions. The author is deeply indebted to SSCAG Risk Sub-Group members who helped develop the questions, and to SCEA and SSCAG for distributing the survey to their membership.

Survey Overview

Risk identification, analysis, and control are essential to program health. The object of cost risk analysis is to avoid cost surprises by proactively eliminating problems early in a program's life.

This survey assesses cost risk analysis as one segment of Risk Management which …

- Efficiently identifies risks
- Assesses risk handling options
- Effectively reduces or eliminates risks to achieve program goals
- Spans all phases of the program

Survey Overview … 2008 vs. 1998: The current 22 questions probe much deeper than the 1998 survey (11 questions), and encompass benefits, methods, training, and tools. The Excel-based survey has 160 multiple-choices and write-in fields (vs. 60 in 1998). It was e-mailed to 2000 aerospace analysts (vs. 300 hard copy in 1998). Responses were received from 105 managers and analysts (vs. 62 in 1998). In summary, the expanded questions and responses resulted in over four times as much information as the 1998 survey.

Issues addressed in both 1998 and 2008 surveys:	Questions
• Focal points	#4
• Integration of risk analysis in baseline estimate	#5
• Tools/models	#8
• Basis for estimating cost uncertainty	#10
• Display/graphics	#11
• Preferred data-curve distributions	#13
• Difficulty of analysis	#14, 15
• Training practices	#16
• Risk mitigation strategies	#19

Twelve new 2008 questions:

• Types of projects assessed	#1, 2
• $-thresholds	#1
• Benefits to program decisions	#3
• Components and data included in risk analysis	#6
• Monte Carlo vs analytic method	#7
• Suggested improvements for industry models	#9
• Level of risk reporting (total program, WBS, phase)	#12
• Best training sources	#17
• Best cost risk references	#18
• Maturity of program cost & risk management	#20
• Desired cost confidence level	#21
• Hurdles to cost risk assessment	#22

Please note that the analysis of each question, below, will discuss ten-year trends for questions contained in both the 1998 and 2008 surveys. To depict 10-year trends, 1998 survey results are shown as light blue lines in the graphs, super-imposed over the darker 2008 bars.

The 1998 survey results were presented at SSCAG symposiums in 1999 and published in SCEA's "*Estimator*" in 2000.

Credits: The author is deeply indebted to SSCAG Risk Sub-Group members who helped develop the questions, and to SCEA and SSCAG for distributing the survey to their membership.

Organizations responding to survey, and customers supported. The survey encompasses a large portion of the aerospace and defense industry.

- **Employer**. Roughly one fourth of survey respondents work for the Federal Government, one half for industrial contractors, and one fourth as consultants or university based (Figure 1). This profile is similar to the 1998 survey, and reflects the demographics of the SCEA and SSCAG professional associations.

- **Customer.** As expected, the profile of customers-supported (Figure 2) shows that almost 80% of the survey respondents support the U.S. Federal Government … either as Government employees or as

prime contractors.

- **Diverse customer base.** All segments of the DoD (Army, Navy, Marines, Air Force, other) as well as NASA and other Government offices are included in the sample.
- **Aerospace and Defense Industry.** The survey extends beyond aerospace (aircraft, missiles, and space) and also includes ground-based defense programs as well. In addition, 14% of the respondents support commercial and foreign governments (ESA, MoD).

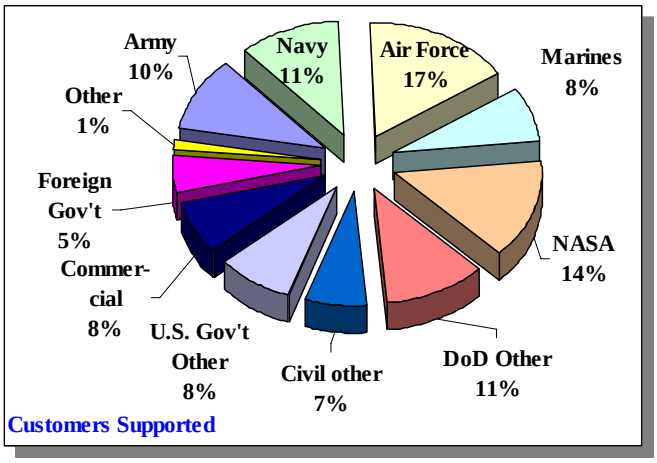


Figure 1 … Customers Supported

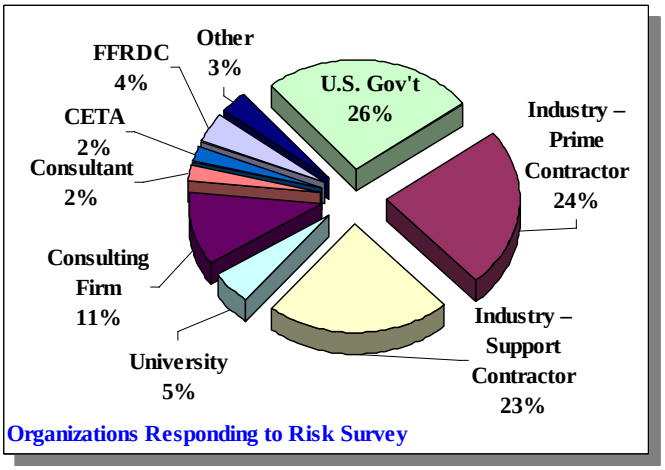


Figure 2 … Organizations Responding to Survey

Survey respondents represent 32 organizations and 63 sub-organizations/sites, much broader than the 1998 survey (26). Major Government defense offices, private contractors, and premier consulting firms are well represented. In addition, The European Space Agency and the United Kingdom MoD participated in the survey (5 surveys).

Aerojet Propulsion
Aerospace Corp - Concept Design Center
Air Force (Hanscom, CAIG, Robins, SMC, Pentagon)
Army (AMCOM)
AT&T Gov't Solutions
BAE Systems
Ball Aerospace
Boeing
Booz Allen Hamilton
Cubic Defense Applications
Ernst & Young
ESA - European Space Agency
J.F. Taylor, Inc.
Lockheed Martin Space Systems
Logapps
MCR Federal
Missile Defense Agency
MITRE
Modern Industries, Inc.
NASA (JPL, Dryden, Hdqtrs, SMD, PAE, IPAO)
Navy (NAVAIR)
Northrop Grumman
Pratt & Whitney Rocketdyne
Raytheon
SAIC
Self Employed Consultant
Sikorsky Aircraft Corporation
Technical Resource Solutions
Tecolote Research Inc
Tybrin Corporation
United Kingdom MoD
Wyle, Inc.

Figure 3 … Participating Organizations

Professional Estimating Associations Represented by Survey Respondents

SCEA and SSCAG members provided primary support to responses, since they were contacted for the survey.

It is noteworthy that ISPA members (contacted via SCEA and SSCAG) showed a larger-than-average interest in the survey and contributed one fourth of the responses.

NASA-CAIG, AIAA, MORS, SCAF, and EACE members also participated, due to multiple memberships in professional associations.

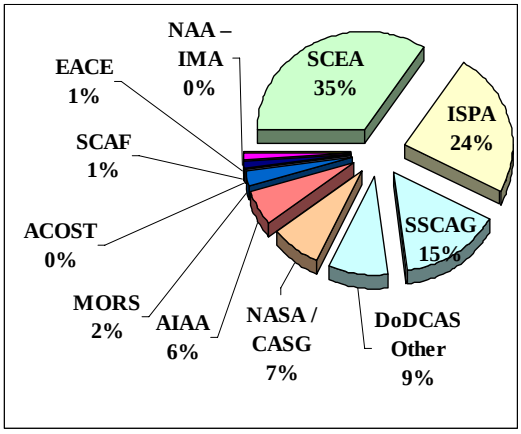


Figure 4 … Professional Associations Represented by Survey Respondents

Survey Findings

The survey asked two kinds of questions:

- "*Multiple-choice*" questions were presented as either (a) vote for one or (b) vote for several options
- "*Percent-of-time*" questions, where responses add to 100%

From the responses, three types of graphics are presented in this paper:

- "*Multiple choices*," where responses add to more than 100%
- "*Single choice*" or "*percent-of-time*", where responses add to 100%
- Absolute number of respondees (questions 9, 17, 18)

Most questions contained an "other" category with write-in blanks. These extemporaneous answers were extremely helpful to expand the number of response categories and clarify responses for this paper.

Over 90% of the respondents identified themselves and the organization they worked for, by name. However, we had promised earlier not to attribute survey answers to specific organizations, in order to elicit more openness. Accordingly, this paper does not correlate responses to named organizations.

Please note that the analysis of each question, below, will discuss ten-year trends for questions contained in both the 1998 and 2008 surveys. To show 10-year trends, 1998 survey results are shown as light blue lines in the graphs, super-imposed over the darker 2008 bars. The 1998 survey bars print as dark black in the "B&W" print mode.

1- When Cost Risk Is Assessed

One of the most fundamental questions asked by analysts is when to perform a cost risk assessment ("CRA"). Project size, contract terms and conditions, customer direction, and type of estimate are possible triggers to perform a CRA. Question 1 asks "under what circumstances does your organization develop cost risk analysis?" As a general rule, project size, obvious risk, and customer direction are the key motivations to assess cost risk.

Figure 5 (next page) shows that four common CRA triggers – technical risk (35%), customer requirement (32%), schedule risk (30%), and $-size (27%) – each have about the same likelihood of triggering a cost risk analysis.

The last two triggers – International (10%) and commercial (8%) – are much less frequently assessed for risk in the U.S. industry.

Figure 6 (next page) depicts $-size "trigger" thresholds, and shows no correlation between $-size and risk assessments. It is significant that 40% of the responses indicated that CRA is performed on all projects, regardless of size. Thus, 24% of the organizations assess risk on all projects, down to $1M.

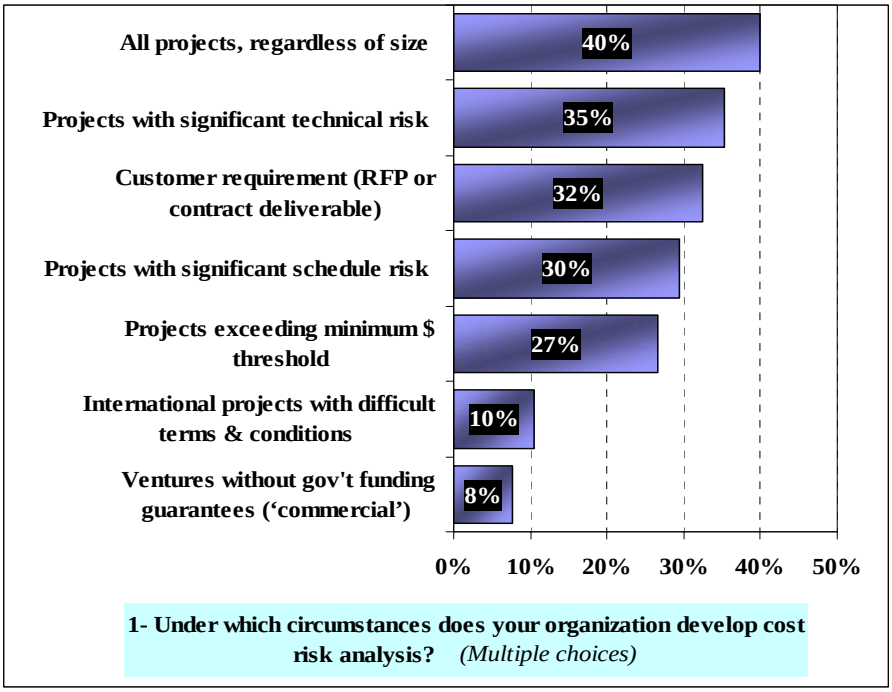


Figure 5 … Types of Estimates for Which Cost Risk is Assessed

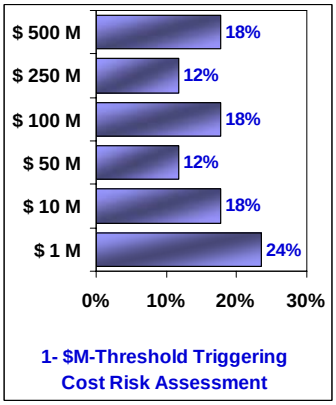


Figure 6 … $-Thresholds

2- What Percent of the Time Is Cost Risk Assessed?

This question assesses the frequency that various types of estimates – ROMs, ICEs, Proposals, design trades – involve cost risk assessments ("CRA").

Independent cost estimates (ICEs) are most commonly assessed for cost risk (51% of the time) for two reasons:

(a) Management needs to know the likelihood of financial success.

(b) The ICE provides an objective evaluation of the estimate.

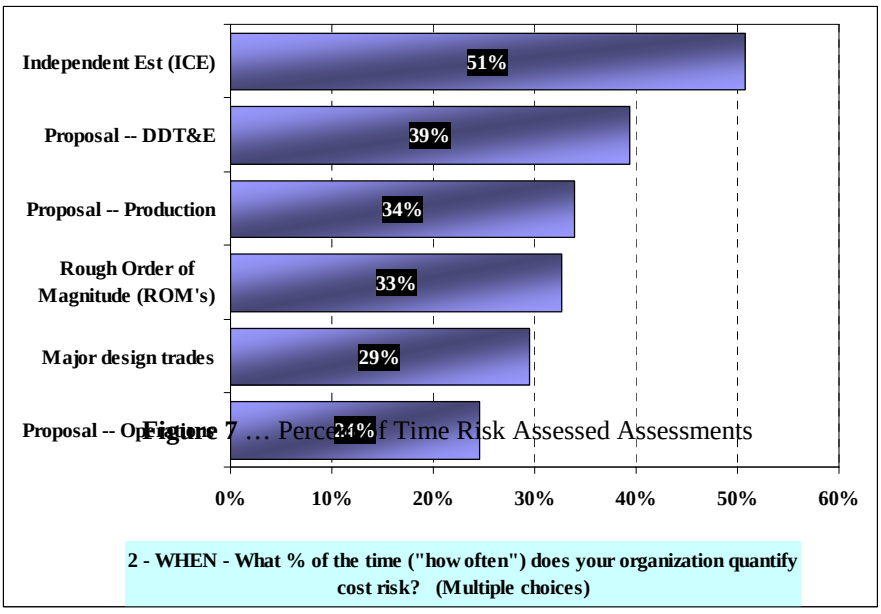


Figure 7 … Percent of Time Risk Assessed Assessments

Figure 7 … Percent of Time Risk Assessed

Cost risk is less frequently assessed for firm bid estimates, whether they be proposals for DDT&E (39%), production (34%), and operations (24%). The apparent reason for lower frequency on proposals is that CRA is most valuable to decision makers when "anchored" to an objective, independent cost estimate. CRA's anchored to proposals do not provide the same objective risk assessment, but merely tell management how risky the proposal team views their estimates.

To be more objective, it is preferable to anchor cost risk assessments (CRAs) to a data-driven (history-based) independent cost estimate, rather than the proposal. Thus, it is not surprising, that independent estimates assess cost risk much more frequently than proposal costs.

Rough-Order-Magnitude (ROM) estimates have considerably less risk than formal proposals. Thus it is not surprising that only 33% trigger a cost risk assessment.

Major design changes include CRA 29% of the time, very similar to ROMs.

3- Decision Benefits of Cost Risk Analysis

This is one of the most important survey questions, as it provides the business rationale for sound risk management and cost control.

The first benefit, "Probability of achieving performance", received an overwhelming 81% score. The vast majority of Government and industry respondents agreed that cost control is paramount, while meeting performance and schedule goals. Thus, a rigorous and well-based cost risk analysis, preferably anchored to the ICE (not proposal, see Q# 2), helps assure confidence in bid and budgeted costs.

The second benefit, "manage, prioritize, and mitigate risk" (68%) emphasizes the impact of CRA (cost risk analysis) on risk management and mitigation. A sound CRA will identify risk areas and lead management to prudently avoid or reduce risk.

The third benefit, "meet customer requirement (50%)," reflects the Government cost control objective. This objective is often stressed in an Request for Proposal (RFP) as "cost realism," "demonstrated past performance," or "historical basis of estimate."

A current AIA Government-industry action team is now developing RFP language which specifically requests contractors to present data-driven cost risk assessments, to aid Government procurement decisions. The recent GPS III RFP asked for low-high cost ranges and supporting rationale.

The customer expects rigorous cost containment, and may well demand more cost risk assessments in future program RFPs.

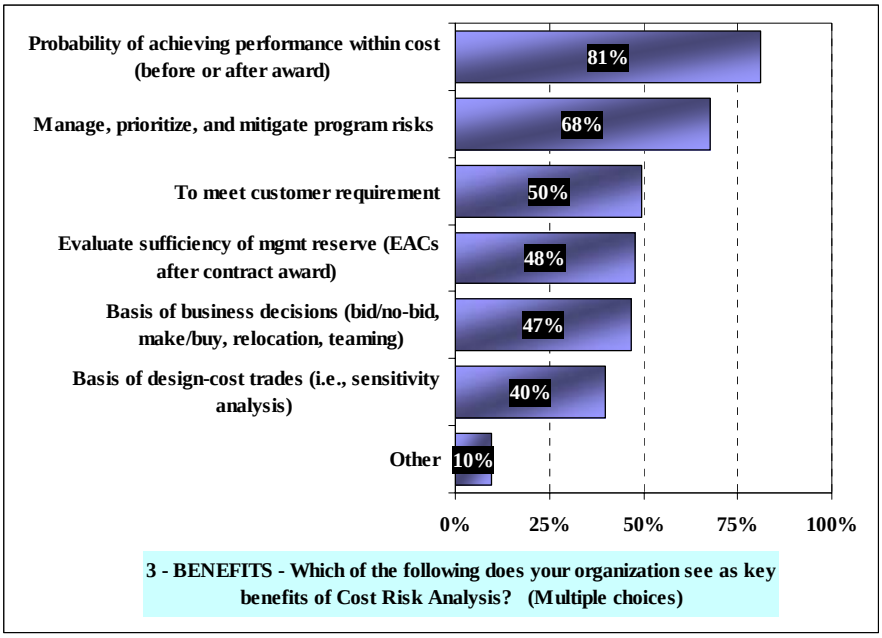


Figure 8 … Decision Benefits of Cost Risk Assessment

The fourth benefit, "evaluate sufficiency of management reserve," (48%), notes the importance of Cost Risk Analysis (CRA) after contract award. Too often, analysts limit their CRA to proposals. Yet, risk analysis is just as important during the life of a contract. CRA after contract award directly influences a program's "Maturity" score, as reflected in question #20. Please note that programs cannot reach the highest maturity in risk management without quantifying and controlling risk after contract award.

The fifth benefit, "business decisions (bid/no-bid, etc.)", at 47%, indicates the importance of CRA on management's strategic choices of team-mates, bidding, location of work force, and sub-contractors. This author's paper, "Impact of Cost Risk Analysis on Business Decisions," (SCEA-ISPA, Denver, June'05), provides 9 case studies, showing how CRA dramatically aided difficult Government and contractor business decisions.

The sixth benefit, "basis of design-cost trades," (40%) reflects system engineers' need for cost feedback and risk analysis to choose between competing design configurations. Well-based choices are critical during the life cycle of a product, from concept, through production.

4- Focal Point to Assess Cost Risk?

Finance Estimating is increasingly the focal point most responsible for cost risk analysis. Over 50% of survey respondents lean on Finance Estimating, up substantially from 35% in the 1998 survey.

Other functionals (engineering and management) are now less responsible than in earlier years.

This shift may result from increased training and resources available to the professional estimators (see Q#16, 17, 18).

Finance Estimating's increased role emphasizes the need for younger estimators to pursue training and experience in cost risk analysis.

It is suggested that Estimators proactively obtain the training and volunteer to perform cost risk analyses, rather than waiting for the "nudge."

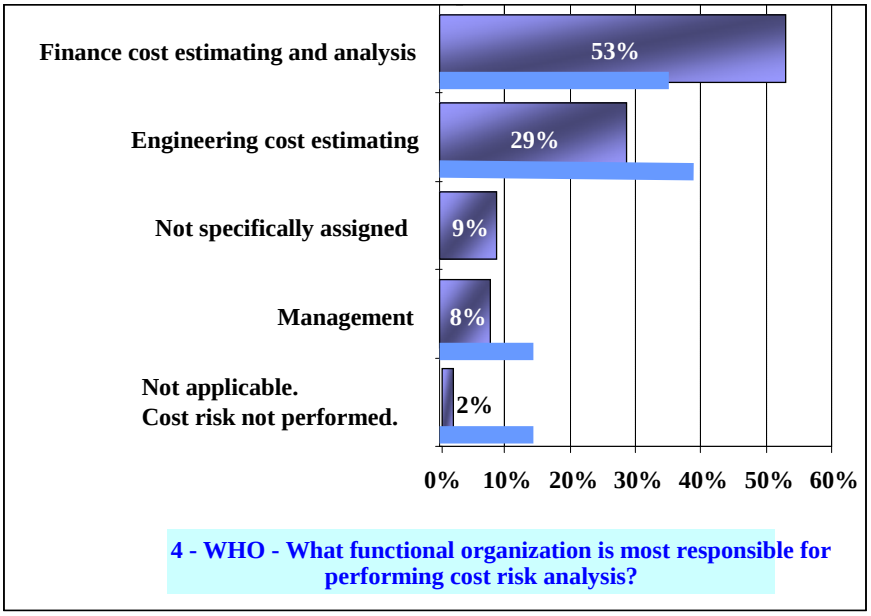


Figure 9 … Focal Point to Assess Cost Risk

In addition, older estimators should take initiative to involve younger colleagues in developing their risk analysis skills, with on-the-job application. There is every reason to believe that estimating is the most qualified team to perform CRA, due to our unique insights into cost history, cost/non-cost relationships, and computer modeling. As we estimators build cost risk proficiency, we increase our value and contribution to management, engineering, and the customer.

5- Risk Integral to Cost Estimate?

Survey responses show that analysis of cost risk is partially (45% of time) or totally (46% of time) integrated into the baseline cost estimate (>90% of the time). Rarely is it an after-thought, performed after the estimate is complete (<10%). However, the industry is split almost evenly on whether the CRA should be totally or partially integrated into the baseline estimate.

This author's experience is that there are several causes for partial vs. complete integration of CRA into the cost baseline:

- Nature of the math cost model
- Type of supporting historical data
- Use of statistical vs. judgmental risk ranges
- Urgency to complete baseline estimates quickly (and worry about risk later)

There has been a slight shift in the past 10 years away from "always" to "partial" integration of CRA in the baseline estimate.

The survey didn't address reasons for this shift, but it may be due to (a) the type of analysts performing CRA and (b) the cost estimating environment. Once upon a time CRA was performed more by specialists (mathematicians, statisticians), who are careful, rigorous, and integrated by nature. These analysts relied on Excel-based models, @RISK, Crystal Ball, and in-house custom models. Question #8 shows that these tools are somewhat less used now than in 1998.

Increasing reliance is now placed on the somewhat simpler risk applications in ACE-IT, SEER, PRICE, and NAFCOM. This trend puts more powerful risk tools in hands of less-mathematically oriented analysts, thereby expanding the workforce competent to assess cost risk.

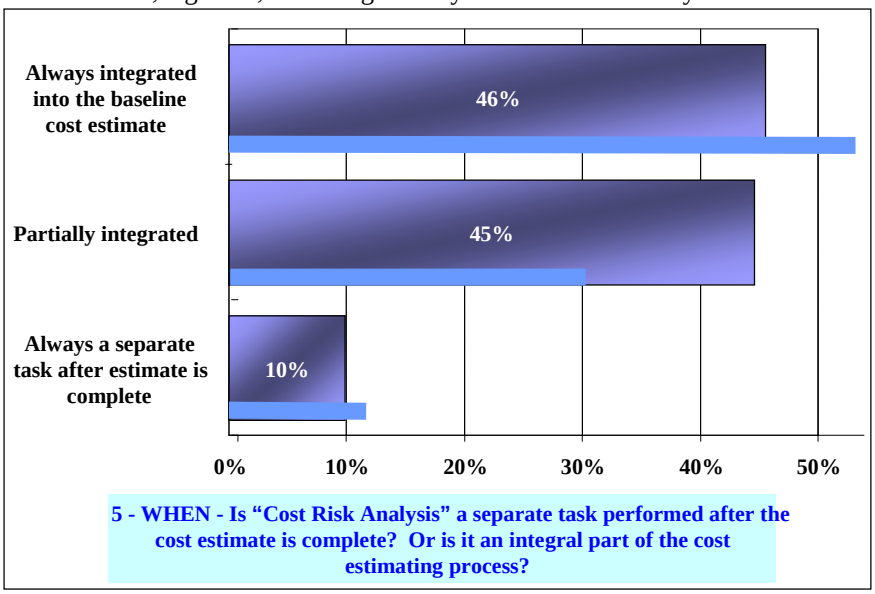


Figure 10 … Risk Integral to Cost Estimate

6- What's Included in Risk Analysis?

This question addresses a number of inter-related issues:

- Do cost risk analyses (CRA) rely on history-based cost uncertainties and CERs? (bar 1)
- Do CRAs consider only technical risk … but ignore business, sub-contractor, and schedule risks? (bar 3)
- Do CRAs consider cost reduction opportunities and risks ("R&O"), or just risks? (bar 4)
- Do CRAs include costs to mitigate risks? Or wait to "knee-jerk react" after the risk occurs? (bars-5-6)

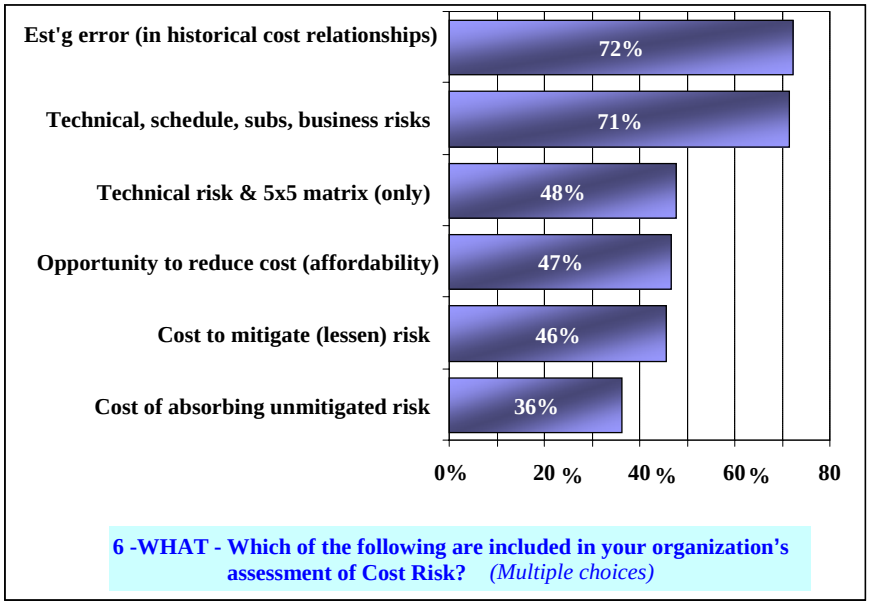


Figure 11 … Items Included in Cost Risk Analysis

It is most encouraging to see that almost 75% of CRAs rely on history-based CERs and data-driven estimating methods to estimate cost confidence (bar-1).

Bar-2, "Technical, schedule, subs, and business risks", strongly indicates comprehensive inclusion of all risk issues 71% of the time.

But the next item, bar-3, tends to disparage the bar-2 high score, by noting that 48% of the time only technical risks are included. This means only 52% of the time (not 71%), all risks are included. Thus, business and economic issues, funding uncertainties, labor wrap rates, escalation, subcontractor uncertainties, unreasonable

schedules, and other concerns may not be quantified. Not so good.

More disconcerting is the fact that cost reductions are included for affordability and "opportunity" analysis (bar-4) only 47% of the time. This low score implies two possible scenarios, each with practical issues:

- Have baseline cost estimates been scrubbed so low (optimistic), that the cost team sees almost no opportunity for further reduction? *If so, this "must-win" lowball estimating approach will produce low-confidence bids, and high likelihood of cost overruns.*
- Has the risk analysis focused solely on cost risks, as emphasized in the technical 5x5 matrix? *If so, this focus on only negative risks shifts the S-curve to the right, and erroneously exaggerates cost risk.*

The final two bars (bar-5 at 46%, bar-6 at 36%) when added together, indicate that 82% of the CRAs quantify costs to (a) prevent or (b) correct program risk events. These two bars indicate that preventive strategies outweigh "let-it-happen" strategies. Both strategies (prevention and correction) have value, depending on this situation. However, the survey indicates there is a 60/40 split toward preventive risk strategies.

7- Methods … Monte Carlo or Analytic?

Despite the great publicity given to Monte Carlo techniques to produce cum-S curves, the analytic ("method of moments") method is used one third of the time.

Proponents of this method applaud its speed (no waiting for 5,000 iterations), relative simplicity (in the hands of math experts), and ability to properly handle correlation.

This question was not asked in the 1998 survey, so trends cannot be assessed.

In general, newcomers to risks assessment find the standardized tools (ACE-IT, PRICE, SEER, etc.) easiest to use, followed by @RISK and Crystal Ball shells around Excel analyses.

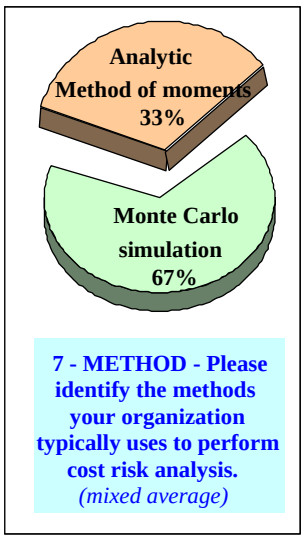


Figure 12 … Methods

8- Tools and Models

Figure 13 (next page) summarize the frequency of use by various cost risk assessment models/tools.

Custom models: 60% of cost risk analyses (CRAs) rely on customized models and CERs to assess risk: Sum the first three bars (Crystal Ball 23%, @RISK 21%, and in-house models 16%). The survey indicates that users evenly split between Crystal Ball and @RISK tools, with a close following by customized models.

Custom models are down about 12% in popularity vs. the 1998 survey, perhaps due to more robust standardized models.

Standardized commercial models are used 40% of the time (ACE-IT, SEER, PRICE, NAFCOM, Risk+, or ProAct). These tools are increasingly robust, with greater flexibility to handle such items as correlation. However, Question #9 resulted in 80 suggestions for model improvement, with "*correlation*" and "*cumbersome*" being the predominant concerns.

All tools provide additional insight into cost risk. However, "standardized" models, though easy to use, may not properly evaluate (a) true, historical cost uncertainty, and (b) correlation of additive WBS elements.

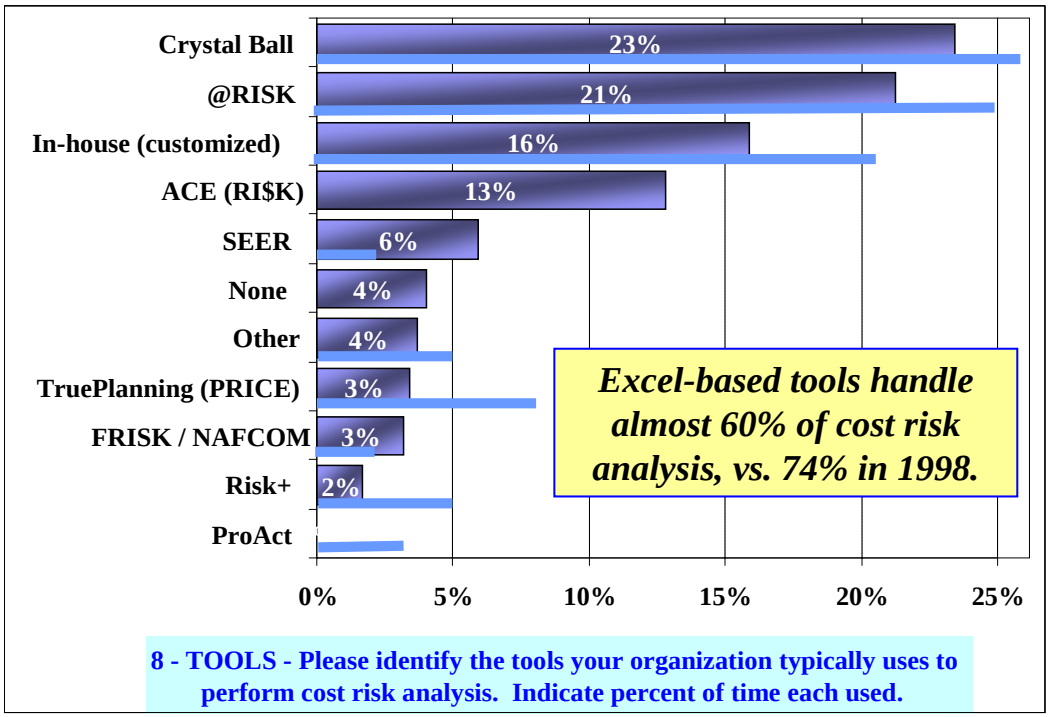


Figure 13 … Tools and Models

9- Risk Tool Suggestions

Survey respondents offered 80 suggestions to improve standardized, industry cost risk models. Since these suggestions relate to tools (not to cost risk analysis), they are not included in this paper, but are being sent directly the tool developer. Key issues include …

- Treatment of correlation
- Ease of use vs. confusion
- Handling schedule risk
- Setting uncertainty ranges.

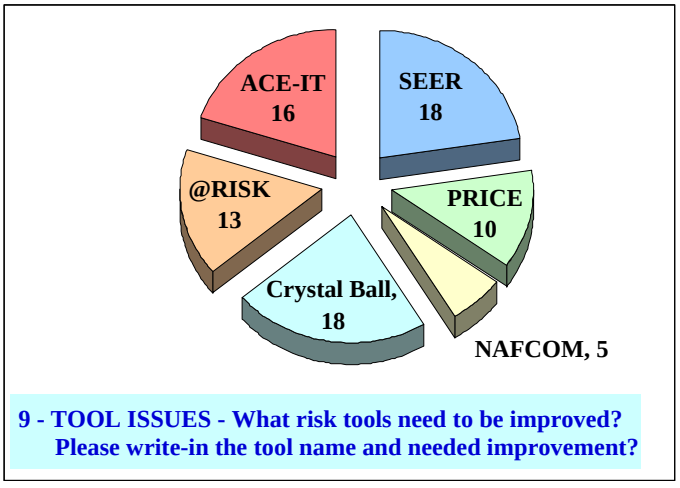


Figure 14 … Risk tool Suggestions

10- Estimating Cost Uncertainty

Figure 15 (next page) shows the various methods used to estimate cost uncertainty … data-driven and subjective.

This is one of the most positive 10-year trends – the increasing use of data-driven (history-based) actuals as the basis for predicting future cost risk. "Statistical analysis from history" (bar-1) almost doubled in use to 40%.

Unfortunately, subjective methods are used 60% of the time to quantify cost uncertainty:

- Bars-2-3-4 total 60%, and reflect three judgment-based methods for estimating cost range and uncertainty.
- Bar-2 "Team Consensus, subjective" (25%) and Bar-3 "One analyst, subjective" (17%) each have the same frequency of use as in 1998.
- Bar-4, "Team consensus, using guided survey," is down from 38% to 16%. As the strongest subjective method, it's unfortunate that this approach has declined, while the weaker methods (bars 2-3) continue in use.

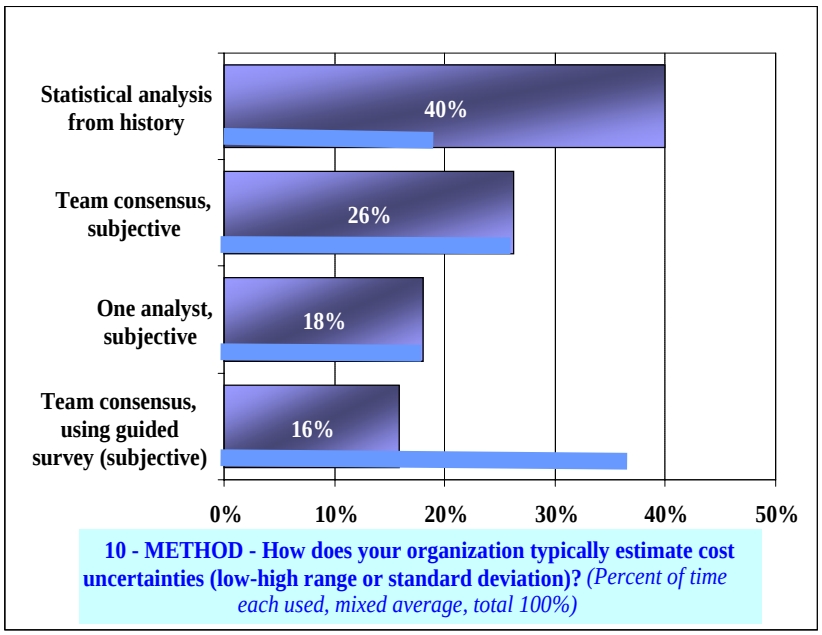


Figure 15 … Method for Estimating Cost Uncertainty

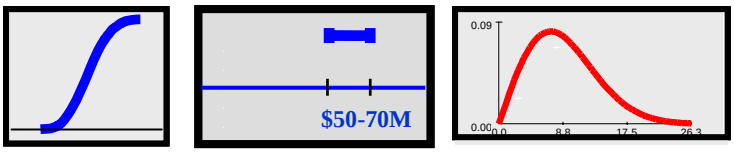
The dramatic improvement in use of history-based methods (to 40%) may be attributed to a number of improvements …

- Historical data collection
- Data analysis and use of statistical cost estimating relationships (CERs) (Question #6)
- Emphasis on cost risk assessment and proposal "cost realism"
- Tool feature, availability, and ease-of-use

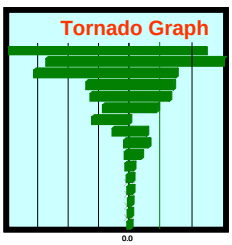
11- Displaying Risk and Uncertainty

Figure 16 (next page) shows that the cum-S curve continues to be the most popular visual aid to display cost risk (48% of the time).

- The cum-S is somewhat less prevalent than in 1998 (60%), as other methods are used more frequently.



- The low-high range is second most popular (21%), and other methods have modest acceptance.
- Far down the priority is the Probability Density Function (PDF), which has never been particularly popular (7%).
- The Tornado Chart is an efficient, powerful means for portraying many areas of relative risk and sensitivity, by cost driver.



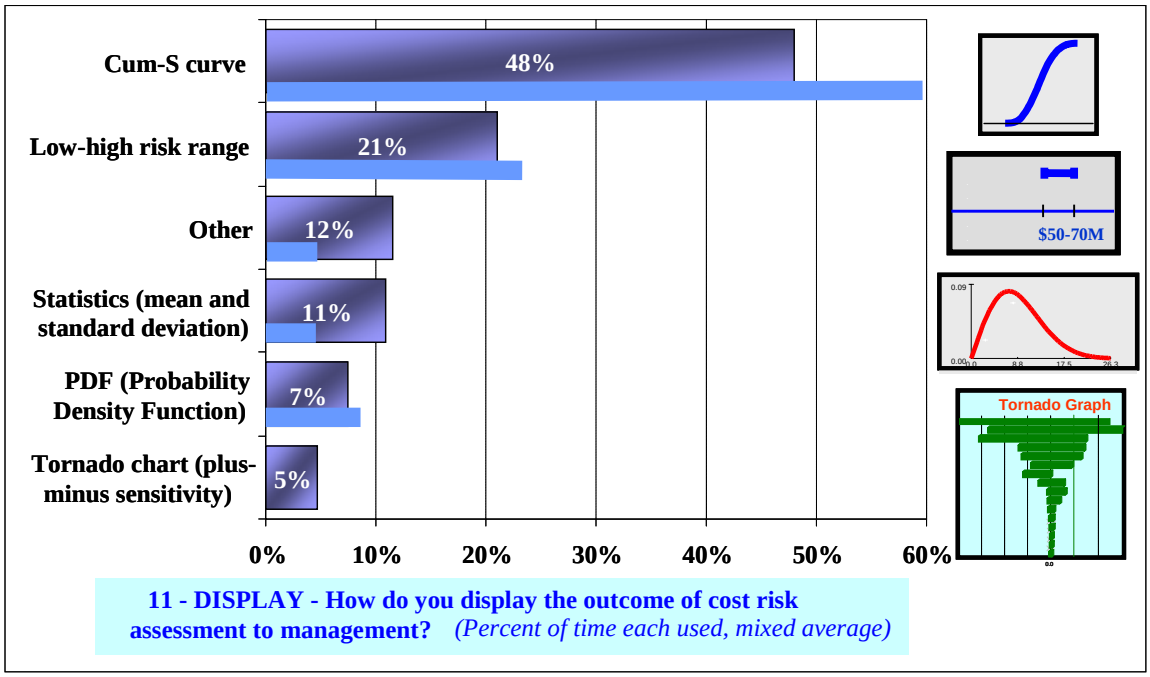


Figure 16 … Displaying Risk and Uncertainty with Graphics

12- Level of Risk Reporting

A new 2008 question asks at what level cost risk is assessed and reported. Roughly half of the respondents report cost risk for the total program, not split down by WBS or by phase. The other half report by WBS and/or phase.

There is certainly no absolute right or wrong here, as risk assessments and cost reviews serve widely differing purposes (see Q# 3 "Benefits of Risk Analysis)."

However, it is often preferable to develop cost risk at low enough levels (WBS and functions) to identify specific issues to be resolved, one at a time. In addition, lower-level risk reporting helps build management and customer confidence in the overall analysis.

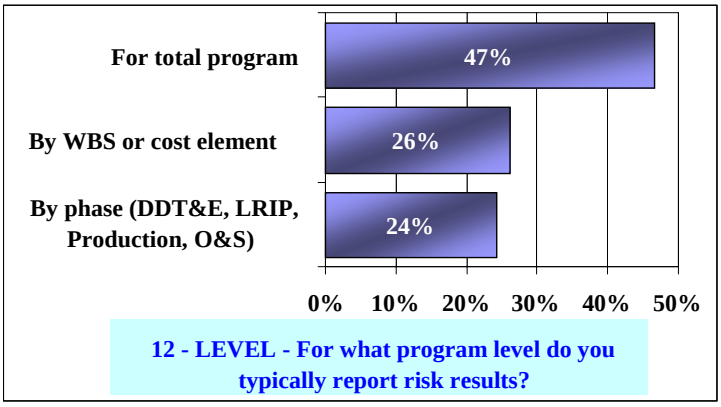


Figure 17 … Level of Risk Reporting

13- Preferred Data-Curve Fits

Cost modelers have their favorite curve fits, depending on the type of analysis being performed and their penchant for precision, high correlation R^2, and low residuals.

Figure 18 (next page) shows that the homely triangular distribution retains top ranking after decades of use. Its popularity is slightly lower at 54% than in 1998 (58%), due primarily to increased use of the log-normal data fits.

Why the shift from triangular and beta to log-normal fits? Question #10 shows that historical data fits (log-normal) have replaced some of the subjective cost ranging (triangular distribution), and likely is the reason for the curve-fit change.

The beta and Weibull curves are likewise less in fashion.

This shift may be due to infusion of less-mathematically-driven cost estimators.

Or the shift may have resulted from well-known experts such as Dr. Paul Garvey or Dr. Stephen Book, who find little impact on total Monte Carlo results with various underlying data curve fits.

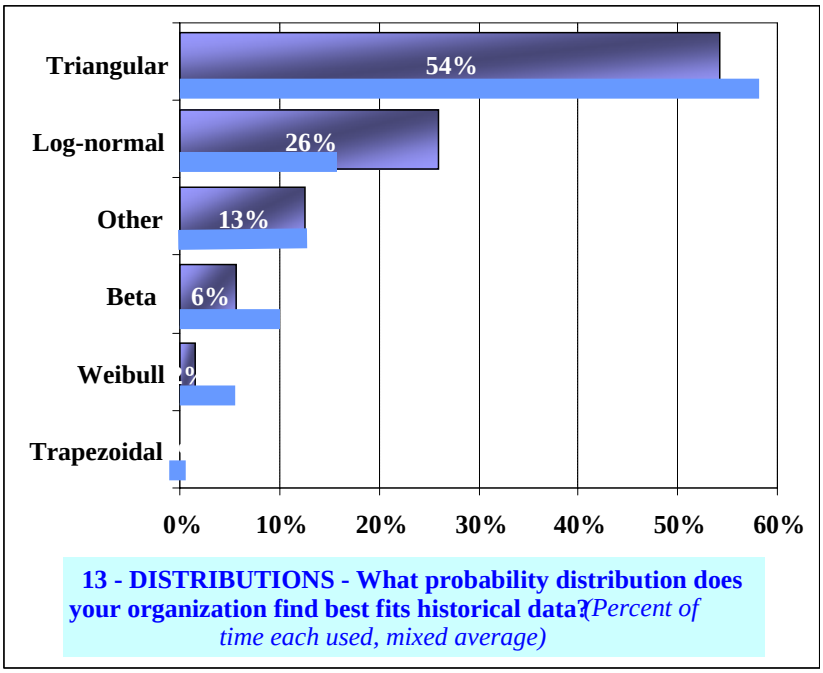


Figure 18 … Preferred Data-Curve Fits

14- Specialized Skill Required?

In summary, 91% find cost risk analysis somewhat or highly specialized, and only 9% believe all estimators should be able to perform the complex analyses. This is not a desirable condition for an industry striving for cost realism and high-confidence cost estimates. There is a keen shortage of trained cost risk analysts. The responses covered a huge breadth … from "only a few can do it" (48%) … to … "all should be able to do it" (9%). And in the middle were those who felt "many can do it" (38%).

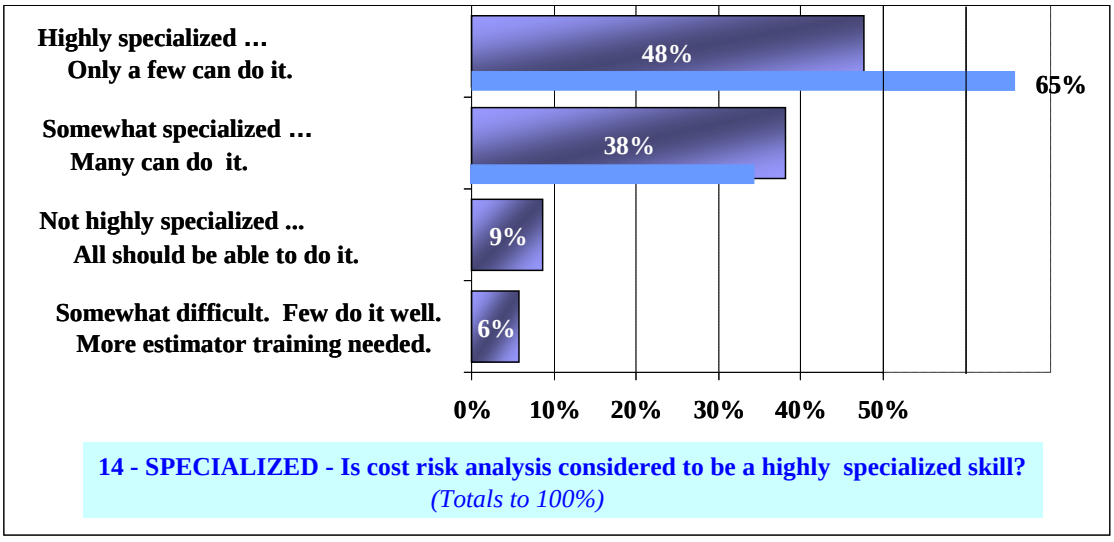


Figure 19 … Extent of Specialized Skill Required

Nevertheless, this is one of the more encouraging trends between the 2008 and 1998 surveys. There has been a significant reduction in perceived specialization. Ten years ago cost risk analysis (CRA) was viewed as "Highly specialized, only a few can do it" (65%), versus 48% today. However, in both 2008/1998 surveys, very few thought that most estimators should be able to perform CRAs.

Several responses wrote in that "many analysts think they can do it, but only a few can do it well" … a loud call for more training and practice.

Other responses wrote that "guidance is available for the interested and competent Estimator." This is a call for making good training, references, and mentorship available to all Estimators.

Several specified that "training is greatly needed."

It is noteworthy that 6% of the responses noted CRA as "somewhat difficult, few do it well, and more training is needed." These write-in comments emphasize the importance of formal and on-the-job training. Cost risk analysis is not terribly difficult to the trained and practiced; but it certainly is intimidating to the novice. Let this be a call for better training in data analysis and tools.

15- Difficult to Assess cost Risk?

Question #15 is the flip side of #14, and asks if cost risk analysis (CRA) is difficult. These answers exactly echoed the previous question, with 79% saying "sometimes" or "yes," and only 7% saying "no."

Following is a sampling of the most prevalent write-in responses:

- "Difficult to do well … easy to do poorly."
- "Difficult without training and experience."
- "Not technically difficult, but hard to explain."
- "Difficult in absence of good data and cost models."
- "Difficult unless one has the right mindset."
- "Gets hard, very fast … need resident 'Advisor-Nerd'."
- "Difficult challenge is to explain CRA meaningfully to management."

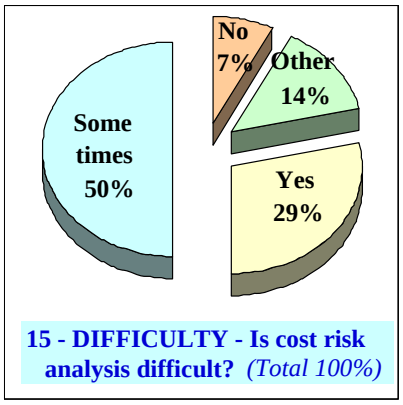


Figure 20 … Difficulty

Comments from the 1998 survey further expanded on the challenge we face in training the next generation of cost risk analysts:

- "Critical skills include the ability to interview capably."
- "Not many understand what's really happening in cost risk analysis."
- "Requires exceptional communication skills, statistics, analytical ability, and knowledge of engineering and manufacturing processes."
- "Adequate training in probability is a necessity."

In summary, the responses from both the 2008/1998 surveys are calling for better and deeper training and on-the-job practice under a skilled mentor. These skills are only partially taught in the typical undergraduate program. Furthermore, major organizations appear to lack sufficient students and resources to efficiently transmit this knowledge "torch" to younger, willing hands.

The next two sections deal specifically with training and resources, as called for in questions 14 and 15.

16- Training Provided to Risk Estimators

The most encouraging training trend is reduction of "no training" from 38% to 13% (when compared with the 1998 survey).

There has been a major shift from "no training" and "internal-only training" to a combination of internal-external training. There's also been an increase in mentoring by more experienced risk estimators. Both trends are positive, increasing outside training and mentoring.

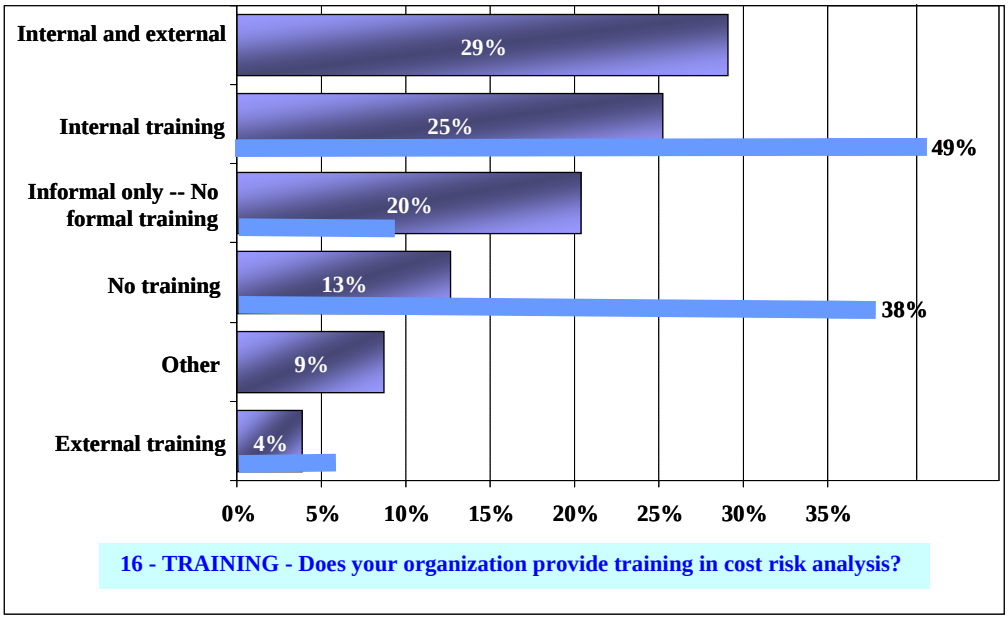


Figure 21 … Training Provided to Risk Estimators

17- Training Sources

Sixteen training sources were identified in the survey.

Of 105 respondents, 88 provide training to their risk estimators via the following sources:

- Licensed industry tools
- Internal
- SCEA-ISPA-SSCAG
- various other institutions

It is encouraging that a number of new training sources are available through SCEA-ISPA-SSCAG professional associations. In addition, training in @RISK and Crystal Ball have been strongly supported by Decisioneering and Tecolote. Finally, larger organizations have developed training resources for their risk estimators.

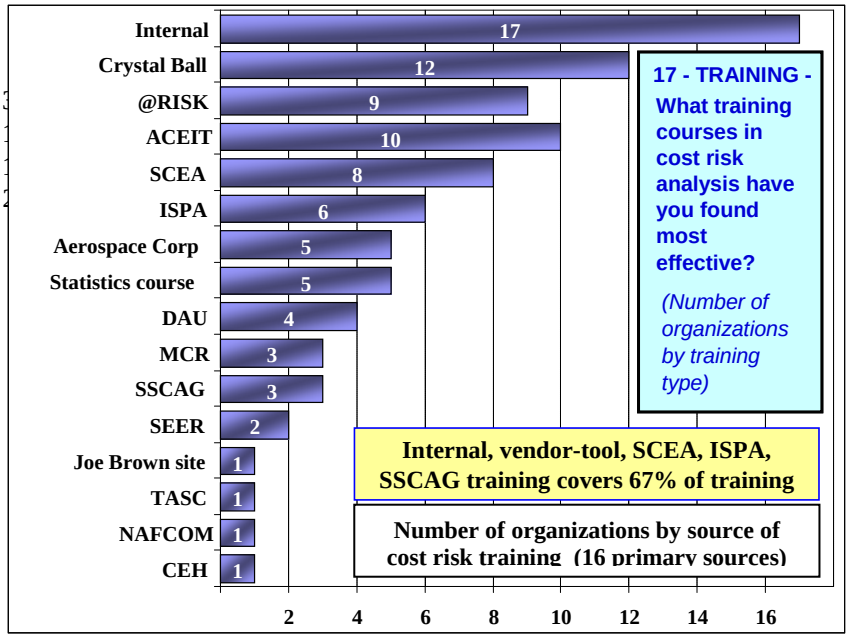


Figure 22 … Training Sources

18- Useful Cost Risk References

Write-in responses to this question displayed a wide diversity of useful cost risk references.

Because the question was open-ended, there was no multi-voting or consensus. Rather, the respondents considered the question for a few moments and wrote in the resources they used most often.

More than half of the surveys left this question blank, while others indicated multiple references.

The table to the right indicates the number of survey responses for the 11 references having 2 or more write-in responses.

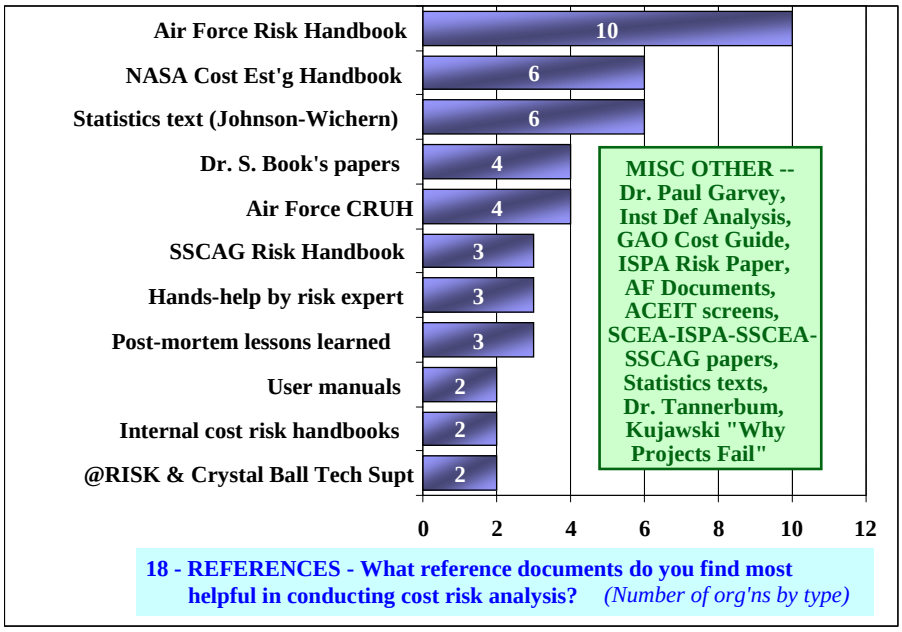


Figure 23 … Useful Cost Risk References

Thirteen additional references were recommended:

- Web-sites
- ACEIT, @RISK, and Crystal Ball 'help' menus
- Dr. Stephen Book's one-day training course
- Dr. Paul Garvey's one-day risk training course
- GAO Cost Estimating Guide
- DCAA Cost Analysis Manual
- Dr. Tannenbum's works
- Program post-mortems and lessons learned
- Internal organization cost risk handbooks
- Risk analysis experts with practical experience
- Johnson and Wichern, *"Applied Multivariate Statistical Analysis"*
- Internal organization toolbox of models and methods
- ISPA-SCEA-SSCAG papers and training materials

19- Cost risk Mitigation Strategies

"Mitigation Strategies" is one of the most important survey questions. The SSCAG Risk Sub-Group diligently re-worded the multiple choices to more precisely communicate the most common cost risk mitigations.

These 8 strategies are force ranked from most to least used. The respondents could check multiple strategies, such that their allocation added to 100%. Thus, figure 24 (next page) displays the weighted average of all responses, as percent of time used.

The yellow block (at the right of the chart) notes that 5 of the 8 strategies are "proactive" and 3 are "stand-off and wait."

Both proactive and stand-off strategies can be effective, depending on the circumstances.

- Proactive strategies are active, "take-charge" initiatives to reduce and control cost risk.
- "Stand-off" strategies either rely on the Government customer to take action or wait for more affordable technologies to reduce technical and cost risk. Sometimes a "stand-off" strategy is wisest, when technical hurdles are insurmountable.

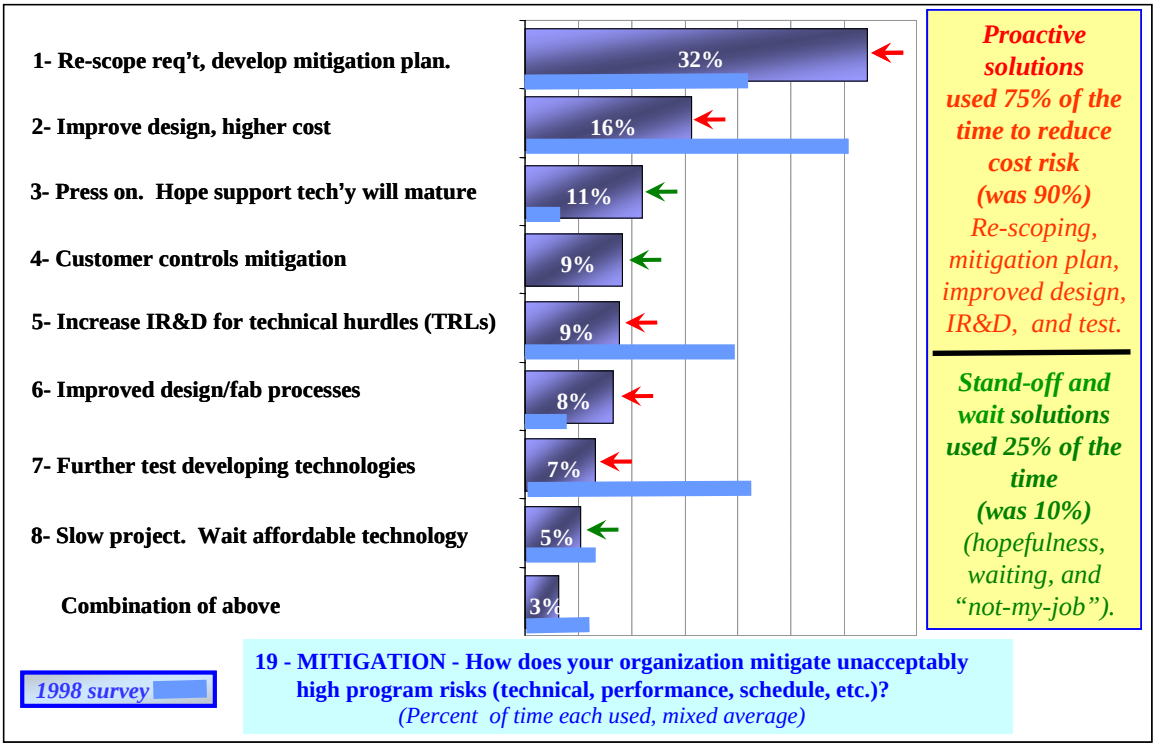


Figure 24 … Mitigation Strategies … Proactive and Stand-Off

On average, survey respondents indicate that proactive and "stand-off" solutions are pursued 75% and 25% of the time, respectively. It is noteworthy that proactive solutions were applied 90% of the time in the 1998 survey. This 15% reduction in proactive solutions may be coincidental (within the statistical 'noise' of a small sample), or due to a different mix of survey respondents.

The light blue line in Figure 24 indicates the percent of 1998 survey responses. Every mitigation category shows significant change from 1998.

- The first two categories (1- re-scope and 2- improve design) show a significant change in strategy. Today there is more emphasis on de-scoping requirements and less toward improving design and associated cost. Thus, the 10-year trend is toward de-scoping and reducing costs.
- Categories 5 and 7 (increase IR&D and further test developing technologies) show a marked reduction since 1998, further indication of a mindset to trim cost growth.
- "Stand-off" categories 3, 4, and 8 (press on, wait on customer direction, and slow down) are substantially up since 1998. This shift appears to indicate (a) increased reliance on customer solutions or (b) "miracle" technical breakthroughs from subs and/or Government labs.
- Category 6 (less expensive design/fab processes), while small, is significant. It shows a proactive reduction in cost through investment in improved design or fabrication tools and processes. In an age of continuous process improvement and learning curves, one would expect this mitigation strategy to be involved much more often than a mere 8%.

In summary, comparing 2008 vs. 1998, organizations now place …

- Greater emphasis on de-scoping requirements, relying on customer and subs' technical breakthroughs, and improving design/fab processes to reduce cost risk.
- Less emphasis on improving design-cost, increasing IR&D, further test developing technology, and waiting for technology to catch up.

20- Maturity of Cost and Risk Management Process

This "Maturity" question is one of the most significant survey findings. In summary, only 25% of organizations believe they are reasonably mature in cost and risk management.

The five maturity levels (figure below) indicate the level of program cost risk management.

Cost risk assessment is a sub-set of step 2 ("Analyze") in the five elements of a mature risk management program: 1) Identify, 2) Analyze Risks, 3) Assess Handling Options, 4) Mitigate, 5) Communicate/Track Results.

The survey maturity scale extends from Level 1 (least mature) to Level 5 (most mature).

- Level 1 sometimes quantifies risk, and Level 2 more frequently quantifies risk
- Level 3 quantifies likely risks and tracks the risks in a mitigation plan
- Level 4 quantifies risk, integrates in a formal Risk Mgmt plan, and tracks to completion … for proposals
- Level 5 does all the above, for both proposals and contractual, post-award EVMS-EAC plans.

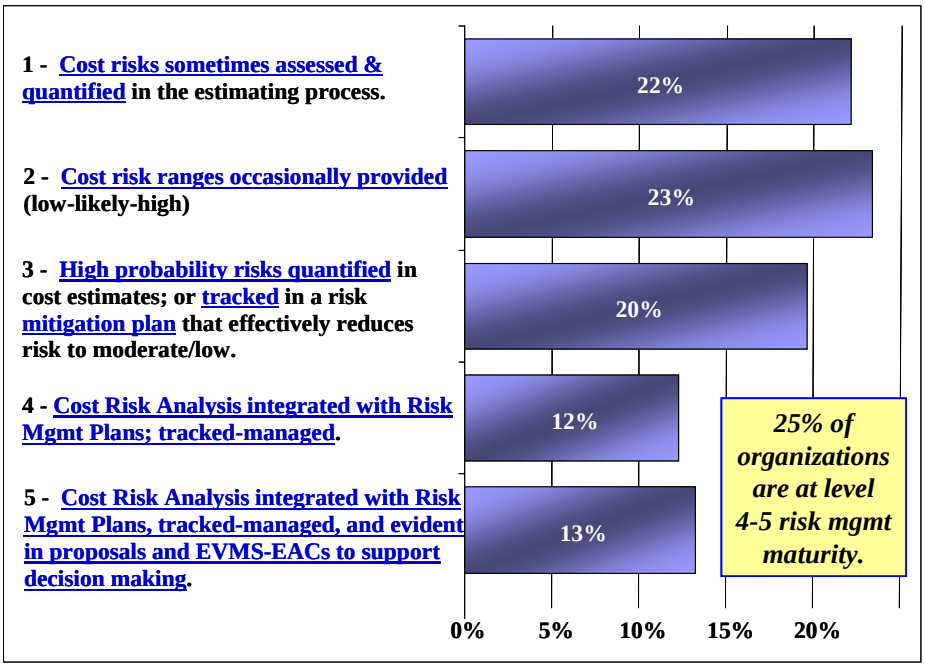


Figure 25 … Maturity of Cost and Risk Management Process

Only one fourth of the organizations rated themselves at level 4 and 5. One fifth rated themselves average, level 3. And almost half rated themselves at level 1 and 2.

These honest self-assessments indicate that program cost risk analysis needs much more emphasis. Furthermore, cost risk analysis must be better integrated into Risk Management in both proposal and execution phases.

21- Acceptable Confidence Levels

Acceptable risk confidence levels are of keen interest to both Government and contractors. The Air Force has publicly stated it desires >70% confidence. Some Government offices are considering yet higher likelihood of success, to reduce schedule slides and cost overruns.

Likewise, contractors desire high-confidence estimates, but know from bitter experience that too much cost margin pushes them above the competitive price line. Figure 25 depicts the desired cost confidence levels of 24-35 responses from each major category, Government, Prime Contract, and Support Contractor.

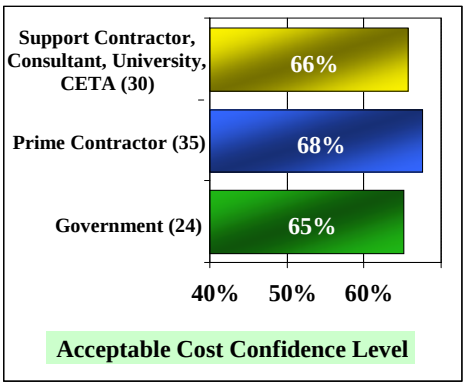


Figure 26 … Cost Confidence Goals

Figure 26 depicts the number of organizations at various levels of desired cost confidence. Roughly 25% of the organizations strive for ~50% confidence, 12% desire 60%, and over 60% seek 70% or more confidence.

The survey responses are a mix of 89 government and industry organizations, each with various procurement objectives, budget constraints, desired cost confidence, multiple past performance issues, and future objectives.

Figure 26 depicts the huge range in desired cost confidence, across Government, Prime, and Support Contractors.

The frequency dip at 60% confidence indicates that organizations desiring more than 50% confidence will generally jump all the way to 70%. Very few organizations shoot as low as 40% or as high as 90%.

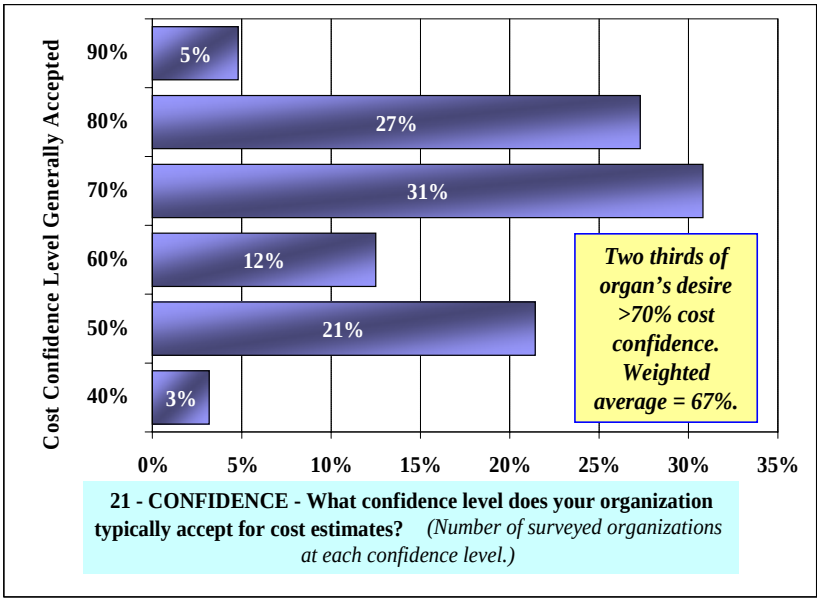


Figure 27 … Percent of 89 Organizations by Cost Confidence

Figure 27 (next page) displays cost confidence goals for Government, Prime, and Support Contractors at various confidence levels.

- Government offices and Support Contractors cover a much wider confidence range (40-90%) than Prime Contractors, which run from 50-80%.
- There is an apparent central tendency of all organizations around 70% … the Governments' favorite goal, and prime contractors' second choice goal.
- It is interesting that the most frequent Prime Contractor confidence goal is 80%.

Please note that the survey represents *desired*, not *actual*, cost confidence levels. That is, survey responses reflect organizations' *desired* level of cost probability, not the actual cost confidence achieved at contract definitization. The Government procuring office may strongly desire 70%-80% confidence in its contract awards, yet negotiate lower cost confidence due to (a) work scope increases vs. hard budget constraints, or (b) the need to hold back funds for future contract growth or IDIQ (indefinite definition, indefinite quantity).

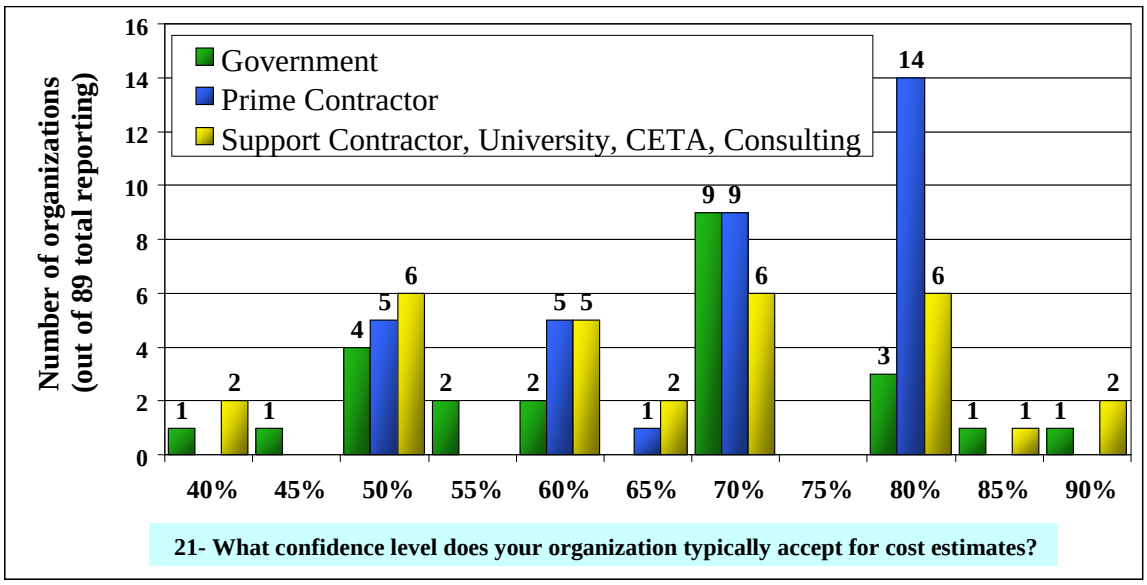


Figure 28 … Organizations by Desired Cost Confidence Level

The fourth chart, Figure 28 in the cost confidence series, groups Government, Primes, and Support Contractors to quickly assess variations. Each bar represents a major Government office (e.g., NASA, Air Force, Navy, Army, MoD/ESA), Prime Contractor, or Support Contractor (e.g., Tecolote, MCR, Aerospace Corp).

Please note that these bars combine multiple responses for each organization, and therefore are a blend of objectives, constraints, past performance issues, and other variability.

This display shows the relative consistency in prime goals (70%) and support contractor cost goals (60-70%).

Figure 28 also depicts large swings in Government office expectations, from 50-70%. Four of the five Government bars are US organizations, and one is an average of United Kingdom's MoD and The European Space Agency (ESA).

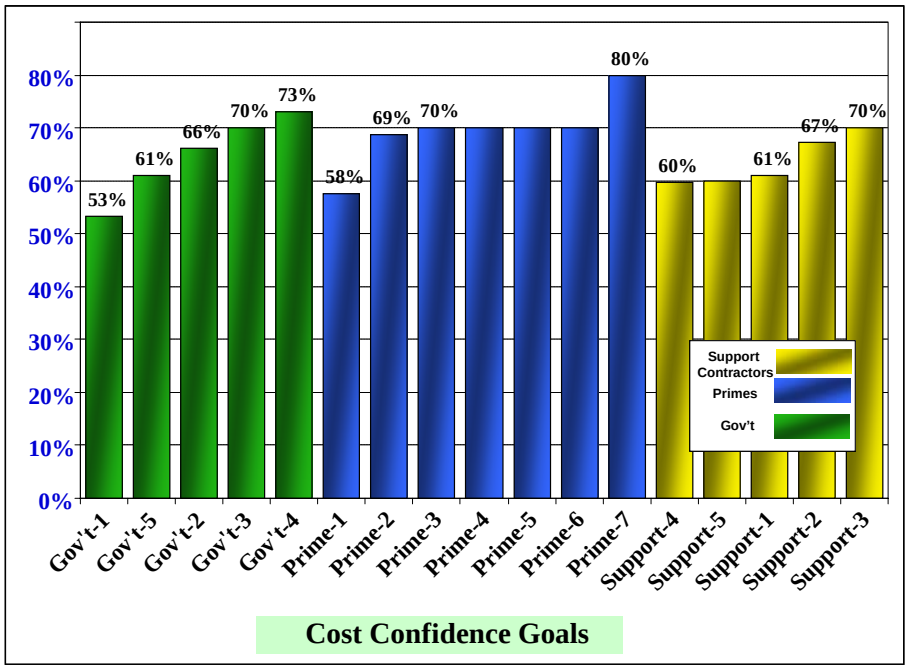


Figure 29 … Organizations by Desired Cost Confidence

22- Hurdles to Cost Risk Analysis

Cost risk estimators have struggled against obstacles, seen and unseen, since the dawn of history. We often feel like the sweaty gladiator in the ring … fighting one giant after another.

Twelve hurdles were multi-voted … respondents could voted for several hurdles.

"Sparse historical data" (75%) is clearly the highest hurdle, followed closely by "limited functional support" (61%), and "overly optimistic targets" (53%).

Half (6) of the hurdles relate to the lack of functional and management support.

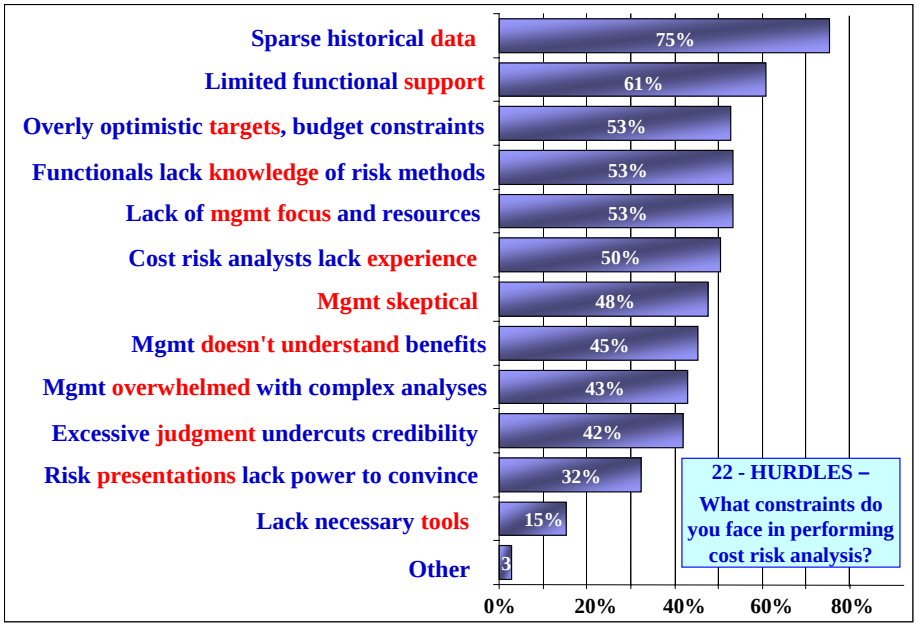


Figure 30 … Hurdles to Cost Risk Analysis

Surprisingly, "excess judgment" (42%), unconvincing presentation style (32%), and "lack of cost risk tools" (15%) are ranked as least important.

Some of the hurdles appear to overlap a bit, such as 3 relating to management focus and resources (53%), skepticism (48%), and confusion with complex analyses (43%).

So, what are we cost risk analysts to do with all these hurdles?

- The pessimist may argue we can't change the hearts and minds of our functionals and management, nor can we conjure up missing historical data, so back off and take the easy road.
- The optimist, however, takes a longer view and remembers that the cost risk analyst "requires exceptional communication skills and the ability to interview capably" (caution note, Question #15). We can be at least partially successful when we diligently apply all our God-given IQ, social polish, tact, imagination, optimism, customer orientation, and good cheer … plus a thick hide and willingness to try again.

What did Teddy Roosevelt know about the perplexities and frustrations of modern aerospace cost risk analysis? Perhaps he anticipated our complex lifestyle when he penned the following inspiration, now inscribed on many American halls …

> "It is not the critic that counts, not the man who points out how the strong man stumbled or where the doer of deeds could have done them better.
>
> The credit belongs to the man who is actually in the arena; whose face is marred by dust and sweat and blood; who strives valiantly, who errs and often comes up short again and again; who knows the great enthusiasm, the great devotions, and spends himself in a worthy cause; who at the best, knows in the end the triumph of high achievement, and who at worst, if he fails, at least fails while daring greatly, so that his place shall never be with those cold and timid souls who know neither victory nor defeat."

Ten-Year Trends

Eleven questions were common to both the 1998 and 2008 surveys. Five of these showed very positive trends, three showed minor negative trend, and three showed no little or no change.

Positive trends:

- Historical actuals, as the basis of cost uncertainty, is used twice as often (37%) versus 1998. The offset reduction is that team consensus is now about half as much at 15%. This dramatic improvement appears to be the result of improved collection of historical data, increased use of statistical CERs (Q# 6), emphasis on "cost realism," and improved tools (question # 10).
- Training is dramatically improved. Today only 30% of surveyed organizations have no formal training, versus 60% in 1998. This training is a blend of internal, tool vendor, and professional association initiatives (question # 16).
- Finance Estimating is much more responsible (53%) for cost risk analysis. Engineering and management are less responsible(35%). The author sees this as a definite improvement, due to Estimating's superior knowledge of historical data, CERs, and the estimating process (question # 4).
- Cost risk analysis is seen as less specialized (48%) than it was ten years ago (65%) (question # 14).
- Greater use of historical data and statistical analysis appears to be driving broader use of lognormal data curve fits, which are slightly more preferred than ten years ago (question #13).

Negative trends:

- Cost risk analysis is still seen as somewhat difficult to do well and to explain. Despite obvious gains in formal training, there continues to be a large shortfall in cross-training, experience, and good data (question # 15).
- Programs (responding to survey) appear to be less pro-active in mitigating risk than ten years ago … 75% today versus 90% in 1998. Proactive strategies include statement of work re-scoping, mitigation plans, improved design, IR&D, and additional testing. On the flip-side, programs appear to be more "stand-off and wait" for developing technologies and customer direction, 25% versus 10% in 1998.

The survey write-in responses did not provide evidence for the apparent change. Nor does the author have a ready answer. The shift could be due to different mix of survey respondents or customer direction changes (question # 19).

- Hurdles, obstacles, and resistance to cost risk analysis appear to be slightly less than ten years ago, but still daunting. Lack of historical data is still the number one issue, followed by insufficient functional and management support. The identified hurdles suggest that management needs to be trained in the benefits of cost risk analysis and held accountable to support and implement the findings.

Neutral trends:

- Industry models (ACEIT, SEER, and FRISK) are handling a higher percentage of cost risk analyses, while @RISK, Crystal Ball, ProAct, PRICE, and internal Excel tools are handling somewhat less (question #8).
- Tornado charts, standard deviation, and other methods are increasingly used in risk presentations. The classic cum-S curve is somewhat reduced in usage (question #11).
- Cost risk analysis is integrated into the baseline estimates 90% of the time, either partially or completely, about the same as ten years ago (question #5).

Summary and Recommendations

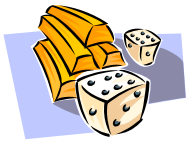
The purpose of this research paper is to summarize how the U.S. Aerospace Industry (Government and contractor) develops and applies cost risk analysis to aid business decisions. This paper is based on a survey provided to 2400 SCEA and SSCAG members in early 2008. It summarizes cost risk assessment methods and tools in current use by Government and private sector analysts.

Survey responses (105) were received from 32 parent organizations, many with multiple sites. Organizations included 5 U.S. Government agencies, 12 major aerospace corporations, 13 support contractors, and 2 European agencies (Ministry of Defense and European Space Agency).

Tabulated results offer a "*maturity metric*" of prevailing practices, and depict positive trends versus the original 1998 survey. The 2008 survey contains four times as much information as the 1998 survey, due to 12 new questions, expansion of old questions, and 60% more responses.

Aerospace program cost overruns and schedule slides have created considerable angst, funding issues, and negative headlines. As a result, DoD and NASA increasingly emphasize the importance of cost risk management and "cost realism" (i.e., "data-driven" estimates). Accordingly, the objectives of this survey and research paper are to …

- Assess current cost risk analysis practices
- Identify preferred tools and methods
- Depict trends in methods and tools from 1998 to 2008
- Encourage analysts to be more proactive in assessing cost risk



Cost risk analysis supports business decisions in several important ways:

- Evaluate program strategies (e.g., bid/no-bid, make/buy, design trades)
- Avoid cost overruns and resist unwarranted cost reductions
- Evaluate sufficiency of management reserve
- Manage and mitigate program risks

Several positive trends have surfaced since the 1998 survey:

- Historical actuals, as the basis of cost uncertainty, are used twice as often (37%)
- Finance Estimating is much more responsible for cost risk analysis (53%)
- Cost risk analysis is seen as less specialized (48%)
- Training has been dramatically improved

Following are the top-ten major findings from the survey:

1. Top 3 motivations to assess cost risk: Project size, obvious risk, and customer direction (40% of the time)
2. Key benefits to business decisions: Probability of success, cost control, customer direction (50-80%)
3. Top 2 situations for cost risk analysis: (a) Independent cost Estimates; (b) DDDT&E proposals (40-50%)

4. Cost uncertainty is based on data-driven history methods (70%)
5. Affordability (reduction) initiatives are included (50%)
6. Costs to mitigate risk and costs to absorb risk are quantified (46% and 36%, respectively)
7. Excel-based tools handle 60% of cost risk analyses (vs. commercial models), down a little in 10 years
8. One fourth of organizations appear to operate at the highest level (4-5) of risk management maturity, where cost risk analysis is integrated to program risk mgmt, tracked-managed, and evident in proposals & EVMS
9. Two thirds of organizations desire >70% cost confidence
10. Most significant obstacles to cost risk analysis …
    a. Sparse historical data
    b. Weak mgmt and functional support
    c. Overly optimistic targets
    d. Lack of cost analyst experience and training

The survey finds several continuing concerns among cost risk managers and analysts:

- Cost risk analysis seen as "difficult" to do well
- Key hurdles include lack of data and weak management support
- Programs appear less pro-active, and more "wait-and-see" in resolving risk issues

On the whole, steady progress has been made since 1998, due to initiatives by government agencies, contractors, and tool/model providers. Training has dramatically improved, and cost risk analysis is more broadly applied by both government and industry management.

Credits. The author is deeply indebted to SSCAG Risk Sub-Group members who helped develop the questions, and to SCEA and SSCAG for distributing the survey to their membership.

Industry metric and report card. This survey serves as a type of industry metric to assess progress toward important goals. The author wishes to specially thank each of the 100+ aerospace managers and analysts who took valuable time to carefully fill out this detailed survey. Each of you has played an important part in ensuring the success of this SSCAG-SCEA project.

Three cheers for the expertise and perseverance of thousands of cost risk analysts across the industry!

Keep up your excellence and perseverance!

Author Bio

The author has been with the Boeing Company for 27 years, with experience in business operations, Finance management, division planning, and cost estimating. He assumed his present position in 1990, leading Parametric Estimating for Missile Defense Systems, Huntsville.

In recent years, he has led estimating teams and been responsible for large competitive cost proposals. He has developed estimating tools, prepared parametric estimates, and assessed cost risk for numerous new programs. He has often been called on to estimate cost trends for evolving technologies and improved design-build processes.

Over the years, he has had the opportunity to cost estimate a wide variety of programs:

- Manned & unmanned space (Orbital Transportation, CEV capsule, HEO Upper Stage, Space Station)
- Lunar-Mars (First Lunar Outpost, unmanned robotic missions, Mars manned vehicles)
- Launch vehicles (Ares Upper Stage and Avionics, Enhanced Expendable Launch Vehicles)
- Missiles and launchers (Joint Common Missile, Avenger, SLAM-RAAM)
- Defensive systems (GMD missile defense, NATA Alliance Shield)
- Satellite (broad-band audio-video communication)
- Ground communication (JTRS radio, Coast Guard National ID)

Hollis was recently selected to receive Boeing's "Estimating Best Practice Champion" award. This high honor recognizes his career efforts in advancing the estimating profession. For twenty years he has helped implement "best-practice" initiatives within Boeing. For example, three years ago, he implemented a widely-recognized cross-training series across Boeing, in data-driven estimating best practices. The series contains 30 modules in parametric estimating tools, statistical analysis of actual costs, and risk assessment. Hollis trains over 150 Boeing estimators, using an on-line virtual classroom.

He provides subject-matter-expert (SME) advice to colleagues across Boeing Defense Systems, with emphasis on risk management, software estimating, and cost-trends for modern design/build processes. He frequently speaks in company day-long forums on risk and affordability.

Outside Boeing, he has presented papers and led discussions on these subjects since 1990. To name just a few, he has presented to SCEA (New Orleans'07, Denver'05), ISPA (Italy'04), SSCAG (Wash-DC'07, Seattle'06, Toronto'98), and AIAA (Albuquerque'01, Huntsville'96).

He is serving on an industry forum (Aerospace Industries Association) to request cost risk analysis within contractor proposals. Previously, he served on a similar team to expand DCAA audit policy to include parametric estimating methods ("Reinvention Labs").

Prior to Boeing, he worked fourteen years for Monsanto Chemical Company, with assignments as Assistant Plant Controller, Corporate Offices senior financial analyst, and Operations Research. He earned an MBA from the University of Texas in 1967 with an emphasis in Management Science. He holds CMA (NAA/IMA) and CCEA (SCEA) certifications, and is a former President of the Huntsville SCEA chapter.

Hollis is a native of San Francisco, with a great-great-grandfather who crossed the plains in the 1870's by wagon, and settled in the wine country of Napa Valley, California. Married for 38 years, he has one daughter and four "grand-munchkins." Favorite interests include swimming, photography, and mountaineering (e.g., Mt. Rainier '07, The Crestone Needle '97, Mt. Whitney '93, The Grand Teton '76).

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