

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 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 (SME) 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 for bias reduction in risk management in the aerospace sector.

Two sentence summary: Cognitive biases such as optimism, planning fallacy, anchoring and ambiguity effect influence the risk identification and analysis processes used in the aerospace sector at the Department of Defense, other government organizations, and industry. This article incorporates practical experience through subject matter expert survey feedback into an academically grounded operational checklist and offers strategies for the project manager and risk management practitioner to reduce these pervasive biases.

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Keywords: risk management; optimism bias; planning fallacy; cognitive bias reduction

The research began with the 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, the authors 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, as it is an appropriate instrument when 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.

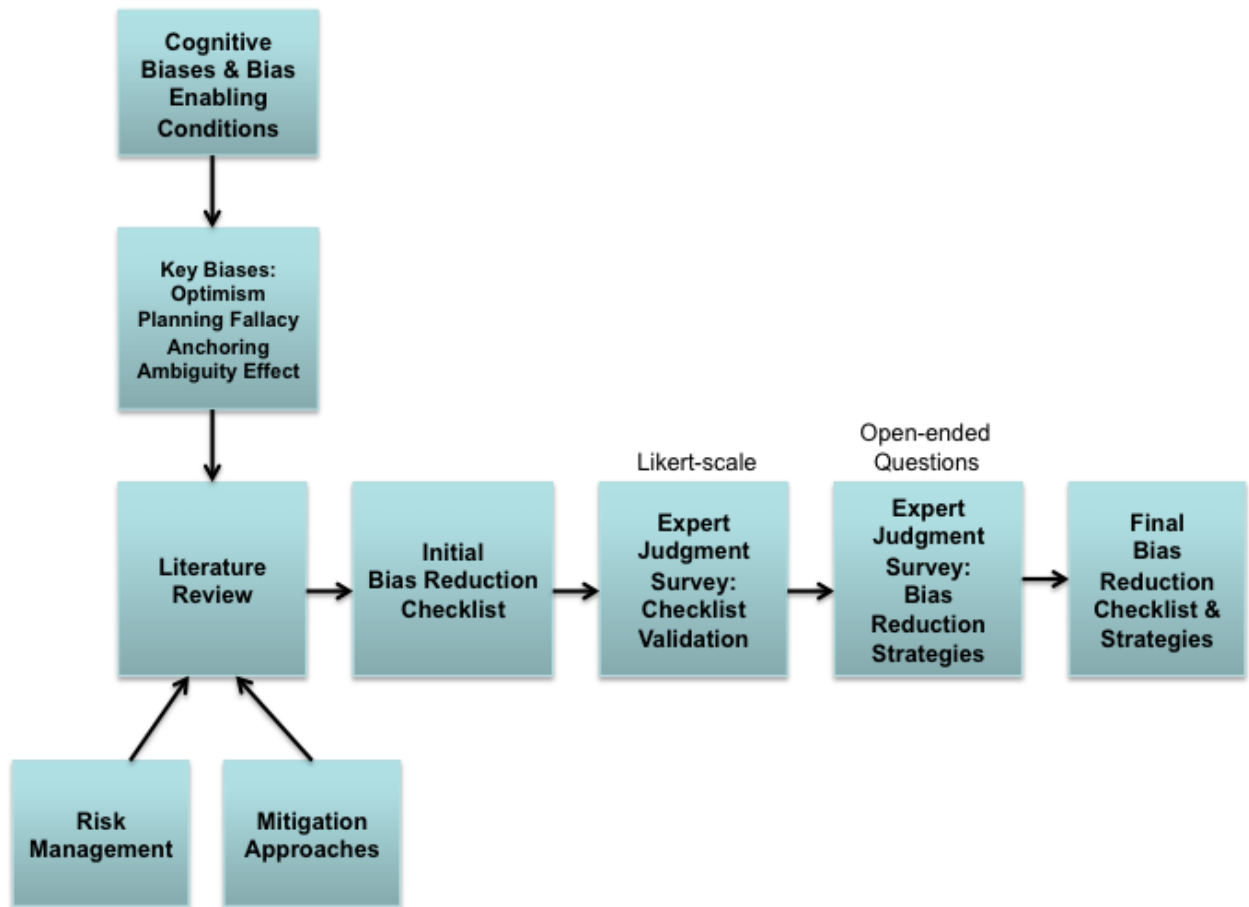


Figure 1. Research Approach

Background and Literature Review

This research offers a practical and implementable project management framework in the form of a checklist to help reduce biases in the aerospace sector and redress the cognitive limitations in the risk identification and analysis process. This checklist 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 expert, and teams, and affect

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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 there are important insights from the transportation sector that 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. Department of Defense (DoD) and National Aeronautics and Space Administration (NASA) have established risk management processes. For example, DoD's Risk and Issue Management Process Overview as shown in Figure 2 is an organized and iterative decision-making technique designed to improve the probability of project success (DoD, 2017)¹. This five-step management process may be used for issues, which are non-probabilistic 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

¹ This guide is one of numerous Department of Defense (DoD) policy and guidance documents that focus on risk management.

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indicates that project risk management practices differ across projects and are affected by project characteristics such as scope, complexity, and category (Omidvar, 2011).



Figure 2. Risk and Issue Management Process Overview (DoD, 2017)

Maytorena, Winch, Freeman and Kiely (2007, pp.315) highlight the “importance of the risk identification and analysis phases of the risk management process”, 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” (Maytorena et al., 2007, pp.315). As for the role of expertise in the risk identification and analysis process, Freudenburg (1988) described the challenges amongst specialists, which may lead to cognitive miscalculations in the risk estimation methods, including the failure to anticipate all the elements, which may lead to

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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, pp. 14). Some of this variability is attributable to the inherent vagueness of new system design at this early phase in the life cycle. It is further exacerbated by other factors including the hectic concurrent engineering design team environment and the absence of 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, pp.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),

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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 (see 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).

In this current paper, 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

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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, lower probability risks continue to pose a challenge to decision-makers and managers across many industries. The gray 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 gray swan could be discoverable. The term gray 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 (Taleb, 2007; Furedi, 2009, pp 197). This definition implies that the black swan is not 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 gray 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.

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In another complementary body of research to this current manuscript, 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 twenty-eight aerospace projects (Emmons, Mazzuchi, Sarkani, & Larsen, 2016). 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, pp. 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

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shares at least three of the factors discussed in (Skitmore, Stradling, & Tuohy, 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.

There are also important and applicable insights 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 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 section, 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,

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comparable projects. The authors' forecasting approach outlines five steps that serve to correct the cognitive biases; the steps cover 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 is sought, 3) performing the estimate informed by intuitive or expert information, 4) analysis of predictability, and 5) making 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 UK planning practice, and its 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, et. al., 2004, Flyvbjerg, 2008). However, because the characteristics and features of the industries and classes of project 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, pp. 302–315), which means there are similarities in the conditions in the bias enabling environment between 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 which 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, there has also been an increased application and acceptance of checklists 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—aerospace, 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 successful in numerous aspects of performance development, error avoidance and project management

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(Boorman, 2001). 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, pp. 29).

The authors envision the *Risk Identification and Evaluation Bias Reduction* checklist as a complement 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, and have devised a series of questions that may be posed by project or risk managers, agency or organization leadership at the onset of the project and throughout the lifecycle to help eliminate cognitive biases. The Decision Quality Control 12-step checklist (Kahneman, Lovallo, & Sibony, 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 mitigating of gray 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 there are established risk management processes. 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, as a cue for critical thinking and questioning, but it not a substitute for it. Of course, any checklist shouldn’t be seen as static but should continually evolve through

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feedback from SMEs, academic research, and practical applications. Additionally, there needs to be a counterbalance 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. In Figure 3, the checklist questions are mapped to the key biases, which they are intended to address.

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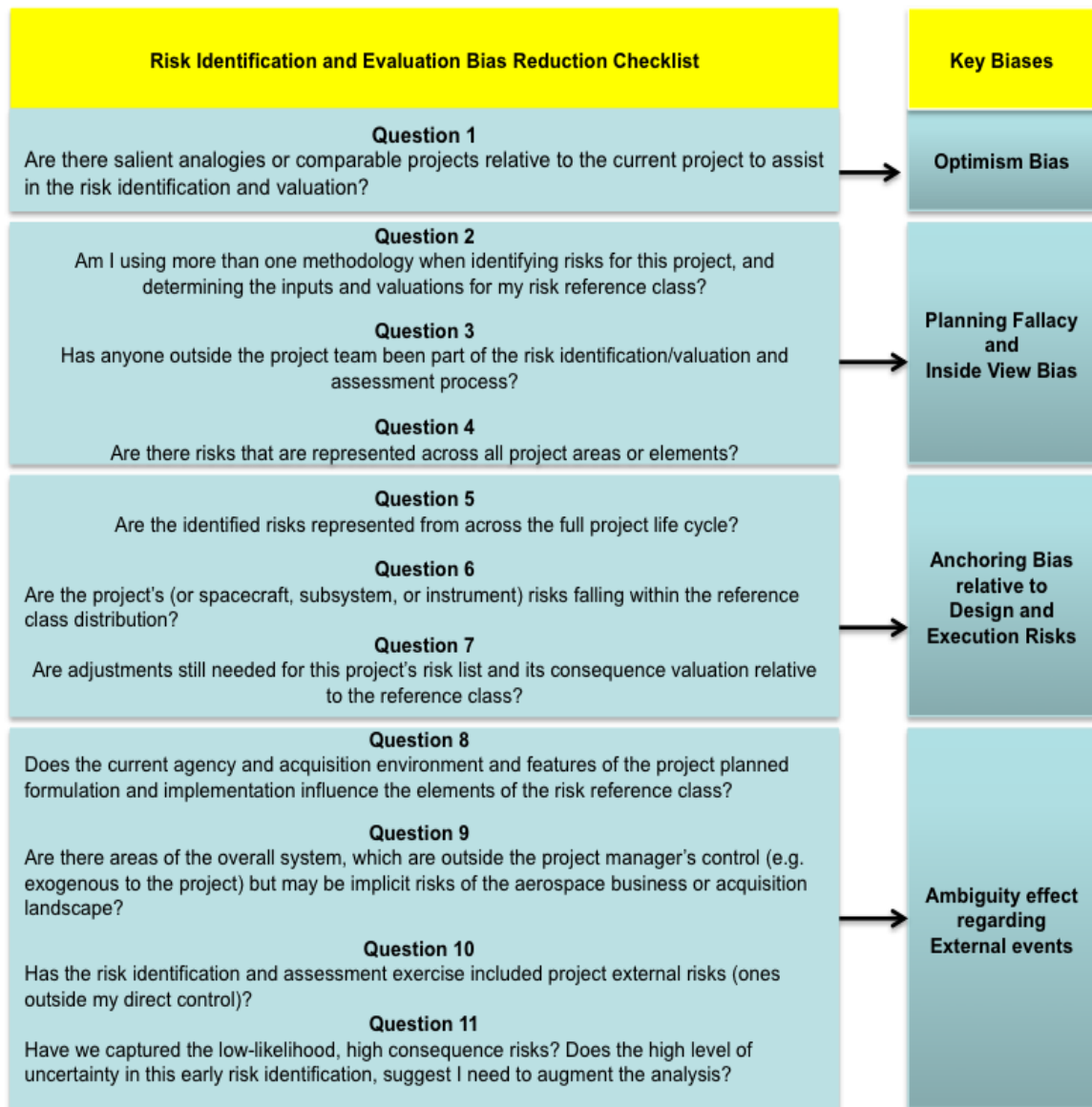


Figure 3: Checklist Questions Mapped to the Key Biases

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.

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<p>1) Are there salient analogies or comparable projects relative to the current project to assist in the risk identification and valuation?</p> <p>-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> <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> <p>-Review methods to include expert judgment, direct experience, and analogous project risk lists. Employ risk training and risk mitigation workshops.</p> <p>3) Has anyone outside the project team been part of the risk identification/valuation and assessment process?</p> <p>-Review members of the risk identification/assessment team for diversity of roles, experiences, perspectives. Augment team to achieve.</p> <p>4) Are there risks that are represented across all project areas or elements?</p> <p>-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> <p>5) Are the identified risks represented from across the full project lifecycle?</p> <p>-Review the temporal dimensions of the risks.</p> <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> <p>-Review risk per element against the reference class.</p> <p>7) Are adjustments still needed for this project's risk list and its impact valuation relative to the reference class?</p> <p>-Hold pre-mortem review.</p> <p>8) Does the current agency and acquisition environment and features of the planned project formulation and implementation influence the risk reference class?</p> <p>-Review the environment and acquisition features that may influence the risk list.</p> <p>9) Are there areas of the overall system, which are outside the project manager's control but may be implicit risks of the aerospace business?</p> <p>-Assess and capture external project sociopolitical environments for risk identification and valuation completeness.</p> <p>10) Has the risk identification and assessment exercise included project external risks (ones outside of my direct control)?</p> <p>-Review supplier and political environments, and program requirements to identify additional risks. Discuss how external project risks will be captured and communicated.</p> <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> <p>-Traditional 5x5 risk matrix needs to be augmented with additional methods for mitigating gray swans. Apply what-if scenarios, red-teaming, scenario planning, lessons learned.</p>
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Figure 4. The aerospace sector initial project leader's *Risk Identification and Evaluation Bias Reduction Checklist*

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, 2016). 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 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 five-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. There was one neutral point, answer (0), "I have no basis for answering this question," offered for all questions. Three of the questions, questions 16 through 18 were open-ended to try to 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 the Table 1. Table 1 shows the descriptive questions and the distribution of the answers, and the Likert 5-point questions and frequency of the responses. There were 33 aerospace sector practitioners selected to participate in the survey to achieve the 17 respondents or sample size (n). Seventy percent of the respondents had at least twenty-five years of experience working in the aerospace sector, and sixty-five percent had at

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least twenty 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, et al, 2007, pp. 602–624). 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. The responses to questions 4 through 15 were treated as dichotomous outcomes, where grouping one was giving a (0) *I have no basis for answering this question*; (1) *Not at all effective(ly)*; or (2) *Somewhat effective(ly)* answer to a question, and grouping two was giving a (3) *Moderate(ly) effective*; or (4) *Very effective(ly)* answer to a question. 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.

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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			
	I have no basis for answering this question	Not at all effective(ly)	Somewhat effective(ly)	Moderately effective(ly)	Very effective(ly)
Optimism Bias					
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 lifecycle (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
	I have no basis for answering this question	Not at all	Somewhat	Moderately	Strongly
Ambiguity Effect Bias					
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 has 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 has the risk identification and evaluation exercises included high-impact, low probability risks?	1	1	4	6	5
	I have no basis for answering this question	Not at all effective	Somewhat effective	Moderately effective	Very effective
Overall Assessment of Risk Identification & Evaluation Bias Reduction Checklist					
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 in 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 is 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, the 90% confidence interval that 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, the 90% confidence interval that 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, the 90% confidence interval that the probability that the risk identification and evaluation is at least moderately effective across all subsystems and elements is between 21% and 61%. There is a lower mean probability for this question, and the confidence intervals are shifted leftward, suggesting there is room for improvement. For question 8, the 90% confidence interval that the probability that the risk

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identification and evaluation has been performed at least moderately effective across the entire project life cycle for past projects is between 11% and 48%. There is a lower probability observed, and overall lower confidence intervals suggest there again is need for improvement. For question 9, the 90% confidence interval that the probability that the identified risks were at least moderately effectively represented by historical risks is between 16% and 54%. There is clearly a more distributed perspective on the role and impact of historical risks. For survey question 10, the probability (point estimate) is 29%, and the 90% confidence interval that the probability that the cost valuation forecasting of the risks it is at least moderately effective is between 11% and 48%. Again, these survey responses suggest there is disparity in the respondents and that the experiences among the SMEs are quite varied. The cost valuation forecasting of the risks is another area that could use 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 are focused around the ambiguity bias and external project events. For question 11, at a confidence level of 90 percent, the probability (point estimate) is 76%, and 90% confidence interval for 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, the 90% confidence interval that 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, the probability (point estimate) is 53%, and the 90% confidence interval for the probability that the risk identification process for past projects included project external risks at least moderately is between 33% and 73%. It is worthwhile codifying through the checklist the need to assess external project risks. For survey question 14,

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the 90% confidence interval that 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. Question 15 focused on the overall value of the checklist. For survey question 15, the responses by the SMEs revealed a 90% confidence that the probability that the overall checklist is at least moderately effective is between 39% and 79%, with a (probability) point estimate of 59% 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. In the survey there was a noted 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.

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Survey Results: Open Ended Questions

The open-ended survey questions 16 through 18 led to additional insights and observations from risk practitioners for enhancements to the checklist and for 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.

Additional Biases	Perfection, organizational, political, cultural, fear-driven, motivational, other human factors
Additions to the Checklist	Identify the project's risk tolerance level, clearly describe the certifying authority for risk, better leveling of consequence and likelihood definitions for the 5x5 risk matrix, better standardization in the risk matrix, proactive vs. reactive risk management teams, capture assumptions, gate reviews, regular and open communications, develop a viable risk mitigation strategy for the low likelihood, high consequence risks
Ad-hoc measures and Strategies Used by Practitioners	Early project team buy-in on risks, review by other project members, multiple methods for risk identification, lessons learned reviews, triangulation, continuous focus on top risks, outside experts, keep risks in front of team, walking the floor, adherence to review against mission objectives

Figure 5: Survey Results: Considerations from the Open-Ended Questions

Survey results: Additional biases. There are some interesting recurring themes and considerations that 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 lifetime 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” is a major factor 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 re-plans to meet managements stated optimistic needs 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

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messenger” might also be present if there is an expectation 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, but that 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, these authors note that validating best practice methods for reducing motivational biases is fundamentally an unexplored research field.

Survey results: Additions to the checklist. There were a few items noted to address, with a majority of respondents indicating the checklist was adequate as presented in Figure 4. One recommendation was to have “the checklist explicitly address the value in identifying the projects 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 which may include: medium to high national prestige, short life, low to medium complexity, single string designs, medium cost, short schedule, and non-critical launch window (Handbook, 1986). Another recommendation from the open-ended survey was to find a

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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 there is subjectivity in these likelihood and consequence estimates for the risks in the risk matrix, it is 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 couple respondents noted “reviews have an imbalance in focus on technical issues and allowing the programmatic issues to go largely unaddressed.” Further it was observed, “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 (low) than the potential consequences, so low-probability/high-consequence risks need special attention.”

Survey results: Ad hoc measures used by practitioners. There were a number of measures 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, “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 other’s ideas. This step helps get buy-in from the team for the inevitable decisions of not to include all risks presented. 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

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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” — 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 non-advocate review (perhaps more than one) and frequently and continuously interacting 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, shown in Figure 6, to enhance its effectiveness in application as a risk management

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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 translate 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 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 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.

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<p>1) Are there salient analogies or comparable projects relative to the current project to assist in the risk identification and valuation?</p> <p>-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> <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> <p>-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.</p> <p>-Review and implement standards on likelihood and consequence definitions with project team, and across projects for improved leveling.</p> <p>3) Has anyone outside the project team been part of the risk identification/valuation and assessment process?</p> <p>-Review members of the risk identification/assessment team for diversity of roles, experiences, perspectives. Augment team to achieve.</p> <p>-Seek an independent technical and programmatic review of the projects risks, likelihood, consequence, and mitigation, to assess for reasonableness.</p> <p>4) Are there risks that are represented across all project areas or elements?</p> <p>-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> <p>5) Are the identified risks represented from across the full project lifecycle?</p> <p>-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> <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> <p>-Review risk per element against the reference class.</p> <p>7) Are adjustments still needed for this project's risk list and its impact valuation relative to the reference class?</p> <p>-Hold pre-mortem review. Ask probing questions and use long interview (i.e., a focused, intensive and structured interview) technique.</p> <p>-Get early project buy-in on risks and keep continuous focus on top risks, and in front of team.</p> <p>-Review the risks against the mission objectives.</p> <p>8) Does the current agency and acquisition environment and features of the planned project formulation and implementation influence the risk reference class?</p> <p>-Review the environment and acquisition features that may influence the risk list.</p> <p>-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> <p>9) Are there areas of the overall system which are outside the project manager's control but may be implicit risks of the aerospace business?</p> <p>-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> <p>10) Has the risk identification and assessment exercise included project external risks (ones outside of my direct control)?</p> <p>-Review supplier and political environments, and program requirements to identify additional risks. Discuss how external project risks will be captured and communicated.</p> <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> <p>-Traditional 5x5 risk matrix needs to be augmented with additional methods for mitigating gray swans. Apply what-if scenarios, red-teaming, scenario planning, lessons learned.</p> <p>-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.</p> <p>-Openly and regularly review the low likelihood, high consequence risks with the project team.</p>

Figure 6. The aerospace sector final project leader's *Risk Identification and Evaluation Bias Reduction Checklist* (post SME feedback)

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The next section includes the 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. There are a number of ways 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 manifestation could be provided from one project to another. The intent is that actualized quantitative risk information – on both mitigations 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

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(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, and 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 (see Emmons, et al., 2016; Bitten, et al., 2013) 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 inter-linkages 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, pp. 48). Project managers, and agency leadership may also gain from an improved awareness of risk systemicity that causes problems and originates in one project, and 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?

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- 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.
- 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 there is a threat of bias with all rational and good decision-makers (Kaufmann & Carter, 2009). Another way to help combat these biases is to ensure additional methods are employed in the

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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.

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, they 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

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importance of lessons observed and lessons learned reviews. The practice of post-project review is a way to advance project manager knowledge, mitigate biases and increase organization learning. Research by Anbari, Carayannis, and Voetsch (2008) also revealed the value of post-project 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 pre-mortem 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

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a project and are there 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, for example, just design risks, or do they cover the full life cycle of the project including execution, operations, and/or maintenance? The project manager who suspects that an especially memorable event has unduly influenced the team and may be anchoring the judgment accordingly will want the team to explore other comparable examples (Kahneman, Lovallo, & Sibony, 2011).

The project manager assesses where the project, or 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 the 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 there may be gaps. In this step, it is important to review the composition of the risk list, to understand what types of risks are represented and is the full project life cycle 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 pre-mortem review (Kahneman et al., 2011) of the project and its identified and valued risks. The pre-mortem is an approach where the project manager and project stakeholders envision a future where the project has failed, and

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then work backward to determine the story and circumstances, which 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 (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: Does 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 project team and partners.

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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?

- Traditional 5x5 risk matrix risk needs to be augmented with additional methods for mitigating gray 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.

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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 there is always uncertainty surrounding 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 the 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, Eden, Williams, & Howick, 2007, pp. 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, pp. 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

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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 there was a prevailing trend in the Defense Department 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 through what-if scenarios these types of environmental and funding risks in the planning. 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 non-linear thinking through red teaming and scenario planning exercises. The red teaming process is used to challenge all the 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.

Traditional risk management tools and resources such as the risk register and 5x5 matrix may be ineffective for managing gray 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

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Monte Carlo analysis (Mathews, 2009). Gale (2011) addressed black or gray 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 there may be challenges 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, and pressures are persistent to display projects as positively as possible, which typically means, with lower costs and higher benefits, to increase the chances of winning resources. Unless there is reason for all cities to debias, a specific city that was unbiased would likely lose in the struggle for funding (Flyvbjerg, Glenting, & Rønne, 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, whereby 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

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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.

Conclusion 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. The authors 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 twenty-eight 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, which influence the risk identification and evaluation process, just

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significant ones. 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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