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for the Army: Misplaced Focus?*

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More Scientists, Engineers, and Basic Research*

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Priming the Innovation Pump: America Needs More Scientists, Engineers, and Basic Research

Col Jason James Denney, USAF

Downward trends in the number of U.S. born scientists and engineers, and basic research and development are threatening U.S. national security and economic prosperity. Leadership in science and technology has long been an unrivaled U.S. advantage; however, the United States has lost and is continuing to lose ground in critical technology metrics. In today's knowledge-based economy, scientific innovation is more important to U.S. economic growth and national security than ever before. Accordingly, the United States must rebuild its foundation of competitiveness—its supply of talented scientists, engineers, and basic research and development resources—that has served Americans so well over the past 50 years. In the 21st century, U.S. success lies at the leading edge of the scientific frontier.

Creating Knowledge

A Statistical Approach to the Development of Progress Plans Utilizing Bayesian Methods and Expert Judgment

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Tiffany L. Lewis, Thomas Mazzuchi, and Shahram Sarkani

The development of progress plans for each identified technical performance parameter (TPP) is a critical element of technical performance measurement. The measured values of TPPs are referred to as technical performance measures (TPMs). These terms are used interchangeably; however, TPMs more directly reflect how technical progress and technical risk are measured and evaluated. Progress plans, or planned performance profiles, are crucial to effective risk assessment; however, methods for developing these plans are subjective in nature, have no statistical basis or criteria as a rule, and are not sufficiently addressed in literature. The methodology proposed herein for progress plan development will involve the elicitation of expert judgments to formulate probability distributions that reflect the expected values/estimates used to establish progress plans.

Analysis of Generation Y Workforce Motivation Using Multiattribute Utility Theory

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Ian N. Barford and Patrick T. Hester

This article explores the difference in assigned levels of workplace motivation and happiness between federal government workforce members of Generation Y versus Generation X and Baby Boomers. Thirty hypotheses were tested, and 11 were found to be statistically significant. Generation Y does assign different levels of importance and partially assigns different levels of happiness to the five motivational factors examined in this study: responsibilities, compensation, work environment, advancement potential, and free time. Advancement potential and free time were rated the highest factors when compared to Generation X and Baby Boomers. Sample size was small due to limited availability of workforce members. This study represents the first attempt to explore motivational factors for the Generation Y workforce within the federal government.

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Application of Real Options Theory to DoD Software Acquisitions

Capt Albert Olagbemi, USAFR, Johnathan Mun, and Man-Tak Shing

The traditional real options valuation methodology, when enhanced and properly formulated around a proposed or existing software investment employing the spiral development approach, provides a framework for guiding software acquisition decision making by highlighting the strategic importance of managerial flexibility in managing risk and balancing a customer's requirements within cost and schedule constraints. This article discusses and describes how an integrated risk management framework, based on real options theory, could be used as an effective risk management tool to address the issue of requirements uncertainty as it relates to software acquisition and guide the software acquisition decision-making process.

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DEFENSE **AR** JOURNAL

Defense Acquisition Research Journal
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Creating Knowledge

Remarks

FROM THE EXECUTIVE EDITOR



This issue marks the debut of the *Defense Acquisition Research Journal (ARJ)*. Its publication marks a continuation of the same peer-reviewed journal that the Defense Acquisition University (DAU) has been publishing since 1994, first under the title *Defense Acquisition Review Quarterly*, and since 2004 as *Defense Acquisition Review Journal*. The *Defense ARJ* carries forward this tradition of scholarly excellence.

This change in name is part of an overall re-emphasis on DAU's research mission. When the university was established by Congress in 1991, the enabling legislation stated that it would "provide for the research and analysis of defense acquisition policy issues from an academic perspective" (DAU Structure, 1991). DAU's mission today supports Department of Defense (DoD) and congressional initiatives by providing the kind of thought leadership that helps improve acquisition outcomes. This journal is central to that mission by providing a high-quality, peer-reviewed forum for disseminating a broad range of research and analysis from across the entire defense acquisition enterprise.

The theme of this issue, "Creating Knowledge," describes the fundamental purpose of acquisition research: to make sense of observations and data through systematic study and analysis, with the goal of creating practical applications to influence acquisition policies, procedures, and outcomes.

COL Michael G. Padgett, USA (Ret.), leads off with an examination of where knowledge is created worldwide, and how the DoD should go about locating and making best use of that knowledge. Col Jason James Denney, USAF, by contrast, looks at how the United States can prime the innovation pump to maintain its knowledge competitiveness in the world. Tiffany L. Lewis et al. explain how expert knowledge and judgment can be better employed in establishing the progress plans for critical program elements. Ian N. Barford and Patrick T. Hester look at how Generation Y—the latest generation of "knowledge workers" to enter the DoD—perceives various motivational factors in their workplace. Finally, Capt Albert Olagbemiro, USAFR et al. examine the use of real options theory to improve knowledge and management of software acquisition risk.

A new feature in the *Defense ARJ* is the Defense Acquisition Professional Reading List. The aim of this list is to enrich the knowledge and understanding of the defense acquisition enterprise workforce.

The books that will be reviewed in this journal reflect important historical and contemporary insights that are directly applicable to today's defense acquisition workforce. Leading off in this issue, Michael Pryce of the Manchester Business School (UK) reviews *The Polaris System Development* by Harvey Sapolsky. The methods and lessons of this highly successful project resonate even after a half-century. I encourage *Defense ARJ* readers to submit reviews of books, following the guidelines set out in the Reading List section.



Dr. Larrie D. Ferreiro
Executive Editor
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Fort Belvoir, Virginia | April 12, 2011

The Defense Acquisition University (DAU) will host its annual Acquisition Community Symposium on Tuesday, April 12, 2011, on its Fort Belvoir Campus. The theme this year is:

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Through a series of speakers, panels, and breakout sessions, the symposium will provide congressional, federal-level, Office of the Secretary of Defense, Service-level, and industry perspectives on implementing affordability initiatives announced by the Under Secretary of Defense for Acquisition, Technology and Logistics in 2010. The 1-day symposium will conclude with a dinner in the evening honoring the winner of the 2011 Alumni Association's Acker Award; induction of new DAU Hall of Fame members; and presentation of the annual Hirsch Research Paper Competition prizes.

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DEFENSE **ACQUISITION RESEARCH** JOURNAL



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INTERNATIONAL SCIENCE AND TECHNOLOGY FOR THE ARMY: MISPLACED FOCUS?

 *COL Michael G. Padgett, USA (Ret.)*

How leaders within the Department of Defense decide where to mine for international science and technology (S&T) is more of a random process than accepted methodology. Considering the importance to the commercial world of optimally located international research and development (R&D) centers, the military services' current practice of abdicating the decision-making process to a subjective evaluation versus application of accepted criteria and current information that allows quantification of the criteria invites technological surprise on the battlefield. By evaluating each criterion, the optimal decision for locating international S&T mining centers is possible. Finding the optimal technologies available for the nation's warfighters ensures world-class technologies for U.S. military programs and saves defense funding of R&D for developing existent S&T solutions.

Keywords: *International Technology Center (ITC); Research, Development, and Engineering Command (RDECOM); Research and Development (R&D); Science and Technology (S&T); Future Investment*



The U.S. Army has International Technology Centers (ITCs) located worldwide. These centers seek the latest science and technology (S&T) across the globe by reporting in which foreign universities, industries, and government laboratories S&T is developed. Once the technology is found and identified as beneficial to a U.S. Army science or developmental program, certain measures are taken to form a collaborative project with the foreign entity to incorporate the foreign technology into the U.S. program.

Importance

The underoptimization of U.S. Army resources is a possible outcome for future decisions if the Army does not dedicate scarce available resources for mining international S&T productively (Dudley & Deylami, 2007, pp. 44–49). If the U.S. Army does not seek the best emerging S&T, alternative and competing science might defeat existing technology (Daniel & Loeb, 2006; National Academy of Sciences, 2007; Segal, 2004). At worst, technological surprise on the battlefield might result in defeat and destruction of the American way of life as we now know it (Defense Science Board, 2007). After setting the boundaries of the least and worst likely outcomes of misallocation regarding mining of international S&T resources, one may predict what is more likely to happen.

However, the U.S. Army does not have a mature process for deciding where to seek international S&T that might render the latest worldwide technologies for U.S. warfighters (Padgett, 2010). The current process used for deciding where the Army should seek beneficial, state-of-the-art S&T that will be incorporated into Army programs is not based on a systematic analysis of the countries and regions where the best S&T resides. This conclusion is based on a recent study that analyzed the Army Materiel Command (AMC) decision-making process, resulting in the location of a new Army International Technology Center (ITC) in Latin America (Padgett, 2010), as well as a review of the literature pertaining to military and commercial sector international S&T research and development (R&D) location decisions.

The Navy and Air Force also engage in seeking international S&T. The Navy's Office of Naval Research (ONR) has a central office in Great Britain, commanded by a Navy captain, dedicated to seeking international S&T worldwide for the ONR. A suboffice of the central office in Great Britain is the Navy's ONR office located in the U.S. Embassy in Santiago, Chile. The ONR office in Santiago was the first Service S&T office in Latin America. Its location in Chile influenced the Army leadership in their decision to co-locate a similar Army office—ITC Americas—in the U.S. Embassy-Santiago (Padgett, 2010).

The Air Force Office of Scientific Research (AFOSR) is charged with seeking international S&T. AFOSR is one of 10 Air Force Research Laboratory (AFRL) technology directorates. AFOSR is the only AFRL directorate that maintains overseas offices for AFRL. Other U.S. government efforts to seek scientific data internationally are not known. Even though the other Services may exercise a more objective approach than the Army's to their decisions on S&T mining center locations, the study found that there are/were no widely accepted objective criteria used by either the Navy or Air Force upon which to base their past S&T mining center location decisions (Padgett, 2010; Roth, Perez, Wylie, & Luoma, 2002).

What is the Background?

Annual U.S. federal government expenditure dedicated to R&D was \$129.1 billion for 2006, of which \$72.1 billion was dedicated to the U.S. Department of Defense (DoD), leaving the remaining \$57 billion for the next five highest federal departments combined (Gottron, 2006). The vast array of DoD laboratories and program offices spends most of the \$72.1 billion internally. Resources are much more limited in the Army's international search for S&T.

The U.S. Army spends only \$9 million to fund the three ITC regions to seek technologies worldwide (V. Baldwin, personal communication, February 26, 2007). This is sufficient for the Army to fund the overhead structures of three regional centers for S&T mining, with each region containing two subordinate offices. However, how and where the \$9 million is spent remains critical since the budget has been relatively constant from 2004 to 2007 and is not expected to increase in the near future; and because the \$9 million is not adequate for seeking S&T from all the countries within a regional territory.

The mission of the Army's ITCs is to promote cooperation between its Research, Development, and Engineering Command (RDECOM) and international researchers. By doing so, the RDECOM is made aware of possible technologies that might be of use to the subordinate Research, Development, and Engineering Centers (RDECs), as well as the Army Research Laboratory. This mission is relatively new, as the ITC centers were formerly called Standardization Groups. The AMC changed the title and mission of the Standardization Groups to ITCs in 2003-2004. The new mission focused on investigation and cooperation in the field of applied research, which is fundamental research to fully develop technologies versus the old mission that focused on standardizing the technologies developed by the U.S. Army with our closest foreign partners worldwide.

What Research Exists?

To more specifically review how the military has made past international S&T decisions, a study was made to examine a specific decision made by the Army to locate the newest international S&T mining center—a center called ITC Americas. ITC Americas was located in Santiago, Chile, with subordinate offices in Argentina and Canada.

A review of literature revealed the criteria used by the civilian sector and government sources in making international S&T location decisions, as well as the information sources used by the civilian sector to compose said criteria (Athukorala & Kohpaiboon, 2005; Doz, Wilson, Veldhoen, & Goldbrunner, 2006; Economist Intelligence Unit, 2004; Goode & Roberts, 2004; National Science Foundation, 2006; Organisation for Economic Co-Operation and Development, 2005). The criteria and information sources used are listed in a later section of this article entitled, “What Does the Existent Literature Say?” To augment the information found in the literature review, the study resulted in a survey of officials within the RDECOM aimed at determining the criteria rated best by the survey respondents for decisions involving the Army’s international S&T locations. The survey provided RDECOM officials with the list of criteria used by the commercial sector for ranking and also provided respondents the chance to suggest their own view of the most important criteria that should be used by the military in international location decisions. As part of this section, a description of the study follows, including the details of the study methodology, population, and survey instrument.

Study Methodology

The specific problem this study examined was to understand, analyze, and explain the internal, external, and political influences on the U.S. Army decision-making process regarding location of a U.S. Army S&T center in Latin America rather than in another world region. The methodology for the study was qualitative and interpretive. The design was a case study on the decision to locate an S&T center in Latin America rather than other world regions. One part of the study involved using some aspects of the participant observer approach by examining the reports written by members of the ITC Americas. The survey in the study filled in the gaps in the literature reviewed and proposed answers to the problem statement and research questions.

The purpose of the qualitative study was to review the decision-making process used by Army leaders when the decision was made

to locate an S&T mining center within Latin America. Fundamental to the decision examined in the study were the factors considered by senior Army leaders in their valuation of one world region over another. The study indicated that the U.S. Army R&D leaders did not identify and leverage the most appropriate criteria upon which to base international S&T mining decisions.

Who Completed the Study Survey?

The population selected for the survey included 30 leaders within the Army R&D community. The 30 leaders received a survey, and the goal was to obtain responses from 20 of the 30 leaders. Persons involved with the decision included both military and civilian members who were part of the Army's S&T organization. The survey was sent to 30 DoD leaders believed to be most affected by the decision to locate the S&T center in Latin America. Most of the Army leaders were within RDECOM. Some of the other leaders were within the Army and Defense Department secretariats.

The survey participant list included senior leaders within RDECOM ($n = 5$), the deputy assistant secretaries of the Army for Defense Exports and Controls ($n = 2$), and the deputy assistant secretary of the Army for Research and Technology ($n = 1$). Also included were the past two leaders of the international section for RDECOM ($n = 2$), leaders within the international secretariat of Office of the Secretary of Defense ($n = 2$), and a past commander of the AMC (AMC; $n = 1$). The AMC was the organization with the final decision authority to locate the S&T office in Latin America. The first group included 13 people.

The second group of leaders was within the subordinate elements of RDECOM, called RDECs, and the Army Medical Command (MEDCOM) ($n = 1$). The RDEC leaders are Senior Executive Service (SES)-graded technical directors and are within the subordinate elements of RDECOM ($n = 7$). The technical directors in the subordinate elements of RDECOM and MEDCOM have advisors, called International Points of Contact (IPOCs; $n = 9$), who are of less senior rank (below GS-15 in grade), and were also in the second group. The IPOCs are the principal advisers for the RDEC technical directors on the integration of international S&T into Army programs. The second group of leaders included 17 people: the seven technical directors, the past deputy commander of MEDCOM's research center, and the nine IPOCs for the technical directors and MEDCOM. Twenty-two of the 30 leaders responded to the survey.

How Was the Survey Constructed and What Did It Reveal?

The survey instrument, a questionnaire with 12 questions, was created specifically for the study. The survey instrument contained

items addressing how Army R&D leaders made the decision to seek quality S&T information in Latin America, the criteria and information Army leaders used to decide to locate an S&T mining activity within Latin America versus other world regions, and the criteria Army leaders considered when they decided to locate an S&T center in Latin America.

The survey results revealed how the decision was made to seek S&T in Latin America versus other world regions, which criteria Army leaders used to open the S&T mining activity within Latin America, and the opinions of the leaders regarding the appropriateness of the criteria proposed in existent literature. The survey also revealed whether information currently available was adequate for international S&T location decisions and the opinions of respondents regarding the accessibility of S&T in one emerging world region versus another.

What Does the Existent Literature Say?

In Military Writings/Studies

The Army hired a contractor, CommerceBasix, to study where it would be best to locate future ITCs (Goode & Roberts, 2004). CommerceBasix analyzed the choices of investing in Latin America, India, Japan, China, Singapore, or Eastern Europe. The RDECOM requested CommerceBasix to focus on at least two but no more than five possible options regarding where to place international S&T locations. The study focused on considerations for current and future locations for Army S&T centers worldwide. Further, the study team expended much effort in detailing the current manning levels of the worldwide Army S&T offices, mission statements, and publishing comments from interviews of the worldwide S&T offices and staff elements within RDECOM. According to Goode and Roberts (2004), the study cited “several direct and indirect determinants are commonly believed to be important factors in innovation.” The factors identified were available capital, economic life cycle of a prospective country, openness of the economy, market-based economic systems, protection for property rights, domestic demand for innovative products, and the balance of trade. The remainder of the study analyzed major countries of the world and how each rated considering the factors selected.

The ONR had contracted for two more focused studies. The Navy was the first to open an S&T office in Latin America, locating their office in Santiago, Chile. The Navy’s original decision to locate their office in Santiago was one of the most significant factors that influenced the Army’s 2004 decision. The first Navy study, by Guza et al. (2002) used database searches to determine what S&T areas

were strongest in each Latin American country. The reason for the study was to provide the information needed to determine where within Latin America an office should be located, and afterward, what S&T areas should be sought in each country within Latin America. The study looked at citations and S&T articles published within major S&T categories, such as bioscience, material science, naval architecture, human factors, electronics, computer science, radars, underwater acoustics, optics, manufacturing, and oceanography. The information to support the conclusions of the study was derived from Inspec[®] Direct and Science Citation Index (SCI) databases. The Navy study did not consider worldwide locations or selection criteria for their recommendations and conclusions, and the study was limited to Latin American countries (Guza et al., 2002).

The second Navy study was conducted by the Center for Strategic Studies (Roth et al., 2002). ONR requested an assessment of the factors that would indicate the best location for a Latin American S&T center. The factors recommended were: economic and political considerations, general living and working conditions, S&T funding levels, and international cooperation and activities. However, once again, this study only considered four countries within Latin America: Brazil, Mexico, Argentina, and Chile. Factors for locations worldwide were not considered (Roth et al., 2002). The Navy decided, as a result of the study's recommendations, to locate their Latin American S&T office in Chile.

The Air Force was also influenced by the Navy and Army decisions to locate S&T offices in Latin America and opened an office in the U.S. Embassy-Santiago in 2009 (J. Fillerup, personal communication, February 21, 2007).

In the Commercial Sector

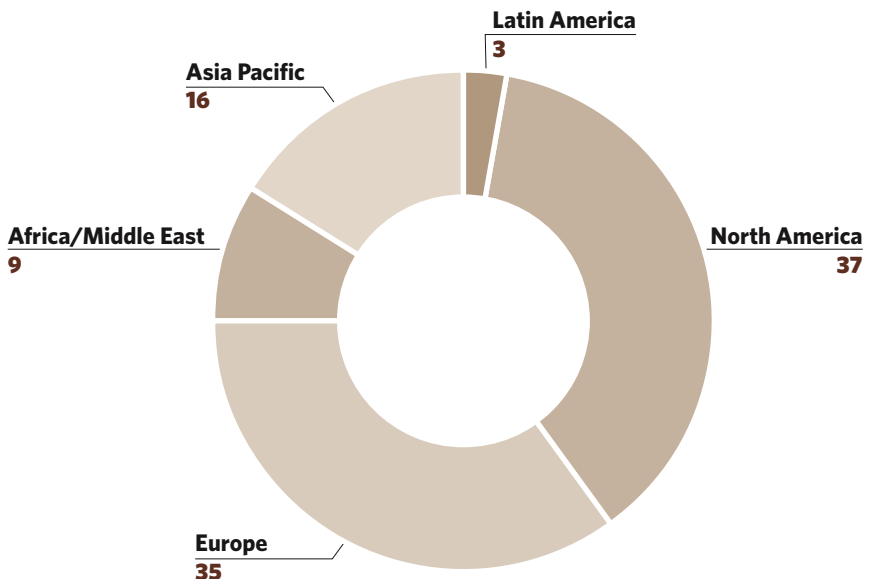
Doz et al. (2006) wrote about the drivers, or selection criteria, for innovation and R&D expansion beyond corporate headquarters, called dispersion. They performed a survey of 186 companies from 19 countries and 17 sectors, with a combined \$76 billion in R&D expenditures in 2004. The number of foreign R&D sites from all countries has increased from 45 percent in 1975 to 66 percent in 2004. Of the total percentage of new sites, 13.9 percent of them were located in China and India. Approximately 78 percent of the new sites remain in the United States or Europe. The remaining 8 percent will go into other Asian and Latin American countries. The forecast was that by the end of 2007, China would have 31 percent of the global R&D staff—up from 19 percent in 2004. The study predicted that the number of R&D sites and staff in Western Europe and the United States would remain unchanged. The Doz report cited the percentage of new sites: China—22 percent; United

FIGURE 1. ECONOMIST INTELLIGENCE UNIT SURVEY QUESTION—FUTURE INVESTMENT TOP 10 LOCATIONS

In which of the following countries does your company plan to spend the most on R&D in the next 3 years (excluding your domestic market) (top 10 locations out of 54)?

1. China	39
2. United States	29
3. India	28
4. United Kingdom	24
5. Germany	19
6. Brazil	11
7. Japan	10
8. France/Italy	9
10. Czech Republic	8

FIGURE 2. ECONOMIST INTELLIGENCE UNIT SURVEY QUESTION—LOCATION OF CORPORATE HEADQUARTERS



**FIGURE 3. ECONOMIST INTELLIGENCE UNIT SURVEY
QUESTION—OVERSEAS R&D EXPENDITURE OVER PAST 3 YEARS**

Roughly what percentage of your company's overseas R&D expenditure over the past 3 years went to the following regions?		
	Under 10%	Over 10%
Latin America	86%	14%
Eastern Europe	78%	24%
Asia	50%	50%

Note. Due to rounding issues in the source from which the data was adapted, not all percentages add up to 100%.

**FIGURE 4. ECONOMIST INTELLIGENCE UNIT SURVEY
QUESTION—ANTICIPATED OVERSEAS R&D EXPENDITURE OVER
NEXT 3 YEARS**

Roughly what percentage of your company's overseas R&D investment will be allocated to the following regions in the next 3 years?		
	Under 10%	Over 10%
Latin America	83%	16%
Eastern Europe	65%	36%
Asia	38%	62%

Note. Adapted from *Scattering the Seeds of Invention: The Globalisation of Research and Development*, by Economist Intelligence Unit, 2004. Due to rounding issues in the source from which the data was adapted, not all percentages add up to 100%.

States and India—19 percent; Western Europe—13 percent; Eastern Europe—12 percent; Asia, excluding China—8 percent; and Latin America—5 percent. The report said the shift of R&D sites is towards India and China.

The Organisation for Economic Co-Operation and Development (OECD) (2005) also proposed selection criteria for R&D locations: patents, licenses, know how, R&D studies, trade in high-tech products, and protection of intellectual property. Rausch (2003), the World Intellectual Property Organization (2006), and two other OECD reports (2008a; 2008b) added to the importance of patents as an indicator of S&T. The OECD 2008 reports said patent statistics measure the output of R&D and its productivity. The reports said patenting activity is more concentrated than R&D effort, and

therefore is a better measure of a country's R&D activity. The OECD report (2008b) also said triadic patents are the best measure since they better reflect the quality of patents. Triadic are those patents filed in the United States Patent Office, Japan Patent Office, and European Patent Office.

A study by the Economist Intelligence Unit (2004) found that cheap labor was an insignificant factor in R&D location decisions. The study done by the Economist Intelligence Unit included 104 senior executives. It found that 52 percent of corporate executives plan to increase their investment in overseas research in the next 3 years, primarily in China and India. The study also addressed developments within Eastern Europe. The study said the relative skill sets of Eastern Europe are increasing, while Western Europe and the United States are declining, making Eastern Europe an attractive location for future R&D investment. Four questions were posed to executives; Figures 1 through 4 reflect their answers.

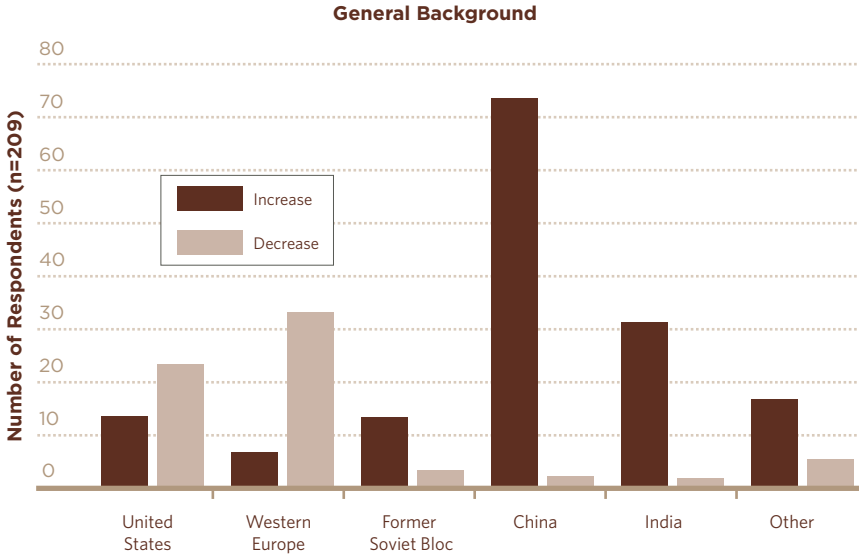
A study by Thursby and Thursby (2006) surveyed over 200 multinational companies across 15 industries regarding factors influencing location decisions for R&D facilities. The majority of companies surveyed were in the United States and Western Europe. The study was done out of concern that location decisions should be based on informed versus anecdotal data. The search used 61 articles, dating from 2002-2005, from the *New York Times* and *Wall Street Journal* describing R&D location decisions. Of the articles, 38 mentioned cost as the primary deciding factor and 29 the quality of R&D personnel. Figure 5 shows the increases and decreases in R&D employment in several world regions and countries.

India and China reflected the largest gains by far. The Thursby study also assessed the locations of U.S. and Western European sites recently opened or future sites the two regions may intend to open (Figure 6).

Cimoli, Ferraz, and Primi (2005) found Latin America to be a minor actor in patenting activity, and the patents filed are usually in chemicals and mechanics, not technology-leading areas such as telecommunications, biotechnology, genetics, and electronics. The report said Latin America innovative processes are adaptive in nature and are rarely inventions and scientific discoveries. Cimoli et al. also cited Latin American technology policy as following divergent and unsynchronized patterns.

The data in an OECD Report (2008b) reflect patent information designed to indicate innovative activity. As depicted in Figure 7, the United States has the top innovative performance at 36.4 percent of the total, followed by the European Union (30.3 percent) and Japan (25.7 percent). Changes that were cited as a measure of patent quality in the triadic patent top 20 indicate innovation in Asia is

FIGURE 5. REGIONS/COUNTRIES WHERE AN INCREASE/DECREASE IN R&D EMPLOYMENT IS ANTICIPATED



Note. Adapted from *Here or There? A Survey of Factors in Multinational R&D Locations*, by J. Thursby and M. Thursby, 2006.

FIGURE 6. LOCATION OF RECENT OR PLANNED INTERNATIONAL TECHNOLOGY CENTERS

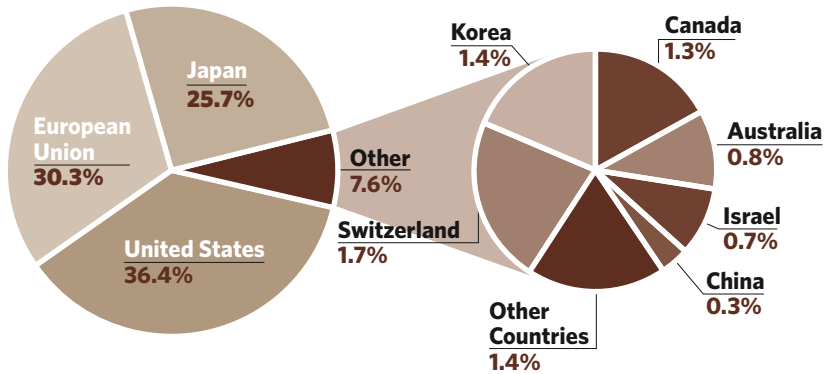
Home Country	Destination					Row Total
	United States	Western Europe	China	India	Other	
United States	0	19	30	9	13	71
Western Europe	14	10	23	9	12	68
Other	0	0	2	0	2	4
Column Total	14	29	55	18	27	143

Note. Adapted from *Here or There? A Survey of Factors in Multinational R&D Locations*, by J. Thursby and M. Thursby, 2006.

surging. No Latin American country is included in the top 30, in raw numbers or as compared to population or gross domestic product (GDP). Three countries from Central/Eastern Europe are in the top 30 of triadic patents as compared with GDP and population density: the Russian Federation, Czech Republic, and Hungary.

Pion-Berlin (2005) said that Latin America, unlike Eastern Europe, in the past has not encountered a security threat sufficient

FIGURE 7. SHARE OF COUNTRIES IN TOTAL TRIADIC PATENT FAMILIES, 2003



Note. Patent counts are based on the earliest priority date, the inventor's country of residence, and fractional counts. Adapted from *WIPO Patent Report: Statistics on Worldwide Patent Activities*, by World Intellectual Property Organization, 2006; and *Compendium of Patent Statistics*, by Organisation for Economic Co-Operation and Development, 2008a.

to motivate an investment in resources and talent to create sophisticated war machines nor “civilian overseers” that understand how sophisticated war machines can work for political purposes. The expenditure toward defense within Latin America is less than Western Europe, Asia, Africa, and North America.

D. Hill published a report (2002) that provided an overall assessment of various regions/countries (Figure 8). The technological infrastructure is viewed as the single most important item in deciding locations for international S&T locations.

A study by Athukorala and Kohpaiboon (2005) said that developed countries constitute around 90 percent of the U.S. Multinational Enterprise (MNE) R&D investment, down from 94 percent in the early 1990s. According to the study, the increase is going to Asia, especially Singapore, Korea, Malaysia, and China. Latin America, except Mexico, has declined in recent years in U.S. MNE R&D investment. These statistics add to the evidence that locating an Army S&T center in Latin America was not based on existent statistics of locations experiencing the greatest level of S&T activity internationally.

Freeman (2005) published a study citing locations where science and engineering (S&E) expertise in the form of university graduates lies worldwide. The study cited PhDs in S&E as the most critical indicator of where knowledge expertise in S&E lies. The top five countries where firms intend to increase R&D efforts outside of their homeland were the United States, India, the United Kingdom, and Germany, with the greatest growth rate of S&Es predicted to be

**FIGURE 8. INDICATORS OF TECHNOLOGICAL COMPETITIVENESS:
1999 (INDEX)**

Higher Numbers = Increased Competitiveness				
Region/ Country	National Orientation^a	Socioeconomic Infrastructure^b	Technological Infrastructure^c	Productive Capacity^d
Latin America				
Argentina	41.3	53.3	27.5	31.0
Brazil	61.5	49.1	40.4	39.6
Mexico	41.8	40.4	21.8	24.8
Venezuela	39.8	49.4	21.3	24.3
East Asia				
China	65.3	52.4	46.4	41.9
Indonesia	53.9	43.8	19.2	23.7
Malaysia	69.5	58.9	31.9	44.1
Philippines	60.9	63.7	24.4	42.6
South Korea	74.9	73.5	44.6	48.8
Thailand	50.7	46.5	20.5	30.6
India	67.7	48.4	46.8	51.3
Poland	69.6	58.4	38.2	44.3
South Africa	50.2	53.6	40.5	28.7

Note. Adapted from *Latin America: High-Tech Manufacturing on the Rise, but Outpaced by East Asia* (NSF Publication No. 02-331), by D. Hill, 2002, National Science Foundation, Directorate for Social, Behavioral, and Economic Sciences.

^a National orientation provides evidence that a nation is taking direct action to achieve technological competitiveness.

^b Socioeconomic infrastructure assesses the social and economic institutions that support a modern technology-based industrial nation.

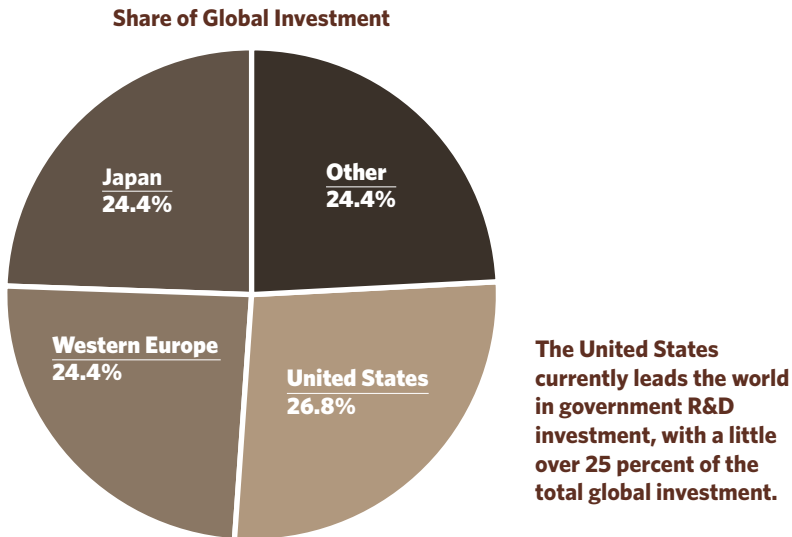
^c Technological infrastructure assesses the institutions and resources that contribute to high technological development.

^d Productive capacity assesses the level and efficiency of physical and human resources devoted to manufacturing.

in China by 2010. Murdock (2005) measured leadership in R&D as strength in investment, scientific publications, and patents. Figures 9 and 10 illustrate the percentage of global R&D investment.

To put this in perspective, Segal (2004) said that no one measure can measure a country's innovation. This is offered to show that location criteria for R&D location decisions found in commercial and government studies vary from study to study.

FIGURE 9. U.S. GOVERNMENT SHARE OF GLOBAL R&D INVESTMENT



Note. Adapted from *Nanotechnology: Where Does the U.S. Stand?* by S. Murdock, 2005. Testimony of Sean Murdock, Executive Director, Nanobusiness Alliance, Hearing before the Research Subcommittee on the House Committee on Science.

What Answers Emerged from the Survey?

Survey respondents thought that the Navy presence in Latin America, prior to the decision to locate an Army office, affected the outcome of the decision. The consolidation of scarce military S&T assets might appear to be optimal, but what if the quantitative data indicate a different location would be more productive than the earlier location decision made by a different Service?

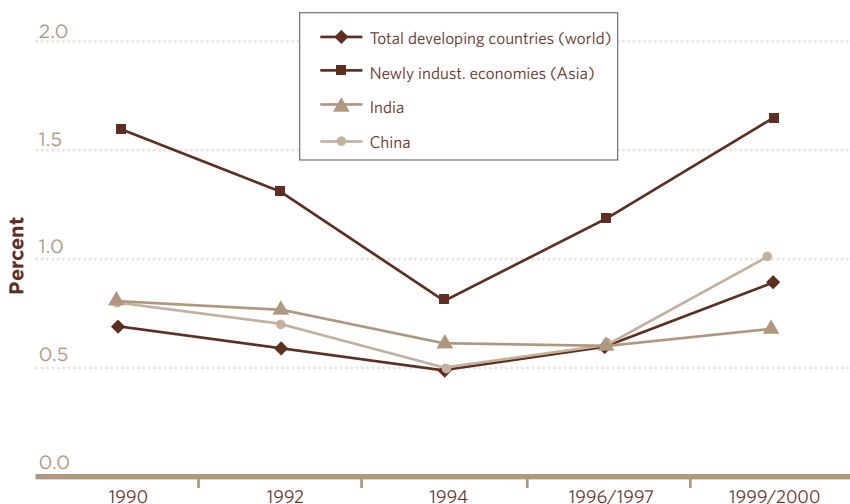
Some survey respondents thought that the decision might have been made to avoid technological surprise on the battlefield. The Army decision authority, who responded to the survey, did not mention avoiding technological surprise as a factor that influenced his decision. However, the decision authority did say that the prior absence of any Army S&T coverage of Latin America affected his decision.

Are There Answers Resulting from the Literature Review and Survey?

Conclusions

No. 1. The 2008 OECD Report indicated that triadic patents were the single most important criterion for selecting international S&T

FIGURE 10. R&D INTENSITY IN DEVELOPING COUNTRIES AND SELECTED COUNTRIES/REGIONS IN ASIA: 1990-2000



mining locations (OECD, 2008b). The reason triadic patents were viewed as an important criterion was based on the view that if a patent was of great value, the originator would want to protect it worldwide as much as possible. Although this decision contradicts the literature of patents—peer-reviewed articles, intellectual property rights protection, among a list of other things—it is a logical one. Knowledge is important, but the statistics reflect that the greatest numbers of S&Es are in China and India, and R&D intensity is not as important as raw R&D expenditures. The latter provides the degree and volume of opportunities for the military.

No. 2. Based on the data reviewed from commercial and military sources found in the literature, the decision made to locate an Army S&T center in Latin America versus another world region was not the most optimal decision for the best long-term interests of the U.S. Army. Instead, the data indicated that the office should have been located in the following locations, in order of priority:

1. India
2. Emerging Asian countries
3. Eastern Europe

China would be the No. 1 priority, but its choice as a viable location for an ITC is viewed as impractical due to the need to protect U.S. Army intellectual property.

No. 3. The decision authority for the S&T center in Latin America made the decision based on a personal evaluation; therefore, the decision was an intuitive-based one, relying on existing information without seeking input from his subordinate expert advisors (Padgett, 2010).

No. 4. The survey responses indicated the decision authority did not seek the expert knowledge of center directors at the subordinate research centers within RDECOM, even though they were general officer-level civilians, prior to making the decision (Padgett, 2010).

No. 5. The decision authority did not use a set of criteria for the decision or seek information that might support some set of criteria, but instead evaluated the existent information subjectively rather than objectively prior to reaching the decision (Padgett, 2010).

No. 6. Overriding factors, three of which evolved as a result of the study, motivated the decision authority to select Latin America as the location of the S&T mining center. Navy presence in Latin America prior to the decision to locate an Army center affected the outcome of the decision. This was followed by quantitative data that indicate a different location would be more suitable in the long term. The data indicate that locating an S&T center in a location where other S&T assets are already located to gain short-term efficiencies from the collocation is not the best alternative for long-term corporate, military, or organizational health.

No. 7. The Army decision authority used other factors to determine where to locate the S&T center, such as politics and security cooperation goals for the military. Survey respondents cited each of these factors repetitively. According to the survey responses, political considerations constituted the largest influence over the decision authority in his evaluation of the S&T center's eventual location.

Recommendations

No. 1. Decisions for international military S&T locations should use the following three objective criteria as the basis for the decision:

1. Triadic patents
2. R&D expenditure rates
3. S&E articles published

The second criterion was cited as the most important factor in a study by Athukorala and Kohpaiboon (2002). The third criterion

appears as the statistical factor used to measure international S&T activity by the National Science Foundation statisticians in their periodic reports (Hill, 2002, 2004).

No. 2. Since a subordinate office of the regional center in Japan, located in Singapore, is presently charged with oversight of India, perhaps a transfer of assets from the ITC in London to Singapore to better cover the explosion of science in India would present the best option. ITC London has the most international S&T resources at present, and those resources are covering an area where the Army S&T community already has strong ties, meaning the resources in ITC London might be better utilized to detect new technologies emerging from India and the emerging Asian countries. The same realignment, using ITC London assets, should be applied for the emerging Asian countries, except that the additional assets should be located in Japan versus Singapore for coverage of the emerging Asian countries.

No. 3. Based on using objective criteria, the office in Latin America should be transferred to Eastern Europe to cover the larger amount of S&T emerging from Eastern Europe. However, if political concerns are overriding in motivating relationship building with Latin America versus Eastern Europe, then the S&T regional office and suboffices in the Americas should remain in place.

No. 4. Senior-level decision authorities should seek the expert judgment of the SES directors prior to making international location decisions.

No. 5. An earlier study indicates the decision authority opted to exclude from consideration the objective data and input from experts when he decided to locate an S&T center in Latin America (Padgett, 2010). If a decision authority opts to exclude from consideration the existent objective data or the advice of subordinate experts, then the decision authority should clearly articulate why the alternative solution provides a more optimal outcome.

Author Biography



COL Michael Padgett, USA (Ret.), is a retired colonel and former member of the Army Acquisition Corps, with over 28 years of military service. His last job was as the first commander of the International Technology Center (ITC)-Americas located in Santiago, Chile. His last 7 years were spent in the Army's RDECOM in colonel-level command and deputy command positions. COL Padgett attended senior service college in South Africa in 2000 and Command and General Staff College in 1993/1994. He holds a doctorate from the University of Phoenix.

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PRIMING THE INNOVATION PUMP: AMERICA NEEDS MORE SCIENTISTS, ENGINEERS, AND BASIC RESEARCH

 *Col Jason James Denney, USAF*

Downward trends in the number of U.S. born scientists and engineers, and basic research and development are threatening U.S. national security and economic prosperity. Leadership in science and technology has long been an unrivaled U.S. advantage; however, the United States has lost and is continuing to lose ground in critical technology metrics. In today's knowledge-based economy, scientific innovation is more important to U.S. economic growth and national security than ever before. Accordingly, the United States must rebuild its foundation of competitiveness—its supply of talented scientists, engineers, and basic research and development resources—that has served Americans so well over the past 50 years. In the 21st century, U.S. success lies at the leading edge of the scientific frontier.

Keywords: *Scientists, Engineers, Research, Economic Growth, National Security*



NOTES:
1. ALL DIMENSIONS SPECIFIED
ALL DIMENSIONS ARE IN INCHES
DIMENSIONS IN PARENTHESIS ARE
TO MAXIMIZE SEAL LIFE.
2. BE ORIENTED UPWARD THE
PUMP IS SUPPLIED WITH A
NORMAL VOLT. ORIENTATIONS
ARE ORIENTED DOWNWARD.
3. 10.40" CRITICAL. WHEN IN
SLIGHT VERTICAL POSITION
POST. COY. AND SEALING
OTHER SPECIFIED
4. ALSO SEE INLET SIDE OF
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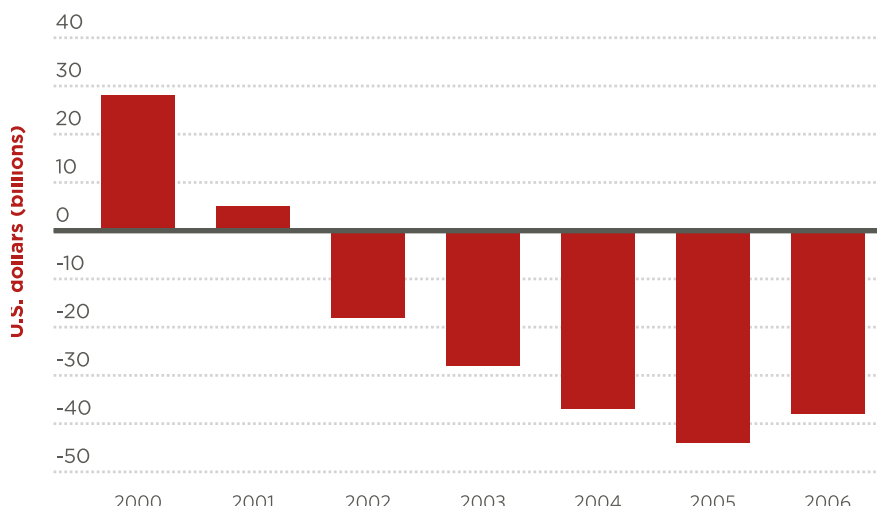
The United States has led the world in science, technology, knowledge generation, and innovation; however, the nation can no longer take its supremacy for granted. Nations fueled by globalization and competitiveness are on a fast track to surpass the United States in scientific excellence and technological innovation. Specifically, downward trends in the number of U.S. scientists and engineers (S&Es), and national basic research and development (R&D) are exacerbating this challenge and have troubling implications for U.S. economic prosperity and national security. Increasing the U.S. supply of quality S&Es and boosting basic R&D resources are essential to national security and economic growth. Continued economic and national security requires effective industry and government action as well as policies to ensure the United States remains at the leading edge of the scientific frontier.

From Producing Stuff to Producing Ideas

The liberal, neo-classical economic doctrine and its principle that capital drives growth has given way to knowledge economics and its principle that innovation drives growth (Atkinson, 2009, slides 40–41). During the industrial revolution, physical capital was the competitive advantage and growth was the product of land, labor, and capital—in other words, how much “stuff” was produced. In 1930, Joseph Schumpeter, an Austrian economist, first pointed out that innovation is the key to economic growth (Schumpeter, 1930). Today, Paul Romer’s **new growth theory** builds on Schumpeter’s premise by stressing that information leads to knowledge and then knowledge leads to innovation (*The Knowledge Economy*, 2009, pp. 4–5). Value is created by combining information and knowledge into new combinations—what Romer calls recipes. A recipe is more valuable than its parts; and new combinations are limited only by a person’s, a corporation’s, or a nation’s ability to innovate (Romer, 2007).

Knowledge quickly becomes obsolete in a globalized environment, so competitive advantage—based on knowledge—requires the continuous creation of more knowledge into innovative products and processes. This framework applies to both economic and national security. The pendulum has swung such that poor countries of the future will have no ideas, whereas poor countries of the past had no natural resources. Taiwan, for example, started with essentially no natural resources but grew rapidly because of its ability to innovate. The U.S. innovation engine—fueled by the supply of S&Es and basic R&D resources—is quickly losing ground to international competitors that are rapidly accumulating intellectual capital and R&D capacity. Of specific concern is the general lack of interest

FIGURE 1. U.S. TRADE BALANCE IN HIGH-TECHNOLOGY GOODS: 2000-2006



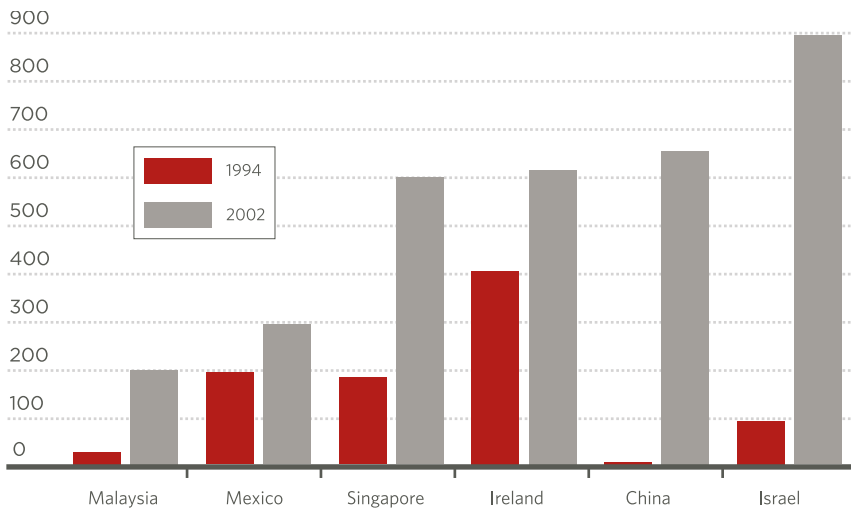
Note. Adapted from *Science and Engineering Indicators 2008*, by National Science Board, 2008, NSB Report No. 08-01.

among American-born youth in pursuing careers in the science, technology, engineering, and math (STEM) fields; and the long-term decline in the national investment in basic R&D (Marshall, Coffey, Saalfeld, & Colwell, 2004, p. 1). If these trends continue, the United States will find itself at a severe disadvantage.

Losing Ground on All Fronts

By most science and technology (S&T) metrics the United States leads the world. However, the nation has already lost and is continuing to lose ground in critical technology output metrics such as its trade balance of high-tech goods (Figure 1), the number of technical articles published, and the number of technical articles cited by others (National Science Board [NSB], 2008, pp. 10-12). In a recent study, 38 of the world's 50 leading research institutions were in the United States; however, other nations are quickly catching up (Freeman, 2006, pp. 2-3). For example, multinational companies are operating 53 state-of-the-art, high-tech industrial parks and 750 R&D centers in China (Berry & Loeb, 2008, p. 6). Growth in overseas R&D infrastructure has increased the off-shoring of U.S. industrial R&D (Figure 2) (Atkinson, 2009, slide 25). In addition, the world's S&T investment increased by 96 percent from 1996 to 2006, with China's growth at 9 percent, dwarfing all other countries, including the United States whose S&T investment decreased by 6 percent

FIGURE 2. BOOM IN RESEARCH AND DEVELOPMENT PERFORMED OVERSEAS BY U.S. COMPANIES

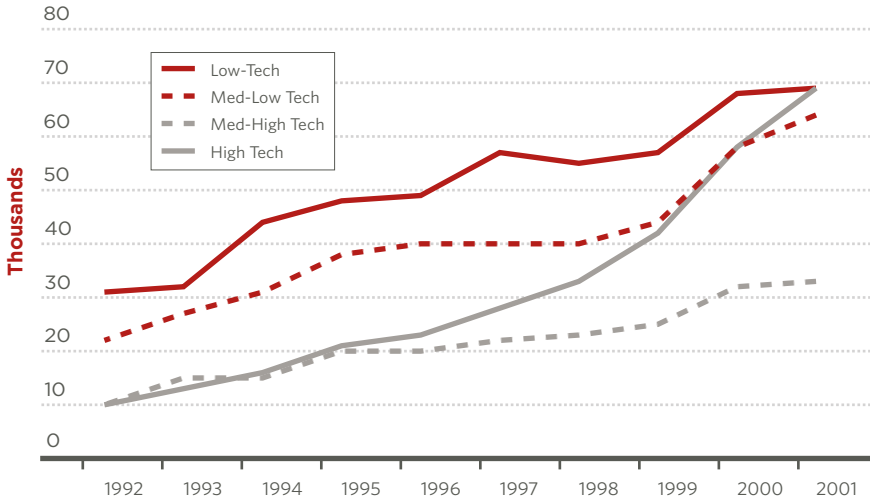


Note. Adapted from *Innovation and U.S. Economic Growth*, by R. D. Atkinson, February 5, 2009, Information Technology and Innovation Foundation presentation to Industrial College of the Armed Forces.

(Berry & Loeb, 2008, p. 2). As a result, China “isn’t just making T-shirts anymore,” it is producing increasing amounts of medium- to high-tech products for both commercial and military use (Figure 3), and other countries are following suit (Atkinson, 2009, slide 29). The U.S. output of native-born S&Es, however, is just as worrisome.

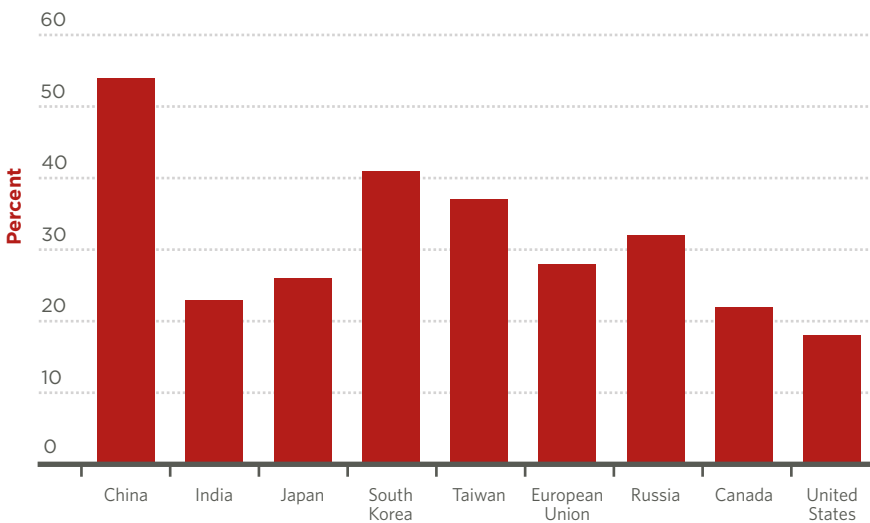
The United States lags behind global competitors in the percentage of undergraduates earning S&E degrees (Figure 4) (Atkinson, 2009, slide 26). In 2002, only 17 percent of U.S. undergraduates earned engineering degrees, as compared to 53 percent in China (National Science Foundation [NSF], 2006, Appendix, Table 2-38). In addition, the U.S. global share of S&E doctorates and undergraduate degrees fell from 40 to 20 percent and from 30 to 14 percent between 1970 and 2000 (Freeman, 2006, pp. 2–3). According to the NSF, 58 percent of engineering doctorates awarded in the United States in 2003 went to noncitizens, while greater than half of the students enrolled in U.S.-taught engineering programs were foreign-born. And in 2004, S&E doctorates awarded to temporary residents increased by 9 percent, compared to 2 percent for U.S. citizens (National Defense Education Program [NDEP], 2009a, p. 2). Also, in a recent survey of more than 270,000 U.S. college freshmen, only 7.5 percent said they intended to major in engineering—the lowest level since the 1970s (Aerospace Industries Association [AIA], 2008, p. 4). While foreign innovations benefit the standard of living in the United States, the government must increase its own supply

FIGURE 3. CHINA ISN'T JUST MAKING T-SHIRTS ANYMORE



Note. Adapted from *Innovation and U.S. Economic Growth*, by R. D. Atkinson, February 5, 2009, Information Technology and Innovation Foundation presentation to Industrial College of the Armed Forces.

FIGURE 4. UNITED STATES LAGS IN PERCENT OF UNIVERSITY STUDENTS RECEIVING DEGREES IN SCIENCE AND ENGINEERING



Note. Adapted from *Innovation and U.S. Economic Growth*, by R. D. Atkinson, February 5, 2009, Information Technology and Innovation Foundation presentation to Industrial College of the Armed Forces.

U.S. military dominance and economic competitiveness, particularly in the defense sector, at risk. “Current military dominance derives from S&T investments made in the 1950s through the 1970s by DoD and other federal agencies”; therefore, shortsightedness today may concede U.S. military dominance 10, 20, and up to 30 years or more in the future (Marshall et al., 2004, p. 3). It is “akin to a farmer who wishes only to harvest and not to sow” (Frosch, 1996, p. 22). To sow the seeds of technology, and to increase the opportunity for greater capability gains, the United States must focus more effort on the earliest stages of the product development cycle, researching and experimenting with new and innovative technologies. “If we do not invest heavily and wisely in rebuilding these two core strengths”—S&Es and basic R&D—“America will be incapable of maintaining its global position long into the 21st century” (U.S. Commission on National Security, 2001, p. ix).

Scientists and Engineers

The productive power of the U.S. economy and its national security lies primarily with its people. The Office of Management and Budget (OMB) estimates that privately owned capital in the United States is worth \$13 trillion, while its human, intellectual capital is worth \$48 trillion (OMB, 2007, p. 195). According to Alan Greenspan, “If we are to remain preeminent in transforming knowledge into economic value, the U.S. system of higher education must remain the world’s leader in generating scientific and technological breakthroughs and in preparing workers to meet the evolving demands for skilled labor” (Greenspan, 2000, p. 4). But this system is being challenged from abroad.

Foreign students, particularly Asian students, are less likely to study in the United States for several reasons. First, foreign countries are growing their own higher education capabilities. From 1994 to 1998, the number of Chinese, South Korean, and Taiwanese doctoral students at U.S. universities dropped by 19 percent, while their enrollment at institutions in their native countries doubled (Task Force, 2005, p. 5). In 2006, five Chinese universities ranked in the top 100 universities for science, with Peking University ranking 12th (Berry & Loeb, 2008, p. 7). Second, foreign countries are developing their own high-tech industries and research capacity. As a result, increasing numbers of U.S.-educated doctoral S&E graduates are returning to their native countries to pursue research opportunities. And finally, tighter visa restrictions post-9/11 deter foreign students from studying in the United States. The cap on H-1B visas for high-skilled specialties decreased from 115,000 in 2000 to only 65,000 in 2007 (Bordoff, Deich, Kahane, & Orszag, 2006, p. 6). Due to security restraints, the United States can no longer rely on a steady influx

of foreign S&E talent to supplement innovation, and must produce more homegrown STEM talent to maintain its economic and national security edge.

Since 1980, S&E positions in the United States have grown by five times the rate of other professions; however, the number of S&E degrees earned by U.S. citizens is decreasing (Task Force, 2005, p. 5). This is especially critical to DoD laboratories and agencies like the National Security Agency, where U.S. citizenship is a security requirement (Bordoff et al., 2006, p. 6). Additionally, the time and cost to pursue S&E graduate degrees have increased while the compensation in S&E fields has declined relative to other high-level occupations (Freeman, 2005, p. 10). These trends clearly signal the need to create incentives—such as higher wages, fellowships, and employment guarantees—to maintain the pipeline of quality S&E talent that our nation’s economy and national security structure sorely need. Unless more U.S. students choose S&E fields, the U.S. public and private innovation sectors will experience a significant “brain drain.”

The DoD is taking action to avoid this “brain drain” through NDEP. The objective of NDEP is to bring more S&Es into the national security enterprise by supporting local educational initiatives. NDEP has an aggressive congressional mandate to award 1,000 innovative scholarships by 2013; to demonstrate DoD’s involvement in K-12 education programs; and to award 50 five-year research fellowships by 2013. NDEP’s primary focus is on middle school students that are “at a game-changing age where they will need to embrace math and science, or likely vanish as potential STEM employees”; however, NDEP also focuses on university students through its Science, Mathematics, and Research for Transformation (SMART) program. SMART funds U.S. S&E students’ education costs in exchange for a 1-year payback in a DoD laboratory for each year of educational support. While NDEP programs have shown success, more has to be done at a national level because the DoD has 83,000 S&Es (70 percent engineers) and replenishing this resource does not occur overnight (NDEP, 2009b, pp. 1, 3). The challenge is even greater in industry.

Industry has been working this issue for some time, but is still struggling to hire the talent it needs. For example, 13 percent of the overall aerospace and defense workforce is qualified for retirement, and within 10 years this figure will grow to 50 percent. Of the 70,000 engineering bachelor’s degrees awarded in the United States annually, most disciplines are not in high demand by DoD contractors (AIA, 2008, p. 3). Industry’s viability depends on a skilled workforce, so industry is seizing ownership of the issue. Lockheed Martin (LM), the top recruiter of new engineers (5 percent

Basic Research and Development

As changes in this century's threat environment create strategic challenges—irregular warfare, weapons of mass destruction, disruptive technologies—this request places greater emphasis on basic research, which in recent years has not kept pace with other parts of the budget.

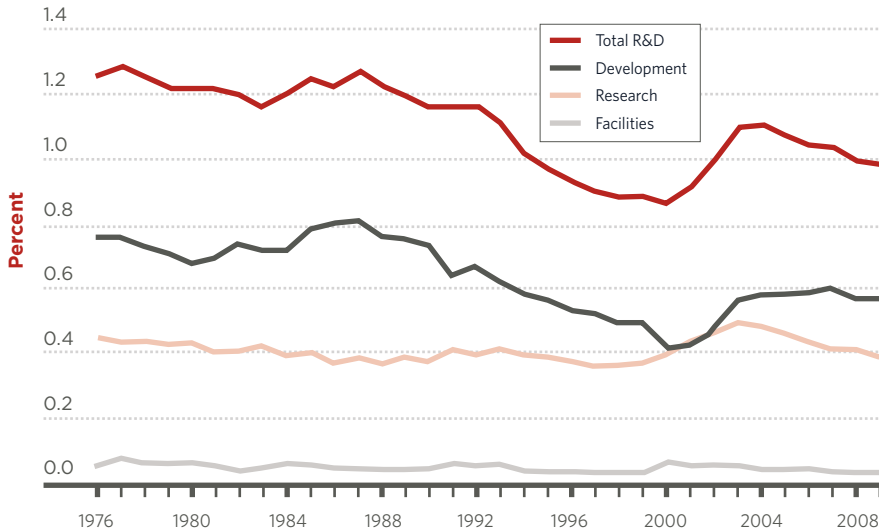
- Robert M. Gates, Secretary of Defense

Secretary Gates' emphasis on basic R&D in his Fiscal Year 2009 Posture Statement is encouraging; however, much more is required at a national level (Rees, 2008a, slide 7). In a global comparison of the basic research share of total R&D expenditures, the United States ranks 16th (NSB, 2008, Figures 4-20, 4-41). DoD's \$271 million basic R&D increase in the Fiscal Year 2009 budget is a step in the right direction; however, it may do little to overcome years of declining and flat budgets (Rees, 2008a, slide 17). In the post-9/11 world, where security and economic threats can appear from anywhere, a diverse and vibrant national basic R&D program is a necessity for economic and national security.

Direct contribution of R&D investment to economic growth in real Gross Domestic Product (GDP) was 6.7 percent during 1995–2002, up from 4.3 percent during 1974–1994 (Bureau of Economic Analysis, 2006). Although R&D contributes significantly to economic growth, the private sector invests less in basic R&D than is justified by societal benefits, because private innovators receive only a small fraction of the benefits their inventions generate. Surveys show that private return on investment (ROI) of basic R&D typically ranges between 7–15 percent, while the social benefit ranges between 30–50 percent (Popp, 2004). While society benefits tremendously, private industry's incentive to conduct basic R&D is low so industry concentrates on short-term, incremental R&D, similar to DoD. This is a significant innovation loss, because the private sector accounts for nearly two-thirds of total R&D (Bordoff et al., 2006, p. 2). Because the private sector invests less than it could in basic R&D, the United States is not realizing its full economic, or for that matter, national security potential. The world's fastest growing economies are on track to catch up to the U.S. basic R&D investment. China, South Korea, and Taiwan increased their R&D investment by 140 percent from 1995–2001, while the United States increased its investment by only 34 percent (Task Force, 2005, p. 9). To compensate for this shortage in private basic R&D, the United States must increase its public investment to maintain its innovative edge.

“Much of the strength of the United States is attributable to its technological prowess, much of which developed out of gov-

FIGURE 5. DECREASING TREND IN RESEARCH AND DEVELOPMENT (R&D) AS PERCENT OF GROSS DOMESTIC PRODUCT, FY 1976–2009*



* FY 2009 figures are the latest American Association for the Advancement of Science (AAAS) estimates of FY 2009 request. R&D includes conduct of R&D and R&D facilities. Data to 1994 are obligations from the National Science Foundation Federal Funds Survey. The 2009 Gross Domestic Product figures are from the United States Government, Office of Management and Budget.

Note. Adapted from AAAS analyses of R&D in annual AAAS R&D reports.

ernment-funded science research” (NDEP, 2009a, p. 3). Publicly funded basic R&D typically yields a high ROI of 30 percent or more (Mansfield, 1991, p. 3). However, “federal basic research in the physical sciences and engineering is flat or has declined as a percentage of GDP over the past 30 years” (Figure 5) (NDEP, 2009a, p. 3; Advancing Science, Serving Society [ASSS], 2009, Figure 1). Yet in times of crisis, public basic R&D has paid off. Basic R&D—conducted by the NSF, the National Aeronautics and Space Administration, and DoD for example—has provided innovations with huge societal payoffs, such as the World Wide Web, portable communications, the Internet, computer graphics, and broadband capabilities to name just a few, some of which have led to multibillion-dollar industries (National Research Council, 2003). The range of potential security and economic threats is increasing; therefore, the United States must increase its investment in basic R&D across the board. While DoD has been and is currently the largest benefactor and contributor to public basic research, it is losing ground fast (Rees, 2008b, p. iv).

Recent trends raise questions about the U.S. public funding of basic R&D. First, basic R&D has shifted from long-term, blue-sky research, which will most likely yield significant technological break-

FIGURE 6. INNOVATION CURVE: BASIC R&D PROVIDES GREATER CAPABILITY GAINS AT LESS COST

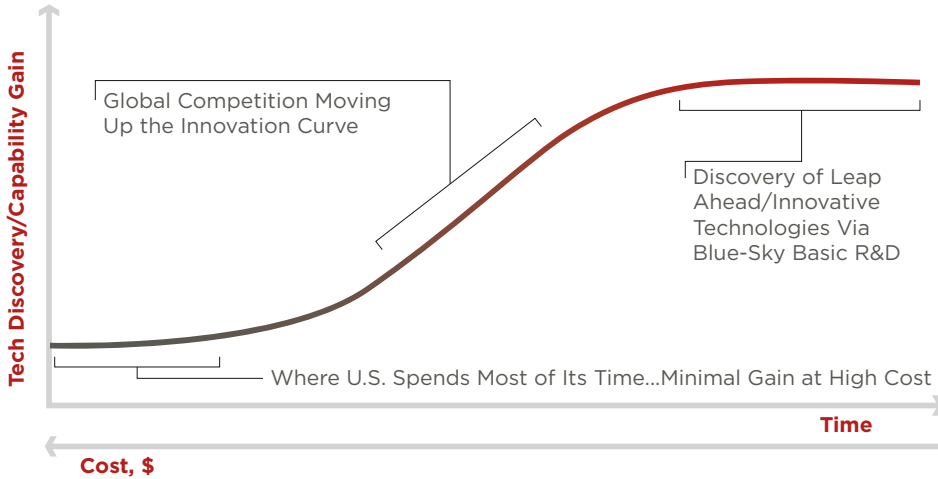
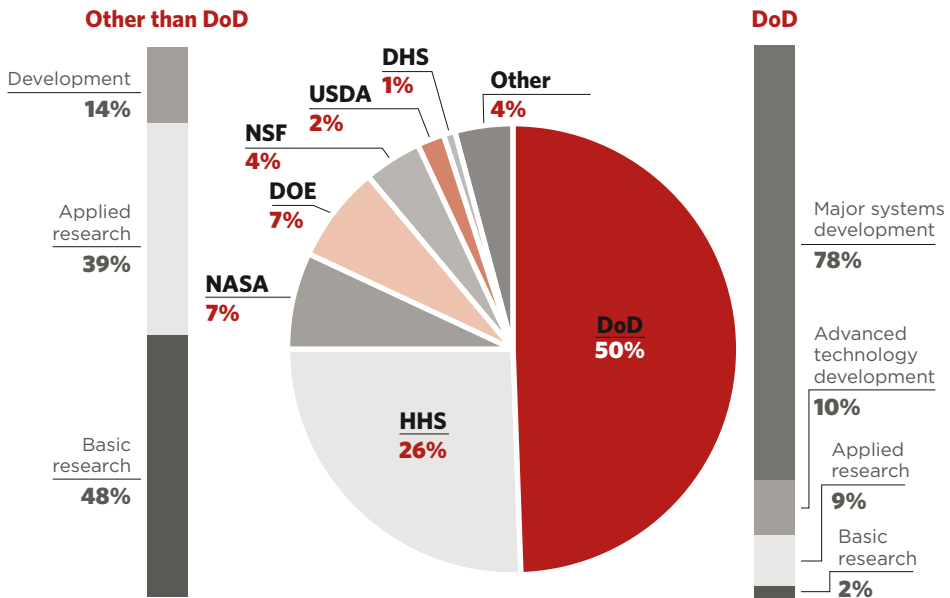


FIGURE 7. FEDERAL OBLIGATIONS FOR R&D BY AGENCY AND TYPE OF R&D: FISCAL YEAR 2007



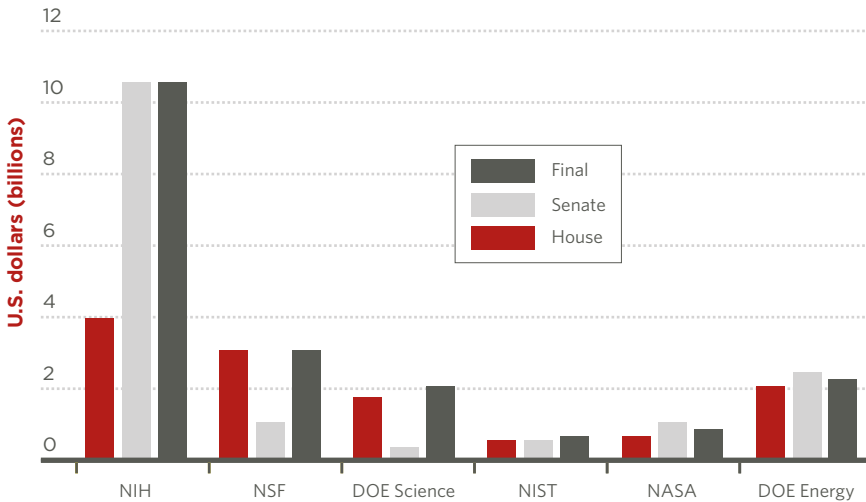
Note. DoD = Department of Defense; DOE = Department of Energy; DHS = Department of Homeland Security; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; NSF = National Science Foundation; USDA = U.S. Department of Agriculture. Detail may not add to total because of rounding. Adapted from *Science and Engineering Indicators 2008*, by National Science Board, 2008, Appendix, Table 4-30; and National Science Foundation, Division of Science Resources Statistics, Federal Funds for Research and Development: Fiscal Years 2005, 2006, and 2007. Due to rounding issues in the source from which the data were adapted, not all percentages add up to 100 percent.

throughs to R&D designed to reach more specific findings in shorter time horizons and at greater cost, such as applied and developmental R&D (Figure 6). Of note is the Defense Advanced Research Project Agency's (DARPA) shortening of go/no-go reviews for projects that are from projects of 12- to 18-month intervals versus prior 36-month intervals. This type of short-term focus hamstrings researchers and reduces the possibility of groundbreaking innovations like the Internet, global positioning technology, and Stealth that DARPA-funded, blue-sky research has produced in the past (Bordoff et al., 2006, p. 9). Similarly, the Services own 80 percent of the defense basic R&D; however, they are primarily interested in mission-focused research, not blue-sky research (Rees, 2008a, slide 22). Figure 7 shows the federal R&D obligations for Fiscal Year 2007. What is most telling is DoD's lack of interest in basic R&D—only 2 percent (NSB, 2008, p. 4-25, Figure 4-6). If DoD wants to

IF DOD WANTS TO CONTINUE ITS LONG-HELD
 STRATEGY OF “QUALITY OVER QUANTITY” VIA
 HIGH-TECHNOLOGY AND MODERNIZATION, IT MUST
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continue its long-held strategy of “quality over quantity” via high-technology and modernization, it must continue to expand its basic R&D investment. Second, the public basic R&D portfolio reflects a growing imbalance. Between 1995 and 2005, biomedical basic R&D increased by 115 percent—four times the rate of increase in basic R&D in the physical sciences, mathematics, and engineering, which are the disciplines most applicable to DoD initiatives (AAAS, 2006). In the \$789 billion American Recovery and Reinvestment Act signed into law on February 17, 2009, \$21.5 billion is for federal R&D with the majority—\$10.4 billion or 48.4 percent—going to the National Institutes of Health (NIH) for medical research, of which \$6.5 billion alone is for biomedical R&D. The next largest share at \$3 billion—a factor of 3.5 times less than the NIH share—went to the NSF (Figure 8) (AAAS, 2006). While advances in medicine are worthy, limiting research—particularly research in the physical and engineering sciences that apply to a broad array of scientific fields, including biomedical—limits innovation potential (National Research Council, 2001). And finally, basic R&D does more than just generate new discoveries and knowledge; it also prevents technological surprise, educates S&Es so that they can be more effective, and sustains the human talent and research infrastructure so critical to national security and economic growth (Rees, 2008b, p. 2). To stop and reverse this innovation implosion, new policies are needed to

FIGURE 8. 2009 ECONOMIC RECOVERY BILL FEDERAL R&D FUNDING—HOUSE, SENATE, AND FINAL BILLS



Note. NIH = National Institutes of Health; NSF = National Science Foundation; DOE = Department of Energy; NIST = National Institute of Standards and Technology; NASA = National Aeronautics and Space Administration. Adapted from *Final Stimulus Bill Provides \$21.5 Billion for Federal R&D*, by American Association for the Advancement of Science, 2009.

increase public and private R&D as well as incentives to increase the number of quality American-born S&Es.

Policy Recommendations

U.S. technological leadership requires effective government policies to keep the nation at the leading edge of the scientific frontier. “The attack [September 11, 2001] was sort of like when Sputnik went up and created the National Defense Authorization Act in 1958”; however, Americans need to once again find the excitement and urgency of 50 years ago that led to technological achievements such as the Apollo moon landings (NDEP, 2009a, p. 2). Time is of the essence because the Apollo generation is ripe for retirement. U.S. leadership should create and pass a National Security Education Act for the 21st Century to provide a strategic framework for national security and economic policies. The following policies, while not an exhaustive list, would be a step in the right direction.

National Innovation Policy Recommendation

Simply funding more basic research and educating more S&Es is not enough. The United States must create national innovation policies to provide focus, to avoid excessive duplication with

limited research dollars, to promote the diffusion of innovative ideas across private and public lines, to advocate for innovative projects, to ensure a continuous supply of quality S&Es and basic R&D resources, and to tie innovation to U.S. economic and national security. In addition, the developer, owner, and executor of innovation policy should be the Office of Science and Technology Policy headed by the Science Advisor to the President, thus providing clout to innovation policy.

S&E Policy Recommendations

Increase the number and value of S&E graduate research fellowships (GRFs). At a minimum, the NSF should triple its GRFs to restore the ratio of GRFs to undergraduate engineering degrees to the ratio that existed in the early 1960s, following Sputnik (Freeman, 2006, pp. 2-3). Increasing GRFs will incentivize the most talented S&E students to continue on to graduate work versus pursuing more lucrative fields (Bordoff et al., 2006, p. 7).

Continue to attract the best and brightest S&Es from abroad. Highly skilled immigrant S&Es contribute significantly to U.S. economic growth. For example, a third of all businesses founded in the Silicon Valley in the 1990s were started by foreign-born S&E entrepreneurs. The Russian-born Sergei Brin started Google; and eBay was started by Pierre Omidyar, an Iranian born in Paris. Also, one-half of U.S. Nobel laureates in science are foreign-born (Bordoff et al., 2006, p. 7). And finally, foreign-born competition will drive U.S.-born S&Es to achieve greater educational heights and innovation to compete.

Increase the H-1B visa caps to pre-9/11 levels. “The U.S. is failing to take full advantage of the global talent pool” (Bordoff et al., 2006, p. 8). The number of international S&E students in U.S. graduate programs declined by 20 percent between 2001 and 2004 (Bordoff et al., 2006, p. 8). The United States must reverse this trend to maintain its innovative edge.

Improve STEM education. By developing programs that demonstrate the practical uses of math and science, the government can generate interest in STEM careers and support students interested in these programs through government-funded fellowship, thus providing a steady stream of S&E talent.

Basic R&D Policy Recommendations

Increase public basic R&D resources (funding and facilities) and apply them based on overall effectiveness. This will help balance basic R&D investment over all scientific fields, particularly the physical sciences,

mathematics, and engineering that have broad applications, to avoid overinvestment in particular areas such as biomedical, at the expense of others.

Incentivize private basic R&D through R&D tax credits. Tax credits would incentivize private firms to conduct basic R&D in areas that reflect public interest, in addition to increasing innovation and spin-off commercial opportunities that increase economic growth (Atkinson & Wial, 2008, pp. 8, 11).

Employ prizes when applicable. Prizes, particularly in the multimillion-dollar range, could entice researchers that would otherwise not do business with the government due to bureaucratic red tape. In addition to bringing in fresh ideas, prize strategies increase the resources brought to bear on a problem because research teams apply their own funds in the hope of winning (Bordoff et al., 2006, p. 10).

Regulate intellectual property rights such that innovation is maximized while protecting innovator's rights. The number of patents granted increased from a rate of less than 1 percent a year from 1930 to 1982 to 5.7 percent a year from 1983 to 2002. In addition, the intellectual rigor required to receive a patent also decreased (Jaffe & Lerner, 2004, p. 25). As a result, excessive and inappropriate patents keep innovation out of the public realm (Nelson & Romer, 1996, p. 19).

Conclusions

Innovation is more important to the U.S. economy and national security now than in the past. Since World War II, the United States has been the leader in innovation; however, international competition is posing a growing challenge to U.S. technological supremacy. The United States has the best market environment in the world to support innovation, but arguably weak innovation policies. Effective government innovation policies are critical to keeping the nation at the leading edge of the scientific frontier. “What makes knowledge, innovation, and technology such powerful drivers of economic growth is that, unlike capital and labor, they do not suffer from diminishing returns”; therefore, America must rebuild its foundation of competitiveness—its supply of S&E talent and basic R&D resources—that have served the country so well for the past 50 years (Atkinson & Wial, 2008, p. 19). The challenges are real and growing, so knowledge generation and innovation must become a national priority. Sir Isaac Newton captured this continuation of

innovation best when he said, “If I have seen further, it is by standing on the shoulders of giants” (Atkinson & Wial, 2008, p. 11).

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A STATISTICAL APPROACH TO THE DEVELOPMENT OF PROGRESS PLANS UTILIZING BAYESIAN METHODS AND EXPERT JUDGMENT

 *Tiffany L. Lewis, Thomas Mazzuchi,
and Shahram Sarkani*

The development of progress plans for each identified technical performance parameter (TPP) is a critical element of technical performance measurement. The measured values of TPPs are referred to as technical performance measures (TPMs). These terms are used interchangeably; however, TPMs more directly reflect how technical progress and technical risk are measured and evaluated. Progress plans, or planned performance profiles, are crucial to effective risk assessment; however, methods for developing these plans are subjective in nature, have no statistical basis or criteria as a rule, and are not sufficiently addressed in literature. The methodology proposed herein for progress plan development will involve the elicitation of expert judgments to formulate probability distributions that reflect the expected values/estimates used to establish progress plans.

Keywords: *Technical Performance Parameter (TPP), Technical Performance Measure (TPM), Planned Performance Profile, Bayesian Methods, Technical Risk*

$$\frac{P(A)P(A|B)P}{P(B)P} = (B|A)P$$

PROGRESS PLAN DEVELOPMENT

The development of individual progress plans for each identified technical performance measure (TPM) is a critical element of technical performance measurement; however, the methods for developing these plans are subjective in nature, have no statistical basis or criteria as a rule, and are not sufficiently addressed in literature. This step is arguably considered the most critical aspect of technical performance measurement because it provides the basis for forecasting successful product development or failure; however, the absence of clearly defined processes to develop planned performance profiles is a void that exists and will be specifically addressed in this article. *Bayesian Methods* and the elicitation of expert judgments to formulate probability distributions that reflect the estimated values will be utilized to establish the performance profiles.

The Practical Software and Systems Measurement (PSM) process presented in Roedler and Jones (2005) is highly flexible and provides the foundation for the execution of Technical Performance Measurement. This process has been adopted by the International Council of Systems Engineering as an accepted practice, and tailoring this approach for a typical DoD program results in a five-phase process: identification, planning, measurement, review, and reporting. Each phase consists of multiple process steps, and the methodology discussed herein occurs during planning. Thus, the latter three phases are not addressed or discussed in this study.

Within the *identification phase*, the customer establishes technical goals and requirements, program priorities are defined, and TPMs are identified to support program goals and priorities ideally traceable to the lowest level work breakdown structure (WBS) work package elements.

The *planning phase* begins upon completion of the identification phase. During the planning phase, program goals are allocated by WBS work package with respect to budget, schedule, and the expected maturity of the technology under review. Additionally, during the planning phase, planned performance profiles and tolerance bands are developed for each TPM identified, initial risk assessments are conducted, and a technical performance baseline is developed.

Why a Statistical Approach is Needed

Establishing the technical baseline and individual progress plans for each identified TPM is a critical element of technical performance measurement and is the means by which technical progress and technical risk are measured and evaluated. This occurs during the planning phase as well as risk assessment, and these activities are consistent with proposed TPM implementation methodologies found in current literature such as Roedler and Jones (2005).

However, it is important to note that a review of current literature suggests that the processes for the implementation and execution of technical performance measurement on acquisition programs are not well defined. Coleman, Kulick, and Pisano (1996, p. 6) refer to them as being ad hoc to a significant degree due to the lack of formally established practices and processes in industry as well as in the DoD. The PSM guidebook entitled *Practical Software and Systems Measurement: A Foundation for Objective Project Management* (Bailey et al., 2000, pt. 4, p. 4-18) refers to the process for developing baseline plans as “Estimation” and states that poor estimates often lead to failed projects and result from the lack of systematic estimation processes as well as other contributing factors. Plans are developed largely through consensus by program management, developers, systems engineers, and subject matter experts who rely on knowledge from previous experience, historical data if available, and known cost and/or schedule baselines. These progress plans are crucial to effective risk assessment; however, the methods for developing them are subjective in nature, have no statistical basis or criteria as a rule, and are not sufficiently addressed in literature. This lack of formal processes to establish performance profiles predisposes them to an inherent degree of error and uncertainty, above and beyond that inherent, due to immature technical development, which translates into higher risk. Thus, employing a formal methodology utilizing an established statistical approach will minimize the level of uncertainty, thereby reducing risk exposure.

Bayesian Framework

The methodology proposed in this article utilizes an expert judgment model within a Bayesian framework for the more complex case of continuous probability distributions. The most general form of Bayes’ Theorem applies to discrete probability distributions, and relates the conditional and prior probabilities of two events using the following equation.

$$P(A|B) = \frac{P(B|A) P(A)}{P(B)} \quad (1)$$

$P(A|B)$ is considered to be the conditional probability of A given B ; $P(B|A)$ is considered to be the likelihood of B given A , $P(A)$ is the prior probability of A (i.e., no information regarding B is considered), and $P(B)$ is the prior or marginal probability of B .

The expert judgment model utilized in this study for the case of continuous distributions was originally presented by Mosleh and Apostolakis (1986) to estimate seismic fragility curves (i.e., the con-

ditional probability that a seismic stress such as wind or earthquake will cause equipment to fail)—an application that, upon evaluation, proved to have similarities regarding the use of expert opinion elicitation for planned performance profile development. In both cases, the general Bayesian framework for continuous distributions uses the opinions of experts as “evidence,” and this evidence is used as input to the decision maker’s state of knowledge using Bayes’ Theorem. Bayes’ Theorem, in its general form for continuous probability distributions, follows:

$$Pr(x | E) = k^l L(E | x) Pr_o(x) \quad (2)$$

$Pr_o(x)$ is the prior state of knowledge (prior distribution) regarding the unknown quantity x prior to obtaining opinions from the experts; E is the set of opinions provided by experts about the value of x ; $L(E | x)$ = the likelihood the evidence E is true, given the true value of the unknown quantity is x ; $Pr(x | E)$ is the decision maker’s posterior state of knowledge (posterior distribution) about the unknown quantity x given the set of opinions E provided by experts and a normalization factor k^l , which is used to make $Pr(x | E)$ a probability distribution. Within this framework, the likelihood function can be equated to the accuracy level of the expert’s estimate. Bayes’ Theorem can also be written as Equation 3 below where (α) consists of the set of (m) parameters of the cumulative (unknown) distribution $\Phi(x | \alpha)$.

$$Pr(\alpha | E) = k^l L(E | \alpha) Pr_o(\alpha) \quad (3)$$

One unique curve $\Phi(x | \alpha)$ is specified by each vector (α) . Thus, the average of the infinite number of distributions $\Phi(x | \alpha)$ is defined by Equation 4 below.

$$\Phi(x) \equiv \int_{\alpha} \Phi(x | \alpha) Pr(\alpha | E) d\alpha \quad (4)$$

Assumptions

The following assumptions apply to the application of the Mosleh and Apostolakis (1986) model to the estimation of seismic fragility curves and also apply to estimation of progress plan values depicted in this illustration.

No. 1.

The unknown distribution being estimated belongs to a parametric family of distributions. This assumption simplifies the construction of the likelihood functions. As a result, the challenge

of estimating the unknown distribution is reduced to the estimation of its parameters.

No. 2.

The unknown (posterior) distribution is assumed to be lognormal with parameters (θ) and (ω). These two parameters are allowed to vary and describe the variability of the distribution. By definition, the minimum possible value for a lognormal distribution is zero, the maximum possible value is $+\infty$, and the parameter values (mean and standard deviation) must be greater than zero. These criteria also apply to the TPM estimates used to establish a planned performance profile. Therefore, the lognormal distribution was deemed the most applicable distribution to use given the information available.

No. 3.

Experts are independent and will be providing independently assessed percentiles. This assumption is intended to simplify the complexity of the model's application to this problem. A model for the case of dependent experts is presented by Mosleh and Apostolakis (1986); however, it will not be explored here.

No. 4.

Standard deviations assigned to each expert reflect the decision maker's level of confidence in the expert's ability to accurately estimate each percentile. If available, historical data reflecting the planned versus actual values of prior predictions should be used to determine the "bias" or "percent error" to associate with each expert's accuracy and standard deviation.

No. 5.

The percentiles being estimated are assumed to be symmetric. Symmetric percentiles (10 percent, 50 percent, and 90 percent) have been assumed for the model presented by Mosleh and Apostolakis (1986). Values for these percentiles are estimated by each expert.

No. 6.

The standard deviations of the percentiles estimated by each expert are independent of the percentiles themselves. In other words, each expert is assumed to have the same level of accuracy estimating each percentile regardless of the percentile itself. Therefore, the standard deviations assigned to each expert for each percentile estimated would be the same. However, there is evidence to support that experts are more likely to be less accurate at higher percentiles, thus reflecting a greater level of uncertainty at these levels (George & Mensing, 1981).

Statistical Approach

The methodology proposed is presented to convey the feasibility of using an expert judgment model developed to estimate seismic fragility curves to develop retrospective progress plans. The development of progress plans is considered to be a key and critical process element of technical performance measurement.

The Cockpit-21 TPM project described in the unpublished white paper by Coleman et al. (1996) presents a suitable example and adequate data and information to convey how the Mosleh and Apostolakis (1986) methodology could have been employed to develop the planned performance profiles for each TPM identified. The example utilizes the model to formulate individual estimates for unknown distributions (as opposed to single values) based on estimates for multiple percentiles provided by experts. The estimated distributions reflect values of specific TPMs for different points in time that have been defined to coincide with key milestone dates. The following process steps are proposed for the development of progress plans and are based on the seismic fragility curve model.

Step 1. Identify TPMs.

Step 2. Define dates and milestones for the progress plans of each parameter.

Step 3. Identify experts that will participate in the estimation process.

Step 4. Assign weights to the experts identified.

Step 5. Assign standard deviations to the experts identified for each percentile estimated. Determine standard deviations for experts with unique weights.

Step 6. Experts estimate a TPM value for each established percentile (10 percent, 50 percent, and 90 percent) for each milestone date.

Step 7. Evaluate the standard deviation (σ) of the lognormal parameters (θ) and (ω).

Step 8. Evaluate the value of the lognormal parameters (θ) and (ω).

Step 9. Evaluate the distribution curve for each estimate using Bayes' Theorem.

Step 10. Define tolerance bands for established performance profiles.

Step 11. Plot the mean values for each curve against its respective milestone date to establish the progress plan.

TABLE 1. COCKPIT-21 TECHNICAL PARAMETERS AND WEIGHTS

Display Electronics Unit (DEU) Parameters (50%)					
Level 1 Parameter	wt.	Level 2 Parameter	wt.		
1. Head-Up Display (HUD) Module Status	20%	1.1 HUD Design and Code Status	30%		
		1.2 HUD Full Qualification Test (FQT) Status	70%		
2. Manpower	20%				
3. Multifunction Display (MFD) Module Status	20%	3.1 MFD Design and Code Status	30%		
		3.2 MFD FQT Status	70%		
4. Requirements Volatility	20%				
5. Software Problem Reports	20%	5.1 Software Problem Reports Closed	50%		
		5.2 Software Problem Reports Open	50%		
Flight Test Problem Reporting Parameters (50%)					
Level 1 Parameter	wt.				
6. Reports Closed	50%				
7. Reports Open	50%				

Identify Technical Performance Measures

Once goals and requirements have been set, TPMs are identified to support the program goals and priorities. The TPMs identified are assumed to have some notable impact to program costs, critical path, or technical risk. Two technical areas representing 50 percent each of the technical performance baseline were identified for the Cockpit-21 project. These areas were the Display Electronics Unit (DEU) software and Flight Test Problem Reporting. Table 1 displays the technical parameters and sub-parameters identified for DEU and for Flight Test Problem Reporting. Additionally, the weight of each parameter at each level is shown.

Define Dates and Milestones for the Progress Plans

The TPM milestone assessment dates for the Cockpit-21 program ranged from June 1992 through January of 1995, and the date range for each parameter varied with respect to its scheduled develop-

TABLE 2. COCKPIT-21 PROGRESS PLAN EVALUATION DATES

Display Electronics Unit (DEU) Parameters	Start Date	Finish Date	# of Estimates
1.1 HUD Design and Code Status	June '93	Feb '94	9
1.2 HUD Full Qualification Test (FQT) Status	June '93	Feb '94	9
2. Manpower	June '92	Feb '94	21
3.1 MFD Design and Code Status	June '93	Feb '94	9
3.2 MFD Full Qualification Test (FQT) Status	June '93	Feb '94	9
4. Requirements Volatility	Nov '92	Feb '94	16
5.1 Software Problem Reports Closed	Nov '92	Feb '94	16
5.2 Software Problem Reports Open	Oct '92	Feb '94	17
Flight Test Problem Reporting Parameters	Start Date	Finish Date	# of Estimates
6. Reports Closed	Mar '94	Jan '95	11
7. Reports Open	Mar '94	Jan '95	11

ment within the project's life cycle. Assessments were scheduled at monthly intervals for each parameter; however, Roedler and Jones (2005) indicate that it is advisable to utilize significant milestones and/or design events to establish performance profile measurement dates. Coleman et al. (1996) also states that dates should be based on events during the development cycle as opposed to a periodic scheme. Therefore, this would be the preferred method for establishing evaluation dates for TPM values when implementing technical performance measurement on future projects. The range of dates and number of estimates associated with each progress plan developed for the Cockpit-21 program are depicted in Table 2. Since TPMs are tracked at the lowest level, it is only necessary to develop performance profiles for the lowest level parameter. Thus, for the purpose of this application, progress plans are not developed for level 2 parameters that have level 3 subparameters; those level 2 parameters are not depicted in Table 2.

Identify Experts

The experts involved in the TPM planning process on a DoD program will most often be the members of the integrated product teams (IPTs) established to test, monitor, and evaluate technical progress. IPTs will primarily consist of contractors/developers. However, government representatives may work with contractors to share responsibilities pertaining to the planning process. Members of each IPT are selected based on their knowledge and experience

regarding previous development efforts with the same or similar technology and may be systems engineers, test engineers, researchers, or analysts. For the purpose of this study, the IPT members are considered to be the experts, and the IPT leads are considered to be more knowledgeable than the other members of the team.

The question of how many experts are optimal was addressed by K. Walker (personal communication, November 11, 2004). She concluded there has been no evidence of an existing argument for an ideally statistically based sample size. Her literature review of 38 studies revealed 90 percent used 11 or less experts, and referenced Steve Hora, who has been repeatedly quoted for his argument of “three and seldom more than six” is sufficient (Hora, 2004, p. 5; K. Walker, personal communication, November 11, 2004). The example presented in this study assumes four experts are participating in the progress plan development process as members of an IPT.

Assign Weights to the Experts

Weights are assigned by the decision maker to each expert providing an estimate as a means to place more or less value on the responses of experts that are assumed to have greater or lesser accuracy with respect to their estimation ability. The more confidence a decision maker has in a particular expert’s ability, the more weight the expert’s estimate should carry with respect to other experts. The weights of all experts should be normalized so that they sum to one. If available, this step is where it would be appropriate to review historical data from previous projects to evaluate the estimation accuracy of experts conducting the estimates to determine the appropriate weighting scheme. Additionally, the experience level of each expert (or IPT member) and their level of knowledge regarding the technical area being evaluated should be considered when assigning weights. The assessment by the decision maker in this example assumes each expert is equally weighted with the exception of the IPT lead. The lead is given more weight to compensate for additional knowledge and experience in the technical area of interest.

Assign Standard Deviations to the Experts

Standard deviations are assigned by the decision maker to each percentile estimated by each expert. Each standard deviation reflects the perceived range of deviation from the true value being estimated at that percentile. The approach to assigning standard deviations is similar to that of assigning weights in that historical data from previous projects should be reviewed, if available, to

evaluate the true estimation accuracy or percentage error realized by experts with prior predictions. This should ensure the proper calibration of the experts and allow the decision maker to account for overconfidence of the experts as discussed by Hora (2004), and errors of estimation as discussed by Winkler (1981). In the case of the Cockpit-21 project, data from previous TPM pilot implementation projects discussed by Coleman et al. (1996), such as the Air Deployable Active Receiver (ADAR) sonobuoy development program and the LAMPS Block-II Upgrade program, would serve as appropriate reference materials for this effort. The model presented in this study assumes the standard deviations of all experts are equal with the exception of the IPT lead, who has a greater weight than the remaining team members (i.e., $\sigma_{JK} = \sigma_K$) where (J) equals the J th percentile and (K) equals the K th expert. To calculate the standard deviation of the IPT lead, Equation 5a must be used where N = the total number of experts, σ_K = the standard deviation of expert (K), and w = the weight of expert (K).

$$\sum_{K=1}^N \sigma_K^{-2} = \frac{\sigma_I^{-2}}{w_I} \quad (5a)$$

This will result in the standard deviation of the IPT lead being less than the remaining IPT members due to the lead being assigned a heavier weight.

Estimate TPM Values by Percentile

The methodology proposed here requires TPM values to be estimated by each expert for each established percentile (10 percent, 50 percent, and 90 percent) by milestone date. Meaning, each expert must predict the true value that has a 10 percent likelihood of being observed, a 50 percent likelihood of being observed, and a 90 percent likelihood of being observed for the given evaluation date. Experts formulate estimates based on the information they have available to them at the time, and this information may include historical and/or current test data, the results of formal functional analysis, and expert opinion based on knowledge and experience.

Table 3 depicts the proposed estimations for the first milestone date of the first technical parameter shown in Table 2 (Display 1.1, HUD Design and Code Status), the basis for the response provided, as well as the assigned weight and standard deviation for each expert. Equation 5a was used to estimate (σ_4) as follows:

$$\sum_{k=1}^4 \sigma_k^{-2} = \frac{\sigma_k^{-2}}{w_i} = \frac{(.10)^{-2}}{.24} = 416.7 \tag{5b}$$

$$\sigma_4 = \left(w_4 \sum_{k=1}^4 \sigma_k^{-2} \right)^{1/2} = \left(.28 (416.7) \right)^{1/2} = .093$$

TABLE 3. HUD DESIGN AND CODE STATUS EXPERT OPINION DATA

HUD Design and Code Status - June 1993						
Expert	wt.	Expert std. dev. (σ_K)	Percentiles			Basis for Response
			10%	50%	90%	
1	.24	0.100	22.0	23.0	26.0	test data, analytical methods
2	.24	0.100	21.5	22.8	24.0	test data, analytical methods, expert opinion
3	.24	0.100	22.0	23.5	24.5	test data, analytical methods
4	.28	0.093	21.5	24.0	25.0	test data, analytical methods, expert opinion

Using the values in Table 2, it is evident that each expert must provide 27 unique estimates (9 estimates x 3 percentiles) to establish a progress plan for this parameter; and a total of 12 estimates (3 percentiles x 4 experts) will be used in the expert judgment model to establish the unknown distribution for each individual estimate. To complete the expert judgment analysis for all parameters and all evaluation dates, this process would be completed for each parameter shown in Table 2, resulting in each expert providing 378 unique estimates (126 estimate dates x 3 percentiles per date).

Evaluate the Standard Deviation of the TPM Values

The unknown distribution associated with each estimate is assumed to be lognormal with parameters (σ) and (ω). The Mosleh and Apostolakis (1986) model uses Equations 6 and 7 to evaluate the values of the standard deviations for (θ) and (ω). The standard deviation for (θ) is denoted by Equation 6.

$$\sigma_{\Theta}^2 = \left[3 \sum_{K=1}^N \sigma_K^{-2} \right]^{-1} \tag{6}$$

σ_{Θ} reflects the standard deviation for (Θ) . The standard deviation for (ω) is denoted by Equation 7, where σ_{ω} reflects the standard deviation of (ω) and $Z_{90} = 1.285$ from tables of the standard normal distribution.

$$\sigma_{\omega}^2 = \left[2Z_{90}^2 \sum_{K=1}^N \sigma_K^{-2} \right]^{-1} \tag{7}$$

Evaluate the Value of the Lognormal Parameters

The unknown distribution associated with each estimate is assumed to be lognormal with parameters (Θ) and (ω) . The Mosleh and Apostolakis (1986) model uses Equations 8 and 9 to evaluate the values of the parameters (Θ) and (ω) . The parameter value for (Θ) is denoted by Equation 8.

$$\Theta_m = \frac{1}{3} \sum_{K=1}^N W_K (\ln x_{10K} + \ln x_{50K} + \ln x_{90K}) \tag{8}$$

The parameter value for (ω) is denoted by Equation 9.

$$\omega_m = \frac{1}{2Z_{90}} \sum_{K=1}^N W_K (\ln x_{90K} - \ln x_{10K}) \tag{9}$$

Evaluate Each Unknown Distribution Using Bayes' Theorem

Now that weights and standard deviations have been assigned to the experts, values have been estimated for each percentile by the experts, the standard deviations of the parameter values have been evaluated, and the parameter values themselves have been evaluated, all requisite information is available to evaluate the value of the unknown (posterior) distribution for the parameter depicted in Table 3. Using the Mosleh and Apostolakis model for Bayes' Theorem, the posterior distribution can be evaluated using Equation 10.

$$Pr(\Theta, \omega | E) = k^{-1} \exp \left\{ -\frac{1}{2} \left[\left(\frac{\omega - \omega_m}{\sigma_\omega} \right)^2 + \left(\frac{\Theta - \Theta_m}{\sigma_\Theta} \right)^2 \right] \right\} \quad (10)$$

Upon evaluation of Equation 10 for the parameter depicted in Table 3, and assuming the same experts are providing all estimates, steps 7 through 9 are repeated for the remaining parameters identified in Table 2 to complete the expert judgment analysis.

Define Tolerance Bands for Performance Profiles

Following completion of the expert judgment analysis, the next step is to define tolerance bands. Tolerance bands reflect the allowable range of variation and level of acceptable risk for a defined TPM estimate on a given milestone date. They alert management that actions may be necessary to get the TPM back on track. Actual values that exceed the allowable range (e.g., 20 percent) for any TPM estimate denote high risk (red) and will trigger management intervention. Additionally, allowable ranges are defined for low-risk items (green), and medium-risk items (yellow) as well. Typically, the bands depicted on a performance profile represent the maximum allowable variation.

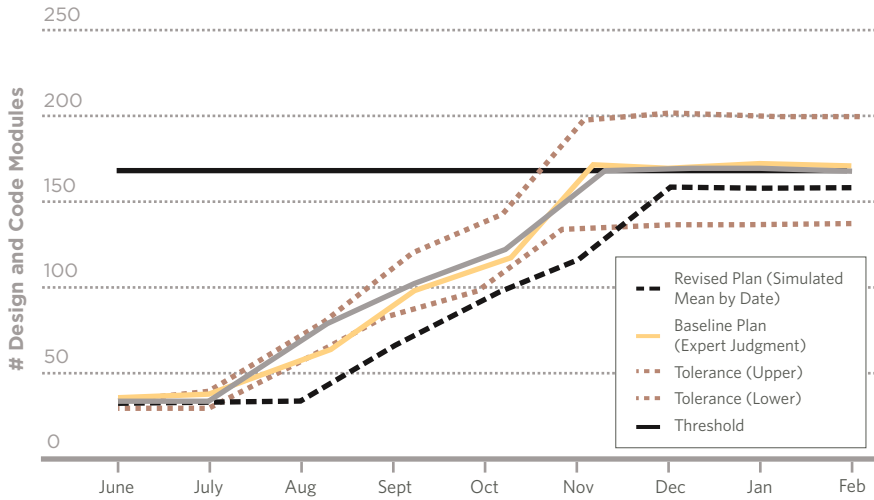
Plot the Expected Values for Each Curve

If the expected values defined in the Cockpit-21 white paper are assumed to be the mean expected values determined using the expert judgment methodology, these values, along with the tolerance bands and the threshold values, would establish the performance baseline for each performance measure when plotted against their respective milestone dates. The Figure depicts the expected values used to define the individual progress plan for HUD Design and Code and the corresponding dates for each estimate. Actual values, a revised plan, and the threshold value are also plotted in the example shown for comparison with the baseline expected values.

Discussion

This article describes how expert judgment can be utilized within a Bayesian framework to develop a formal statistical model to quantify expert opinions as probability distributions for the purpose of establishing TPM progress plans. To demonstrate these attributes, key assumptions were made, and actual TPM data were

FIGURE. HUD DESIGN AND CODE PROGRESS PLAN EXAMPLE



used to illustrate the application of the methodology. Baseline progress plans are crucial to effective risk assessment; however, the methods for developing these plans for each parameter are subjective in nature, have no statistical basis or criteria as a rule, and are not sufficiently addressed in literature. This lack of formal processes to establish performance profiles predisposes them to an inherent degree of error and uncertainty (i.e., risk). The formal methodology presented in this article offers an alternative that will arguably produce more accurate progress plans and will minimize the level of uncertainty, thereby resulting in reduced risk exposure. This proposed methodology provides program management with another decision-making tool that can be used to strengthen established systems engineering processes.

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$$\frac{P(A|B) = P(B|A)P(A)}{P(B)}$$

ANALYSIS OF GENERATION Y WORKFORCE MOTIVATION USING MULTIATTRIBUTE UTILITY THEORY

 *Ian N. Barford and Patrick T. Hester*

This article explores the difference in assigned levels of workplace motivation and happiness between federal government workforce members of Generation Y versus Generation X and Baby Boomers. Thirty hypotheses were tested, and 11 were found to be statistically significant. Generation Y does assign different levels of importance and partially assigns different levels of happiness to the five motivational factors examined in this study: responsibilities, compensation, work environment, advancement potential, and free time. Advancement potential and free time were rated the highest factors when compared to Generation X and Baby Boomers. Sample size was small due to limited availability of workforce members. This study represents the first attempt to explore motivational factors for the Generation Y workforce within the federal government.

Keywords: *Baby Boomers, Generation X, Generation Y, Motivational Factors, Utility Measurement*



Introduction

Researchers, supervisors, and human resource professionals have long struggled with perfecting management strategies for employees. The three most prevalent working generations currently are Baby Boomers, Generation X, and Generation Y. To understand Generation Y's employment motivations and attitudes, two ideas must be discussed: (a) a working definition of generation, and (b) an understanding of preceding generations' motivations and attitudes.

Several prevalent definitions of "generation" exist. Kupperschmidt (2000) defines a generation as an identifiable group, or cohort, which shares birth years, age, location, and significant life events at critical developmental stages. Palese, Pantali, and Saiani (2006) categorize generations as those born within the same historical timeframe and culture. Crumpacker and Crumpacker (2007) add that birth rate, along with historical events, defines each generation. These groups develop a unique pattern of behavior based on these common experiences (Kupperschmidt, 2000).

Further exploration of literature shows that two common elements distinguish a generation: the birth rate and significant life events (Crumpacker & Crumpacker, 2007; Kupperschmidt, 2000; Smola & Sutton, 2002; Cennamo & Gardner, 2008; Sayers, 2007). When the birth rate increases and remains steady, that signifies the beginning of a new generation. When the birth rate of a newly formed generation begins to decline, that marks the end of a generation (Crumpacker & Crumpacker, 2007). Each generation has its own set of significant life events. Each generation shares the same experiences, or is aware of them, as they advance and mature through different stages of life—although not every person in a generation personally experiences these defining events (Crumpacker & Crumpacker, 2007). Caution is given to stereotyping individuals based on generational values and characteristics (Weingarten, 2009).

The eldest of the current working generations, referred to as the Baby Boomers, were born between the years 1946 and 1964 (Egri & Ralston, 2004; Smola & Sutton, 2002; Westerman & Yamamura, 2007; Dries, Pepermans, & DeKerpel, 2008; Crumpacker & Crumpacker, 2007; Hubbard & Singh, 2009). Baby Boomers experienced significant life events that shaped their values, including the social revolution of the 1960s, the women's movement, President John F. Kennedy/Martin Luther King Jr./Senator Robert F. Kennedy assassinations, U.S. landing on the moon, the substantial role of television within society, the Vietnam War, the Watergate scandal, and high inflation of the 1980s (Dries et al., 2008; Crumpacker & Crumpacker, 2007; Weingarten, 2009).

Baby Boomers are classified with such values and attributes as team orientation, optimism (Hess & Jepsen, 2009), and expecting the best from life (Smola & Sutton, 2002). Prior to the 1980s, this generation knew of prosperity and fortunate outcomes (Kupper-schmidt, 2000) being the center of their parents' world (Crumpacker & Crumpacker, 2007), similar to the prosperity that Generation Y has been accustomed to (Shih & Allen, 2007). During the recession in the 1980s, businesses downsized and reorganized, which conveyed to the Baby Boomers that a lifetime career with one organization might not be a certainty (Mirvis & Hall, 1994). Because of this, Baby Boomers were characterized as free agents in the workplace (Kupper-schmidt, 2000), described by Crumpacker and Crumpacker (2007) as highly competitive micromanagers, irritated by lazy employees, with a positive demeanor towards professional growth.

The middle cohort of current working generations, referred to as Generation X, was born between the years 1965 and 1979 (Egri & Ralston, 2004; Smola & Sutton, 2002; Crumpacker & Crumpacker, 2007), and it has the least amount of people of the three generations under review. For this generation, the life events that had a profound impact were the Iranian hostage crisis, Iran Contra scandal, introduction of HIV/AIDS as a pandemic, oral contraceptive pills, the 1973 oil crisis, the impeachment of President Richard M. Nixon, introduction of computers and the Internet, and the Cold War (Dries et al., 2008; Crumpacker & Crumpacker, 2007; Weingarten, 2009). As Generation X matured, so did technology (Cennamo & Gardner, 2008).

This generation grew up with both parents in the workforce, or in a divorced household, and as a result, many were latchkey kids, becoming independent at a young age (Crumpacker & Crumpacker, 2007; Weingarten, 2009). Smola and Sutton (2002) describe this generation as experiencing social insecurity, rapidly changing surroundings, and a lack of solid traditions. Generation X carried the trend of distancing themselves from companies just as the Baby Boomers did (Dries et al., 2008), making them distrustful of organizations (Westerman & Yamamura, 2007). Generation X entered the workforce competing with the Baby Boomers for jobs during the 1980s' recession, which made many of these individuals cynical towards the older generation (Crumpacker & Crumpacker, 2007).

The newest generation to enter the workforce was born between the years 1980 and 2000 (Weingarten, 2009; Cennamo & Gardner, 2008; Sayers, 2007). Although authors differ as to when Generation Y either begins or ends (Smola & Sutton, 2002; Kupper-schmidt, 2000; Hess & Jepsen, 2009; Westerman & Yamamura, 2006; Crumpacker & Crumpacker, 2007; Broadbridge, Maxwell, & Ogden, 2007; Sayers, 2007), prevalent literature agrees on Generation Y begin-

ning in 1980 (Smola & Sutton, 2002; Weingarten, 2009; Crumpacker & Crumpacker, 2007; Essinger, 2006) and ending in 2000 (Clark, 2007). Other terms associated with Generation Y are “Millennials” (Howe & Strauss, 2000), “Net Generation” (Shaw & Fairhurst, 2008), and “Generation Next” (Loughlin & Barling, 2001; Zemke, Raines, & Filipczak, 2000; Martin, 2005).

The momentous events that Generation Y experienced were the fall of the Berlin Wall, the induction of music television (MTV) into society, Columbine High School shootings, 9/11 terrorist attacks, more frequent natural disasters, and the obesity epidemic (Dries et al., 2008; Crumpacker & Crumpacker, 2007). Sujansky (2002) writes that this generation has seen more substantial life-changing events early on than preceding cohorts. Possibly the most significant difference this generation possesses over others is the integration of technology into their daily lives and the omnipresence of how technology has always been in their world (Oblinger, 2003; Martin, 2005; Weingarten, 2009). Martin (2005) describes Millennials as independent, confident, and self-reliant. This may be due to the extensive protection and praise given to them throughout their formative years (Crumpacker & Crumpacker, 2007).

In business, Generation Y exhibits the propensity for working in teams while being collaborative, results-oriented individuals, and having an ardor for pressure (Shih & Allen, 2007). Unfortunately, Generation Y followed their two previous generations and have partitioned themselves away from organizations (Dries et al., 2008), knowing that lifetime employment at an organization is very unlikely. Generation Y expects to change jobs often during their lifetime (Morton, 2002; Kim, Knight, & Cruisinger, 2009), especially if their talents are underutilized (Kim et al., 2009; Weingarten, 2009). Millennials want lifelong learning (Alch, 2000), expect on-the-job training (Morton, 2002) to stay marketable (Sayers, 2007; Holden & Harte, 2004; King, 2003), and proactively plan their own careers and professional development (Westerman and Yamamura, 2007; Kim et al., 2009; Zemke et al., 2000).

Generation Y aspires for a work/life balance (Crumpacker & Crumpacker, 2007; Zemke et al., 2000) to achieve professional satisfaction and personal freedom (Sayers, 2007). Generation Y is almost automatic at multitasking with technology as if it's an extension of their being (Freifield, 2007; Kofman & Eckler, 2005; Rowh, 2007; Loughlin and Barling, 2001), and may change a job task considerably to create a more appealing outcome (Wrzesniewski & Dutton, 2001). They need clear directions and management assistance for tasks, while expecting freedom to get the job done (Martin, 2005) via empowerment (Morton, 2002). However, this cohort despises micromanagement, becomes irritated with laziness,

and abhors slowness (Weingarten, 2009). To some, Generation Y's work values and attributes paint a picture of being high maintenance (Hira, 2007). Twenge, Zhang, and Im (2004) describe Generation Y as having a "high external locus of control," which further exemplifies their confidence inside and outside of the workplace. However, Crumpacker and Crumpacker (2007) note the need for constant approval and highlight Generation Y's emotionally needy personality.

A heightened government retirement of the Baby Boomers is almost certain in the next several years, which will leave employment gaps that Generation X and Y must fill. Barr (2007, p. D01) reports approximately 60 percent of the 1.8 million government employees will be eligible to retire over the next 9 years. The Office of Personnel Management expects many of the Baby Boomers (about 40 percent) to retire from the government. Retention of the newly hired Generation Y workforce is critical to the preservation and existence of the civilian government workforce.

In the analysis discussed in this article, 18 government workers, comprising six each of Generation X, Generation Y, and the Baby Boomers Generation, were surveyed regarding five motivational factors according to importance and level of happiness. The survey was designed to provide insight on the overall average job satisfaction of each respondent (how happy each respondent is with their job compared to the average of all respondents); the overall average job satisfaction of each generation (how happy each generation is with their jobs compared to the average of all generations); normalized average importance for each generation (how each generation values the five motivational factors converted to a single scale); average level of happiness for each generation (how each generation is satisfied with their current jobs based on the five motivational factors); the overall average utility (how all generations combined express value and satisfaction for each of the five motivational factors); and average attribute utility for each generation (how each generation expresses value and satisfaction for each of the five motivational factors). The research questions that this study seeks to answer follow.

Research Questions

Using the previous research on generational life events coupled with work values and attitudes, the following research questions were generated for analysis in this study:

No. 1. Does Generation Y assign different levels of importance to the five motivational factors than Generation X and Baby Boomers?

No. 2. Does Generation Y assign different levels of happiness to the five motivational factors than Generation X and Baby Boomers; and which of these factors is ranked the highest across generations?

No. 3. Does Generation Y's average attribute utility of the five motivational factors differ from Generation X and Baby Boomers?

Method

Participants. Government workers, six in each of the three age groups categorized by Generation Y (born between 1980 and 2000), Generation X (born between 1965 and 1979), and Baby Boomers (born between 1946 and 1964), who work at Naval Sea Systems Command, Virginia Beach Detachment, were selected at random by the detachment security manager. All 18 respondents were given an unsealed envelope that included a cover letter and an identical three-page survey. All participants were asked to voluntarily complete the anonymous survey and return the envelope sealed to ensure confidentiality. Twelve respondents were male (67 percent), and six were female (33 percent).

The mean age of the survey respondents was 36.56 (standard deviation = 11.08). Deeper examination into respondent demographics shows 13 people (72 percent) had completed either a bachelor's or master's degree.

Materials and Procedure. The motivational factor survey was arranged with six demographic questions, one motivational factors' ranking question, and one level of happiness question for a total of eight questions. The demographic set (questions 1–6) consisted of: age, gender, job classification (either management or nonmanagement), occupational category (government-designated categories based on the type of job a person has), highest education completed, and pay plan.

The motivational factors ranking (question 7) presented the five motivational factors and asked the respondent to rank them according to importance. Each factor was given a bounded definition unique to working within a government context. Factor 1 (responsibilities) was defined as the value given to all responsibilities inside the office and while on government travel. Factor 2 (compensation) was defined as the value of the total government compensation package, which includes salary, pension, retirement plan, annual bonuses, cost of living increases, etc. Factor 3 (work environment) was defined as the value given to the job location, people working in the location, and physical work environment. Factor 4 (advancement potential) was defined as the value given to a career path clearly defined for advancement. Factor 5 (free time) was defined

as the value given to the amount of free time away from work. Free time is allocated by the following means: compressed work schedule, accrued sick days, accrued annual days off, and the number of holidays given.

The level of happiness (question 8) consisted of each respondent ranking the level of happiness in their current position using each of the five motivational factors.

Motivational Factor Rankings. Motivational factor rankings were determined by each respondent in their survey. Each respondent was given a maximum of 100 points to distribute among each of the five motivational factors. The more points the participant gave to a particular factor, the more they valued that factor.

Level of Happiness Rankings. Level of happiness rankings were determined by each respondent in their survey. Each respondent was asked to rank the five motivational factors based on their current position. The format chosen was a 10-point Likert scale (1 = being extremely dissatisfied and 10 = being extremely satisfied).

Procedure. The detachment's security manager handed each respondent an open envelope, with a cover letter and an identical survey. Participants were notified in writing that their completion of the survey indicated their consent to participate in this study. Respondents were told if they had any questions regarding the survey to direct them to the security manager. The surveys were not traceable to the survey respondent, and the deadline to finish was 1 week. Once completed, the surveys were to be placed back in the envelope, sealed, and returned to the detachment security manager. The security manager collected all 18 surveys, and they were returned to the primary author.

Results

Analysis focused on respondents' values for importance and level of happiness for each of the five motivational factors. For initial data reduction and ease of calculation, respondents' ages were grouped together by their generation, as defined earlier in this article. The motivational factors (MF) were then normalized as shown in Equation 1 to ensure that each factor could be evaluated on a 100-point scale and compared with one another:

$$MF = 100 \left(\frac{x - OBJ_{\min}}{OBJ_{\max} - OBJ_{\min}} \right) \quad (1)$$

OBJ_{min} is the minimum respondent value (5), OBJ_{max} is the maximum respondent value (50), and x is the individual respondent's value.

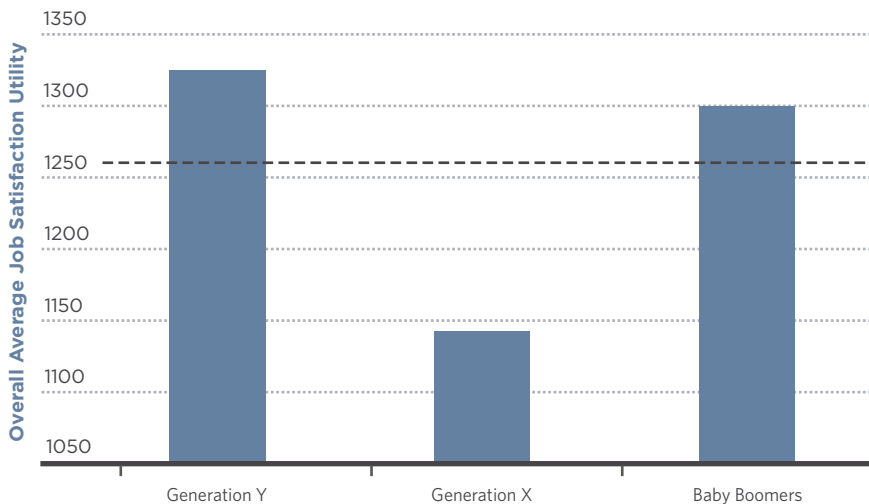
Overall utility, denoted as average job satisfaction (AJS), was then calculated using a traditional weighted sum approach, whereby each MF is multiplied by its relative importance (level of happiness [LOH]), as shown in Equation 2.

$$AJS = \sum_{k=1}^5 MF_k LOH_k \tag{2}$$

The next step was to analyze each generation separately and average their respective job satisfaction. Figure 1 depicts the overall average job satisfaction utility for each age group. These averages were also used in computing the overall job satisfaction utility for the entire group of respondents (average = 1256.17, denoted by the black dashed line shown in Figure 1). The job satisfaction level was compared to the average job satisfaction utility for the entire group.

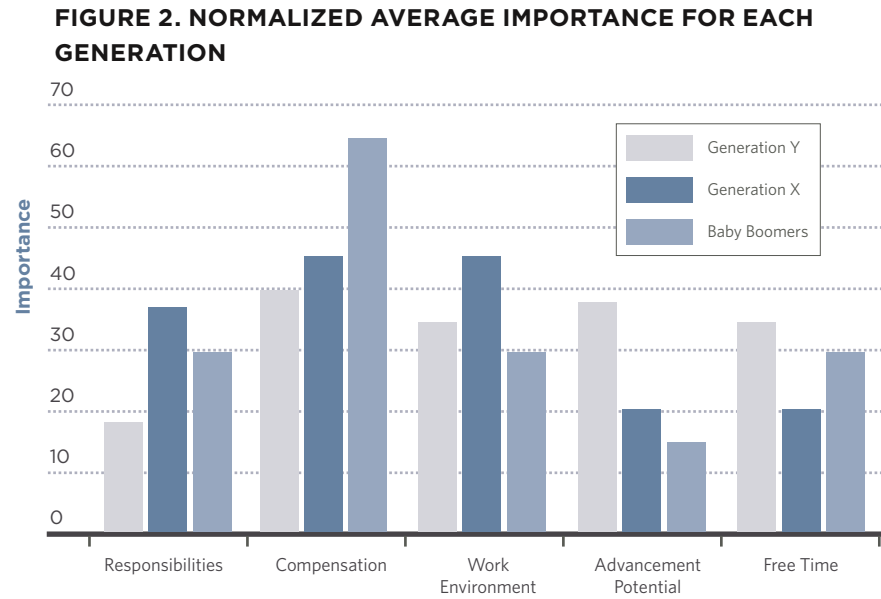
The results of Figure 1 show Generation Y and Baby Boomers are well above the average job satisfaction of all respondents. Conversely, it shows Generation X is well below the average job satisfaction of all respondents. Possibly, the Baby Boomers felt more comfortable with being honest and Generation Y shaded their opinions somewhat.

FIGURE 1. OVERALL AVERAGE JOB SATISFACTION UTILITY FOR EACH AGE GROUP



Question No. 1. Does Generation Y assign different levels of importance to the five motivational factors than Generation X and Baby Boomers?

To determine whether Generation Y assigns different levels of importance, the data were analyzed using a two-tailed hypothesis test at a 0.10 significance level. Generation Y results were compared to Generation X, and then Baby Boomers for a total of 10 tests. Of those 10, five were statistically significant and therefore reported. Figure 2 shows the normalized average importance for each generation.



Generation Y views responsibilities as much less important than Generation X and Baby Boomers and least important of all the motivational factors. These results are statistically significant.

Generation Y ranked compensation as less important than Generation X and Baby Boomers. This was expected, but only the comparison between Generation Y and Baby Boomers is statistically significant.

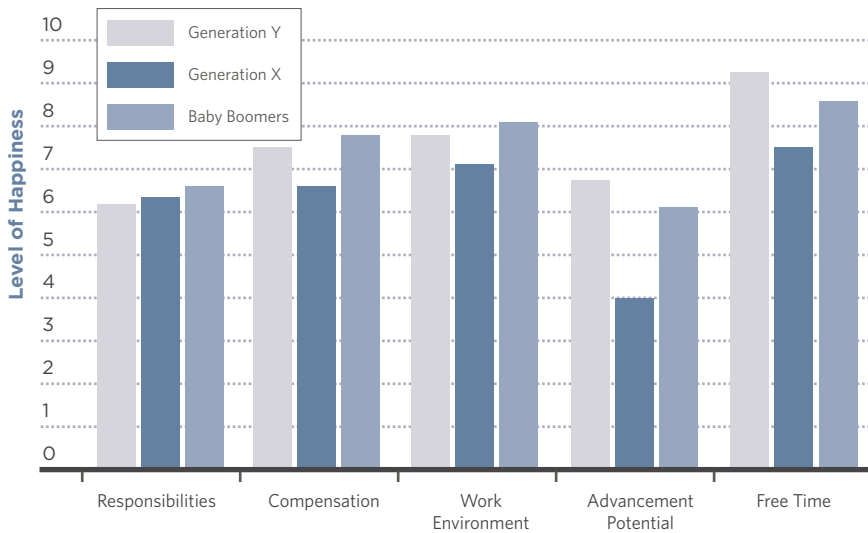
Generation Y ranked advancement potential higher than Generation X and Baby Boomers. Again, the results between Generation Y and Baby Boomers are statistically significant.

Generation Y ranked free time higher than Generation X and Baby Boomers. This time the results between Generation Y and X are statistically significant.

Question No. 2. Does Generation Y assign different levels of happiness to the five motivational factors than Generation X and Baby Boomers, and which of these factors is ranked the highest across generations?

The data were analyzed using a two-tailed hypothesis test at a 0.10 significance level. Generation Y results were compared to Generation X, and then Baby Boomers for a total of 10 tests. Of those 10, two were statistically significant and therefore reported. Figure 3 shows the average level of happiness for each generation.

FIGURE 3. AVERAGE LEVEL OF HAPPINESS FOR EACH GENERATION



Generation Y is satisfied with their current advancement potential in the government more than Generation X and Baby Boomers. However, only the results between Generation Y and X are statistically significant. These results show that Generation Y is very satisfied with their current advancement potential within the Federal Government.

Generation Y is currently satisfied with their current free time more than Generation X and Baby Boomers. Again, the results between Generation Y and X are only statistically significant. These results show that Generation Y is very satisfied with their current free time within the Federal Government.

Results of all three generations' motivational factors were averaged from the average attribute utility for each generation and plotted in Figure 4. Compensation was the highest, with advancement potential being the lowest motivational factor.

FIGURE 4. AVERAGE MOTIVATIONAL FACTORS

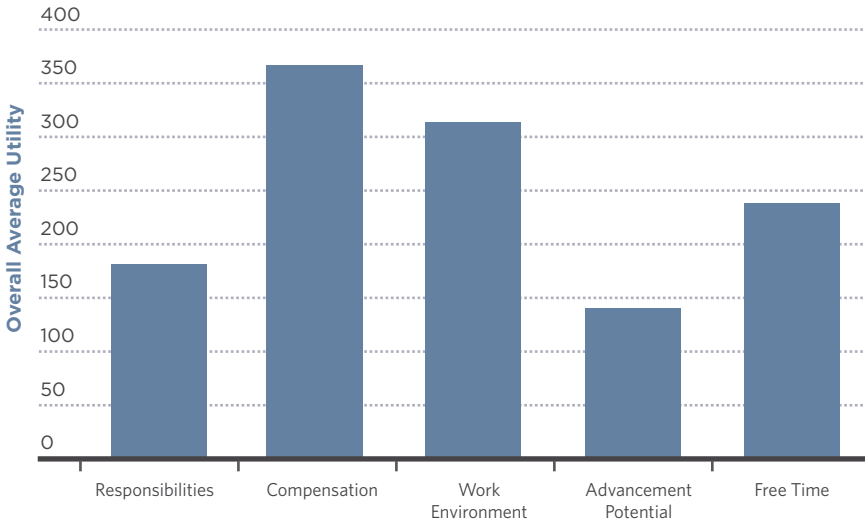
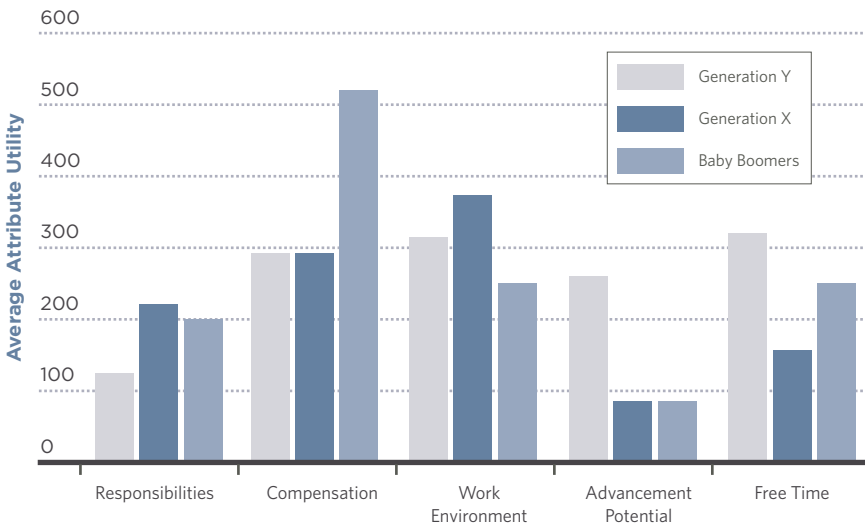


FIGURE 5. AVERAGE ATTRIBUTE UTILITY FOR EACH GENERATION



Question No. 3. Does Generation Y’s average attribute utility of the five motivational factors differ from Generation X and Baby Boomers?

The data were analyzed using a two-tailed hypothesis test at a 0.10 significance level. Generation Y results were compared to Generation X, then Baby Boomers for a total of 10 tests. Of those 10, four were statistically significant and therefore only reported.

Figure 5 shows the overall average job satisfaction utility based on each attribute for each generation.

Generation Y's average attribute utility for compensation was less than Baby Boomers, which was statistically significant, but slightly more than Generation X, which was not significant.

Generation Y's average attribute utility for advancement potential was much higher than both Generation X and Baby Boomers. Both results were statistically significant.

Generation Y's average attribute utility for free time was also higher for Generation X and Baby Boomers, although the comparison to Generation X was only statistically significant.

Discussion

This analysis aimed to investigate if Generation Y assigns differing levels of workplace motivation and happiness than Generation X and Baby Boomers in a federal government context. Three research questions were developed based on the literature review: (1) Does Generation Y assign different levels of importance to the five motivational factors than Generation X and Baby Boomers? (2) Does Generation Y assign different levels of happiness to the five motivational factors than Generation X and Baby Boomers? and (3) Does Generation Y's average attribute utility of the five motivational factors differ from Generation X and Baby Boomers?

The results of the first research question would be a tentative yes. Generation Y has a statistically significant difference in four of the five motivational factors pertaining to level of importance. This shows Generation Y does have varying levels of importance for four of the five motivational factors when compared with Generation X and Baby Boomers.

The low values Generation Y attributes to the responsibilities' motivational factor are of intense concern. One possible explanation may be that the government is not providing enough responsibilities to fully engage Generation Y. Another possible explanation may be that Generation Y is not happy with their current responsibilities, and this has impacted their responses to what motivates them.

Generation Y ranks compensation as the highest motivational factor but not by much over the other factors. The importance ranks much less for Baby Boomers, and this response is expected. The reason is the Baby Boomers are nearing retirement age and are trying to reach their maximum earning potential, which dictates the amount they will receive from their pension. Overall, Generation Y places a much higher importance on advancement potential and free time than the other generations.

The answer to Question No. 2 is a cautious yes. Although two of the 10 possible combinations are statistically significant, two (advancement potential and free time) do provide some insight. The two highest importance levels over the other generations, discussed earlier, are advancement potential and free time, which corresponds with the level of happiness calculations. Not only does Generation Y regard advancement potential and free time as very important, but they are content with their levels of both motivational factors.

The results of Question No. 3 are also a tentative yes. Advancement potential and free time are emerging as the most diverse attributes compared to Generation X and Baby Boomers. Based on the literature, Generation Y proactively plans their professional development and expects to achieve it within the federal government. The majority of Generation Y research is done on the work/life balance factor. Research points to this new generation aspiring to attain this balance in their everyday lives. The results presented here promote this same idea.

Conclusions

Questions may be raised about the sample size, concise question set, and significance level used. A much larger sample size and more extensive survey are needed to gain an in-depth understanding of this generation. The authors plan to expand the participant pool in the near future to include a statistically significant number of respondents. The expectation is that the survey and results (although limited due to small sample size) described in this article, coupled with the literature review, will begin to unveil what Generation Y expects from a long and prosperous career in federal civilian service. This can help management in aligning corporate incentives to motivate Generation Y workers, not only by compensation but by the other motivational factors.

The federal government's workforce climate is shifting, and conducting internal studies allows management to be more aware and able to adapt to emerging situations. This study provides the initial basis for conducting more detailed studies specific to the federal government. The government can be in the forefront of understanding and retaining Generation Y by conducting research, validating results based on proven mathematical techniques, and slowly changing the retention landscape with these results. By motivating Generation Y using the outlined factors, governmental managers can tailor retention plans specific to this generation to ensure a sustainable workforce for the future.

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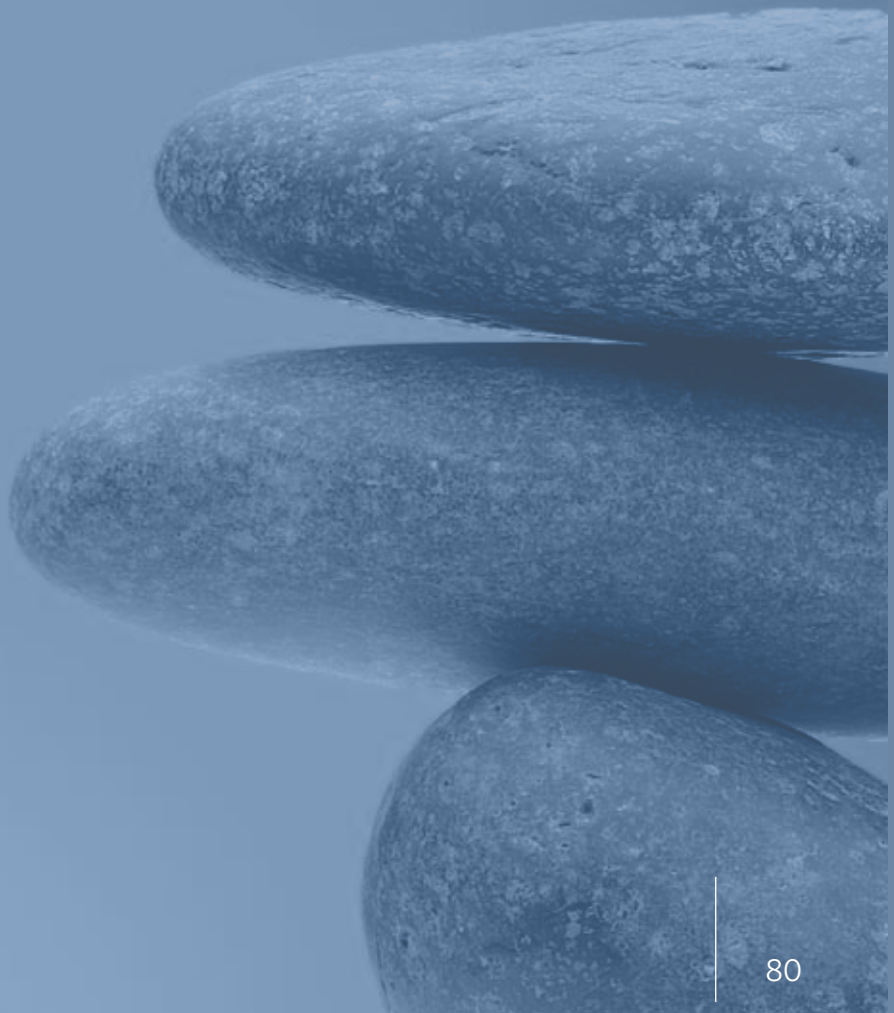
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APPLICATION OF REAL OPTIONS THEORY TO DoD SOFTWARE ACQUISITIONS

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and Man-Tak Shing***

The traditional real options valuation methodology, when enhanced and properly formulated around a proposed or existing software investment employing the spiral development approach, provides a framework for guiding software acquisition decision making by highlighting the strategic importance of managerial flexibility in managing risk and balancing a customer's requirements within cost and schedule constraints. This article discusses and describes how an integrated risk management framework, based on real options theory, could be used as an effective risk management tool to address the issue of requirements uncertainty as it relates to software acquisition and guide the software acquisition decision-making process.

Keywords: *Risk Management, Software Acquisition,
Strategic Investment, Evolutionary Acquisition (EA),
Real Options Theory*



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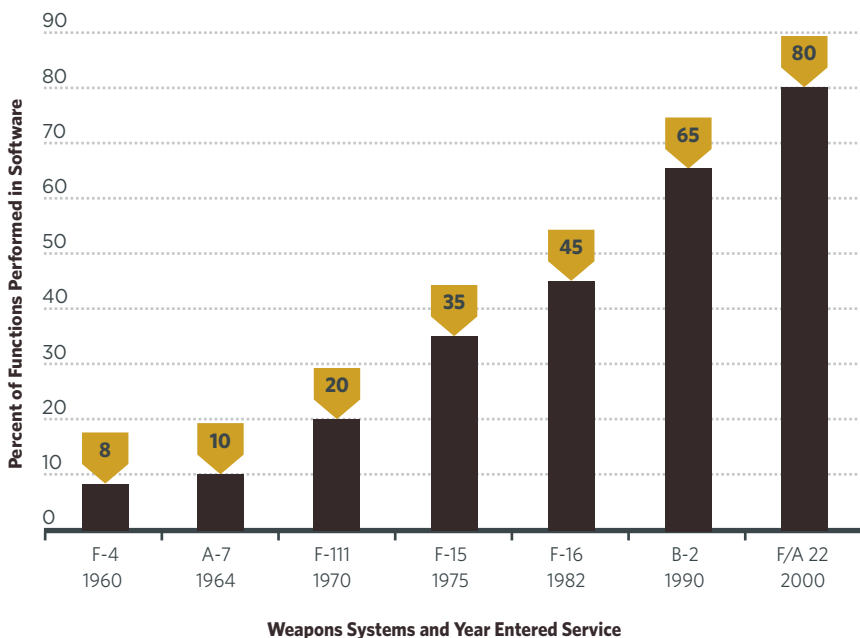
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Software is currently the major expense in the acquisition of software-intensive systems (Figure 1), with its role as a technology platform rising from providing a mere 8 percent of weapons systems functionality in 1960 to over 80 percent of functionality in 2000 (Department of Defense [DoD], 2000).

FIGURE 1. SOFTWARE GROWTH IN WEAPONS SYSTEMS



Note. Adapted from *Report of the Defense Science Board Task Force on Defense Software*, November 2000, by Defense Science Board, Department of Defense, pp. 11-12.

Considering the immense presence and ever-increasing role that software plays in weapons systems, software is and should be treated as a capital investment; accordingly, an approach emphasizing a strategic investment methodology in its acquisition is necessary. This approach would emphasize the linking of strategic program management decisions to current and future unknown software requirements within the stipulated parameters of cost, risk, schedule, and functionality. This strategic program management approach is needed to align the software investment under consideration within the context of the overall portfolio of existing/planned software investments to ensure that synergies in efficiencies are leveraged in the delivery of the intended/desired joint capability.

The key to the implementation of a strategic program management framework is a disciplined requirements engineering approach that embodies a risk management-driven model in the acquisition planning process. This framework would link and build

issue of software investment choices for future capabilities. Through these capabilities, the option holder may choose to adjust, reduce, increase, or abandon the investment in the future, thereby stabilizing returns from these assets. Prior to its application in any domain, the real-options approach calls for the existence of five pre-conditions. These pre-conditions, as outlined by Mun (2006), follow:

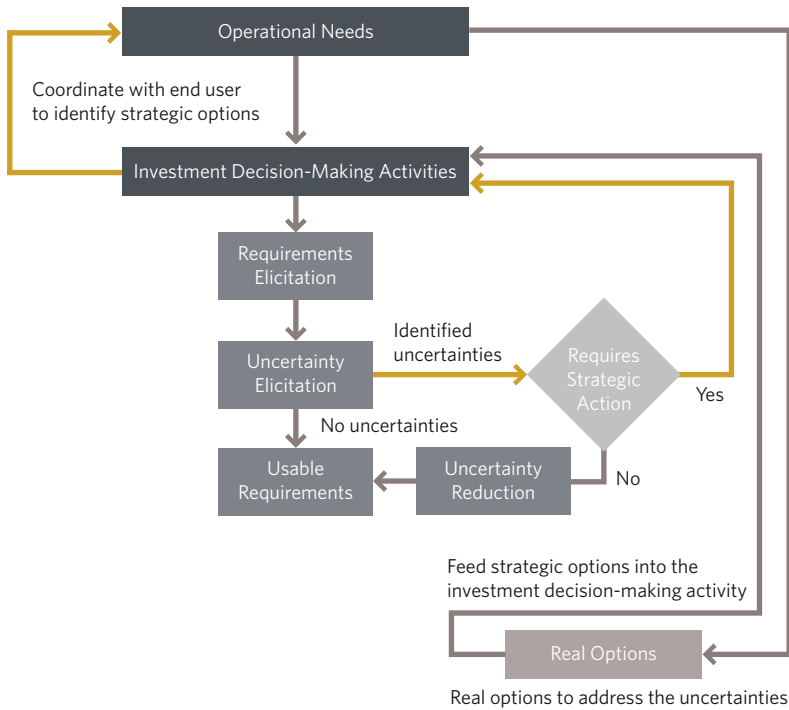
1. A basic financial model must be created to evaluate the costs and benefits of the underlying software asset.
2. Uncertainties must exist during the software acquisition process; otherwise, the real options analysis becomes useless as everything is assumed to be certain and known.
3. The uncertainties surrounding the software acquisition process must introduce risks, which directly impact the decision-making process.
4. Management must have the flexibility or options to make mid-course corrections when actively managing the project.
5. Management must be smart enough to execute the real options when it becomes optimal to do so.

Since software acquisition encapsulates the activities related to procurement decision making, development, implementation, and subsequent maintenance, each of these pre-conditions can be directly correlated to the various activities associated with a software acquisition effort. The uncertainties that surround these activities manifest themselves in the form of risks and could range from changing or incomplete requirements or insufficient knowledge of the problem domain, to decisions related to the future growth, technology maturation, and evolution of the software.

While risks associated with large-scale software acquisition have been effectively managed through the application of stochastic frameworks and project management techniques, a framework based on the real options approach is best suited for the DoD acquisition process because of its capacity to overcome the limitations of classical financial analysis techniques, such as the discounted cash flow (DCF) or net present value (NPV) approach, both of which treat projects/investments as passively managed, rather than actively managed projects/investments, albeit a gross misrepresentation of the norm in software acquisition.

Software Acquisition Uncertainties

To tackle the issue of uncertainties surrounding software acquisition, a formal and distinct uncertainty elicitation phase is proposed as part of the software investment decision-making process (Figure 2) to obtain information on the relevant uncertainties from

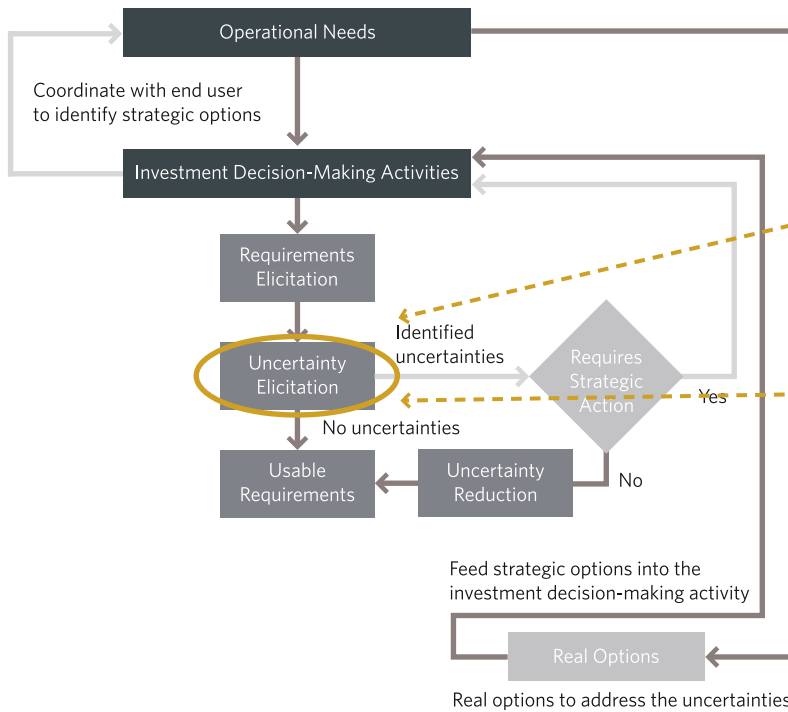
FIGURE 2. UNCERTAINTY ELICITATION MODEL

a strategic point of view. Stakeholders in this phase would normally include representatives of the Joint Requirements Oversight Council, in concert with independent requirements subject matter experts, to identify and document uncertainties as they are revealed from an independent point of view.

Implementing an explicit uncertainty elicitation phase would facilitate the identification of uncertainties very early on in the acquisition process, so the necessary steps could be taken to either refine the requirements to address the uncertainties or identify strategic options to mitigate the risks posed by the uncertainties.

During the uncertainty elicitation step in the model, uncertainties are captured from two perspectives—the managerial and technical perspective—as illustrated in Figure 3. Managerial uncertainties of people, time, functionality, budget, and resources contribute to both estimation and schedule uncertainties, which are considered to be pragmatic uncertainties.¹ Technical uncertainties—incomplete, ambitious, ambiguous, changing, or unstable requirements—contribute to software specification uncertainties, which lead to software design and implementation, software validation, and software evolution uncertainties—all of which can be categorized as exhibiting both Heisenberg-type² and Gödel-like³ uncertainties.

FIGURE 3. PRECONDITION 2

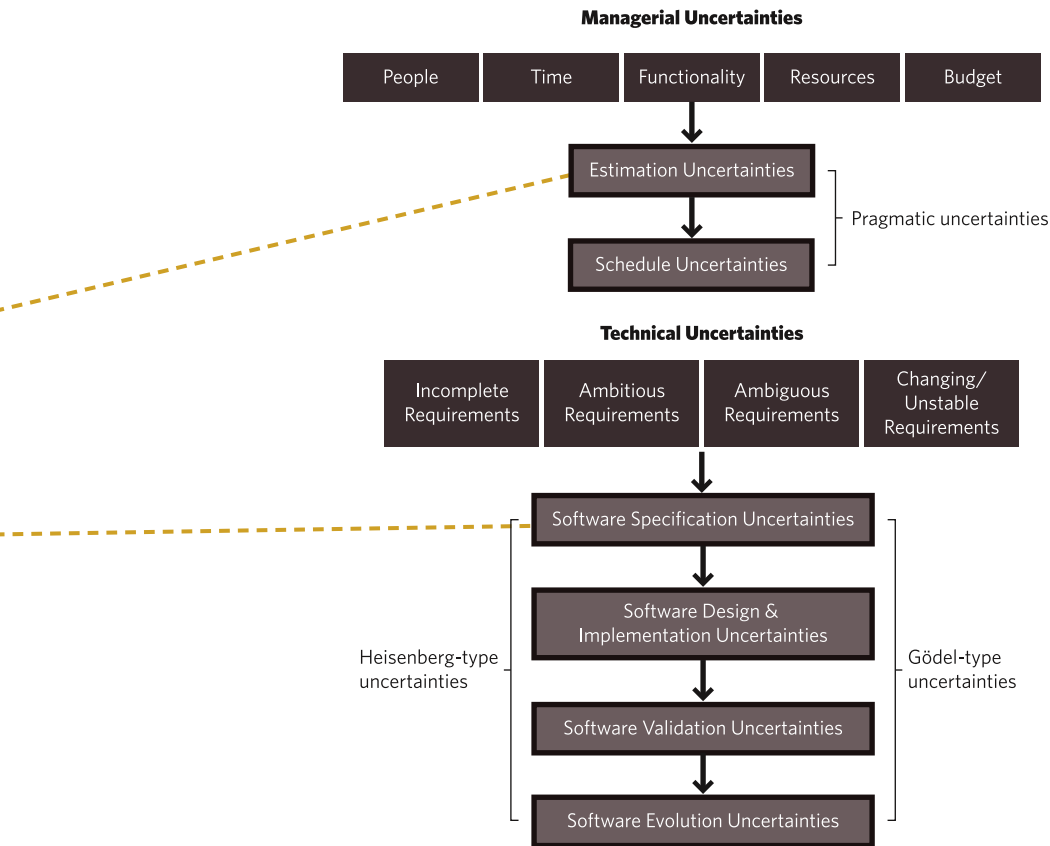


If the uncertainty cannot be resolved, strategic real options could be developed to address the risks posed by the uncertainty, providing management the flexibility to address the risks posed by the uncertainties when they become revealed at a later date during the acquisition effort.

The Real Options Valuation Framework

To develop the appropriate options to hedge against the risks due to the uncertainties surrounding a software acquisition effort, we formulated a generalized real options framework (Figure 4) in line with the five preconditions outlined by Mun (2006). This proposed framework consists of the following six phases, each of which explicitly addresses and establishes compliance with the preconditions.

1. Needs Assessment Phase
2. Risk Determination Phase
3. Options Analysis Phase
4. Options Valuation Phase
5. Investment Valuation Phase
6. Execution Phase



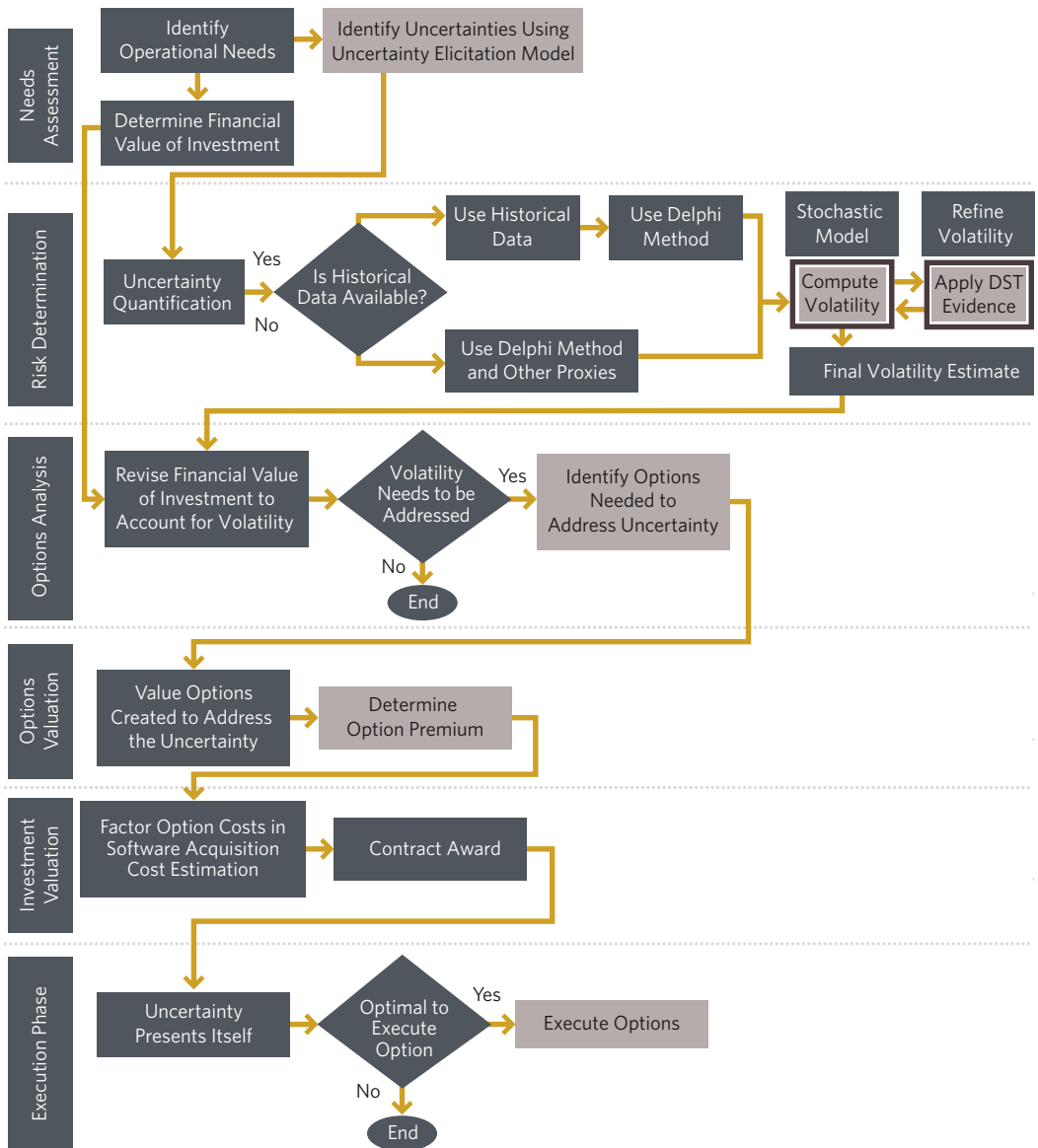
We further validated the framework and illustrated its viability, as an example, by applying it to the Future Combat Systems Network (FCSN), the software component of the U.S. Army Future Combat Systems program (Congressional Budget Office, 2006, pp. 2–21)

Results

Phase I: Needs Assessment

Business Case. The needs assessment phase culminates with the establishment of a business case along with the associated financial model. The financial model is used to evaluate the costs and benefits of the underlying software asset being considered for acquisition in compliance with the first precondition of the real options approach. The traditional discounted cash flow model with a net present value⁴ (NPV) is employed to satisfy this requirement, and NPV is computed in terms of five high-level determinants (Erdogmus & Vandergraaf, 2004):

FIGURE 4. REAL OPTIONS FRAMEWORK



Note. DST = Dempster-Shafer Theory. A mathematical theory of evidence/generalization of probability theory where probabilities are assigned to sets as opposed to mutually exclusive and exhaustive propositions termed “singletons.” Information from multiple sources can be combined in the form of belief assignments, which serves to aggregate the information with respect to its constituent parts.

$$NPV = \sum \frac{(C_t - M_t)}{(1 + r)^t} - I \quad (1)$$

I is the (initial) *development cost of the FCSN*

t is the (initial) *development time* or time to deploy the FCSN.

C is the *asset value of the FCSN over time t*

M is the *operation cost of the FCSN over time t*

r is the rate at which all future cash flows are to be discounted (the *discount rate*) where the standard assumption in [1] is $(C - M)$ is always positive.

An NPV of \$6.4 trillion was computed for the FCSN using estimated values of \$163.7 billion, 13 years, and 3.0 percent for variables I , T , and r respectively based on key assumptions in Olagbemi (2008, pp. 121-148).⁵ Furthermore, a value of $C - M = \$10$ trillion was estimated along the lines of the assumptions by Olagbemi (2008, pp. 121-148).

Uncertainty Identification. Uncertainty identification is the next crucial step performed during the needs assessment phase. In this step, the uncertainty elicitation model is used as a mechanism to identify uncertainties. When applied to the FCSN, it was determined that requirements uncertainty fostered by technological maturation issues (Government Accountability Office [GAO], 2008a, pp. 89-90) plagued the FCSN program from the onset and introduced several other corresponding uncertainties. Thus, the following uncertainties were determined to have been retroactively predictable within the context of the proposed real-options framework.

Technical Uncertainties

1. Requirements uncertainties
2. Integration uncertainties
3. Performance uncertainties

Managerial Uncertainties

1. Estimation uncertainties (size and cost of the software)
2. Scheduling uncertainties

Phase II: Risk Determination

The risk determination phase consists of two steps: *uncertainty* quantification and *volatility* determination.

Uncertainty Quantification. Uncertainty implies risk; consequently, uncertainty must be duly quantified as a risk factor with the goal being to assign an appropriate numerical value to the uncertainty. This is accomplished by gathering evidence using historical data from previous acquisition efforts that faced similar risks. In the

absence of historical data, the Delphi method⁶ is suggested. The objective of the evidence-gathering activity is to equate/ approximate the software engineering uncertainties of the current software acquisition effort to a quantifiable property (risk factor) based on historical evidence depicted by previous software acquisition efforts. Such evidence-gathering activity is necessary to gauge the magnitude/impact of the risk on the underlying asset. In our study, while a suitable proxy for the FCSN program was not readily available (from a size perspective, FCSN represented the largest software investment/development effort to date), data obtained from the Joint Strike Fighter⁷ (JSF) program (JSF software component was one-fifth the size of the FCSN program) were extrapolated and fitted accordingly to mirror the size of the FCS. These data were then utilized as a source of historical information for comparative purposes. The risk of requirements changes in the FCSN program was estimated to be 12 percent (as opposed to 1.44 percent for the JSF program, which is one-fifth the size of the FCSN program) using the Capers Jones formula shown below (Kulk & Verhoef, 2008).⁸

$$r = \left(\sqrt[t]{\frac{\text{SizeAtEnd}}{\text{SizeAtStart}}} - 1 \right) \cdot 100 \quad (2)$$

where t is the time period in years during which the estimates were observed.

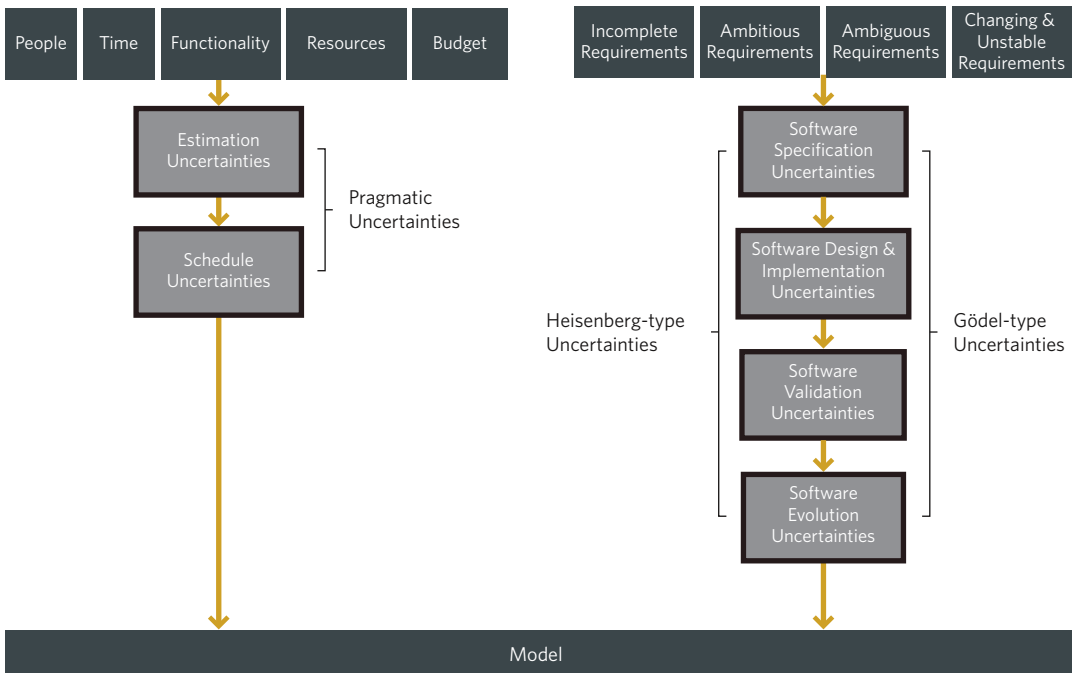
The Capers Jones approach, which is a transposition from the financial industry, assumes requirements are compounded within a project and asserts that the method of average percentage of change of the overall requirements volume lacks information because it does not give any information on the time in which the change occurred. Determining time is an important, key factor in software engineering since requirements changes become more expensive to implement the further we are into the software development process.

Volatility Determination. Volatility is used to quantify the effect of the risk in the form of variations in the returns associated with the software investment, and the accuracy of its estimation is a key factor in real options valuation because it drives the value of an option and is positively related to value. While high volatility signifies high risk and implies a higher discount rate and lower value in traditional NPV valuation, a high volatility in real options analysis is linked to high-option value. This link results from greater volatility, which creates a wider range of possible future values of the opportunity as the option would only be exercised if the value

of the opportunity exceeds the exercise price (Hevert, 2007).

Figure 5 depicts identified uncertainties, which were fed into a Monte Carlo model—Risk Simulator⁹ software—taking into account interdependencies between both the technical and managerial uncertainties associated with the software acquisition effort. The software emulated all potential combinations and permutations of outcomes (i.e., to determine the effects of requirements volatility of 12 percent on integration, performance, scheduling, estimation, and its overall impact on the software acquisition effort). The analysis indicated that requirements volatility introduced an overall volatility of 0.0866 percent in the FCSN program. The volatility of 0.0866 percent resulted in a reduction in the NPV of the FCSN program from \$6.4 trillion to \$6.1 trillion. This reduction in NPV is a result of the potential of increased costs in light of the risks facing the FCSN

FIGURE 5. MODELING SOFTWARE ENGINEERING UNCERTAINTIES



Note. Adapted from *Real Options Analysis: Tools and Techniques for Valuing Strategic Investment and Decisions*, by J. Mun, 2006. The Risk Simulator software was developed by Mun.

program, which ultimately reduces the value of the investment effort from a financial point of view.

To improve/refine the accuracy of the volatility estimates, the Dempster-Shafer Theory of Evidence (DST)¹⁰ is employed to provide increased belief, partial belief, ignorance, or conflict with the initial estimates (Arnborg & Högskolan, 2006). This is accomplished by establishing “belief functions” that reflect the “degrees of belief” between the revised NPV estimate, computed at \$6.1 trillion in light of the risks posed by requirements uncertainty and the FCSN cost estimates provided by two independent sources—the Cost Analysis Improvement Group (CAIG) and the Institute of Defense Analyses (IDA) (Congressional Budget Office, 2006).

The independent belief functions based on the CAIG and IDA, which inferred basic probability assignments associated with each of the FCSN risk factors (requirements, integration, estimation risk, etc.), were combined using an orthogonal matrix to determine the most probable beliefs for the set of risk factors. Where the combined functions reflected “belief” in our estimates, our estimates were considered to be valid and were left untouched. In situations where the combined belief functions reflected conflict with our estimates, our estimates were revised accordingly to reflect the estimates computed using the DST approach. Further, we ran the Monte Carlo simulation with the revised risk estimates again, thus resulting in a “refined” volatility of 0.0947 percent. The derived volatility, which reflects an increase from the initial volatility estimate of 0.0866 percent, results in a further reduction of NPV in the FCSN program from \$6.1 trillion to \$5.7 trillion. This reduction implies a \$7 billion shortfall (\$6.4 trillion–\$5.7 trillion) between the original and the refined NPV as a result of the volatility of the software investment. Details of the volatility computation can be found in Olagbemiro (2008, pp. 121-148).

Phase III: Options Analysis

This phase involves the identification of options. Once the volatility of the software acquisition effort has been determined, possible options could be identified to manage the risks associated with the software investment effort (Figure 6). In this study, three broad categories of options are explored relative to software acquisition.

1. Expand/Growth options
2. Wait/Deferment options
3. Contract/Switch/Abandon options

To take advantage of the options identified, the issue of software design is revisited. From a software architectural perspective,

FIGURE 6. SAMPLE OPTIONS TO ADDRESS SOFTWARE INVESTMENTS

Real Option Category	Real Option Type	Description and Example
Expand/ Growth	Scale up	Option to scale up through cost-effective, sequential investments as knowledge of the product increases
	Switch up	A flexibility option to switch products, processes, given a shift in underlying price of input and output demands
	Scope up	Investment in proprietary assets of one industry enables company to enter another industry cost effectively - Link and Leverage
Wait/ Defer	Study/Start	Delay investment until more information or skill is acquired, e.g., introduction of new requirements
Contract/ Switch/ Abandon	Scale down	Shrink or shut down a project partway through if new information changes the expected payoffs, e.g., introduction of new requirements
	Switch down	Switch to more cost-effective and flexible assets as new information is obtained, e.g., switch from custom development to Commercial Off-the-Shelf
	Scope down	Limit scope of (or abandon) software project when there is no further potential in the business opportunity the software is meant to address

Note. Adapted from *Real Options Analysis: Tools and Techniques for Valuing Strategic Investment and Decisions*, by J. Mun, 2006.

the decomposition of the software into components, modules, or subsystems serves to introduce flexibility from which the program manager could exploit and benefit. Since the software design is a key activity aimed at conceiving how a software solution would solve a particular problem, factoring modular decomposition into the design would support the following two propositions (Damodaran, 2002, pp. 796–815):

1. Some projects that look attractive on a full-investment basis may become even more attractive if the project is partitioned or decomposed into components because we are able to reduce downside risk at the lowest possible level.
2. Some projects that are unattractive on a full-investment basis may be value-creating if the firm can invest in stages.

A successful modular decomposition would introduce flexibility into the acquisition process by recasting the software effort as a series of options to start, stop, expand, or defer the development of a module or subsystem when requirements uncertainty is encountered. Note that the FCSN software effort has been decomposed into six components: Combat Identification, Battle Command and Mission Execution, Network Management System, Small Unmanned

Ground Vehicle, Training Common Component, and System of Systems Common Operating Environment (GAO, 2008b, pp. 2–31). The FCSN software development effort could be recast as a series of deferment/learning options and investment/growth options. Such options may include start, stop, scale down (e.g., staff), reallocate resources, or resume development when uncertainty is resolved; or defer development in the face of requirements uncertainty. This whole strategy is based on the correct partitioning/decomposition of the FCSN into the appropriate systems or subsystems.

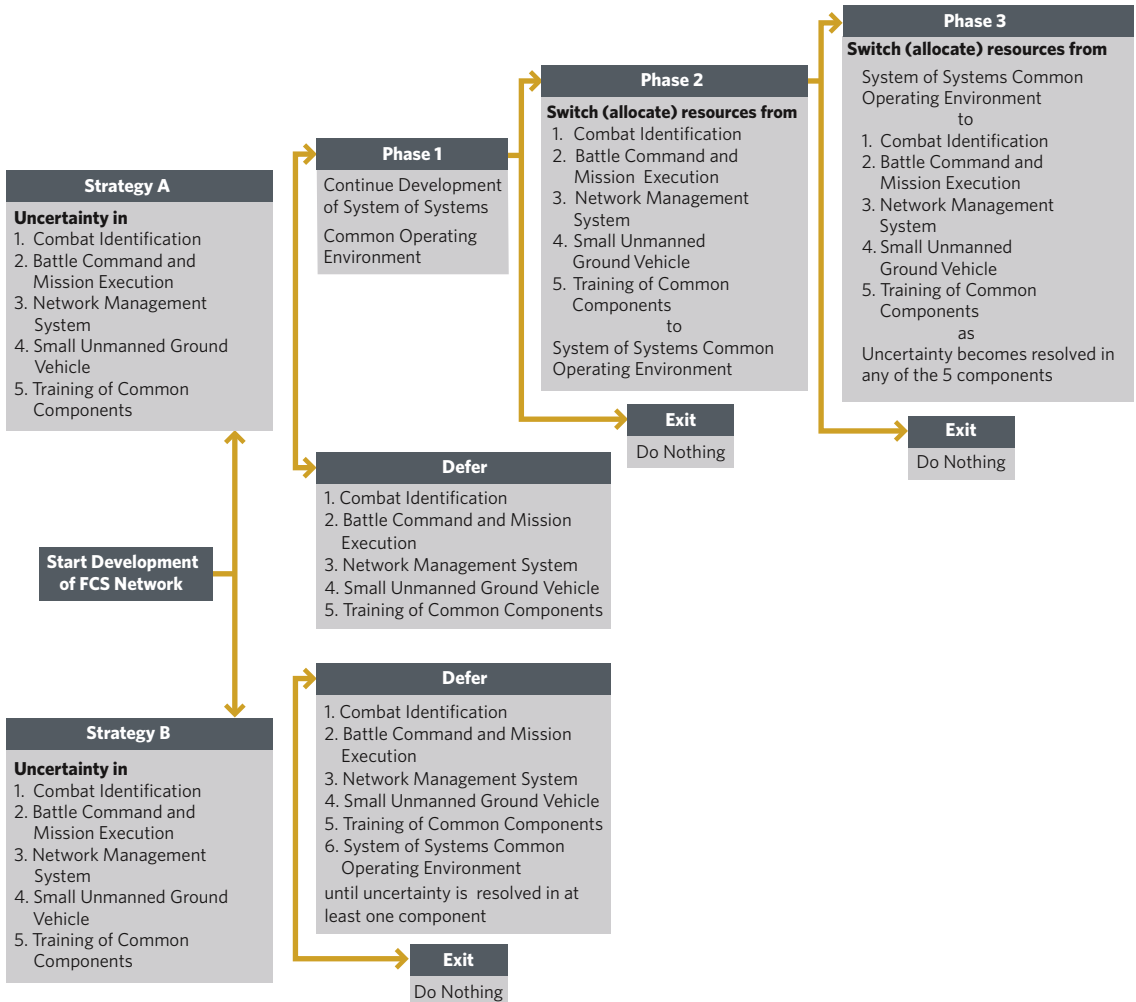
To highlight this strategy, we present a scenario.

Scenario: At least one out of the six software components is not facing requirements uncertainty. In this scenario, we assume that of the six component systems, one is not facing any form of uncertainty, while five of the software components are facing uncertainty. We proceed to develop different options to address this scenario. For our study, we examine two possible options: compound option and deferment option.

Compound Option. In the event that at least one of the software components is not facing requirements uncertainty, while all the others are facing requirements uncertainty, an option could be developed to *scale down* the resources/staff allocated to the software components facing requirements uncertainty. The staff could then be *switched* to work on the software component that is not facing requirements uncertainty, while the uncertainties in the other components are addressed using our uncertainty elicitation model. (Note: The assumption with this approach is the software component development effort upon which the staff engineers are being reallocated to work is not already behind schedule and hence does not violate *Brooks Law*.)¹¹ If the development effort upon which the staff are being assigned to work is late (behind schedule), the number of staff, experience level, and role that the added staff would play in the software development effort must be taken into consideration. We therefore framed the real options in this case as: *an option to contract and scale down* from an uncertain system, *an option to switch* resources to another system, and *options to expand and scale up* staff assigned to the development of a system not facing uncertainty (shown as Strategy A in Figure 7). This is essentially a *compound option*—an option whose “exercise” is contingent on the execution of the preceding option.

Deferment Option. In the event that five out of the six software components are facing requirements uncertainty, then an option could be developed to *stop and defer all development*, including the

FIGURE 7. FCS STRATEGY TREE DEPICTING STRATEGY A AND B FOR GIVEN SCENARIO



development of the software component that is not facing requirements uncertainty for a specified period until uncertainty is resolved (shown as Strategy B in Figure 7). This is an option to *wait and defer*.

Phase IV: Options Valuation

Valuation plays a central part in any acquisition analysis. Options are usually valued based on the likelihood of the execution of the options. Several methods are available for computing and valuing real options, such as employing the use of closed-form models, partial differential equations, or lattices. For our study, we utilize the binomial approach and apply risk-neutral probabilities as this method elicits great appeal due to its simplicity, ease of use, and the ability to solve all forms of customized real-life options.

We utilize the Real Options Super Lattice Solver (SLS) 3.0 software developed by Real Options Valuation, Inc., for the task. The basic inputs are presented in the Table.

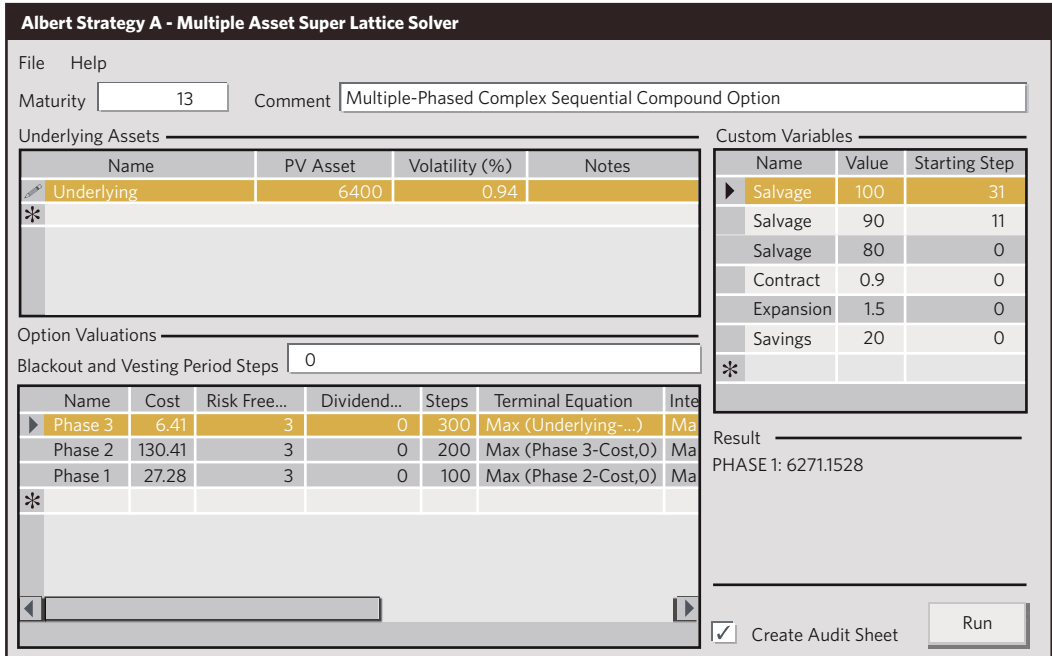
TABLE. REAL OPTIONS SUPER LATTICE SOLVER (SLS) 3.0 INPUTS

Real Option on Software		
Symbol	Acquisition Project	Description
S	Value of Underlying Asset (Asset Price)	Current value of expected cash flows (expected benefits realized from investing in the software effort [NPV])
K	Exercise Price/Strike Price	Price at which the created option would be realized (investment cost, or cost of investing in options, which is an estimation of the likely costs of accommodating changes)
T	Time-to-Expiration	The useful life of the option (time until the opportunity disappears/maturity date of the option contract)
r	Risk-Free Interest Rate	Risk-free interest rate relative to budget and schedule (interest rate on U.S. Treasury bonds)
cv	Volatility	Uncertainty of the project value and fluctuations in the value of the requirements over a specified period of time (volatility in requirements, cost estimation, and schedule estimation based on Dempster-Shafer Theory of Evidence)

Strategy A. The Real Options SLS software was populated (Figure 8) based on the following underlying values:

1. Development/Implementation cost of FCSN is \$163.7 billion.
2. Value of underlying asset is \$6.4 trillion.
3. The risk-free rate is 3.0 percent.
4. Volatility of our project is 0.0947.
5. Duration of software development is 13 years.
6. Lattice steps were set to 300.

FIGURE 8. SCREEN CAPTURE OF AUTHORS' MODEL IN THE REAL OPTIONS SLS SOFTWARE



The model was executed, and the lattice of the underlying asset (FCSN) (Figure 9) as well as the options valuation lattice for Strategy A (Figure 10), was created. The terminal values in our lattices (apex of lattice) are the computed values that occur at maturity, while the intermediate values in the lattices are the computations that occur at all periods leading up to maturity. All these values are computed using backward induction.

The option analysis that represents the value of the option under Strategy A returned a value of \$6.27 trillion (Figure 10). The options valuation lattice of each phase under Strategy A was created and values computed using backward induction, working backward from Phase III to Phase I to arrive at the results depicted in Figure 10.

Strategy B. In Strategy B, which calls for a “defer and wait” approach, an assumption is made that the duration for deferment option would be 3 years. We set up our model (Figure 11) using the same assumptions used in Strategy A, but set the duration of the deferment option to 3 years.

The model is executed and similar to Strategy A; the lattice of the underlying asset (Figure 12) is generated. In contrast, the option analysis returned a value of \$6.25 trillion (Figure 13).

FIGURE 11. OPTIONS SUPER LATTICE SOLVER DEFERMENT MODEL

Albert Strategy B - Single Asset Super Lattice Solver

File Help

Comment

Option Type American European Bermudan Custom

Basic Inputs

PV Underlying Asset (\$) Risk-Free Rate (%)

Implementation Cost (\$) Divident Rate (%)

Maturity (Years) Volatility (%)

Lattice Steps *All inputs are annualized rates

Blackout Steps and Vesting Period (For Custom and Bermudan Option)

Example: 1, 2, 10-20, 35

Terminal Node Equation (Options at Expiration)

Example: Max(Asset - Cost, 0)

Custom Equations

Intermediate Node Equation (Options Before Expiration)

Example: Max(Asset - Cost, OptionOpen)

Intermediate Node Equation (During Blackout and Vesting Period)

Example: OptionOpen

Custom Variables

Variable Name	Value	Starting Step
*		

Benchmark

	Call	Put
Black-Scholes	6251 ...	0.00
Closed-Form American	6251 ...	-623 ...
Binomial European	6251 ...	0.00
Binomial American	6251 ...	0.00

Result

Custom Option: 6251.0292

Create Audit Sheet

opposed to the current \$5.7 trillion in light of the risks caused by the uncertainties in five of the six software components. This premium would also include the administrative costs associated with exercising an option from an integrated logistics support point of view, i.e., costs associated with contractual agreements, software development retooling costs, costs associated with infrastructure setup of the infrastructure, etc.

In analyzing both strategies, Strategy A is more attractive than Strategy B. Instead of waiting for another 3 years at an additional cost of up to \$550 billion (after which uncertainty would hopefully have been resolved) and then proceeding to spend \$163.7 billion at once to develop all six software components, the staged-phase approach in Strategy A calls for budgeting up to \$570 billion for the option up front. The staged-phase approach also calls for spending some \$163.7 billion for the System of Systems Common Operating Environment component, and then investing more over time as the requirements are firmed up for the other five components. Therefore, under these conditions, Strategy A, which employs the compound sequential options, is the optimal approach.

FIGURE 12. STRATEGY B UNDERLYING ASSET VALUE LATTICE (FCS NETWORK)

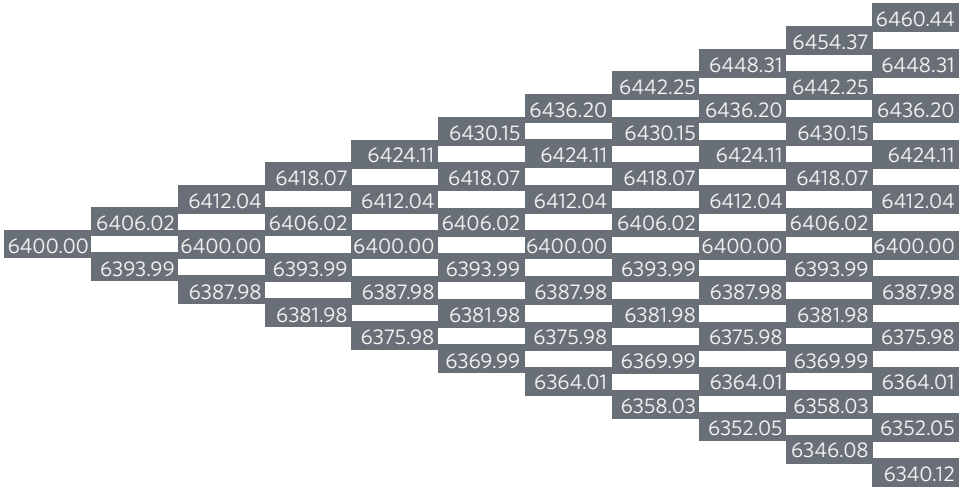


FIGURE 13. STRATEGY B OPTIONS VALUATION LATTICE UNDER DEFERMENT



Phase VI: Execution

The execution phase deals with the last precondition of real options valuation theory, which asserts that decision makers must be smart enough to execute the real options when it becomes optimal to do so. The options premium has two main components: intrinsic value and time value, both of which contribute to the valuation of the underlying software investment. For example, assuming that the contract for the FCSN includes an option for Strategy A, program managers must then be willing to exercise the compound sequential option when they observe that five of the six software components are at risk due to uncertainties.

Discussion

Our proposed approach addresses the risks associated with software-related capital investments by taking a proactive approach towards risk management by emphasizing the planning for, and paying for risk up front. This is not to say that risk management strategies are not being adopted today, but rather highlights a failure of management to take a strategic approach towards risk management. The status quo emphasizes the employment of what is deemed to be a “tactical” approach in the form of the spiral development process, which results in the elimination/reduction of much needed functionality from the scope of the software investment effort—usually when the acquisition effort is already in the development phase. Therefore, the proposed methodology in this article would help address some of the limitations of the spiral development process by serving as a mechanism through which the much desired and needed planning associated with the spiral development process is provided.

Conclusions

Uncertainties associated with software-related capital investments lead to unnecessary and sometimes preventable risks. As DoD often sets optimistic requirements for weapons programs that require new and unproven technologies, the application of the real options valuation methodology would be beneficial as it would enable the DoD to incorporate the appropriate *strategic options* into acquisition contracts. The options would serve as a contract between the software executive and the contractor (in the case of a government acquisition) to buy or sell a specific capability known as the options on the underlying project. The real options valuation approach is able to overcome the limitations of traditional valuation techniques by utilizing the best features of traditional approaches and extending their capabilities under the auspices of managerial flexibility. Barring the use of an explicit uncertainty elicitation phase as proposed in our research, and the development of options to hedge against the risk—and ultimately execute the options as they appear—we believe the current acquisition process would continue to be plagued by the risks of cost and schedule overruns.

The cost-reduction strategy of reducing testing resources proposed by DoD on the JSF program, while risky in itself, still did not address the root causes of cost-related increases as identified in GAO Report No. 08-569T (GAO, 2008c, pp. 2-17), further underscoring the importance of a preemptive and strategic approach of identifying uncertainties early on in an acquisition effort and paying

for risk up front. By employing our proposed approach, the DoD would be able to optimize the value of their strategic investment decisions by evaluating several decision paths under certain conditions to lead to the optimal investment strategy.

Authors' Note

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Author Biographies



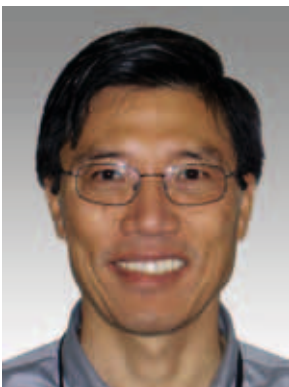
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ENDNOTES

1. Pragmatic uncertainties are problems in actually performing the development activities.
2. Heisenberg-type uncertainties occur as the system is being developed, grow during use, and exhibit themselves in the form of changing requirements due to unsatisfactory behavior post-implementation.
3. Gödel-like uncertainties occur when the properties of a program cannot be known from the representation because the software systems and their specifications are abstract models of the real world.
4. The NPV valuation approach is still utilized because the real options approach “builds” on traditional methods such as the NPV by incorporating strategic flexibility in the form of “options.”
5. NPV of \$6.4 trillion is computed based on: (a) value of the FCSN program (future value less operating costs, i.e., sum of $[C - M]$ was \$10 trillion; (b) initial development cost I was \$163.7 billion; (c) r is 3 percent; and (d) time t to develop the FCSN is 13 years.
6. The Delphi method is a subjective estimation methodology based on the elicitation of the opinion of an expert or groups of experts to guide decision making by predicting future events.
7. At the time of this study, the JSF software acquisition effort represented the largest development effort after the FCSN.
8. The requirements volatility of 12 percent was computed based on start and ending SLOC (Source Lines of Code) for the FCSN program. SLOC is used for demonstration purposes only. A more suitable metric such as function points is recommended.
9. The Risk Simulator software was developed by Johnathan Mun.
10. DST is a mathematical theory of evidence/generalization of probability theory where probabilities are assigned to sets as opposed to mutually exclusive and exhaustive propositions termed “singletons.” Information from multiple sources can be combined in the form of belief assignments, which serves to aggregate the information with respect to its constituent parts.
11. Brooks Law states that adding people to a late project makes it later.

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Featured Book

**Book Reviewed:**

*The Polaris System Development:
Bureaucratic and Programmatic
Success in Government*

Author(s):

Harvey M. Sapolsky

Publisher:

Cambridge, Harvard University
Press

Copyright Date:

1971

ISBN:

0674682252

Hard/Softcover:

Hardcover: 261 pages

Reviewed by:

Dr. Michael Pryce, Research
Fellow, Manchester Business
School, UK

Review:

During the Cold War, the U.S. Navy set about creating a stealthy nuclear deterrent against the Soviet Union, based upon creating a force of nuclear submarines carrying Fleet Ballistic Missiles (FBMs) known as Polaris. From 1955 until 1960, this capability was developed and fielded under a Special Project Office (SPO) led by Admiral William F. Raborn.

Sapolsky sets out in this book to “describe a government program which worked, a public bureaucracy which was successful” (p.1). As such, it is a “success study.” His basic aim is to find out how a large government bureaucracy can successfully manage a technologically challenging, large-scale weapons acquisition program.

Sapolsky focuses not on the technical accomplishments of the Polaris program, but on the political/management success. He does so by examining the four strategies that the supporters of the program used to protect and manage its resources:

- Differentiation—“the attempts of organizations to establish unchallengeable claims on valued resources by distinguishing their own products or programs from those of competitors” (p. 43);
- Co-optation—“the attempts of organizations to absorb ‘...new elements into [its] leadership or policy-determining structure...as a means of averting threats to its stability or existence” (p. 47);
- Managerial Innovation—“the attempts of organizations to achieve autonomy in the direction of a complex and risky program through the introduction of managerial techniques that appear to indicate unique managerial competence” (p. 58); and
- Moderation—“the attempts of organizations to build long-term support for their programs by sacrificing short-term gains” (p. 54).

Sapolsky attempts to separate the myths of the program’s success, which have largely been attributed to managerial innovations such as PERT (Program Evaluation and Review Technique), from the realities such as the perceived strategic need for the program and the management competency of the SPO, all of which created an environment that was highly conducive to eventual success. He also shows that in following a technical strategy that did not seek a fundamental advance in the state of the art, the Polaris project was also able to deliver the required performance on time and on cost.

This book, although 30 years out of print and describing a now-defunct weapon system, is essential reading for managers and decision makers who want to understand the critical factors that drive program success.

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Research involves the creation of new knowledge. This generally requires using material from primary sources, including program documents, policy papers, memoranda, surveys, interviews, etc. Articles are characterized by a systematic inquiry into a subject to discover/revise facts or theories with the possibility of influencing the development of acquisition policy and/or process.

We encourage prospective writers to coauthor, adding depth to manuscripts. It is recommended that a mentor be selected who has been previously published or has expertise in the manuscript's subject. Authors should be familiar with the style and format of previous *Defense ARJs* and adhere to the use of endnotes versus footnotes, formatting of reference lists, and the use of designated style guides. *It is also the responsibility of the corresponding author to furnish a government agency/employer clearance with each submission.*

MANUSCRIPTS

Manuscripts should reflect research of empirically supported experience in one or more of the areas of acquisition discussed above. Research articles should not exceed 4,500 words.

Audience and Writing Style

The readers of the *Defense ARJ* are primarily practitioners within the defense acquisition community. Authors should therefore strive to demonstrate, clearly and concisely, how their work affects this community. At the same time, do not take an overly scholarly approach in either content or language.

Format

Please submit your manuscript with references in APA format (author-date-page number form of citation) as outlined in the *Publication Manual of the American Psychological Association* (6th Edition). For all other style questions, please refer to the *Chicago Manual of Style* (15th Edition).

Contributors are encouraged to seek the advice of a reference librarian in completing citation of government documents because standard formulas of citations may provide incomplete information in reference to government works. Helpful guidance is also available in Garner, D. L., and Smith, D. H., 1993, *The Complete Guide to Citing Government Documents: A Manual for Writers and Librarians* (Rev. Ed.), Bethesda, MD: Congressional Information Service.

Pages should be double-spaced and organized in the following order: title page, abstract (120 words or less), two-line summary, list of keywords (five words or less), body of the paper, reference list (works cited), author's note (if any), and any figures or tables.

Figures or tables should *not* be inserted (or embedded, etc.) into the text, but segregated (one to a page) following the text. When material is submitted electronically, *each figure or table should be saved to a separate, exportable file* (i.e., a readable EPS file). For additional information on the preparation of figures or tables, see CBE Scientific Illustration Committee, 1988, *Illustrating Science: Standards for Publication*, Bethesda, MD: Council of Biology Editors. Restructure briefing charts and slides to look similar to those in previous issues of the *Defense ARJ*.

The author (or corresponding author in cases of multiple authors) should *attach to the manuscript a signed cover letter* that provides all of the authors' names, mailing and e-mail addresses, as well as telephone and fax numbers. The letter should verify that the submission is an original product of the author; that it has not been previously published in another journal (monographs and conference proceedings, however, are okay); and that it is not under consideration by another journal for publication. Details about the manuscript should also be included in this letter: for example, title, word length, a description of the computer application programs, and file names used on enclosed CDs, e-mail attachments, or other electronic media.

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SUBMISSION

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- One copy of the typed manuscript, including:
 - Abstract of article
 - Two-line summary
 - Keywords (5 words or less)

These items should be sent electronically, as appropriately labeled files, to *Defense ARJ* Managing Editor, Norene Fagan-Blanch at: Norene.Fagan-Blanch@dau.mil.

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In most cases, the author will be notified that the submission has been received within 48 hours of its arrival. Following an initial review, submissions will be referred to referees and for subsequent consideration by the Executive Editor, *Defense ARJ*.

Contributors may direct their questions to the Managing Editor, *Defense ARJ*, at the address shown above, or by calling 703-805-3801 (fax: 703-805-2917), or via the Internet at norene.fagan-blanch@dau.mil. The DAU Home Page can be accessed at: <http://www.dau.mil>.