EFCOG Final Report

Improve Planning and Forecasting, and Reduce Risk, Using Behavioral Science to Mitigate Bias

Project Delivery Working Group

Risk Management Task Team

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Approvals

Prepared by:

Melinda DeLong
Risk Management
Task Team
Date: 9/20/18

Josh E. Ramirez, PMP, MSM-PM
Risk Management
Task Team
Date: 9/26/18 per email

Haily Gomez
Risk Management
Task Team
Date: 9/26/18

Approved by:

Gavin C. Winship
Risk Management
Task Team Chair
Date: 9/24/18

Charles A. Simpson
Project Management Working Subgroup
Vice-Chair
Date: 9/26/18

Rodney W. Blackmon
Project Management Working Subgroup
Vice-Chair
Date: 9/26/18 per email

Ryan Dodd
Project Management Working Subgroup
Chair
Date: 9/26/2018

Executive Summary

The Energy Facility Contractors Group (EFCOG) is a self-directed group of contractors of U.S. Department of Energy Facilities. The purpose of EFCOG is to promote excellence in all aspects of operation and management of DOE facilities in a safe, environmentally sound, secure, efficient, and cost-effective manner through the ongoing exchange of information and corresponding improvement initiatives.

The EFCOG Project Management Working Subgroup (PMWSG) established a Risk Management Task Team to promote, coordinate, and facilitate the active exchange of successful Risk Management programs, practices, procedures, lessons learned, and other pertinent information of common interest that have been effectively utilized by DOE contractors and can be adapted to enhance operational excellence and cost effectiveness for continual performance improvement by other DOE contractors.

As part of the EFCOG Risk Management Task Team activities initiatives are identified, prioritized and planned. The planned activities are established in advance of the fiscal year start as part of an EFCOG Project Delivery Working Group (PDWG) Annual Work Plan.

One such initiative is the investigation into how to eliminate “bias” in schedule development and schedule uncertainty with a goal of identifying and defining the different types of bias that influence practitioners when estimating uncertainty ranges and risk impacts, and providing recommendations (up to and including tools to avoid bias), to enable a more reasonable calibration of risk and uncertainty and resulting in a more accurate derivation of Management Reserve and Contingency.

This Draft Report presents the results and recommendations identified during this initiative. This report is part of Deliverable 2.5.1 of the EFCOG PWDG FY2017 Annual Work Plan. When the evaluation has been completed by the Team, this report will be updated and issued as a final report.

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1.0 Purpose

Resource loaded risk informed schedule development relies heavily on subject matter experts and estimating techniques to determine the estimated necessary resource loading and likely durations for any given activity, including levels of estimate uncertainty and risk impacts. There is a certain level of subjectivity inherent in these estimates, which is then impacted by the logical biases that each person brings with them to the estimate. It is important that these biases be identified, and avoided if possible, to improve the accuracy of the resulting schedule and derived Management Reserve and Contingency recommendations. The purpose of this initiative is to investigate methods for identifying and eliminating bias in schedule development and provide useful recommendations and tools to reduce the effect of bias on the resulting schedules and identified risk postures.

The EFCOG FY 18 Work Plan item 2.5.1 is shown in Table 1:

Table 1. EFCOG FY18 Work Plan (Extract) Item 2.5.1

2.5 Investigate eliminating bias in schedule development and schedule uncertainty.	Identifying and defining the different types of bias that influence practitioners when estimating uncertainty ranges and risk impacts, and providing recommendations (up to and including tools to avoid bias), enables a more reasonable calibration of risk and uncertainty and will result in a more accurate derivation of Management Reserve and Contingency.	2.5.1 Using the roadmap issued as a deliverable in late FY17, complete the study and issue a report with recommendations

This report has been developed to evaluate and recommend PRM improvements in the area of reducing bias in schedule development and schedule uncertainty and satisfies the FY18 Work plan deliverable for 2.5.1.

2.0 Overview

Decision-making is a substantial portion of project management, forecasting, scheduling, risk analysis and overall business management. The decision-making process includes many subconscious actions that most people are either unaware of or know little about. The EFCOG Risk Management Task Team undertook this initiative in an effort to explore and better understand some of those processes that decision-makers go through before a decision is made.

Several years of research led the authors of this report to focus on some of the biases that are specifically associated with decision-making in forecasting, scheduling, risk analysis, and estimating. Additionally, they identified real world examples of government and private sector projects that were affected by these planning biases. While performing the research on the effects of biases on decision-making, it was found that many other studies provided evidence of the ability to plan and forecast with higher accuracy when implementing bias mitigation techniques.

Based on real cost studies of the negative impact of optimistic planning and forecasting, these impacts have been shown to be up to 4.6% of project cost. In addition to the cost of optimistic forecasting, other problems associated with optimistic planning and forecasting include but are not limited to:

- Pareto-inefficient allocation of resources, i.e., waste;
- Delays and further cost overruns and benefit shortfalls; and
- Destabilizing of policy, planning, implementation, and operations of projects (Flyvbjerg, 2007).

Furthermore, an optimistic tilt in monthly forecasting represents a general mindset towards unrealistic planning that has a negative material impact on the Department of Energy's (DOE) project portfolio. This planning fallacy affects the analysis of risk and the estimation of resources, schedule durations, and cost. With optimistic plans that become performance measurement baselines, these unrealistic plans result in variances, missed milestones, additional costs, excessive change control, and eroded public trust. By understanding the sources of bias, decision-makers have the opportunity to improve planning processes, which will result in improved project performance outcomes.

3.0 Research and Results

A road map was developed to show the path forward for this initiative (Attachment 1). Each Roadmap activity was completed, and the results of this effort are detailed in the next sections. Results of these actions are presented in this report out of chronological order to improve clarity.

3.1 Identify and Define Types of Bias

The following section identifies and defines the types of bias that influence practitioners when estimating uncertainty ranges and risk impacts. Later, mitigation strategies for reducing or eliminating these biases will be discussed.

Prior to delving into the distinct variations within bias, it is important to understand an underlying influence that makes decision makers more prone to bias: Cognitive Dissonance. Cognitive Dissonance is defined in the field of psychology as the discomfort a person feels when they simultaneously hold inconsistent or conflicting ideas, attitudes, or beliefs. Specifically, avoidance of cognitive dissonance affects how each decision maker approaches the problem and how to solve it, including when estimating uncertainty ranges, etc. In a practical sense, decision makers may shy away from difficult discussions, differences of professional opinion, and unpopular decisions in order to avoid cognitive

dissonance. Allowing this tendency to influence estimates reduces the validity and reliability of those estimates, and must be avoided. It is important for all decision makers to recognize this underlying influence, and make an effort to avoid shortcutting the estimating process, even when this effort is uncomfortable, in order to improve the accuracy of the resulting estimate.

Beyond the avoidance of cognitive dissonance, there are five basic types of biases that influence decision makers that will be explored in this report:

- Self-Serving Biases
- Automatic Associations
- Relative Thinking
- Faulty Reasoning
- Social Influence

Each of these bias types include one or more specific biases that affect decision making in general, as well as estimating uncertainty in particular. The definitions for each of these biases, as defined by Stanford's Strategic Decision Group except where otherwise noted, is included below. Additional information is provided for biases that most commonly impact cost and schedule estimating.

Please NOTE: Merge Bias, also known as Correlation Bias, is not a true cognitive bias and so has been excluded from this report.

3.1.1 Self-Serving Biases

Self-Serving biases are those which serve to protect the thinker's current mindset. The "tendency to overestimate one's positive qualities and underestimate one's negative qualities relative to others. Another aspect of it is to attribute success to internal or personal factors and failure to bad luck or situational factors."

Overconfidence – the "tendency to believe one's abilities exceed objective accuracy." This bias is stronger the more confident the thinker is in the situation.

Confirmation Bias – The "tendency to favor information that confirms one's beliefs or hypotheses".

Hindsight Bias – the "'knew-it-all-along' effect, or the tendency to see events that have already occurred as being more predictable than they were before they took place".

Planning Fallacy – "a prediction phenomenon, all too familiar to many, wherein people underestimate the time it will take to complete a future task, despite knowledge that previous tasks have generally taken longer than planned."

Optimism Bias – "we overestimate the likelihood of positive events, and underestimate the likelihood of negative events" (e.g. "That could never happen to me"). Optimism Bias is a contributor to the Planning Fallacy, characterized by being overly similar to best-case scenarios.

Additional information regarding Optimism Bias - The bias toward optimism has also been studied using fMRI (Figure 1) scans that show how people react to past and future events. Events experienced in the past have less relative association with optimism, and expectations of future events show higher ratios of optimism. Results indicate that past events may be more constrained, while future events are open to interpretation, allowing people to detach themselves from possible negative events (Sharot, et al., 2007).

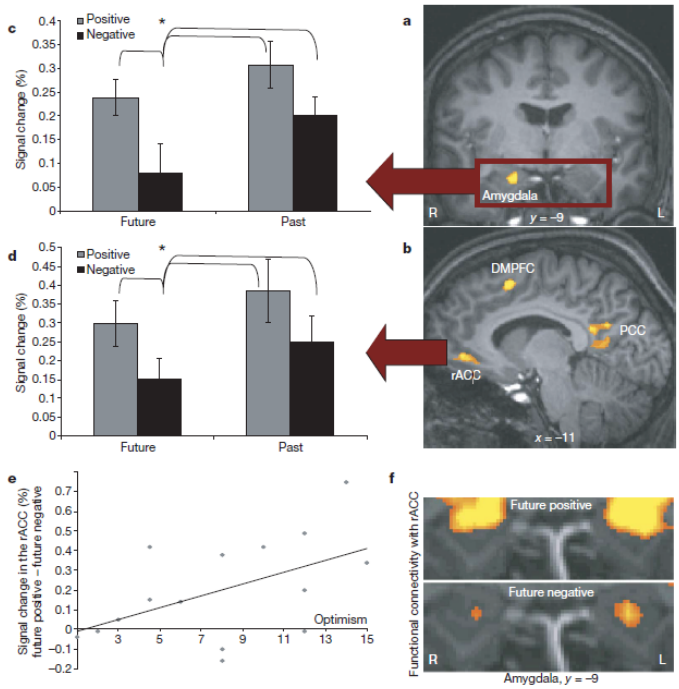

Figure 1. fMRI showing the brain's bias toward future positives (Sharot, Ricardi, Raio, & Phelps, 2007)

Prater, et al. (2017) reviewed 33 different papers regarding optimism bias in the project management discipline. Their findings show that the industry does have some knowledge of the bias, but that mitigation factors are limited, and of those mitigations the reference class approach is predominant. These mitigations are explored in greater detail in the "Tools for Avoiding Biases" section of this report.

Optimism bias is an issue that is prevalent in many projects, with 20-45 percent of all projects not meeting original cost and schedule baselines; this has not changed in 70 years (Flyvbjerg, 2006), even though we have had many project management tools and improvements available to do so (Prater, Kirytopoulos, & Ma, 2017). Optimism in predictions can be generally more problematic than pessimism,

as it is likely to cause planners to delay other projects, resulting in use of unanticipated resources in completion of the current project (Min & Arkes, 2012).

3.1.2 Automatic Associations

Psychologists have discovered that there are really two modes for thinking. First named by Keith Stanovich and Richard West, and later explored in greater detail by Daniel Kahneman, these two modes are referred to as System 1 and System 2. System 1 involves automatic associations, what is often referred to as "intuition". System 2 involves the slower, deliberate use of logical faculties such as making a difficult decision or performing a math calculation. System 1 makes a decision maker prone to many biases, as it works to find the easiest solution to any given decision. The following biases are expressions of System 1 and must be mitigated through deliberate use of System 2.

Availability Effects – "the tendency to use recent, vivid, and salient events as cues to probability judgments, evaluations, predictions, and more."

Ease of Recall – the tendency to interpret feelings of familiarity and the relative ease in remembering relevant events as a higher probability of occurrence (and vice versa) in making probability estimates or predictions.

Anchoring Effects – "the tendency to rely too heavily, or 'anchor', on one trait or piece of information when making judgments and decisions." Anchoring can occur even when the information is irrelevant.

Halo Effects (Positive and Negative) – "the tendency to infer that someone (or something) has a positive trait given positive information about a different trait", and vice versa.

Narrative Fallacy – "a tendency to look at sequences of facts and weave them together into an explanation or forcing a logical link, regardless of whether the facts are meaningful or related".

3.1.3 Relative Thinking

Another example of System 1 finding the simplest way to an answer is the tendency towards relative thinking. Simply put, the automatic functions within the mind fail to look at decisions objectively, due to being influenced by word choice in the question or the surrounding environment. Relative thinking includes:

Framing Effects – "Changes in judgments and choices due to reference points that serve as the 'status quo'. With positive frames, outcomes are described as 'gains'. In the domain of gains, people generally prefer to avoid risk. With negative frames, outcomes are described as 'losses,' and people often prefer to take risks." For example, many people will limit how much money they are willing to gamble for a potential gain, while most people are willing to pay for voluntary insurance to reduce potential losses even though the likely return on investment is very low.

Status Quo Effect – "an **irrational** preference for the current state of affairs".

Fatalistic Thinking – including attitudes like "it is what it is," meaning that no action taken could affect the end result.

3.1.4 Faulty Reasoning

System 1 limits energy consumption by focusing the use of attention only to what it considers relevant, resulting in faulty reasoning. Types of faulty reasoning in relation to complexity:

Selective attention – due to limited cognitive resources, the mind cannot focus on everything at once. As a result, it has a tendency to ignore important information while paying attention to irrelevant details. This includes things like "Order effects" (Primacy and Recency), the inability to combine many cues reliably, and the substitution heuristic (unconsciously substituting the answer to an easy question rather than answering a harder questions). Faulty Reasoning in relation to Uncertainty includes:

Mishandling relevance – results in misjudging probability due to an inaccurate understanding of cause and effect. This is caused by the automatic associations discussed previously, (e.g. statistical correlation is often confused with cause and effect, due to the narrative fallacy and the ability to create a story that explains the correlation, even if the story is patently wrong).

General difficulty in understanding uncertainty – results in a tendency to trust one's intuition, rather than working through the calculations, and leads to inaccurate estimates.

Deliberate Ignorance – "the practice of refusing to consider or discuss logic or evidence disproving ideologically motivated positions" or "the deliberate inattention of risk actors to risk".

Additional information regarding Deliberate Ignorance - Also known as willful ignorance, strategic ignorance, or the ostrich effect, deliberate ignorance is a person's avoidance of certain information that may be negative in nature and has the potential to cause mental discomfort, disagreeing with an individual's beliefs or preconceived notions. People may respond by deliberately or systematically avoiding exposure to the information (Karlsson, et al., 2009; Kutsch & Hall, 2010; Ramasesh & Browning, 2014; Van der Weele, 2012).

Willful ignorance in the project management context is found in the research by Ramasesh and Browning (2014) under their described category of mindlessness in the management of knowable unknown unknowns. Their research recognizes the impacts of biases and heuristics and the cognitive barriers in the perception of reality. They define willful ignorance by saying that actors may avoid inputs that are unappealing or inconvenient as it may challenge their model of reality. This, in their view, is different than how ignorance is typically defined. Ignorance is generally defined as being unaware of something, where willful ignorance is the state of being fully aware or suspicious of facts, but not acknowledging their existence and the implications of the avoided facts.

Kutsch and Hall (2010) state that stakeholders on a project may experience anxiety from exposure to negative information about a project, and thus may suppress it. They state that the PM discipline takes a

"hyper-rationality" approach to managing risk in a project. The focus on "doing things right" versus "doing the right things" is quite prevalent. Their study shows that project managers often deliberately ignore information pertaining to risk. Certain risk factors may be deemed as irrelevant by means of being too taboo to be revealed to their clients or themselves, cognitively irrelevant, or not decidable in terms of the solutions not being verifiable.

3.1.5 Social Influence

Finally, it is important to acknowledge the part that social influence plays in decision making and estimating. The research in to all of the ways that decision makers are affected by social influence is vast and varied; the most common biases stemming from social influence are included here:

Groupthink – "phenomenon that occurs within groups of people. It is the mode of thinking that happens when the desire for harmony in a decision-making group overrides a realistic appraisal of alternatives. Group members try to minimize conflict and reach a consensus decision without critical evaluation of alternative ideas or viewpoints".

Misinterpreting Consensus – "groups have a tendency to believe that consensus means high quality decisions. This confusion makes them forgo conflict and difficult conversations that may result in better searches, better option generation, and better understanding of the outcomes".

Suggestibility – "being inclined to accept and act on the suggestions of others."

Conformity – "the act of matching attitudes, beliefs, and behaviors to group norms."

Authority Bias – the "tendency to attribute greater accuracy to the opinion of an authority figure (unrelated to its content) and be more influenced by that opinion".

Strategic Misrepresentation - "the planned, systematic distortion or misstatement of fact—lying—in response to incentives in the budget process."

3.2 Information Gathered from Industry and Academia beyond DOE

Applicable information from private industry and scholarly sources was reviewed for examples of common biases, sources of bias in estimating, and examples of tools used to mitigate those biases. The following sections contain a sample of the examples of common biases that have been gathered from Industry and Academia.

3.2.1 UK Department of Transportation Study

The United Kingdom's Department of Transportation (DoT) conducted a study on optimism bias in its job industries and recommended actions to mitigate the effect of optimism bias. The phenomenon of optimism bias is well-known in the UK, especially in DoT rail projects. It is so familiar that Network Rail, the government-owned company that operates the rail system, has procedures that try to mitigate the impact optimism bias has on their forecasting.

The unique part about this study is that, although there was already an awareness of optimism being an issue, DoT moved forward with it to find any gaps and make changes to ensure the most was being done to minimize the effect of optimism bias. The study was also conducted to help improve the guidelines and procedures used in an effort to keep pace with new findings.

Researchers gathered data from many recent projects that ranged in size, type, complexity, and geographic location, and suggested optimism bias "uplifts" for individual projects based on conditions during the appraisal stage. According to De Reyck, Grushka-Cockayne, Fragkos, Harrison, and Read (2017), who conducted the study, optimism bias uplift is "expressed as a percentage increase of the original cost forecast." As the analysis progressed, it became apparent that optimism bias was a problem in all different phases of the projects. It was concluded that uplifts were needed throughout every stage.

After more investigation, it was recommended that the uplifts only be used in the earlier stages of the appraisals and that risk assessments should be used in the later stages of the project. If the risk assessment was done thoroughly and correctly, it would eliminate the need for any optimism bias adjustments. This was evident in Network Rails' numbers where the risk assessment was properly carried out and, as expected, the cost forecasting was fairly accurate. Additionally, the authors recommended that the uplifts should not be added to the project's total budget, because it had potential to lead to overspending.

The remaining recommendations that De Reyck et al. (2017) suggested were data capturing, making a standardized procedure for data entry, providing a cost estimate for the overall project, and recording adjustments separately.

The purpose of data capture is to examine past projects and compare them with current projects for accuracy in the estimates. This makes estimating realistically without optimism easier because the past data can be used as proof or evidence of actual cost and schedule. The related data entry procedure then creates a standard that will help eliminate errors or variances due to standardizing the entry methods used.

In their analysis, the authors (De Reyck et al., 2017) identified five different stages of project development, or GRIPs, which are as follows:

- GRIP 1 – Output Definition
- GRIP 2 – Feasibility
- GRIP 3 – Option Selection
- GRIP 4 – Single Option Development
- GRIP 5 - Detailed Design

The GRIPs were also divided into groups based on if the project was a renewal or an enhancement.

The researchers concluded that GRIP 1 and 2 (whether it was an enhancement or renewal project) need an uplift of more than 60% applied to the cost estimate. The other GRIP levels were below 20% and some were even below 10%. These uplifts are applied to the Quantitative Risk Assessment (QRA), which could possibly eliminate them if the QRA is done properly and thoroughly.

3.2.2 Longitudinal Field Study of Hindsight Bias in Decision Making

R. Pieters et al. (2004) conducted a study to determine if knowledge of the outcome of an event and of behaviors actually taken in response to it changes would change how a person remembers a prediction they made prior to the event and what they had planned to do about it. In order to study this phenomenon, the researches elicited and recorded the predictions of 392 CentER Data panel members prior to the 1999-2000-millenium change regarding the potential for the millennium bug, Y2K, to cause harm to computers, the subject individually, and to society in general. Each participant was asked to predict how likely Y2K was to cause harm, how bad they believed that harm would be, and what actions they intended to take to be prepared for any negative impacts. Each participant was then interviewed again in the first week of 2000 to document the preventative actions actually taken, and the participant's memory of what they had intended to do. Finally, each participant was interviewed again in March 2000 to determine their opinion of the actual outcome of Y2K, as well as their memory of their original prediction and intentions.

The study showed that the participants had originally predicted worse impacts from Y2K than actually occurred, and had stated intentions to take more mitigating actions than they actually took to prevent personal impacts. As a result, when asked to remember their original prediction and intentions, the respondents stated that they had predicted the Y2K impacts would be minimal and that they hadn't planned to take preventative measures. This shows that the participants memories were impacted by the knowledge of what actually occurred, and provides an example of Hindsight Bias. The study's authors state, "the resulting false sense of forecasting and planning competency may lead people to be less vigilant and pay less attention to future forecasting and planning tasks."

3.2.3 Study of Young Driver's Optimism Bias for Accident Risk and Driving Skill

Multiple studies, conducted since the 1980's, have shown that most drivers believe themselves to possess above-average driving skills and to underestimate their likelihood of an accident in comparison to their peers. This is a clear example of Optimism Bias. Further studies then showed that young drivers are especially likely to exhibit Optimism Bias in this fashion. With this in mind, White et al (2001) conducted a study to determine what, if any mitigating actions could be taken to reduce optimism bias in drivers.

In the study, 243 drivers aged 17-25 with a minimum of 6 months of driving experience were divided into "insight manipulation" and "control" groups. The participants in the insight manipulation group completed a hazard prevention test consisting of watching short video clips and identifying existing and potential hazards in the driving scenario depicted. The control group did not participate in the hazard

prevention test. Participants from both groups then completed a questionnaire to assess the individual's driving skill and accident risk, and their opinions of their own driving skills, ability to identify hazards, and accident risk in specific driving scenarios.

The results of the study supported previous evidence that young drivers are influenced by Optimism Bias, however it did not sufficiently support the effectiveness of the proposed mitigation. Instead, it showed that Personal Accountability had marginal impact on the optimism bias of very inexperienced drivers but was less effective against more experienced drivers. Further studies were recommended to identify more effective mitigation tools.

3.3 Identify and Review Current Literature

A search for relevant literature on biases in projects was conducted in FY18. This review includes a review of best practices, lessons learned, and project review information (e.g. GAO reports on challenged projects) specific to DOE and other government agencies. These materials were then reviewed to ensure that all practical recommendations and tools for avoiding bias were incorporated in to the final recommendations included in this report.

The review of literature regarding biases highlighted the following examples of bias in planning and the resulting impact of estimate accuracy.

3.3.1 Example of Optimism Bias from DOE Oak Ridge

At the DOE Oak Ridge site, a project was planned to rework underground ventilation ducts that went to a ventilation stack. The plan was to fill the ducting with a polyurethane foam, but there was only one small-business vendor that had the expertise to perform the work.

The project, budget, and schedule appeared to be planned optimistically around a single insulator resource with no planning for uncertainty in resource availability. When the sole resource became unavailable, the project was forced to re-plan from the beginning to find an available insulator and a different material. This put the project behind schedule and over budget as a result (Harness, 2014).

3.3.2 Example of Deliberate Ignorance from WMATA

The Washington Metropolitan Area Transit Authority announced a safety improvement project called SafeTrack for its Metrorail system. The project planned to overhaul Metrorail's tracks by replacing 45,000 crossties and 35,000 fasteners at a cost of $120 million within a year's time (Goldstein, 2017).

When the project began in June 2016, project managers realized that data collected on track conditions was either incomplete or not considered. Additionally, an analysis of possible project alternatives was not completed, and the project management plan was insufficient. The inspections conducted were not comprehensive and the actual condition of the rails' infrastructure lacked sufficient detail. Because of these unidentified risks, the project's resources were underestimated.

This choice of underperforming the inspections could be considered an act of deliberate ignorance. Along with the inspections, they admittedly chose to move forward with the project believing there were no issues or a need to consider alternatives. This is very likely to result in significant budget and schedule overruns.

3.3.3 GAO Audit Example of Planning Fallacy from DOE AMWTP

The U.S. Department of Energy (DOE) operates the Advanced Mixed Waste Treatment Project (AMWTP) in Idaho Falls, Idaho, which began treating mixed waste in 2008. A U.S. Government Accountability Office (GAO) audit indicated that the planning process resulted in an underestimation of the timeline for the permitting review and approval process. Due to an optimistic schedule, the project was delayed multiple times, resulting in cost overruns. Additionally, revisions to the permit applications were required due to necessary modifications in the vitrification process, causing a two-year delay to the project (Wells, 2000).

3.3.4 Example of Anchoring Effect and Confirmation Bias from DOE West Valley

The DOE's West Valley Demonstration Project was a nuclear fuel processing facility in New York State that operated between 1966 and 1972. When operations ceased, some of the plant's facilities were completely gutted and repurposed, while others had piping added.

Years later, the project planned for the removal of the piping from the cells. The primary issue was that planning relied on less accurate estimates that did not take into consideration more current data. As an example, 4,500 LF [linear feet] of piping had to be removed versus 1,400 LF anticipated (Eckert, 2013). This caused the project to fall behind schedule and go over budget as a result of underestimating the amount of resources needed. Planners had likely unintentionally anchored to the initial information, and confirmation bias limited their search for contradictory evidence, thereby creating unrealistic estimates that relied too heavily on the first piece of information they found.

3.3.5 Example of Optimism Bias from DOE Tank Farms

Forecasting accuracy has been examined at Tank Farms, by one of the authors of this report, to determine areas for improvement. To gauge the accuracy of prediction in forecasting, level-of-effort (LOE) activities were removed from the accuracy calculations. This was done because LOE earns as it is budgeted and is not representative of forecasting accuracy, as the forecaster has no control over the variability of the forecast. Prior to removal of LOE, Tank Farms sometimes saw optimism rates around 10 percent. When excluding LOE, it wasn't uncommon to see optimism rates between 30 and 50 percent in some cases. It is important to note that these are high level averages, without determination of impact from actual performance in execution and the effects of change control. However, in aggregate, it appears that there is a noteworthy degree of optimism bias that warrants further analysis.

Tank Farms uses a nonconventional tool called the Budgeted Cost for Work Performed-Forecast (BCWPf), which is an estimate of future Earned Value based on forecasted (current schedule) work accomplishment. BCWPf is then compared to actual BCWP for the forecasted period. This enables Tank

Farms to measure the degree of overestimation/underestimation of work to be performed and determine rate of performance on a month-to-month basis. Similar measurement techniques could be utilized at other project sites to determine optimism rates.

3.3.6 Example of Optimism Bias and Selective Attention at Hanford

An additional example was provided by one of the authors of this report, whom had witnessed the negative effects of optimism bias and selective attention on the project performance. In 2016, a project was begun to perform large scale repairs to the Sand Filter Media Beds of the only Water Treatment Facility at the Hanford site. The total project cost nearly doubled, and the project was completed more than a year late. A Post-Mortem was conducted to determine the underlying causes for the project failure. It was determined that the original estimate reflected optimism bias in that it was assumed the project would be easy and had very little risk. However, the project required multiple outages at the Water Treatment Facility in order to complete the repairs. The initial schedule for this project assumed that the project team would be able to initiate an outage and have access to the Water Treatment Facility whenever it was needed for the project. However, since this is an operating facility whose output ensures compliance with Nuclear Safety and Fire Safety requirements at the site, this was an invalid assumption reflecting the Selective Attention bias. The project was forced to re-plan the work to include outages only on weekends, greatly extending the duration of the project. Additionally, the single functional Sand Filter Media Bed failed, forcing additional delays in the project as recovery efforts eliminated the opportunity for the necessary outages for a period of time as well as diverting labor resources. This scenario was never considered during project planning, likely due to Optimism bias, in spite of the risk having been identified and included in reporting prior to the project's development.

3.4 Tools for Avoiding Biases

Fortunately, there are mitigation strategies that can be employed to limit or eliminate the impact biases have on schedule development and uncertainty estimation. Table 2 provides a quick reference guide for these tools, while the following sections provide greater detail on which of these tools works best to mitigate specific biases. The following sections provide more detailed examples of these tools in relation to individual biases.

Table 2. Mitigation Strategies Reference Guide

Mitigation Strategies		
Title	Description	Bias Mitigated
Unpacking Tasks	Plan out every detail, activity, event, or stage in the schedule, cost, resource or risk assessment before the project is approved and initiated.	Optimism Bias Narrative Fallacy Planning Fallacy
Outside View	Look to see if there is previous projects/activities/events to compare to that have statistical information and data relevant to the project to help make more accurate estimates	Overconfidence Confirmation Bias Hindsight Bias Planning Fallacy Optimism Bias Halo Effects Status-Quo Effect Faulty Reasoning Deliberate Ignorance Strategic Misrepresentation
Critical Thinking	The ability to analyze and objectively evaluate an issue to form a judgment or decision.	Framing Effects Fatalistic Thinking
Dissonance Mitigation	The effort of reducing discomfort caused by contradictory actions, beliefs, behaviors, or attitudes.	Status-Quo Effect
Reference Class	Benchmarking, or making predictions based off of past occurrences, events, projects, or activities and their outcomes.	Overconfidence Confirmation Bias Hindsight Bias Planning Fallacy Optimism Bias
Bias Awareness	Becoming aware of the biases that one has a tendency to struggle with, or have unintentionally allowed to affect decision making.	Ease of Recall Fatalistic Thinking

Mitigation Strategies		
Title	Description	Bias Mitigated
Develop Insight/Awareness	To gain and provide detailed descriptions, understanding, statistics and expectations for the project, risks, schedule, and budget.	Narrative Fallacy General Difficulty Understanding Uncertainty
Consider Alternatives	The consideration of different possibilities of risks, effects, cost factors, etc.	Hindsight Bias
Minimize Time Pressure	Reduction of the feeling of time pressure in a time constrained environment to allow for adequate decision-making.	Misinterpreting Consensus Optimism Bias
Personal Accountability	Create an expectation of non-biased decision-making for oneself and develop the ability to justify decisions, response, or action to hold oneself accountable.	Group Think Conformity Strategic Misrepresentation
Structured Data Acquisition	The implementation of deliberately obtaining more data to avoid making on the-spot-decisions.	Confirmation Bias Optimism Bias Ease of Recall
Affective De-biasing	The process of becoming aware of one's emotional influence on decision-making and becoming capable of preventing the impact on decision-making.	Availability Effects Anchoring Effects
Slow down Strategies	Being capable of slowing down to fully and accurately process the decision. Decision-making accuracy goes down when the decision is rushed.	Misinterpreting Consensus

Mitigation Strategies		
Title	Description	Bias Mitigated
Recalibration	This refers to stepping back and anticipating additional risks and adjusting for them. This is best achieved by determining and evaluating the relevant base rate (e.g. “how often does event occur in projects similar to this one?”)	Mishandling Relevance Suggestibility
Checklists	The process of creating a To-Do list to ensure that there is not something forgotten, overlooked, bypassed, or left unconsidered.	Availability Effects Selective Attention
Consider-The-Opposite	Refers to obtaining evidence that will support the decision that goes against the decision one is leaning towards. This method helps one consider all options, risks, and unknowns.	Overconfidence Confirmation Bias Group Think
Pre-mortems	A formal process for eliciting risks associated with a project by using the thought that the project has already failed, and imagining the possible causes of failure.	Optimism Bias Overconfidence Fatalistic Thinking
Postponing Consensus	This is a decision maker waiting to get the group view or ideas until the decision maker had looked through the details and been able to form their own opinion.	Group Think Authority Bias Misinterpreting Consensus Suggestibility Anchoring Bias
Effective Management of Relevance	The idea of being able and encouraged to call out the "elephant in the room", or in other terms being encouraged to point out the sometimes obvious, yet socially awkward, problems to mitigate deliberate ignorance.	Overconfidence Conformity General Difficulty Understanding Uncertainty

Mitigation Strategies		
Title	Description	Bias Mitigated
Reduce Cognitive Load	Avoid making large decisions or conducting complex analysis at the end of the day when one's mind has already been overloaded. High cognitive load is associated with reduced processes capability, higher rates of error, and increased decision fatigue.	All Biases by reducing Cognitive and Decision Fatigue
Joint Evaluation	This refers to the process of considering two options at the same time, rather than evaluating each separately, to improve the validity of the evaluation.	Availability Effects
Feedback Frequency	Receive routine feedback on forecasting frequently to make minor adjustments for accuracy. Feedback frequency is implicated in the process necessary to improve skill.	All Biases
Noise Reduction	Noise refers to "chance variability of judgment", which means the chance of receiving multiple outcomes for the same issues due to different viewpoints/understandings. Noise reduction is the effort of getting everyone closer to the same understanding/viewpoints so that everyone can perform the same tasks with similar outcomes. Noise reduction includes the elimination of irrelevant information to improve the decision process.	Faulty Reasoning General Difficulty Understanding Uncertainty

3.4.1 Pre-planning for eliciting estimates

Consider the following:

> *Cognitive Fatigue* - "a decrease in cognitive resources developing over time on sustained cognitive demands, independently of sleepiness".
>
> *Decision Fatigue* – "deteriorating quality of decisions made by an individual after a long session of decision making".

Whenever possible, schedule estimate interviews and risk elicitations early in the day and early in the week in order to avoid cognitive and decision fatigue and thereby improve the quality of the information elicited.

3.4.2 Tools for Avoiding Self-Serving Biases

A generally useful tool for avoiding Self-Serving Biases is using an outside perspective[1] to evaluate the estimate being considered. Routinely ask questions such as "How would the client (or other outsider) see it?" to encourage the expert to consider their estimate from a different perspective. Additionally, seek out unbiased data[2], and request opinions from unbiased sources to validate the estimate provided. Tools for avoiding specific self-serving biases are provided below:

Overconfidence – In order to avoid overconfidence in estimating, a subject matter expert must exhibit Calibration and Discrimination[3]. In this context, Calibration is knowing the extent and limitations of your knowledge; meaning that the subjective estimate of a probability reflects the actual frequency of the event in a set to which the event would belong. Discrimination is the ability to distinguish between actual indicators of the likelihood of an event and irrelevant information; specifically, the expert providing the estimate assigned a higher probability to events that actually occur and lower probability to events that do not happen. These characteristics can be improved by adopting and encouraging an attitude of curiosity rather than defensiveness when new information arises. One good tool for reducing overconfidence is to ask the expert to make a list of things that would change their opinion on the estimate they've already provided[4], another is to request outside review and feedback of the projections once gathered.

Confirmation Bias – The best method for reducing confirmation bias is to routinely seek out evidence that could prove the current opinion wrong. For instance, if a Project Manager estimates that the construction portion of a simple road project will only take a certain amount of time, then it would be prudent to check with local municipalities to determine how long similar projects are taking to

[1] i.e. Outside View
[2] i.e. Reference Class
[3] i.e. Effective Management of Relevance
[4] i.e. Consider-the-Opposite

complete[5]. Additionally, the bias can be further mitigated by requesting reviewers to challenge the underlying assumptions and logic of the provided estimate.

Hindsight Bias – This bias is unlikely to effect the value of the estimate provided, however it does effect management's perception of the value of the estimate once the actuals are known. In order to reduce this likelihood, have reviewers document their predictions ahead of time, and encourage individuals exhibiting this bias after completion of the activity to consider what other potential outcomes could have resulted[6]. These actions will help to highlight the weaknesses in the "I knew it all along" mentality.

Optimism Bias – This bias is best mitigated by consulting statistics, where available, of similar projects to validate the provided estimate. This is best done by first determining what type of project is being estimated, and obtaining statistics for similar projects across the complex where possible. This set of data is called the "reference class" of the project. Use those statistics to formulate a rough estimate to start from, and then have the expert make adjustments to the rough estimate based on specific information known about the project in question.

3.4.3 Tools for Mitigating Automatic Associations

Availability Effects – In order to avoid availability effects, it is important to phrase questions in a way to limit influence on the expert's intuition[7]. Specifically, it is helpful to phrase a question using data rather than a single vivid image (e.g. "10 percent of similar projects have had delays due to ecological reviews" vs. "A 6-week delay to this project for ecological reviews would be seriously impactful"). It is also important to validate estimates by collecting data wherever possible to reduce the reliance on intuition.

Ease of Recall – The key element for reducing bias in estimates resulting from ease of recall is to build the estimate beyond mere memory. Remind the expert providing the estimate that being able to easily recall instances of an event does not necessarily make them more likely to occur[8], and then gather evidence from external sources or perspectives to help bolster the estimate.

Anchoring Effects – In order to mitigate anchoring effects, develop and implement forecasting approaches that avoid providing anchors. For example, if you are estimating the duration of an activity it is better to ask the expert "How long do you believe that activity will take" than to ask "Will this activity take more or less than 10 days". Special care must be taken not to introduce an anchor in the estimating process, as people in general have a great deal of difficulty adjusting far enough from the anchor.

Halo Effects (Positive and Negative) – Halo effect is another bias that benefits best from an outside perspective. If the Project Manager has enjoyed positive relations with a design contractor on past water projects and cannot imagine running in to any difficulties with them on the current electrical

[5] i.e. Structured Data Acquisition
[6] i.e. Consider Alternatives
[7] i.e. Effective De-Biasing
[8] i.e. Bias Awareness

project, for instance, it is prudent to request opinions from other Project Managers that have used the contractor for electrical projects to validate that the contractor really is capable of performing the related work.

Narrative Fallacy – The Narrative Fallacy is very strong in estimating, as the experts will find a much easier time of creating an estimate for an event they can easily talk through, even if the imagined story is missing critical elements. In order to combat this tendency, it is best to consider the plan by its individual components[9] rather than as a single "story". Additionally, it is important to use analysis tools that allow for full simulation of the options to support the estimate (e.g. Monte Carlo simulation), which will greatly improve the validity of the final estimate[10].

3.4.4 Tools for Avoiding Relative Thinking

Framing Effects – Framing may be the single most important element in estimating. The estimate must be based on clearly understood and documented scope and the associated proposed approach. The individual interviewing an expert to elicit an estimate must question and test this frame to ensure it adequately captures the activity being estimated[11].

Status Quo Effect – Most individuals are reluctant to make changes from the current state. In order to encourage experts to think around this bias, it is helpful to ask them "If you were making this choice for the first time now, would you choose the current option? Why or why not?[12]" This line of questioning will help to discriminate between valid reasons to avoid change as opposed to a general resistance to change. It is also helpful to elicit opinions from individuals outside of the current situation to get an outside perspective.

Fatalistic Thinking – Within the Department of Energy complex, and likely in other industries as well, there is often a feeling that the person being asked to estimate cost, schedule, and risk impacts of a project are "stuck with a budget and schedule" that was identified and committed to by the department without identifying the underlying validity of the commitment or considering potential risk. While this may be true due to agreements with other stakeholders, the process of identifying a valid baseline estimate and associated risks is still an important tool for improving the probability of final success. The reason for this is simple; if the project team does not proactively identify weaknesses and threats to the project, they cannot mitigate them, resulting in poorer performance. Often, explaining this relationship to the person exhibiting Fatalistic Thinking will help to soften their resistance.

[9] i.e. Unpacking Tasks
[10] i.e. Develop Insight/Awareness
[11] i.e. Critical Thinking
[12] i.e. Dissonance Mitigation

3.4.5 Tools for Avoiding Faulty Reasoning

Selective attention – This bias is difficult to mitigate, since it is difficult to know when the bias is occurring. However, the following recommendations can help reduce its impacts:

Mishandling relevance – Have the individual talk through the rationality behind the provided estimate, and have this logic be reviewed by an expert in the related field to determine if the expected cause and effect is reasonable[13]. If not, adjust the estimate accordingly.

General difficulty in understanding uncertainty – In order to improve the quality of estimates involving uncertainty, it is important that the individual providing the estimate be trained in estimating uncertainty, or have a trained professional available to guide the discussion and identification of uncertainty.

Deliberate Ignorance – There is no way to force a person to admit something they do not want to admit. As such, the only good mitigation for deliberate ignorance is ensuring diversity in the project team so that counterarguments can be heard and included in the final estimate.

3.4.6 Tools for Mitigating Social Influence

Groupthink – The influence of Groupthink can be avoided by using facilitation techniques, such as silent brainstorming, to elicit differing ideas from individuals prior to discussing them as a team[14]. If the team appears to be succumbing to this influence, it can be useful to play the devil's advocate to help diversify the viewpoints in the conversation. Finally, one method that has shown to be useful is applying a "pre-decisional accountability to an unknown audience". An example would be to have the team imagine how they would justify their decision making to the public if the project went poorly[15].

Misinterpreting Consensus – A facilitator can help mitigate a team misinterpreting consensus as quality estimates by embracing conflict early on in the decision or estimating process. Specifically, encourage time for quieter individuals to provide their input without being drowned out by the more outgoing[16]; question and verify assumptions that are accepted by the group; and use a questioning attitude rather than an air of advocacy for any specific conclusion[17].

Suggestibility – If an estimate is being elicited from a group, Suggestibility can be avoided by using facilitation methods such as silent brainstorming in order to gather everyone's ideas before they are influenced by the thoughts of their peers. A facilitator should also encourage competing viewpoints and limit advocacy until everyone has had a chance to think through the issue in their own time.

[13] i.e. Recalibration
[14] i.e. Postponing Consensus
[15] i.e. Personal Accountability
[16] i.e. Minimize Time Pressure
[17] i.e. Slow down Strategies

Conformity – Conformity can be avoided by encouraging disagreement if everyone is in agreement; ask someone to play devil's advocate. A facilitator should encourage discussion among individuals with differing viewpoints, which will make individuals feel more comfortable not "going with the flow".

Authority Bias – If a person with authority is included in the preliminary estimation process, it is important that they keep their opinions and viewpoints to themselves until the rest of the group has had an opportunity to consider their own opinions and provide input. This will alleviate the group of feeling like they have to agree with the authority, or worse, forget that they had a differing opinion.

4.0 Recommendations

Recommendations are divided into two sections. Short-term recommendations are those actions and mitigations that can be implemented almost immediately, with relatively minor changes in existing planning and forecasting protocols, and little assistance from experts in the behavioral sciences field. Medium to long-term outlook recommendations are those that will require additional efforts in training, procedure changes, contractor flow-down requirements, and culture change, to name a few. Short-term mitigations provide the reader with actionable steps that in most cases can be used today, while long-term mitigations will address needed improvements that mitigate systemic planning and forecasting error on a larger scale across the DOE complex.

4.1 Short Term Recommendations

Pre-Work

Prior to developing a cost and schedule estimate, it is important to consider how the estimate will be approached in order to minimize introducing bias and to plan for mitigating the inherent bias each person brings to the table. First, the estimator must have an awareness of common biases she is likely to encounter, and plan for mitigating expected biases throughout the estimating process. In particular, the estimator should consider moderators and precursors of bias, including:

- Time Pressure – begin the estimating process as early as possible to eliminate or reduce time pressure which is related to an increase in optimism and other biases.
- Confirmation Bias – avoid identifying a target estimate, such as what a stakeholder would prefer that the project cost or a pre-determined completion date. A target will create anchoring around the desired value and will lead to an increase in confirmation to "prove" the estimate is valid.
- Social Pressures – consider the makeup of the team who will be involved in developing the estimate and be prepared to mitigate biases stemming from social pressure such as group think and authority bias.
- Inertia – inertia is the endurance of a stable state associated with inaction and the concept of status quo bias (Madrian & Shea 2001). A person who is estimating time or resources must be constantly aware of the brain's need to conserve energy and resist cognitive effort.

The estimator should also take this opportunity to identify the reference class for the project and begin to pull together available data by identifying and reviewing similar projects.

Team Development

When determining the team that will help develop the estimate, the team should be carefully selected in order to reduce unwanted social pressures and improve diversity. Diversity in work positions, such as having representatives from Operations, Engineering, and Project Controls will help to identify hidden dependencies in the schedule. Additionally, it is important to consider logical diversity in the group, to help reduce group think and conformity. Finally, be sure that the "right people" are included in order to unpack activities. This may mean bringing in an expert to help understand a set of tasks that the project team is unfamiliar with.

Framing

During estimate gathering, it is important to fully understand and clarify the scope of the project and ensure that the team members providing input clearly understand the scope and its limits. Outline any assumptions underlying the estimate and document them. Use the scope information to help guide the estimate or risk elicitation process.

Ask open ended questions, and allow silence to grow as needed, in order to avoid introducing biases through anchoring. Deliberately work through each of the project phases and "unpack" each activity be logically walking through each step that would have to be completed in order to perform that activity. This step should include identifying the responsibility party and the actions they have to perform, repeating until all activities have been unpacked. If the team appears to be overly optimistic, it is possible to strategically introduce bias in order to reach a more accurate estimate. For instance, it can be helpful to use a narrative of a potential set of circumstances to convince a team that it is more likely to occur than they are estimating. However, this kind of nudging should only be used where the estimate is deviating dramatically from the reference class.

Throughout the process, watch for indications of underlying biases, and work to mitigate them using the tools provided previously in this paper. Keep an eye on how comfortable the team is as they work through the process, as some uncertainty and associated discomfort is expected. Overconfidence is likely the result of an underlying bias (e.g. misinterpreting consensus). It is important to remember that the less we know, the more confident we will be in a wrong answer (and inversely, the more we know, the more unsure we will be of a correct answer).

Validate

Finally, after eliciting the estimate information from the team, the estimator must validate the estimate against the reference class identified earlier. Is the estimate reasonable when compared to similar projects and adjusted for unique attributes of the project? Are risks commonly encountered in similar projects considered and reflected in the estimate or included in the plan? Adjust the estimate as necessary, being sure to document the adjustments and the associated logic.

4.1.1 Medium to Long-Term Outlook

The long-term outlook on de-biasing involves sometimes wholesale changes at the project, program, and portfolio levels, with implications for both DOE and its primes and lower tier contractors. In order for decision-making in planning and forecasting to improve, the system must work as a cohesive unit as information is passed from level to level. One example of interorganizational decision-making (Chisholm, 2017) and its impact is the Anchoring Effect bias. With the Anchoring Effect, a number that is given becomes the cognitive anchor from which all estimations are then subconsciously based. Therefore, an anchor can start at DOE headquarters, be relayed to a prime contractor, and then passed to lower tier subcontractors, exposing the whole system to an anchor point and reducing the effectiveness of the required risk analysis needed for effective planning.

Eventual de-biasing at all levels will require training for every person that handles estimating of durations, resources, or other costs. In addition to training, choice architecture (Thaler et al., 2014) can be used at the process level to remove bias through default planning and forecasting processes. Choice architecture can also be incorporated into policy and procedure and flowed down to prime and lower tier contractors through DOE requirements or best practices. Tools such as EVM systems can also indicate areas for improvement and enable potential defaults for de-biasing processes. One example currently being piloted is at the Tank Farms, where EVM is being used to trend optimistic forecasting through forecast-BCWP. And finally, culture change is a potential improvement area where DOE could focus efforts around de-biasing through increasing critical thinking, reducing in-group bias to enable information flow, and decreasing conformity bias so that obscure risk identification becomes possible without retaliation.

Training

Eventual training for implementation of bias mitigation could include functions such as:

- Scheduling
- Baseline management
- Risk analysis
- EVM
- Cost estimation

Training would be required for, but not limited to, the following project roles:

- Project Managers
- Control Account Managers
- Project Controls Engineers
- Risk Analysts
- Cost Estimators
- Other subject matter experts who contribute to planning and forecasting

Changes in Standard Roles

De-biasing estimates may require rethinking and revising of some project roles. For instance, a Cost Estimator (CE) or Project Controls Engineer (PCE) generally supports the Control Account Manager (CAM) or Project Manager (PM) with inputting time and resource estimates into the system, resulting in outputs of formal baselines or monthly forecasts. Because the person who owns the work – such as the CAM or PM – will typically be more optimistic with their *inside view*, the CE or PCE can act as the *outside view* to counteract unrealistic predictions in schedule and cost planning and forecasting. In some cases, this may require revisions of current roles, as CEs and PCEs currently may only provide support by taking the inputs of CAMs and PMs without formal responsibility for advising on the accuracy of project management time and resource estimation inputs.

Future roles that are responsible for estimates of time and resources should involve advanced training in not only technical project management processes, but also behavioral project management processes. Personnel that do any type of major estimations will need to be competent in both technical and behavioral prediction methods.

It is important to note that post-estimate and other external reviews that are conducted on the draft estimates are *not* effective as an outside view, as the reviewers are anchored to the estimate. Independent Cost Estimates can provide an outside view, since they are based only on the scope rather than on any previous estimates, however this is done so late in the process its ability to effectively improve the estimate is reduced. The outside view mitigation must take place during the estimating process to have the greatest effectiveness.

Policy and Procedure Changes

Another method of bias mitigation is change to policies and procedures related to risk, EVMS, project controls, and cost estimation. Decision-making and de-biasing must be incorporated throughout the full suite of planning processes, with an emphasis on proper integrated sequencing between functional areas.

A method that can be implemented to de-bias estimates is choice architecture (Thaler et al., 2014). Choice architecture is the changing of defaults and other processes so that people make better decisions without overt direction to do so. An example of choice architecture in forecasting would be to require obstacles identification and documentation in task duration estimation, causing the planner to default to identifying obstacles to task completion, thus introducing more realistic durations in schedule forecasts.

Flow-down to Subcontractors

If estimates of time and resources are inputs from sources outside the organization, such as subcontractor estimates and proposals, the estimate may be affected. Long-term changes to policy should include subcontractor requirements to de-bias their estimating processes so that realistic

estimates flow up to DOE tier-2 and tier-1 estimates. Eventual requirements may include verification or audit of subcontractor planning and forecasting processes.

Change in the Culture

Long-term change in culture is a major part of de-biasing planning and forecasting processes. At the highest level, planning and forecasting is generally associated with prediction of project execution, and then executing work against that prediction. Accurate prediction in project management is of utmost importance in DOE work, and prediction takes place both in formal baseline planning and monthly forecasting.

Prediction is highly associated with cognitive errors and biases, and this is reflected in poor performance on cost and schedule objectives throughout the project management discipline. In order to reduce these errors, it not only takes process and procedural changes (passive measures), but also training and coaching (active measures) across each organization, and a focused effort on formally recognizing behavioral impacts on error in project prediction. Humans in general are resistant to the recognition of risk, are overly optimistic about project outcomes, highly resistant to any change in current states, greatly affected by time pressure, and generally resistant to any element that feels negative. However, in order to reduce project risk and increase prediction accuracy at the DOE portfolio level, the culture must learn and accept that recognizing uncomfortable risk today means risk reduction and mitigation tomorrow. Leaders across all levels must encourage open discussion of risk and allow the extra time and processes required to reduce risk to the department, as not doing so not only impacts schedule and cost estimations, but also has an inherent impact on safety.

5.0 Conclusions

Cost and Schedule estimating is prone to cognitive bias, and when these biases are not mitigated, the resulting estimate is likely to be inaccurate and lead to poor project outcomes. However, behavioral science and neuroscience provides tools to help mitigate theses biases. This paper has provided a broad explanation of the relevant biases, as well as a collection of the recommended tools to mitigate them. Organizations that choose to follow the recommendations included herein will experience improved accuracy in estimates, fewer unexpected risks, and thus improved project performance.

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Attachment 1. Investigating How to Eliminate Bias Roadmap