

A man in a dark suit is walking a thick, braided rope that stretches across the frame. He is looking upwards and to the right, with his arms outstretched for balance. The background is a large, classical building with a prominent dome, likely the US Capitol. The scene is overlaid with abstract white and blue lines, including a jagged white line that resembles a stylized arrow or path. The overall tone is professional and aspirational.

MITIGATING COGNITIVE BIASES IN **RISK IDENTIFICATION:** Practitioner Checklist for the **AEROSPACE SECTOR**

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This research contributes an operational checklist for mitigating cognitive biases in the aerospace sector risk management process. The *Risk Identification and Evaluation Bias Reduction Checklist* includes steps for grounding the risk identification and evaluation activities in past project experiences through historical data, and emphasizes the importance of incorporating multiple methods and perspectives to guard against optimism and a singular project instantiation-focused view. The authors developed a survey to elicit subject matter expert judgment on the value of the checklist to support its use in government and industry as a risk management tool. The survey also provided insights on bias mitigation strategies and lessons learned. This checklist addresses the deficiency in the literature in providing operational steps for the practitioner to recognize and implement strategies for bias reduction in risk management in the aerospace sector.

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This article and its accompanying research contribute an operational *Risk Identification and Evaluation Bias Reduction Checklist* for cognitive bias mitigation in risk management for the aerospace sector. The checklist described herein offers a practical and implementable project management framework to help reduce biases in the aerospace sector and redress the cognitive limitations in the risk identification and analysis process. Detailed discussion focuses on the development of strategies targeted at reducing four cognitive biases and their influence on the risk identification process, and to the development and validation of the practitioner checklist.

Background and Literature

The authors' research began with a review of the literature, which covered the areas of risk management, cognitive biases, and bias enabling conditions. The biases of *optimism*, *planning fallacy*, *anchoring*, and *ambiguity effect* were deemed particularly influential to the risk identification and evaluation processes. The authors reviewed and synthesized the bias mitigation literature and developed the initial bias reduction checklist. After the development of the initial checklist, they designed and administered

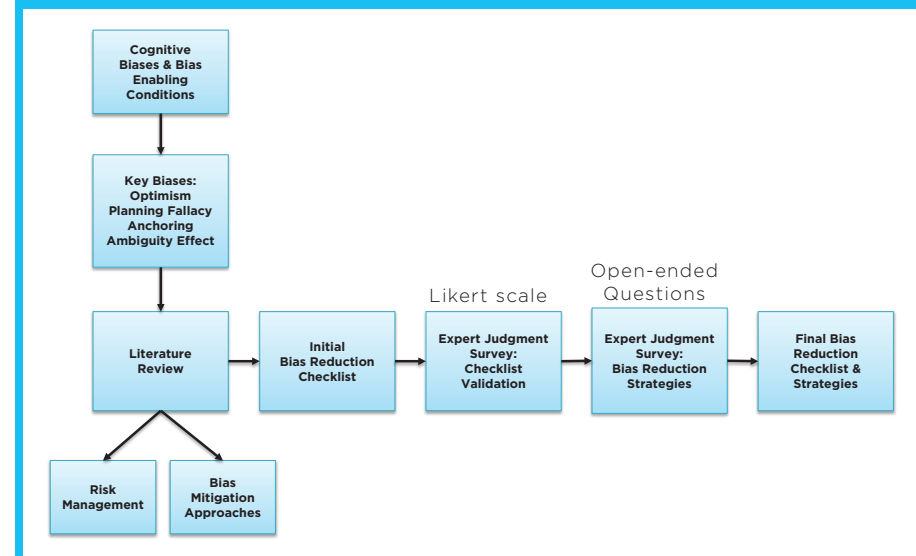
the survey to seek feedback and validation of the checklist as a risk management tool. A Likert-scale instrument was used for the survey, which is an appropriate instrument for measuring attitudes and beliefs. The answers to the open-ended questions of the survey provided insights, lessons learned, as well as other measures that are used by practitioners to

reduce biases. The survey design, data collection, and analysis followed the academic literature guidelines for garnering attitudes and feedback on the effectiveness of the checklist as a risk management tool.

Nonetheless, the authors recognize that like any of the measurement methods in the science disciplines, the social or attitude survey method is not error-free (Fowler, 2013). The authors incorporated the feedback from both the

Likert survey and the open-ended questions into the final checklist. Finally, a discussion follows on the checklist implementation and potential challenges. The research approach is highlighted in Figure 1.

FIGURE 1. RESEARCH APPROACH

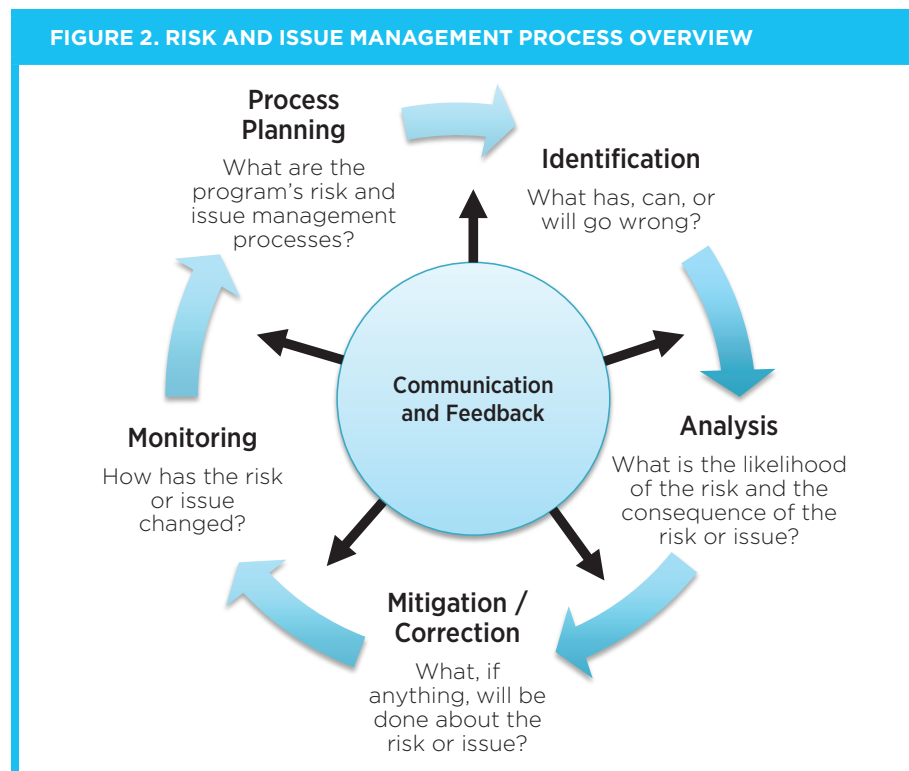


The checklist presented herein is grounded in the academic literature surrounding cognitive bias mitigation and, in particular, the Nobel-prize-winning efforts of Kahneman and Tversky (1977) in reference class forecasting. The review of the literature begins with a discussion of risk management in the aerospace sector and a description of the risk identification practices and challenges. Subsequently, the nature of cognitive biases is described. These biases are persistent across industries, individual experts, and teams, and affect humans' ability to impartially identify and assess risks. Bias enabling conditions in the project environment are also examined, and the characteristics common to both the transportation and aerospace sectors are highlighted. Although the research is tailored to the aerospace sector, important insights from the transportation sector are also considered. Finally, the review of the literature concludes with a discussion of the approaches to reduce the cognitive biases.

Risk Management

Risk management includes a documented process, and both formal and informal practices applied in government programs and commercial industries alike. The Department of Defense (DoD) and the National Aeronautics and Space Administration (NASA) have established risk management processes. For example, the *Department of Defense Risk, Issue, and Opportunity Management Guide for Defense Acquisition Programs* represents but one of numerous DoD policy and guidance documents that

focus on risk management. Figure 2 depicts an overview of the risk and issue management process, which is an organized and iterative decision-making technique designed to improve the probability of project success (DoD, 2017). This five-step management process may be used for issues that are nonprobabilistic in nature, or risks. This process is intended to be a proactive and continuous approach that identifies discrete risks or issues, assesses the likelihood and consequence of these risks or consequences of the issues, develops mitigation options for all the identified risks, monitors progress to confirm that cumulative project risk is truly declining, and communicates the risk status (DoD, 2017). The DoD risk-mitigation options include acceptance (and monitoring), avoidance, transfer, and control (DoD, 2017). Similar continuous risk management processes have also been represented in the NASA guidance (NASA, 2007) and *A Guide to the Project Management Body of Knowledge* (Project Management Institute, 2013). A review of the literature also indicates that project risk management practices differ across projects and are affected by project characteristics such as scope, complexity, and category (Omidvar, Jaryani, Zafarghandi, Nasab, & Jam Shidi, 2011).



Note. (DoD, 2017)

Maytorena, Winch, Freeman, and Kiely (2007) highlight the “importance of the risk identification and analysis phases of the risk management process” (p. 315), since they can have a great influence on the correctness of the risk assessment activity. Their research suggests that the role of experience in this process is much less meaningful than it is regularly presumed to be. Alternately, “information search approach, education, and training in risk management have a significant role in risk identification performance” (p. 315). As for the role of expertise in the risk identification and analysis process, Freudenburg (1988) described the challenges amongst specialists that may lead to cognitive miscalculations in the risk estimation methods, including the failure to anticipate all the elements. Such miscalculations may then lead to mistakes and bias in the estimating. The identification or risk discovery methods and tools typically include brainstorming, personal knowledge and experience, questionnaires, lessons learned, and risk management tools such as Failure Modes Effects and Analysis, Fault Tree Analysis, and Probability Risk Analysis.

Risk identification is a continuing process throughout the life cycle of the project; however, it is critically important in the early conceptual design and formulation phases to ensure the appropriate risk and programmatic posture is established. A study by the Jet Propulsion Laboratory noted “significant variability in risk identification and risk reporting in the early conceptual design” (Hihn, Chattopadhyay, Hanna, Port, & Eggleston, 2010, p. 14). Some of this variability is attributable to the inherent vagueness of new system design at this early phase in the life cycle. Further exacerbating factors include the hectic concurrent engineering design team environment and the absence of an organized risk identification and ranking process that would potentially increase the level of evenness across risk-recording activities. This team concluded, “Generating risk checklists that can be used for risk identification guidance during early concept studies would enable more consistent risk reporting” (Hihn et al., 2010, p. 14).

Cognitive Biases

The issue of bias based on human mental shortcuts (also called heuristics) in subjective assessment and decision making is not new. Examples of heuristics may be rules of thumb, educated guess, gut reaction, or common sense. Tversky and Kahneman (1974) describe types of bias present when making judgments under uncertainty. Kahneman and Tversky (1977) indicate both experts and laypersons share many errors of judgment; in particular, they cite studies of electrical engineers (Kidd, 1970) and intelligence analysts (Brown, Kahr, & Peterson, 1974), which have confirmed the presence of common cognitive biases in the professional judgments of experts.

Houghton, Simon, Aquino, and Goldberg (2000) examined biases present when teams versus individuals were faced with decisions. Additionally, these authors and others (for example, Flyvbjerg, 2008) demonstrated that these trends remain even when one is cognizant of their existence and nature. A review of the literature in the area of cognitive biases suggests that the research and work has expanded since the early work in the 1970s, and tends to center around four classes of cognitive biases: *social biases*, *decision-making biases*, *memory biases*, and *probability and belief biases*. Decision-making studies have predominantly recognized 21 biases that negatively influence human judgments (Caputo, 2013). Studies focused on probability and belief cognitive biases have revealed a similar number (Baron, 2007).

Based on their research, the authors speculated that four decision-making and probability and belief biases would have a strong influence on the risk identification and evaluation process. The four biases are: optimism, planning fallacy, anchoring, and ambiguity effect.

Optimism bias is a decision-making bias demonstrated when humans are assessing the magnitude or consequence of a risk event. It is the tendency to be overoptimistic regarding favorable outcomes or the tendency not to identify or fully see the potential negative outcomes. Kahneman and Tversky (1977) revealed the planning fallacy bias, which impacts planning, decision making, and prediction, where humans tend to underestimate the costs, schedules, and risks of planned activities and overrate their benefits. Kahneman and Tversky (1977), and later, Lovallo and Kahneman (2003) argued that this misjudgment is a consequence of the trend to adopt an internal approach or inside view to prediction and estimation, focusing on the elements of the specific problem, obstacles, and resources instead of the distribution of outcomes in similar problems or projects. This approach is akin to attempting to envision the future of a project by considering only its plans and the potential obstacles to be faced. An outside view of forecasting, in contrast, fundamentally considers a broader set of environmental issues to make predictions (Kahneman, Lovallo, & Sibony, 2011). The anchoring bias is the common predisposition to rely on initial information, results, or experience (i.e., the “anchor”) when making judgments (Tversky & Kahneman, 1974). For this bias, there may be a tendency to be *anchored* toward identifying certain types of risks versus other types relative to what ultimately is realized through the project life cycle. The ambiguity effect is a bias where decision making is impacted by lack of information, or where ambiguity

and uncertainty are high. The ambiguity effect regarding external events is focused on the ability to identify potential sociopolitical, environmental, and funding risks outside the project manager’s direct control.

The identification and analysis of large-consequence, low-probability risks continue to pose a challenge to decision makers and managers across many industries. The term *grey swan* is based on the metaphor *black swan*, which was discussed by Taleb (2007) as a highly unlikely, major-consequence risk event. The black swan is referred to as an “unknown unknown” category of risk event (Furedi, 2009, p. 197; Taleb, 2007). This definition implies that the black swan is *not* discoverable. Conversely, the grey swan is the representation for a large-consequence and infrequent event that *is*, to some degree, foreseeable (Hole & Netland, 2010)—also referred to as a “known unknown” risk event (Taleb, 2007). This definition implies that the grey swan could be discoverable. Hole and Netland (2010, pp. 21–27) highlight that “traditional risk assessment methods underestimate the risks of large-consequence, hard-to-predict, and rare events”; they note that the grey swan class may contain project failure, whereby the project may fail because of increased cost, conflicting system goals between key stakeholders, unexpected changes in political climate, or hard-to-detect and unanticipated problems with design or chosen hardware.

“ Seventy percent of the respondents had at least 25 years of experience working in the aerospace sector, and 65% had at least 20 years of experience working in the risk and project management disciplines.

In another complementary body of research to this current article, the impacts of these four biases in the risk identification and evaluation process were investigated through the examination of empirical data from the risk matrices for 28 aerospace projects (Emmons, Mazzuchi, Sarkani, & Larsen, 2017). In that research, the authors use statistical analysis to assess, test, and confirm hypotheses covering these four biases. Data for the hypotheses testing were in the form of hundreds of identified and estimated risks across the projects. This current manuscript is limited in focus to the development of strategies targeted at reducing these four cognitive biases and their influence on the risk identification process, and to the development and validation of the practitioner checklist.

Bias Enabling Conditions

Hogarth's (1987) work examined the enabling conditions under which biases were more likely to occur. Many judgmental biases can be ascribed "either to characteristics of the task or project under evaluation, or to those of the schema, i.e., the strategies, heuristics, assumptions, attitudes, etc., of the judge or assessor" (Skitmore, Stradling, & Tuohy, 1989, p. 107). Increased probability for bias happens when the decision has a "high degree of complexity; when it has a high degree of procedural uncertainty; and when it is performed under circumstances involving a high degree of stress" (Skitmore, Stradling, & Tuohy, 1989, pp. 107–108). Heuristics and biases were also discussed as impacting military decision making, which must operate under an environment characterized by volatility, uncertainty, complexity, and ambiguity (Williams, 2010). Busby's (1996) work investigated biases in the aerospace sector in risk assessment, but was limited to a qualitative assessment of the processes and strategies that were followed by project managers and resource estimators. However, decision making in the aerospace sector shares at least three of the factors discussed in Skitmore et al. (1989)—uncertainty, complexity, and ambiguity. Large projects such as new aerospace system developments often cost upwards of hundreds of millions, or even billions of dollars. They are typically complex and demanding in terms of scale, teaming arrangements, priority, and novel technology. They often involve technological advances or new applications of technologies, new processing, and unique manufacturing.

Important and applicable insights may be gleaned from the literature on biases and the bias enabling environment to be considered from the transportation sector. For example, in the transportation sector, *Megaprojects* is the term used to discuss the type of project that has some key defining factors: funding requirements are large (on the order of hundreds of millions of dollars); human resource demands are commensurately large; the projects have high complexity, with technology development requirements; and such projects have the potential to greatly impact their environment (Flyvbjerg, Bruzelius, & Rothengatter, 2003). These transportation projects have all of the necessary characteristics to create a high potential for bias environment. Flyvbjerg et al. (2003) demonstrated how optimism, inadequate consideration of risks, and external project factors such as weak or lacking sponsors and stakeholders, greatly affected three large-scale European civil engineering programs. Both the aerospace and transportation sectors have environments that are conducive to enhancing cognitive biases in their risk management processes. In the subsequent discussion, the authors will examine the approaches to reduce these pervasive biases.

Bias Mitigation Approaches

Kahneman and Tversky (1977) originally suggested an approach to mitigate cognitive biases called reference class forecasting. A reference class is defined as a set or grouping of past, comparable projects. The authors' forecasting approach outlines five steps that serve to correct the cognitive biases:

1. Determination of a reference class for comparison to the activity or case at hand;
2. Evaluation of the distribution for the reference class whereby relevant distributional data are sought;
3. Performance of the estimate informed by intuitive or expert information;
4. Analysis of predictability; and
5. Any additional adjustments to correct expert or intuitive assessments.

These steps directly inform the development of the 11-step bias reduction checklist. In the academic literature, this technique surrounding debiasing is based on categorization theory, or the process of matching characteristics of one element to a category of other elements (Hogarth, 1987; Ryan, 1996). Lovallo and Kahneman (2003) later expanded upon this initial work, described as adopting an *external approach* or *outside view* on the project or problem using distributional evidence from previous similar projects or problems. Flyvbjerg (2006, 2008) describes the first confirmed instantiation of practical reference class forecasting in the United Kingdom (UK) planning practice, and its subsequent endorsement by the American Planning Association. Observables in the UK suggest that reference class forecasting has led to improved mindfulness of the optimism bias in the development of important local transport arrangements (Flyvbjerg, Glenting, & Rønne, 2004; Flyvbjerg, 2008). However, because the characteristics and features of the industries and classes of projects are different, applications of debiasing techniques in one sector may not be directly transferable to another. Nevertheless, transportation and construction projects usually do involve a "high degree of uncertainty, vagueness, complexity, and vulnerability to both internal and external conditions" (Fidan, Dikmen, Tanyer, & Birgonul, 2011, p. 307), which means there are similarities in the conditions existing in the bias enabling environment between the aerospace and transportation sectors.

Research Objectives

The authors observe that there was not a good translation of the academic literature, which was heavily behavioral decision theory-focused, into an operational framework that could be applied to assist project leaders and risk discipline practitioners in reducing the cognitive biases. This current research intends to remedy these inadequacies in the risk management process through the development of a bias reduction checklist stemming from the academic literature. SMEs from the aerospace sector were surveyed for both validation of the checklist and insights into how to manage risks and reduce the pervasive biases we humans—experts and laypersons alike—bring to the risk management process. Government agency leadership and project managers can use the checklist at project initiation and throughout the life cycle to improve the risk identification and valuation estimating capability, and bring greater transparency to the overall process.



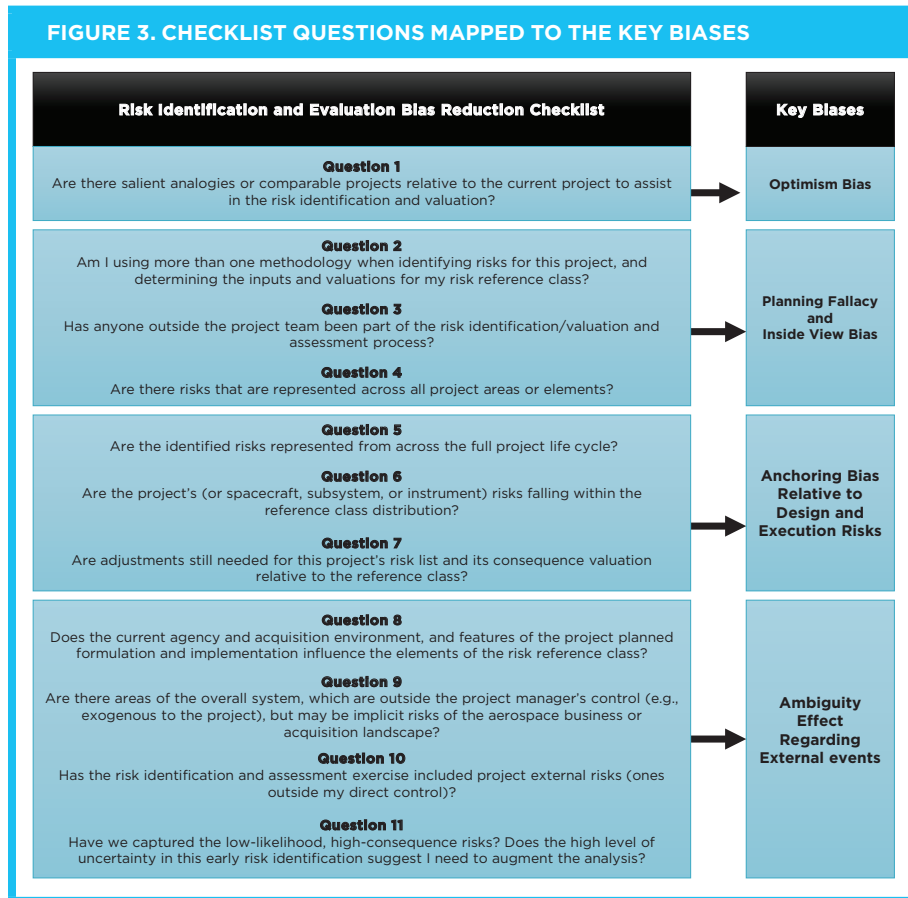
Applications of Checklists and Derivation of the Checklist for Bias Mitigation

Checklists have been widely used in the aerospace and aviation sectors. Within the last decade, an increased application and acceptance of checklists have emerged in the healthcare sector. In fact, NASA's public website discusses how the methods of checklist development and application have

been effectively transferred to the medical sector, as cited by *The New England Journal of Medicine*, to result in reductions in human errors and lower death rates (Green, 2012). These sectors—aviation, and medical—have some of the common characteristics of a bias enabling environment the authors surveyed in the literature: high complexity, high uncertainty, and high stress. Checklists have been demonstrated successfully in numerous aspects of performance development, error avoidance, and project management (Boorman, 2001). Notably, checklists can serve as “important tools for decreasing error and improving overall standards, especially during stressful conditions when memory, attention, and cognitive functions can be affected” (Hales, Terblanche, Fowler, & Sibbald, 2008, p. 29).

The authors envision the *Risk Identification and Evaluation Bias Reduction Checklist* as a complementary and practical augmentation to the risk management process. The authors grounded the checklist development in the academic literature and have adapted Kahneman and Tversky's (1977) five-step methodology of reference class forecasting to the aerospace sector. Additionally, they have devised a series of questions that may be posed by project/risk managers or agency/organization leadership at the onset of the project, and throughout the life cycle to help eliminate cognitive biases. The Decision Quality Control 12-step checklist (Kahneman et al., 2011), developed to mitigate biases in decision making, also informed the development of this list of questions, discussion, and recommendations. This bias reduction checklist is intended to address the remaining gap and focus questions specifically around the risk identification and analysis process, the project external risks and environmental review, and mitigation of grey swan risks. The intent is that the checklist questions could be utilized by any organization; however, they have been tailored to aerospace so they are most applicable to government agencies such as DoD, NASA, or the private aerospace sector where established risk management processes are in place. The checklist application should enhance situational awareness of the project team in analyzing risks, and could contribute to a more open culture that recognizes the human error factor. Ultimately, the use of the checklist should improve the overall project team's performance and enhance project success. As with any framework, checklist, or tool, the intent is to assist the practitioner by serving as a cue for critical thinking and questioning; however, such assistance is not a substitute for sound risk analysis. Of course, any checklist should not be seen as static, but should continually evolve through feedback from SMEs, academic research, and practical applications. Additionally, a counterbalance is needed in the application of the checklist as it should not be too onerous or unnecessarily

time consuming. Each question of the checklist was developed to address the four key biases that influence the risk management process. Question 1 addresses the optimism bias; Questions 2 through 4 address the inside view and planning fallacy bias; Questions 5 through 7 address the anchoring bias; and Questions 8 through 11 address the ambiguity effect regarding external events. The checklist questions (Figure 3) are mapped to the key biases that they are intended to address.



The initial aerospace sector project leader's *Risk Identification and Evaluation Bias Reduction Checklist* is shown in Figure 4. The aerospace sector SMEs were provided this initial checklist to assess through the survey. The format of this checklist is a question followed by steps for bias reduction.



Practitioner Survey to Garner Expert Judgment and Validation of the Checklist

A survey was used to collect data from SMEs on the bias reduction checklist as an additional applied risk management tool (Emmons, 2017). Participants were selected from organizations that are involved in project and risk management activities, government DoD military space, and/or NASA civil space programs. The respondents were from DoD, NASA, Federally Funded Research and Development Centers, and private sector aerospace organizations. All of the respondents had multiple years of experience working on DoD and/or NASA programs either as a civil servant or in a support contractor capacity. Chief engineers, principal engineers, project managers, and project engineers were included in the survey group. The minimum requirement to be selected as a survey participant was at least 5 years of experience in both the aerospace sector and project or risk management areas.



The survey consisted of 18 questions. The survey questions 1 through 3 were covering the participants' background. Twelve of the questions—survey questions 4 through 15—were measured by numeric rating scales (Likert scale) using numbers from 0 to 4. One neutral point answer (0), “I have no

basis for answering this question,” was offered for all questions. Three of the questions—questions 16 through 18—were open-ended to try and garner explicit feedback. All of the survey responses were captured, and the results informed the recommendations in the implementation of the final checklist. The survey scale was provided before each of the questions and is captured in Table 1. Table 1 shows the descriptive questions, distribution of the answers, and the Likert 5-point questions and frequency of the responses. Thirty-three aerospace sector practitioners opted to participate in the survey, resulting in the 17 respondents who comprised the sample size (n). Seventy percent of the respondents had at least 25 years of experience working in the aerospace sector, and 65% had at least 20 years of experience working in the risk and project management disciplines. All of the respondents answered every Likert-scale question.

Because the survey used Likert-scale data, it was analyzed using an ordinal approach. In an ordinal interpretation, “quantitative analysis is primarily interested in the proportions of respondents choosing a certain grade on the attitude scale; in view of this interest, the multinomial distribution is a natural stochastic model of response behavior” (Göb, Mccollin, & Ramalhoto, 2007, p. 611). The basic technique for this research is simplified by collapsing the response to two outcomes and uses the binomial distribution to examine statistically the number of respondents who believe the answer to a question is at least moderately effective versus not effective. Questions 4 through 15 were treated as dichotomous outcomes, where grouping one responded with the following answers:

(0) *I have no basis for answering this question*

(1) *Not at all effective(ly)*

(2) *Somewhat effective(ly)*

Grouping two, however, responded with the following answers:

(3) *Moderate(ly) effective*

(4) *Very effective(ly)*

Successes or (m) is the frequency of the answers (3) and (4) to the survey questions. The binomial parameter test uses the successes for the sample proportion determination based on a binomial outcome of x in n independent Bernoulli trials.

TABLE 1. FREQUENCY OF RESPONSES TO SURVEY QUESTIONS

Background Questions	At least 5 years but < than 10 years	At least 10 years but < than 15 years	At least 15 years but < than 20 years	At least 20 years but < than 25 years	At least 25 years or more
1. How long have you worked in the aerospace sector?		1	3	1	12
2. How long have you worked in the risk management or project management disciplines?	1	2	3	3	8
	YES	NO			
3. Are you currently working in the project or risk management disciplines?	16	1			
Optimism Bias	I have no basis for answering this question	Not at all effective(ly)	Somewhat effective(ly)	Moderately effective(ly)	Very effective(ly)
4. How effective do you feel past project risk data (i.e., data on identification, valuation, and manifestation of past risks) is to the practice of identifying and evaluating new project risks?	1	2	4	6	4
Planning Fallacy and Inside View Bias					
5. For the projects you have been involved with, how effective is it to have more than one methodology for identifying and evaluating project risks?	2	1	1	3	10
6. For the projects you have been involved with, how effective is it to have outside project team perspectives for identifying and evaluating project risks?			1	5	11
7. For the projects you have been involved with, in your view, to what extent have the risks been identified and evaluated effectively across all subsystems, project areas, or elements of said projects?		1	9	5	2
Anchoring Bias					
8. For the projects you have been involved with, in your view, to what extent have the risks been identified and evaluated effectively across the entire project life cycle (i.e., design risks, development risks, execution risks, operation risks are all represented)?		4	8	3	2
9. For the projects you have been involved with, in your view, were the risks that were identified and evaluated effectively represented by historical risks (i.e., risks which had occurred on past projects)?		5	6	4	2
10. For the projects you have been involved with, in your view, how effective was the cost valuation forecasting of the identified risks?	3	6	3	4	1
Ambiguity Effect Bias	I have no basis for answering this question	Not at all	Somewhat	Moderately	Strongly
11. To what extent does the acquisition environment of your organization/agency influence the risk identification and evaluation process for a project?	1	1	2	3	10
12. For the projects you have been involved with, in your view, to what extent do the features of a given project formulation and implementation plan influence the risk identification and evaluation process?	1	1		4	11
13. For the projects you have been involved with, in your view, to what extent have the risk identification and evaluation exercises included project external risks (i.e., risks outside the project manager's direct control)?	1		7	5	4
14. For the projects you have been involved with, in your view, to what extent have the risk identification and evaluation exercises included high-impact, low-probability risks?	1	1	4	6	5
Overall Assessment of Risk Identification & Evaluation Bias Reduction Checklist	I have no basis for answering this question	Not at all effective	Somewhat effective	Moderately effective	Very effective
15. Given your overall review of the risk identification and evaluation bias reduction checklist questions (Q1-Q11) and the corresponding recommended next steps, please provide an overall effectiveness rating for the checklist in its ability to assist you within your organization/agency in mitigating the unintended biases discussed.		1	6	7	3

Practitioner Survey Results: Findings and Discussion

Survey Results: Likert-scale Instrument

Questions 4 through 15 elicited responses through the Likert-scale instrument. Table 2 captures the results of the survey.

TABLE 2. DICHOTOMOUS OUTCOMES OF LIKERT RESPONSES

Survey Question	m (# of successes)	Point Estimate for Probability of Success	Lower 90% Confidence Limit	Upper 90% Confidence Limit
4	10	59%	39%	79%
5	13	76%	59%	93%
6	16	94%	85%	100%
7	7	41%	21%	61%
8	5	29%	11%	48%
9	6	35%	16%	54%
10	5	29%	11%	48%
11	13	76%	59%	93%
12	15	88%	75%	100%
13	9	53%	33%	73%
14	11	65%	46%	84%
15	10	59%	39%	79%

Survey question 4 yields a 90% confidence interval that the probability that past project risk data are at least moderately effective to the practice of identifying and valuating risk, is between 39% and 79%. This will be an important step in addressing the optimism bias.

For question 5, at a 90% confidence interval, the probability that more than one methodology for identifying and evaluating risks is at least moderately effective, is between 59% and 93%.

In survey question 6, at a 90% confidence interval, the probability that getting an outside project perspective to inform the risk identification and evaluation activity is at least moderately effective, is between 85% and 100%.

For survey question 7, at a 90% confidence interval, the probability that the risk identification and evaluation is at least moderately effective across all subsystems and elements, is between 21% and 61%. This question denotes a lower mean probability, and the confidence intervals are shifted leftward, suggesting room for improvement.

For question 8, at a 90% confidence interval, the probability that the risk identification and evaluation has been performed at least moderately effective across the entire project life cycle for past projects, is between 11% and 48%. A lower probability is observed for this question, and overall lower confidence intervals suggest, again, room for improvement.

For question 9, at a 90% confidence interval, the probability that the identified risks were at least moderately effectively represented by historical risks, is between 16% and 54%. Clearly, there is a more distributed perspective on the role and impact of historical risks.

For survey question 10, at a probability (point estimate) of 29% and a 90% confidence interval, the probability that the cost valuation forecasting of the risks is at least moderately effective, is between 11% and 48%. Again, these survey responses suggest disparity among the respondents, and that the experiences among the SMEs are quite varied. The cost valuation forecasting of the risks is another area that suggests room for improvement, and the survey responses validate this view. These responses help corroborate the need for specific checklist items focused in these areas.

Survey questions 11 through 14 focus on the ambiguity bias and external project events. For question 11, at a confidence level of 90%, the probability (point estimate) is 76%; at a 90% confidence interval, the probability that the acquisition environment influences the risk identification process at least moderately, is between 59% and 93%. Discussion of the acquisition environment will be an important step in the checklist.

For question 12, at a 90% confidence interval, the probability that the project formulation and implementation plan influences the risk identification process at least moderately, is between 75% and 100%.

For survey question 13, at a probability (point estimate) of 53% and a 90% confidence interval, the probability that the risk identification process for past projects included project external risks at least moderately, is between 33% and 73%. As a worthwhile endeavor, program/project managers and acquisition practitioners are encouraged to codify the need to assess external project risks.

For survey question 14, at a 90% confidence interval, the probability that past projects included high-consequence, low-probability risks at least moderately, is between 46% and 84%. Many respondents have noted experience in capturing high-consequence, low-probability risks.

“ Risk identification is a continuing process throughout the life cycle of the project; however, it is critically important in the early conceptual design and formulation phases to ensure the appropriate risk and programmatic posture is established.

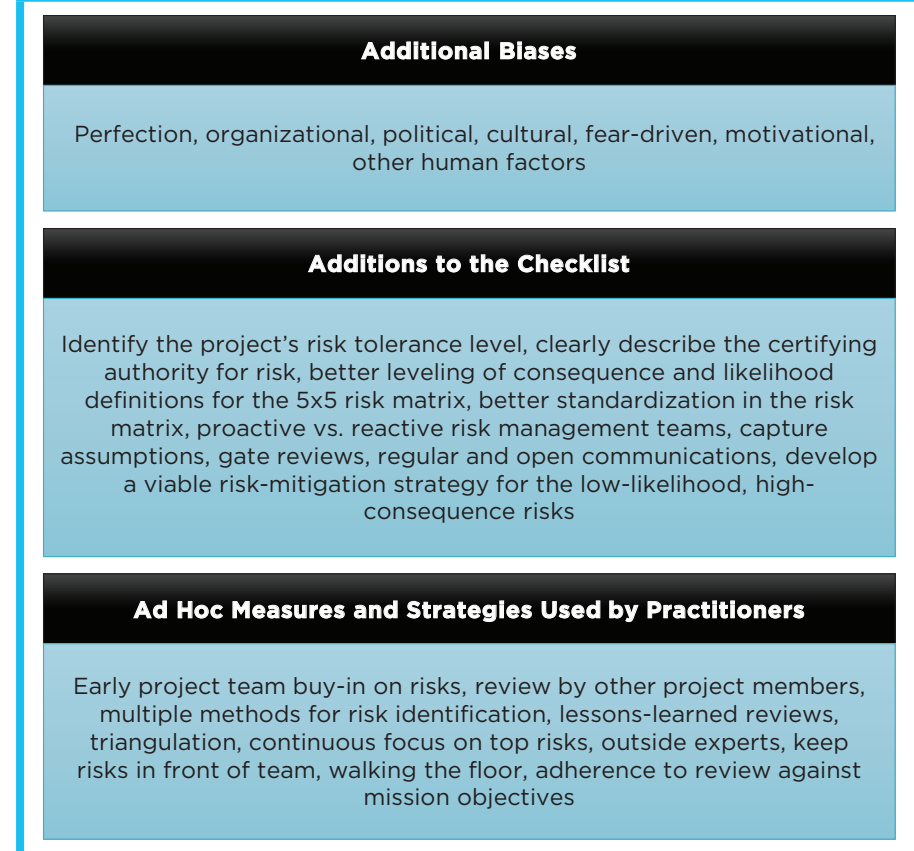
Question 15 focused on the overall value of the checklist. For survey question 15, the responses from the SMEs, which reflected a 90% confidence interval that the probability the overall checklist is at least moderately effective, is between 39% and 79%, with a (probability) point estimate of 59%, thereby indicating a reasonable acceptance level by the SMEs.

Survey questions 8 through 10 surrounding the anchoring bias (checklist questions 5 through 7) yielded the lowest point estimate. Noted in the survey was an imbalance across the life cycle in capturing risks; and the role of historical risks, although necessary, was not sufficient for addressing the issue. Additional steps are needed in the checklist.

Survey Results: Open-ended Questions

The open-ended survey questions—16 through 18—led to additional insights and observations from risk practitioners for both enhancements to the checklist and future research. The survey questions were targeted to elicit missed biases, gaps in the checklist, and other ad hoc measures that the practitioners used to decrease cognitive biases in the risk management process. Figure 5 captures the additional considerations that were identified by the practitioner survey. The discussion of these factors and the additional survey insights are covered in the subsequent section.

FIGURE 5. SURVEY RESULTS: CONSIDERATIONS FROM OPEN-ENDED QUESTIONS



Survey Results: Additional Biases

Some interesting recurring themes and considerations were raised in the open-ended questions regarding additional factors or biases that influence the process. As noted by a survey respondent:

A perfection bias whereby the team pursues perfection and captures risks associated with a perfect system (e.g., design, build, test) rather than assess risks against the objectives of the system was identified. An example was provided: if a Reaction Wheel Assembly shows a risk of failure at seven-year mission duration, but an R&D mission has a one-year requirement/three-year goal life-time objective, invariably the Reaction Wheel Assembly risk will be put forth.

Another theme observed by multiple respondents was the “presence of organizational, political, and cultural biases.” “Fear of cancellation” and “fear of unwanted attention” are major factors in ascribing project risks, as noted by respondents. One observed:

This fear can lead to a bias toward aggressive schedules, and optimistic cost to complete estimates. In the worst case, this bias manifests itself as undue pressure on the team and prevents real proactive steps to improve the situation.

This excessive pressure is a clear contributing factor to the optimism bias. As a result of this bias, teams may spend more time justifying replanning to meet management’s stated optimistic objectives rather than actually focusing on buying down risk in an efficient proactive manner. The “human factors” were also highlighted in the open-ended questions such as “inflated egos, and allowing someone to drive or dominate the discussions [on risks] into certain well-defined or understood areas.” The culturally driven biases were also cited as “driving the risk identification process, whereby there is a reluctance to admit certain risks since making them public through a risk list brings unwanted attention to the project.” Another respondent noted, “Typically, problems are worked too long and not identified as risks until it is too late to effectively handle them.” A culture of “shoot the messenger” might also be present if the prevailing expectation is that risks could have been addressed reasonably well by the project, and the result will be understated [or not stated] until they become problems and costly to remedy. Academic research by Montibeller and von Winterfeldt (2015) supports this survey theme of *motivational* and *organizational* biases, as the authors observe that most behavioral research to date speaks to the cognitive biases. Equally significant, but much less studied, are the motivational biases, which include the conscious or unconscious distortions of judgments and decisions because of organizational context, self-interest, fear, and social pressures. The authors point out that these types of biases are often more difficult to correct. Moreover, they also note that validating best practice methods for reducing motivational biases is fundamentally an unexplored research field.

Survey Results: Additions to the Checklist

A few additional items from the survey results were noted and recommended for inclusion in the checklist. A majority of respondents, however, indicated the checklist was adequate (Figure 4). One recommendation was to have “the checklist explicitly address the value in identifying the project’s risk tolerance level, e.g., mission class or categories provide guidance on the risk posture.” Another suggested:

Clearly establishing the mission risk at all levels of management, including the certifying authority, so that the risk process can be better optimized to only accept and manage those risks that exceed the risk profile of the missions, i.e., for a DoD Class C mission, medium risk tolerance; risks that are evaluated as green may be placed on a watch list [in case the situation changes and the likelihood were to rise], but not tracked or managed [no mitigation plan].

For background, a DoD Class C mission is defined as a medium or higher risk effort with characteristics that may include: medium-to-high national prestige, short life, low-to-medium complexity, single-string designs, medium cost, short schedule, and noncritical launch window (DoD, 1986). Another recommendation from the open-ended survey was to find a way to “better level the likelihood and consequence estimates between projects. Outside project influence was noted as a good start, but overall better standardization was suggested.” Because subjectivity is inherent in any likelihood and consequence estimates for the risks in the risk matrix, it remains challenging to compare between projects and teams. Ultimately, risk identification and mitigation are better in teams that are proactive versus reactive, and this is established by the tone of project management. A few respondents noted, “Reviews have an imbalance in focus on technical issues and allowing the programmatic issues to go largely unaddressed.” Further, it was observed that, “This challenge is exacerbated for the larger programs.” Another respondent stated, “Checklists are (nearly) always incomplete and should be used as a guideline rather than an absolute.” Another noted, “Projects need to value and encourage open communication and discussion on risk consequences.” This step is part of creating the right environment for transparent and open risk analysis. Another respondent noted, “Likelihood estimates are more likely off (lower) than the potential consequences, so low-probability/high-consequence risks need special attention.”

Survey Results: Ad Hoc Measures Used by Practitioners

A number of measures were applied by risk and project practitioners for reducing biases. These measures were discussed in the open-ended questions of the survey. A couple of respondents mentioned that “getting all the project personnel involved at the beginning to provide their input for risk identification and rating” was an important measure taken to reduce biases. Getting the whole team involved sends a message that you are willing and open to others’ ideas. Of all risks presented, this step helps get buy-in from the team on the inevitable decisions involving which risks to exclude.

A number of respondents also cited using team members from other similar projects to review the risk list and assess for reasonableness. One respondent mentioned, “using multiple risk identification, and analysis tools and methods for safety consequences in order to cross-check that all safety risks are identified.” “Lessons-learned reviews and drawing on outside experts” was also cited as was ensuring the “team is represented from many different backgrounds (and specialties).”

Respondents mentioned “triangulation on programmatic assessment”—simply put, no reliance on just a single method for assessing budget and schedule. For example, the recommendation from the survey was to “seek the project assessment, contractor assessment, and nonadvocate review (perhaps more than one), and frequently and continuously interact with personnel that are actually tasked with performing the work.” Asking probing questions can assist one in better judging reality throughout the project, especially true rates of progress, lack of resources or technical concerns, and then the proactive measures can be employed. It was also noted by respondents, “Various phases of the project life cycle (development, execution, through to hardware delivery) each require different risk identification and mitigation techniques.” Another important suggestion was to “require a strict adherence to assessing risks only against the mission objectives, which many times include technical objectives and also cost and schedule (e.g., strict on-orbit need dates to support the warfighter).” Regular focus (every project status meeting) on the top, near-term, and most significant risks was also recommended in the survey. The project manager needs to be asking “What actions have taken place since the last status?” A couple of respondents reiterated the importance of “keeping the risks in front of the project staff until the risk is closed or accepted.”

Final Checklist: Implementation of the Bias Reduction Checklist

The recommendations and themes from the SME survey were incorporated into the final checklist (Figure 6) to enhance its effectiveness in application as a risk management and bias reduction framework. The SME feedback was focused around the biases of optimism bias (checklist question 1), planning fallacy and inside view (checklist questions 2–4), anchoring (checklist questions 5–7), and the ambiguity effect (checklist questions 8–11). The revised checklist (Figure 6) compared to the initial checklist (Figure 4) reflects changes in the additional bias reduction steps. For checklist questions 2–4, the SME survey themes of *reviewing lessons*

observed and learned, standardization on likelihood and consequence definitions across projects for improved leveling, and seeking an independent review of technical and programmatic risks and their assessed likelihood and consequences were captured explicitly. These three additional steps were added to expand Figure 4 into Figure 6. For checklist questions 5–7, steps outlining the importance of *capturing full life-cycle risks including development and execution and assessing funding profile pinch points* were captured. Also, the use of *probing questions and the long interview technique* were included. *Continuous focus on the risks and keeping them in front of the team, early project buy-in, and review against mission objectives* were SME survey themes captured in the additional steps in the checklist. These steps, which are included in Figure 6, should improve the effectiveness of the checklist questions 5–7, which had the lowest point estimate from the SME survey as demonstrated through survey questions 8–10. For checklist questions 8–11, SME survey themes of *establishing and communicating the requisite decision authority position on the risk posture, and codifying the environment assumptions and conditions (funding and other)* were added. *Development and implementation of a risk-mitigation strategy for the low-likelihood, high-consequence risks, and regularly and openly reviewing these types of risks* were also noted by the SME survey, and included in the extra steps.



FIGURE 6. AEROSPACE SECTOR FINAL PROJECT LEADER'S RISK IDENTIFICATION AND EVALUATION BIAS REDUCTION CHECKLIST (POST-SME FEEDBACK)

<p>1. Are there salient analogies or comparable projects relative to the current project to assist in the risk identification and valuation?</p> <ul style="list-style-type: none"> • Compile a formal risk list and database of past project risks (identified, mitigated, and manifested). Define analogous aerospace projects through characteristics such as complexity and mission type. Identify analogous projects. Build a reference class. Build a risk repository based on project performance outcomes.
<p>2. Am I using more than one methodology when identifying risks for this project, and determining the inputs and valuations for my risk reference class?</p> <ul style="list-style-type: none"> • Review methods to include expert judgment, direct experience, and analogous project risk lists. Employ risk training and risk-mitigation workshops. Review lessons observed and learned from past projects. • Review and implement standards on likelihood and consequence definitions with the project team, and across projects for improved leveling.
<p>3. Has anyone outside the project team been part of the risk identification/valuation and assessment process?</p> <ul style="list-style-type: none"> • Review members of the risk identification/assessment team for diversity of roles, experiences, and perspectives. Augment the team to achieve diversity. • Seek an independent technical and programmatic review of the project's risks, likelihood, consequence, and mitigation to assess for reasonableness.
<p>4. Are there risks that are represented across all project areas or elements?</p> <ul style="list-style-type: none"> • Review this risk identification and valuation distribution of outcomes for the reference class. Review the risk list composition. Review the distribution of the risk cost-magnitude consequences.
<p>5. Are the identified risks represented from across the full project life cycle?</p> <ul style="list-style-type: none"> • Review the temporal dimensions of the risks. Development and execution risks should be represented. Assess potential pinch points of these risks against expected annual funds.
<p>6. Are the project's (or subsystem or instrument) risks falling within the reference class distribution? Additional Note: Reference class forecasting, also called comparison class forecasting, is an approach to forecast the future by examining past situations, initiatives, or projects and their ultimate outcomes. A reference class distribution for a system (or subsystem) would be formulated by identification of similar systems and the manifested risks of these systems.</p> <ul style="list-style-type: none"> • Review risk per element against the reference class.
<p>7. Are adjustments still needed for this project's risk list and its impact valuation relative to the reference class?</p> <ul style="list-style-type: none"> • Hold a premortem review. Ask probing questions and use a long interview (i.e., a focused, intensive, B23 and structured interview) technique. • Get early project buy-in on risks and keep continuous focus on top risks, and in front of team. • Review the risks against the mission objectives.
<p>8. Does the current agency and acquisition environment, and features of the planned project formulation and implementation influence the risk reference class?</p> <ul style="list-style-type: none"> • Review the environment and acquisition features that may influence the risk list. • Establish and seek concurrence with the requisite decision authority on the acceptable risk posture for the project. Communicate the agreements and guidance with project team and partners.
<p>9. Are there areas of the overall system that are outside the project manager's control, but may be implicit risks of the aerospace business?</p> <ul style="list-style-type: none"> • Assess and capture external project sociopolitical environments for risk identification and valuation completeness. Codify the understanding of these constraints, conditions, and assumptions for the project team.
<p>10. Has the risk identification and assessment exercise included project external risks (ones outside of my direct control)?</p> <ul style="list-style-type: none"> • Review supplier and political environments, and program requirements to identify additional risks. Discuss how external project risks will be captured and communicated.
<p>11. Have we captured the low-likelihood, high-consequence risks? Does the high level of uncertainty in this early risk identification suggest I need to augment the analysis?</p> <ul style="list-style-type: none"> • Traditional 5x5 risk matrix needs to be augmented with additional methods for mitigating grey swans. Apply what-if scenarios, red-teaming, scenario planning, lessons learned. • Develop and implement a risk-mitigation strategy for the low-likelihood, high-consequence risks. Seek concurrence on the strategy at the requisite decision authority for the organization. Communicate the guidance to the project team. • Openly and regularly review the low-likelihood, high-consequence risks with the project team.

The next section includes discussion surrounding the four key biases, the final checklist questions, and suggested additional steps for bias reduction. The integration of the SME feedback into the checklist is also highlighted.

Optimism Bias

Question 1. *Are there salient analogies or comparable projects relative to the current project to assist in the risk identification and valuation?*

- Compile a formal risk list and database of past project risks (identified, mitigated, and manifested). Define analogous aerospace projects through characteristics such as complexity and mission type. Identify analogous projects. Build a reference class. Build a risk repository based on project performance outcomes.

Question 1 of the checklist addresses the optimism bias. A number of methodologies can be leveraged to define and evaluate the reference class for a project to inform the risk identification and valuation process. Risk lists from other completed or current, ongoing analogous projects covering risks from inception, valuation, through to manifestation could be provided from one project to another. The intent is that actualized quantitative risk information—on both mitigation and manifestation—will be captured. An analogous aerospace project for these purposes could be determined through characteristics such as overall project complexity, mission type, mission class, acquisition approach, and overall budget. The project, subsystem, new technologies, and/or instrument/sensor-level analogies and the specific cost valuation of the risks could be one way to capture the reference class. Building a reference class of project (hardware/software/test) risks that is comparable to the project under review, and sufficiently extensive to be statistically meaningful is important. A reference class or comparison class is an approach to forecast the future by examining past situations, initiatives, risks or projects, and their ultimate outcomes.

A formal risk list for different project reference classes could be developed to help inform the initial identification/valuation of risks at the project onset and maintained through development. A risk database or repository could be compiled for instruments, subsystems, and project levels, which could then inform the development of select reference classes for new project risk lists. A common taxonomy such as the one used and adapted for the complementary research (Bitten, Emmons, Bordi, & Scolese, 2013; Emmons et al., 2017) is useful to facilitate the risk tracing and the potential root cause—from identification, categorization, valuation, mitigation, and potential manifestation for projects. Constructing an “ever-growing knowledge

base of risks, and a risk repository, with their interlinkages across projects (the systemicity), will help ensure that the risk assessment process can be completed in as comprehensive a manner as possible” (Ackermann, Eden, Williams, & Howick, 2007, p. 48). Project managers and agency leadership may also gain from an improved awareness of risk systemicity that causes problems and originates in one project, but can affect other projects and affect the portfolio strategically.

Planning Fallacy and Inside View Bias

Question 2. *Am I using more than one methodology when identifying risks for this project, and determining the inputs and valuations for my risk reference class?*

- Review methods to include expert judgment, direct experience, and analogous project risk lists. Employ risk training and risk-mitigation workshops. Review lessons observed and learned from past projects.
- Review and implement standards on likelihood and consequence definitions with project team and across projects for improved leveling.

Question 3. *Has anyone outside the project team been part of the risk identification/valuation and assessment process?*

- Review members of the risk identification/assessment team for diversity of roles, experiences, and perspectives. Augment team to achieve diversity.
- Seek an independent technical and programmatic review of the project’s risks, likelihood, consequence, and mitigations to assess for reasonableness.

Question 4. *Are there risks that are represented across all project areas or elements?*

- Review this risk identification and valuation distribution of outcomes for the reference class. Review the risk list composition. Review the distribution of the risk cost-magnitude consequences.

Questions 2 through 4 of the checklist address the planning fallacy and inside view bias. At least one necessary, but not sufficient, condition to mitigate the biases is to create a greater awareness amongst the project leads

and team at the onset of the project conceptualization, that a threat of bias is inherent in all rational and good decision makers (Kaufmann, Michel, & Carter, 2009). Another way to help combat these biases is to ensure additional methods are employed in the project conceptualization, and in the risk identification, valuation, and assessment process. Expert judgment and direct experience of project managers remain important methods in risk identification, as discussed by Maytorena et al. (2007). However, each has noted biases or limitations that need to be complemented with analogous project risk lists that also inform the development of the reference class with identified/valued and, ultimately, mitigation and manifestation risk and cost data. Historical data on frequency of risk events can help make the likelihood assessments more objective. Capturing and examining the quantitative cost-magnitude consequence of risks realized or mitigated can make the consequence determination less subjective. The SME survey highlighted that additional work was needed on the risk likelihood and consequence definitions used across projects to improve leveling.

“The premortem is an approach where the project manager and project stakeholders envision a future where the project has failed, and then work backward to determine the story and circumstances that could have led to the project failure (Klein, 2007).”

Risk-mitigation workshops across projects, and before a new project starts, should include participants with “considerable project experience, and the focus of the workshops would be on project characteristics, experienced risks, and the interactions between them” (Ackermann, Eden, Williams, & Howick, 2007, p. 43). Project management texts, training, and practical guidance emphasize the significance of project closure reviews as occasions to increase an organization’s knowledge and enhance learning (Royer, 2000). Regrettably, project closure steps, although regularly defined in the plan, in practice are frequently only superficially performed if they are done at all (Royer, 2000). Even when the organizational culture dismisses the significance of project closure reviews, “project managers should take it upon themselves to document their risk management experiences during the project, and proactively share them with other project managers” (Royer, 2000, pp. 7–8). This experience can aid in the early formulation of a project risk checklist or formal risk list to ultimately assist in examining

potential project risks, early risk mitigation, and contingency plans. The SME survey feedback emphasized the importance of lessons observed and lessons-learned reviews. The practice of postproject review is a way to advance project manager knowledge, mitigate biases, and increase organizational learning. Research by Anbari, Carayannis, and Voetsch (2008) also revealed the value of postproject review in enabling forthcoming project success, and in enhancing the competitiveness and effectiveness of an organization.

Anchoring Bias

Question 5. *Are the identified risks represented from across the full project life cycle?*

- Review the temporal dimensions of the risks. Development and execution risks should be represented. Assess potential pinch points of these risks against expected annual funds.

Question 6. *Are the project's (or spacecraft, subsystem, or instrument) risks falling within the reference class distribution?*

- Review risk per element against the reference class.

Question 7. *Are adjustments still needed for this project's risk list and its consequence valuation relative to the reference class?*

- Hold premortem review. Ask probing questions and use long interview (i.e., a focused, intensive, and structured interview) technique.
- Get early project buy-in on risks and keep continuous focus on top risks and in front of team.
- Review the risks against the mission objectives.

Questions 5 through 7 of the checklist address the anchoring bias. These questions are targeted around assessing whether the risks are identified and evaluated through all the phases of a project, and whether there is a balance of risk types around elements and subsystems. Question 5 focuses on the temporal dimension of the current risks, i.e., are they all anticipated to manifest in the next 3 months, 6 months, or beyond? For example, are they just design risks or do they cover the full life cycle of the project including execution, operations, and/or maintenance? Accordingly, the project manager

who suspects that an especially memorable event has unduly influenced the team and may be anchoring their judgment will want the team to explore other comparable examples (Kahneman et al., 2011).

The project manager assesses where the project—depending on the level at which this approach is implemented (e.g. instrument, spacecraft subsystems—power systems, mechanical systems, attitude control, etc.)—risks fall relative to others of the reference class. Each of the SMEs for a given subsystem could be asked to make a judgment on where this subsystem under evaluation and its particular risks would fall relative to the reference class. The project manager and team would evaluate the primary contributors on the risk list and how they compare to the historical actualized cost-change, risk-event distributions. Examining across the risk reference class would provide insight as to where gaps may lie. In this step, it is important to review the composition of the risk list, to understand what types of risks are represented, and to project whether the full project life cycle is covered. Also, the risk identification and valuation distribution of outcomes for the reference class should be evaluated as part of this step. The distribution of the cost-magnitude consequences should be examined for the project relative to the reference class project or elements.

Project team and decision makers should hold a premortem review (Kahneman et al., 2011) of the project and its identified and valued risks. The premortem is an approach where the project manager and project stakeholders envision a future where the project has failed, and then work backward to determine the story and circumstances that could have led to the project failure (Klein, 2007). This step is to guard against anchoring and optimism biases, as well as other cognitive biases, or potential groupthink in the process. Omidvar et al. (2011) and others had emphasized communication failure as one of the fundamental causes of unsuccessful risk mitigation and ultimately project failure. To counteract this type of undesirable outcome, Mullins (2007) recommends the long-interview approach (McCracken, 1988) as a way to dig deep into a project and ask more probing questions of project participants and stakeholders at all phases of the project. This technique was also cited in the SME survey as a way to better assess the project realities throughout the project life cycle. Oftentimes, it takes individuals outside the direct project team to be able to successfully execute the long-interview technique and reveal the potential biases and mindsets (Mullins, 2007). Getting early buy-in on the risks and maintaining continuous focus on the risks with the team were also noted by the SMEs.

Ambiguity Effect

Question 8. *Do the current agency and acquisition environment and features of the project planned formulation and implementation influence the elements of the risk reference class?*

- Review the environment and acquisition features that may influence the risk list.
- Establish and seek concurrence with the requisite decision authority on the acceptable risk posture for the project. Communicate the agreements and guidance with the project team and partners.

Question 9. *Are there areas of the overall system, which are outside the project manager's control (e.g., exogenous to the project), but may be implicit risks of the aerospace business or acquisition landscape?*

- Assess and capture external project sociopolitical environments for risk identification and valuation completeness. Codify the understanding of these constraints, conditions, and assumptions for the project team.

Question 10. *Has the risk identification and assessment exercise included project external risks (ones outside my direct control)?*

- Review supplier and political environments, and program requirements to identify additional risks. Discuss how external project risks will be captured and communicated.

Question 11. *Have we captured the low-likelihood, high-consequence risks? Does the high level of uncertainty in this early risk identification suggest I need to augment the analysis?*

- The traditional 5x5 risk matrix risk needs to be augmented with additional methods for mitigating grey swans. Apply what-if scenarios, red teaming, scenario planning, and lessons learned.
- Develop and implement a risk-mitigation strategy for the low-likelihood, high-consequence risks. Seek concurrence on the strategy at the requisite decision authority for the organization. Communicate the guidance to the project team.
- Openly and regularly review the low-likelihood, high-consequence risks with the project team.

Questions 8 through 11 of the checklist address the ambiguity effect bias. It is important, as part of the defining of the risk reference class, to assess the current external project sociopolitical and agency environment. Project acquisition and implementation characteristics such as international partnerships, agency partnerships, and agency initiatives would also need to be considered in the reference class definition. For complex aerospace development projects, uncertainty always surrounds external project events. A funding interruption may occur, an additional program requirement may be levied, or a partner agency will face delay in the delivery of an instrument or hardware subsystem. Because external project risk events are outside the direct control of the project manager and team, they tend not to be the area of focus and may be accepted as the nature of the business. However, “knowledge of customers, suppliers, and issues relating to the political environment,” such as funding, or potential new program requirements, is useful when studying the “detailed risk issues during risk-mitigation workshops, and in managing projects that involve these participants” (Ackermann et al., 2007, p. 48). Where identifiable risks can be managed, in comparison, “unmanaged assumptions are neither visible nor apparent as risks, so can be the most dangerous” (Royer, 2000, p. 10). Assumptions, current agreements, and understandings about the project and the project environment



should be observed and codified to safeguard that varying situations or conditions don't invalidate these initial assumptions and change them into risks (Royer, 2000). For example, in the NASA Human Exploration mission directorate, funding for the Constellation program was not consistent with its early formulation plans, and this disconnect continued from inception through cancellation. This inconsistency in funding levels was not completely unanticipated and was, in fact, the topic of lessons learned

from prior projects and programs, but the environmental circumstances intensified the shortage in funding (Thomas, Hanley, Rhatigan, & Neubek, 2013). In an earlier and similarly illustrative example, Jordan (2015/2000) examined real growth projections spanning multiple administrations, and demonstrated that a prevailing trend throughout DoD was to forecast the availability of considerably more resources than would ultimately become available. The large disconnect between administration projections and the actual funding for projects had greatly affected the program managers (Jordan, 2015/2000). To help protect against this, the project or program manager should consider, within the planning phase, what-if scenarios for these types of environmental and funding risks. Additionally, as recommended in the SME survey, the acceptable risk posture for the project should also be established and concurrence provided at the requisite levels. The alignment with the current agency or organization risk management approach should also be reviewed. It is important to assess whether a project or system assumption could fail to hold in a given way, and focus on the contributing factors and potential scenarios that could lead to the failure of the various assumptions. Masys (2012) corroborated the need to use lessons learned for nonlinear thinking through red teaming and scenario planning exercises. The red teaming process is used to challenge all aspects of a project team's plans and assumptions. Successful red teaming helps guard against unexpected events. These steps are useful to inform the project vulnerability or robustness assessment, and become an important part of the explicit communications around the project narrative.

“ It is important to assess whether a project or system assumption could fail to hold in a given way, and focus on the contributing factors and potential scenarios that could lead to the failure of the various assumptions. ”

Traditional risk management tools and resources such as the risk register and 5x5 matrix may be ineffective for managing grey swans because, in practice they have not accurately reflected the actual consequence and would posit these risks in the medium or low category. What-if scenarios can be used for large uncertainty planning, often incorporated as part of a Monte Carlo analysis (Mathews, 2009). Gale (2011) addressed black or grey swan risks from a practitioner perspective and insisted that every risk identification exercise in a complex system include black swan risks

due to the severity of the consequences. As highlighted by the SME survey, it is also important to develop and implement a viable risk-mitigation strategy for these types of low-likelihood, high-consequence risk events, with concurrence of the strategy at the requisite decision authority for the project-implementing organization.

Other Considerations and Challenges for the Practitioner

The project manager and the organization leadership could pose these questions to help mitigate the cognitive biases in the project risk identification phases, but challenges may arise in implementing the outlined recommendations. A recognized barrier to the implementation of this outside-view approach is the existence of political and organizational pressures in service of strategic purposes (Flyvbjerg, 2006). Flyvbjerg discusses examples of UK cities competing aggressively for approval and for limited national funds for transportation projects; pressures are persistent to display projects as positively as possible, which typically means lower costs and higher benefits, thereby increasing the chances of winning resources. Unless an incentive is offered all cities to debias, a specific city that was unbiased would likely lose in the struggle for funding (Flyvbjerg et al., 2004). Additionally, a shift in corporate or organizational culture may also be needed to obtain project risk lessons and use the information effectively. Christensen's (2015/2000) work highlighted how an organization's response to project performance cost variance analysis could be an indicator of its culture. While a positive culture views the news as an opportunity, a negative culture will take the news very differently, and potentially punish the messenger or contain the information. Some project leaders and practitioners may not perform a complete costing or may not document the events sufficiently regarding project risks' identification and manifestation because of fear that disclosing such problems could be detrimental to one's career (Garon, 2006). These same types of challenges regarding organizational and cultural biases at play with the cognitive biases were raised in the aerospace sector SME survey.

Conclusions and Implications of the Research

This research contributes an operational *Risk Identification and Evaluation Bias Reduction Checklist* for cognitive bias mitigation in risk management for the aerospace sector. The authors performed a review of the literature and devised a checklist. They also designed and administered

a corresponding survey. Feedback from the survey made the checklist more useful and, through this process, the authors made new discoveries about the cultural and motivational biases.



The authors believe their current work will accomplish a greater awareness of the cognitive biases, along with increased transparency in the aerospace sector culture if the recommendations and strategies are implemented. Additionally, this checklist will complement any current efforts to improve risk management at organizations such as the DoD and NASA. Finally, the use of the checklist should improve the overall project team's performance and enhance project success. The authors have continued to expand their work in the area of cognitive biases, and in another compatible manuscript, examined empirical data from the risk matrices for 28 aerospace projects.

As with any research, there were limitations involved in this study. This research does not suggest that the cognitive biases of optimism, planning fallacy, anchoring, and ambiguity effect are the *only* factors that influence the risk identification and evaluation process—just the significant factors. The expert judgment survey and other academic research also identify political, cultural, and motivational factors as influencing the process. Future research could investigate these other factors. Potential research could consider testing the checklist recommendations and bias reduction techniques, and their applications in both the defense acquisition environment and in the aerospace sector. Such research could focus on evaluating the proficiency of the checklist in reducing the effects of cognitive biases.

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