

Building the S&E Workforce for 2040

Challenges Facing the Department of Defense

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Executive Summary

As emerging technologies develop and mature, it is vital that the Department of Defense (DOD) be able to recognize relevant breakthroughs as they emerge and provide the advocacy needed to exploit them quickly. Meeting this responsibility will become increasingly difficult because of the great complexity of the topics involved and the emergence of scientific and technological disciplines that are not extant in the current DOD science and technology (S&T) enterprise, public or private.

Historically, the Nation has maintained within the Federal Government, and in quasi-government organizations, a highly competent cadre of scientists and engineers who would act as trusted advisors, and were of sufficient numbers and stature to adjudicate among the often conflicting advice and proposals from the larger community on emerging science and technology. Most of the internal government scientific and technical competence of DOD has resided in the military laboratories and the military research and development (R&D) centers. The quasi-government organizations include Federally Funded Research and Development Centers (FFRDCs) and Government Owned Contractor Operated (GOCO) laboratories. This model worked well for many years and helped the United States to maintain an edge over adversaries by fielding technologically superior war-fighting systems. Many of today's most important military technologies can be traced back to the government and quasi-government laboratories. However, the future viability of the model is in doubt. Indications of this are manifest in the increasing number of new weapon systems that are experiencing serious technical difficulties, many of which should have been anticipated before the programs were approved. A scientific and technical accountability gap has emerged. It appears that the government is not maintaining adequate/appropriate technical competence and/or is not making proper use of the competence that it has maintained.

This paper examines some of the trends that have led to this situation. It focuses on the government component of the model. It is expected that many of the same considerations will apply to the quasi-government component, also. This is an important issue in that, if the traditional model fails, then what model would replace it? Certainly DOD can and, as appropriate, should outsource as necessary to get its traditional government work done. This, However, outsourcing does not provide DOD with a certificate of non-responsibility for the consequences. The responsibility for the decisions and their consequences cannot be passed to the private sector. The government should remain properly sized and competent to exercise the stewardship with which it is entrusted. It is reasonable to strive for a government that is as small as possible, so long as the result is not a government that is smaller than possible.

To estimate future science and engineering needs, this paper examines trends beginning in the late 1920s and continuing through the present time. The robust nature of these trends is used to make predictions of future needs. It is shown that, since WWII, the U.S. defense program, on average, has experienced slow but real growth, while the total DOD civilian workforce, on average, has shown a significant decline. These trends have led to the emergence of a "shadow workforce" in the private sector to compensate for the government workforce drawdown. The paper projects that the shadow workforce will soon dominate the government workforce, which raises questions about whether or not the government is in charge of its own program. During the same period, the DOD S&E workforce, on average, has shown real growth similar to the real growth in the average defense program. However, an examination of the DOD S&E workforce indicates that its makeup in terms of scientific and technical disciplines is more representative of the Nation's 1960 S&E workforce than of today's national S&E workforce. This failure to keep pace with technological developments raises concerns about DOD's ability to judge the "art of the possible" regarding the new technologies that have emerged over the past few decades—and may account for some of the problems that have appeared in new weapon system developments.

There are several additional and disturbing trends evident at this time. For example, on average, the defense program is approaching zero exponentially when measured relative to Gross Domestic Product (GDP), while total Federal outlays, on average, have been increasing relative to GDP. Furthermore the DOD civilian S&E workforce is approaching zero exponentially relative to the national S&E workforce. As a

result, a significant shadow S&T workforce is providing DOD “brain cells” regarding new developments in science and technology, and thereby new directions for defense. Furthermore, the practicing S&Es in the government are increasingly viewed as just other performers for getting work done. These trends blur the distinction between what is public and what is private.

Some argue that the government cannot employ the scientific and technical talent needed. This paper compares the scientific and technical stature of S&Es currently employed by three Federal Government institutions in three separate agencies with non-government S&Es employed in similar undertakings. The three Federal Government institutions compared very favorably. This suggests that the argument that the government cannot employ the needed talent is without merit.

Most of these workforce trends are simply the result of the various tradeoffs needed to get the government’s business done. However, there are a number of significant potential negative consequences of allowing these trends to continue indefinitely. For example, if the growth in total Federal outlays should accelerate due to problems in areas such as Medicare, Social Security or servicing the national debt, then it could become difficult under the current trends to maintain defense readiness. Furthermore, if the DOD civilian S&T workforce continues to decline relative to the national workforce, a point will be reached where it becomes irrelevant. It will not be able to renew itself. It will not be able to maintain competence in newly developing fields of science and technology while at the same time maintaining competence in the traditional fields that will continue to be important to DOD. This could result in the government not being able to distinguish a good S&T proposal from a bad one, or to competently oversee S&T work that has been funded. In addition, the DOD S&T workforce will not be able to provide compelling advocacy within the government for important new S&T initiatives that are derivative of newly emerging fields. In this situation, and with the emergence of ever-more-complex science and technology, one can expect increasing problems with future weapon systems.

At some point these trends need to be addressed such that DOD does not reach a subcritical state in its program, its total civilian workforce, and its S&E civilian workforce. Since defense outlays are becoming such a small fraction of the national economy, dealing with these trends appears to be more of a political issue than an economic issue. The paper suggests that one method of addressing some of the concerns would be to establish a floor for the average defense program when measured relative to GDP. This floor would need to be low enough to be acceptable to the economy and high enough that it can maintain readiness. If this is done, then many of the concerns become resolved. The total DOD workforce and the shadow workforce can, on average, be maintained in a desired balance. The DOD S&T workforce, on average, can be maintained at a fixed percentage of the national S&T workforce, thereby creating opportunities to grow government competence in emerging fields of science and technology while maintaining the necessary competence in existing fields. For this to happen, the current practice of appearing to control government growth by artificially constraining the DOD workforce would need to be abandoned and replaced by a strategy that controls the size of the average DOD workforce in accordance with the percentage of GDP assigned to the average defense program. Under this approach, the total defense program (and workforce) at a particular time would be the sum of the average plus the transient terms (which will be positive or negative) associated with dealing with particular transient events in play at that time. By making use of past trends, the paper develops simple models for making rough estimates of the DOD S&E workforce needs in 2040 to achieve a particular numerical balance between the public sector S&E workforce and the national S&E workforce. The paper also suggests that a strategy be put in place that attempts to evolve the DOD S&T workforce such that its scientific and technical disciplinary make-up is always representative of the national S&E workforce, regardless of what balance is chosen. The matter of what particular balance is needed is, of course, a matter of public policy and cannot be obtained purely from analysis.

A large number of DOD S&E vacancies will occur over the coming years due to the much-discussed retirement of the “baby boom” generation. This exodus creates an excellent opportunity to renew the DOD S&E workforce (and the DOD workforce in general). Recent studies indicate that a significant number of young people would seriously consider Federal jobs. This interest is especially high regarding jobs that provide intellectual challenges and the opportunity to innovate and exercise creativity. These are criteria against which DOD S&E positions should fare very well.

Introduction

The 21st century will see significant developments as a result of emerging science and technology (S&T). For example, a number of critical breakthroughs in areas such as molecular biology, genetics, and bioinformatics have led to the emergence of the rapidly growing biotechnology sector of the economy. This new field will ultimately have a significant impact on the Department of Defense (DOD). As biotech and other emerging technologies develop and mature, it is vital for DOD to be able to recognize relevant breakthroughs as they emerge and to provide the advocacy needed to take rapid advantage of them. Meeting this responsibility will become increasingly difficult because of the highly complex scientific and technical nature of the topics involved and the emergence of scientific and technical disciplines that are not extant in the current DOD S&T enterprise, public or private.

The problem of exploiting new technologies is amplified by the fact that S&T has become an increasingly global undertaking. DOD will need to maintain a window on the *global* S&T program and its developments, which will require a broad array of S&T subject matter experts to provide the best scientific and technical capability to U.S. forces and to ensure that the Nation will not become vulnerable due to a surprise development in S&T. Within the United States, the requisite subject matter expertise will reside in a broad array of institutions ranging from purely public to purely private. In accessing this expertise it is necessary to confront the reality that most of the institutions that must participate will have a conflict of interest due to the obvious fact that they will seek DOD funding in the areas where they are subject matter experts. Historically, this reality has been dealt with by maintaining, within the government, and in quasi-government organizations, a highly competent cadre of scientists and engineers who would act as trusted advisors with sufficient numbers and with sufficient stature that they could adjudicate among the often conflicting advice and proposals that were forthcoming from the larger community of S&Es.

Most of the internal government scientific and technical competence of DOD has resided in the military laboratories and the military R&D centers. This is likely to remain the case. The quasi-government organizations include Federally Funded Research and Development Centers (FFRDCs) and Government Owned Contractor Operated (GOCO) laboratories. The underlying assumption of this approach is that the government and quasi-government organizations would maintain the requisite and recognized scientific and technical authority and would be funded in such a way that they were not potential direct beneficiaries of their advice and recommendations. In addition to serving the role of trusted advisor, these government and quasi-government organizations have been important players in the task of providing a window on important developments in S&T, and they formed an important advocacy group within the government on the need to establish important new S&T initiatives. These organizations maintained the necessary scientific and technical expertise by remaining active contributors to the defense and to the Nation's S&T enterprise.

The model described above worked well for many years and helped the United States to maintain an edge over adversaries by fielding technologically superior war-fighting systems. Many of today's most important military technologies can be traced back to the government and quasi-government laboratories. Among these are radar, nuclear weapons, the Global Positioning System, night vision devices, air-to-air missiles, and reconnaissance satellites. In the coming years, DOD will be required to make decisions regarding increasingly complex, diverse, and competing technologies. Making the proper decisions will require access to objective and authoritative scientific and technical expertise.

Traditionally the government and quasi-government model described above would play an important role in this decisionmaking process. However, the future viability of the model is in doubt. Indications of this are manifest in the increasing number of new weapon systems that are experiencing serious technical difficulties many of which should have been anticipated before the programs were approved. The U.S. Comptroller General stated recently that DOD "did not have a comprehensive plan to ensure its

workforce had the right skills and capabilities to manage and assess contractor performance.”¹ A recent discussion of this development can be found in the Government Accountability Office (GAO) report “Defense Acquisitions: Assessment of Selected Weapon Programs.”² It seems that there is a growing lack of scientific and technical accountability that should have been provided by the traditional model. There are a number of reasons for this including: a developing trend to view the government and quasi government S&Es as contractors, a failure to utilize the scientific and technical expertise resident in the DOD laboratory system and a failure of the DOD S&E workforce to remain current in the rapid (exponential) global expansion of scientific and technical disciplines. This paper will examine some of the trends that have led to this situation. It will focus on the government component of the model. However, it is expected that many of the same considerations will apply to the quasi-government component also. This is an important issue in that if the traditional model fails then what model would replace it? Absent a viable new model, the demise of the traditional model will, in the words of Jerome Wiesner, create a situation where “the public interest is increasingly naked before hungry contractor cliques.”³

This paper will address issues confronting DOD regarding the development of the 2040 DOD S&E workforce needed to keep the traditional model viable. The paper will attempt to identify special problems likely to confront DOD over the intervening time period. It is, of course, impossible to accurately project 30 years into the future regarding emerging fields of science and technology. There is no “first principles” basis from which to make such predictions. There are, however, considerable data regarding the evolution of S&T, the S&E workforce, and the defense program since WWII. The trends in this data can be very helpful in making rough order of magnitude (ROM) estimates of future states. This is the approach that will be used in this paper. The underlying analytical technique utilized will be that of separation of time scales. This allows the data to be expressed as a sum of a base function that changes slowly with time, upon which is superimposed a relatively rapidly varying function that oscillates about the base function. In the case considered here, the rapidly varying function is usually associated with specific transient events, such as WWII, the Korean War, and the Vietnam conflict. The future transients are not predictable. However, the base functions appear to have some robust characteristics and are the basis upon which our ROM estimates will be made.

Historical Trends in the DOD Program

The purpose of this paper is to address future DOD S&E manpower requirements. Such predictions are always best when cast in the reality of the past. Furthermore, S&E manpower requirements only make sense when cast within the context of the program that the manpower supports. In that regard, it is helpful to examine the post WWII history of the DOD program and DOD civilian employment therein. The term “DOD Program” refers to funds available for DOD expenditures while the term “DOD civilian employment” refers to civilian Federal employees of DOD. Figure 1 provides a summary of DOD expenditures from 1929 through 2006. The funds are expressed in FY 2000 dollars. The huge impact of WWII is evident. It can be viewed as a discontinuity followed by a train of oscillations with an average periodicity of about 17 years. The major peaks in these oscillations represent the Korean War, the Vietnam Conflict, the “Reagan buildup,” and the Iraq War. The line represents the base about which the oscillations occur during the period from 1940 through 2005. The trend line (base function) is linear in

¹ GAO-07-789CG *DOD Transformation: Challenges and Opportunities* (Washington, DC: Government Accountability Office, April 20, 2007).

² GAO-06-391 *Defense Acquisitions: Assessments of Selected Major Weapon Programs* (Washington, DC: Government Accountability Office, March 31, 2006).

³ H.L. Nieburg, “In The Name of Science (Chicago: Quadrangle Books, 1966), 338.

Figure 1. Defense Spending 1929 - 2005 (FY 2000 Dollars)

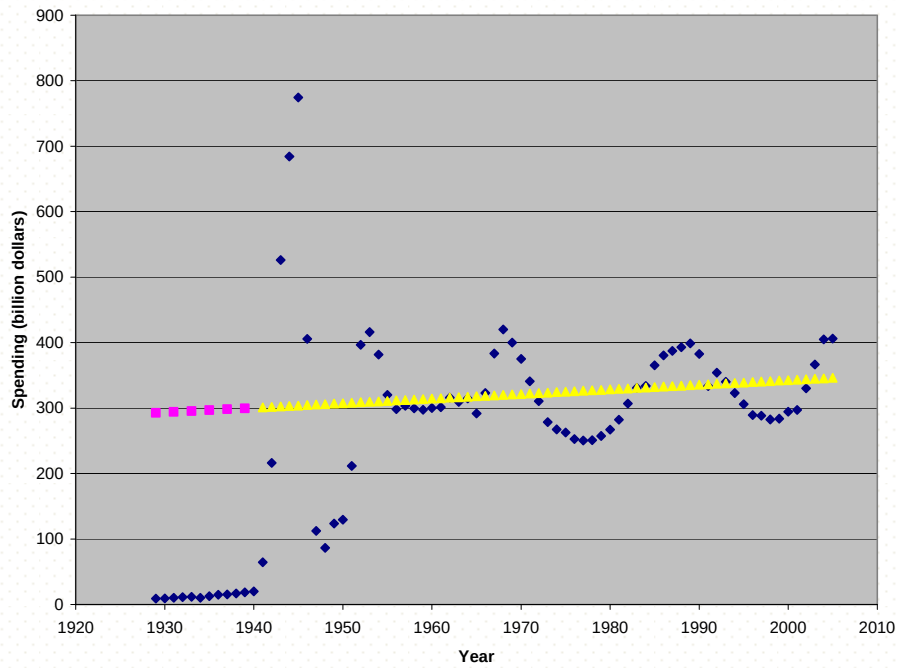
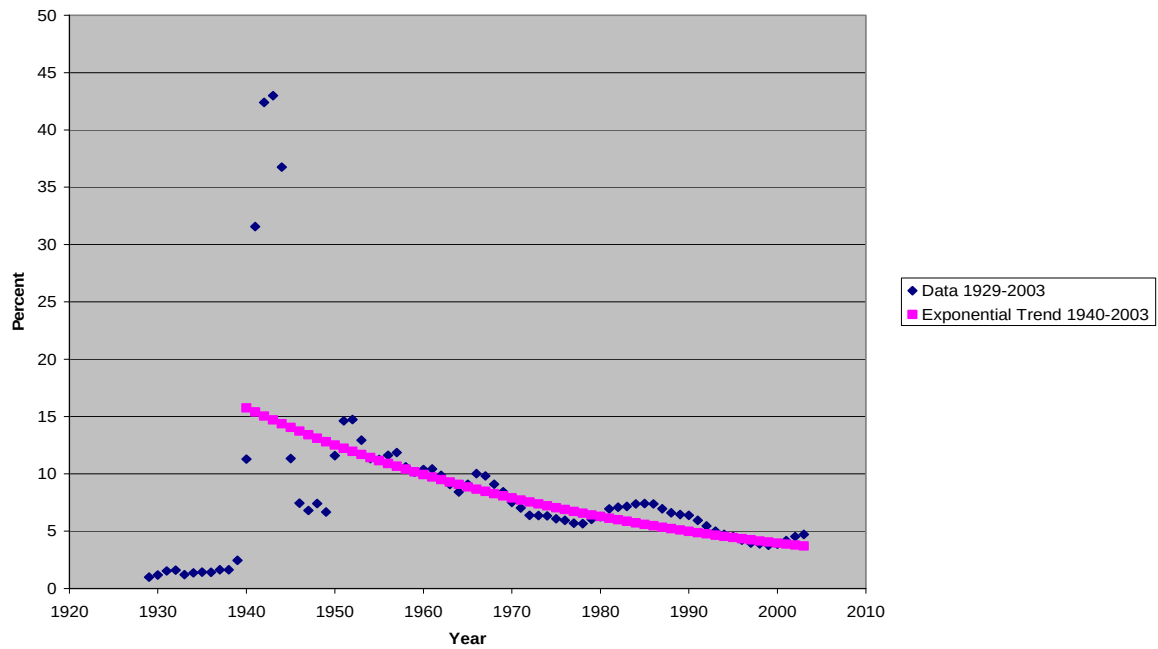


Figure 2. Defense Outlays as Percent of GDP 1929-2003



Source: Office of Management and Budget, *Historical Tables, Budget of the United States Government, Fiscal Year 2005*, available at <<http://www.whitehouse.gov/omb/budget/fy2005/pdf/hist.pdf>>.

this case and shows that the program has, on average, experienced slow but real growth of about .87 billion FY 2000 dollars per year. The backward extrapolation from 1940 makes clear the large permanent change of state in the defense program caused by WWII.

It is also helpful to put the DOD program into perspective regarding the economy that it protects. Figure 2 provides a summary of defense spending relative to GDP from 1929–2003.

Prior to WWII, defense spending appears to have been in equilibrium with GDP at about 1.5 percent of GDP. It is clear that WWII created a large transient that drove the defense program far out of equilibrium with respect to the economy at large. It appears that, since the war, defense spending has been searching for a new equilibrium. While this search has been interrupted by transients—the Korean War, the Cold War, the Vietnam Conflict, the Reagan buildup, and now the Iraq War—the search has led, on average, to a steadily reducing defense program when measured relative to GDP. Fortunately, the growth in GDP has allowed some small but real growth in the defense program, even as it fell relative to GDP. If the past trend continues then, by 2050, the defense program will be about one percent of GDP.

As illustrated in figure 1, a decline relative to GDP does not imply a decline in absolute terms. Indeed, since WWII the absolute size of the defense program has, on average, been maintained, even though defense expenditures have fallen relative to GDP. Conceivably, the size of the program could continue indefinitely if the economy continues to grow. While this is comforting, it is also troubling that the defense program should approach zero when measured relative to the Nation's economy that it exists to protect. At some point this trend may become a threat to national security in that adequate preparedness may not be maintained relative to the scale of the Nation's economic interests.

To make predictions regarding the workforce, it is necessary to have a model for the future program. Figure 2 suggests that the defense program as a percent $P(t)$ of GDP can be written as

$$P(t) = P_{tr}(t) + P_b(t), \quad (1)$$

where $P_{tr}(t)$ is a transient contribution having to do with specific events, such as Korea and Vietnam, and $P_b(t)$ is a base or underlying program about which the transients occur. Figure 2 suggests the following analytical representation for this base program:

$$P_b(t) = (P_o - P_{ss})e^{-(t-t_o)/\tau} + P_{ss} \quad (2)$$

Here τ is the characteristic relaxation time, P_o is the trend line percent of GDP in year t_o , and P_{ss} is the steady state or equilibrium percent of GDP to which the trend line asymptotes for very large times. The precise analytical form of $P_{tr}(t)$ is unknown, except that it is zero before a specific event begins and zero again after the specific event is finished. Within this model, a key question relates to determining the proper value of P_{ss} . Since defense is a government function rather than a product of the free market, the value of P_{ss} should be decided by the government. This quantity is the asymptotic limit (or steady state value) to which the defense base program measured as a percentage of GDP will relax. One would expect that the percentage should be small enough that it is acceptable to the economy and large enough that it can maintain preparedness for the inevitable future conflicts. The transients above this base would presumably be handled by special appropriations that have a size and duration appropriate to the specific transient.

The pre-WWII data suggest that P_{ss} is in the range of 1 percent to 1.5 percent. Another approach to determining P_{ss} is to look at current, non-U.S. military spending and non-U.S. GDP. The world's non-U.S. military spending is estimated to be about 522 billion dollars.⁴ The non-U.S. GDP is estimated to be about 34.9 trillion dollars.⁵ This gives a ratio of non-U.S. military spending to non-U.S. GDP of 1.495 percent. If one considers only the top 14 nations (after the United States) regarding military spending, the ratio is 1.58 percent. This data suggests that 1.5 percent is probably a reasonable estimate for P_{ss} . However, since

⁴ Stockholm International Peace Research Institute, available at <http://www.sipri.org/contents/milap/milex/mex_database1.html>.

⁵ International Monetary Fund, available at <<http://www.imf.org/external/data.htm>>.

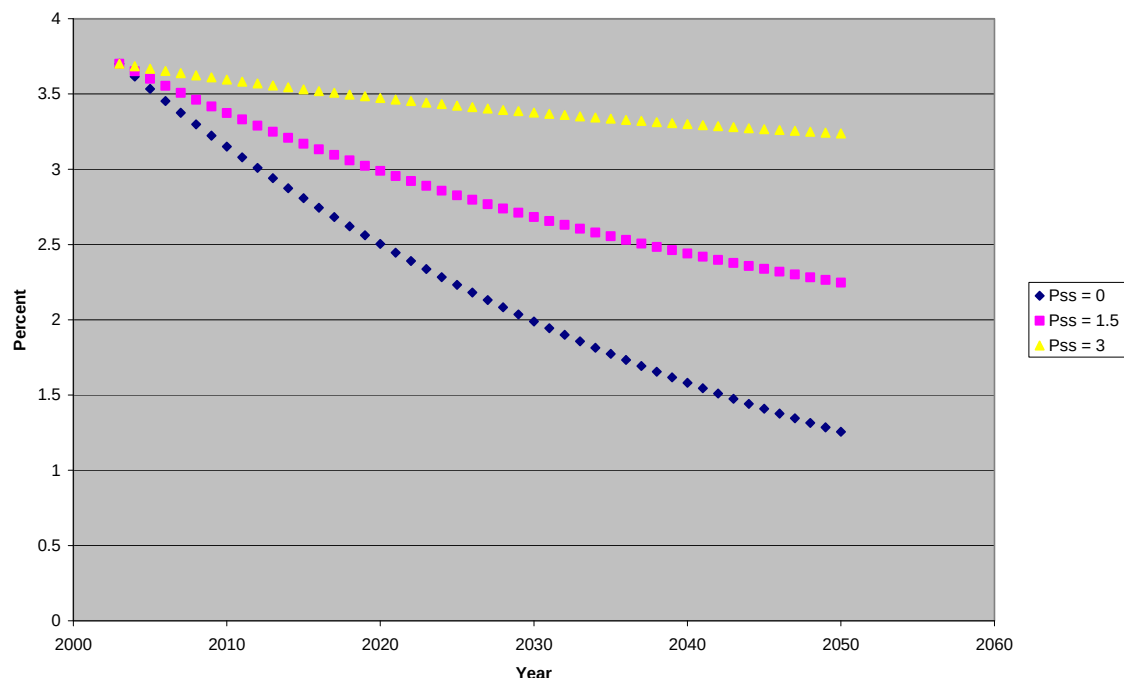
we do not know what the future will hold, we will estimate the future defense base program beyond the data given in figure 2 by choosing several values of P_o , τ and P_{ss} . This study will use 2003 as the initial year. In 2003 $P_o = 3.7$ and $\tau = 43.5$. By making use of eq. (2), figure 3 projects the base program beyond 2003 for three values of P_{ss} (0, 1.5 and 3).

The projected absolute size of the defense base program in any future year is just the product of the inflation-adjusted GDP times the function $P_b(t)$. If one assumes that GDP will continue its average real growth of 3.3 percent, then, from figure 3, one can project the absolute size of the future base program relative to the 2003 base program. This is shown in figure 4.

Figure 4 shows that, in all cases, the defense base program grows in real terms. This results from the fact that the historical decline in the defense base program relative to GDP has been slower than the historical growth in GDP. If past trends continue then the inflation adjusted defense base program could be maintained even if no floor was set for the Base program relative to GDP (i.e. $P_{ss} = 0$). It is not clear, however, that past trends will continue. In this regard, it is informative to examine total Federal outlays as a percentage of GDP. This is done in figure 5.

The post-WWII Federal total outlays have, on average, risen relative to GDP, while defense outlays have fallen. Projections by the Congressional Budget Office suggest that this trend will continue or accelerate in the coming years as a result of expected growth in non-defense outlays.⁶ This could result in an acceleration of the decline of the defense base program relative to GDP and thereby jeopardize the ability to maintain the absolute size of the defense base program. The size of the government's S&E workforce that supports the defense program will undoubtedly be tied to the long-term evolution of the defense base program. How this works out will significantly affect the development of the DOD S&E workforce and, therefore, the predictions made herein.

Figure 3. Extrapolated Defense Base Program as a Percent of GDP



⁶ A 125-Year Picture of the Federal Government's Share of the Economy, 1950 to 2075 (Washington, DC: Congressional Budget Office, July 3, 2002, available at < <http://www.cbo.gov/ftpdocs/35xx/doc3521/125RevisedJuly3.pdf>>.

Figure 4. Projection of Absolute Size of Defense Base Program Relative to 2003 Base Program

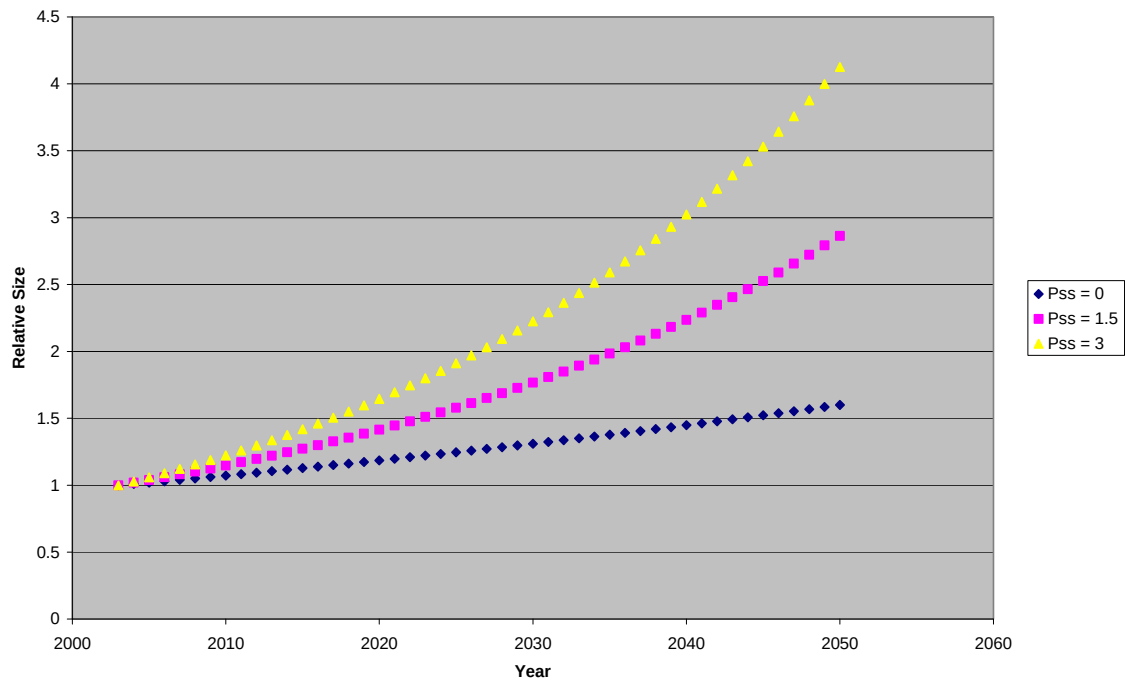
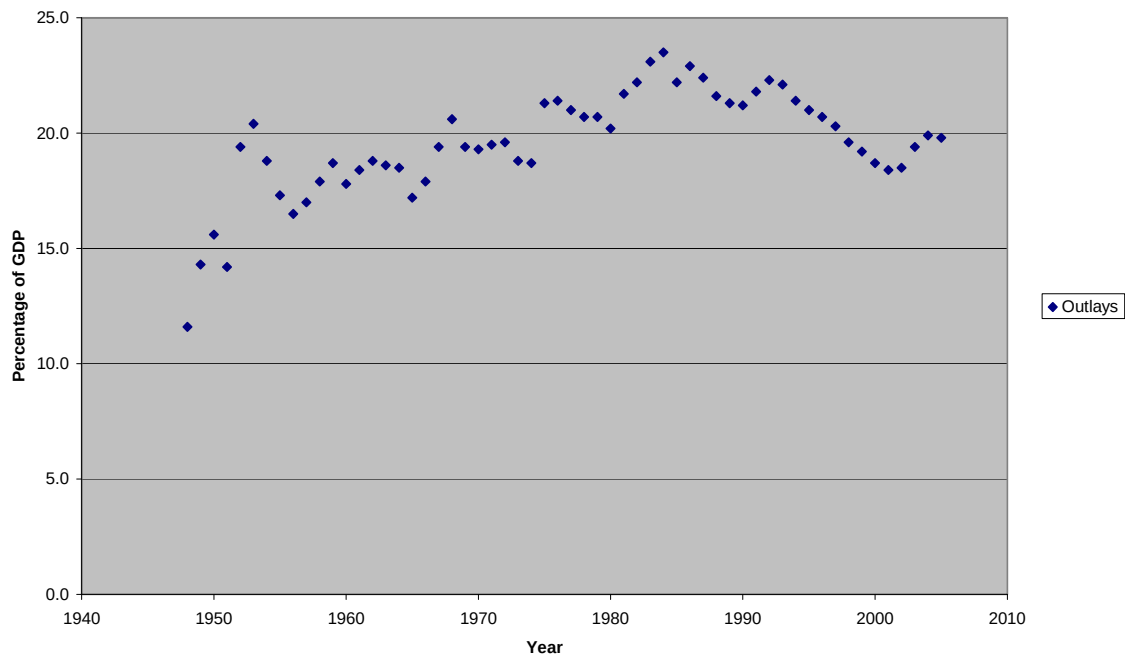


Figure 5. Federal Outlays as Percentage of GDP
Source: US Budget 2006 Historical Tables

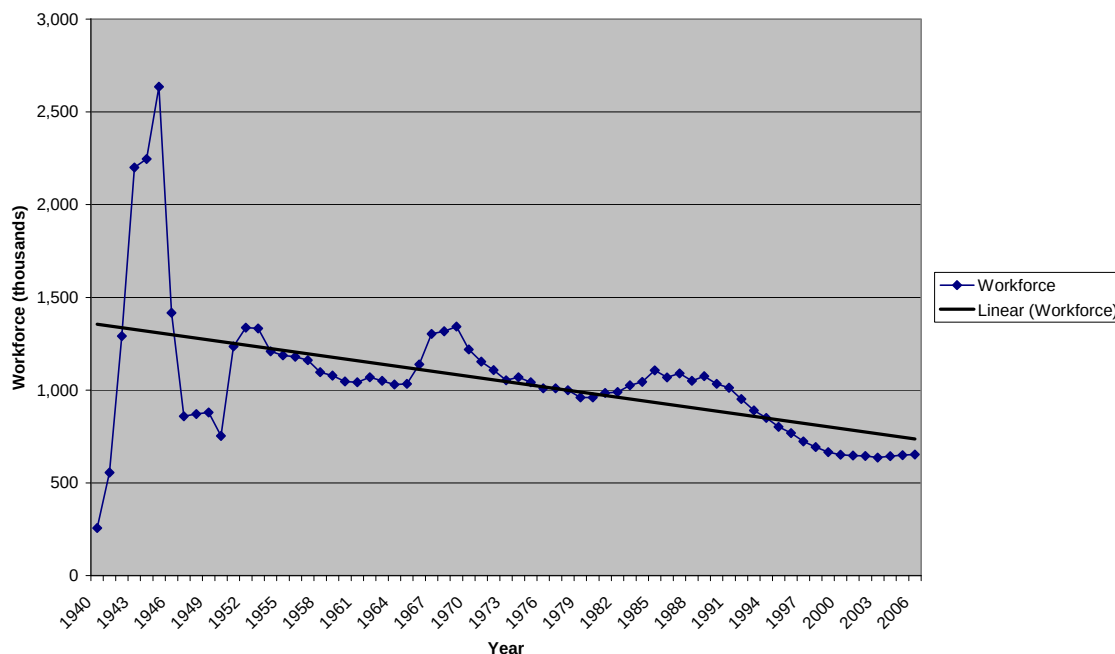


DOD Workforce Trends

The previous section provided a brief summary of historical trends in the defense program and trends relative to the economy at large. This section will attempt a similar review of the DOD S&E workforce. We will first examine the total DOD civilian workforce and then show that its behavior has been different from the behavior of the S&E workforce. Figure 6 summarizes the total DOD civilian workforce that supported the DOD program during the period from 1940 to 2005. Like figure 1, this figure shows a discontinuity caused by WWII followed by a series of oscillations. However, unlike the DOD Program, the total DOD civilian workforce is shown to oscillate about a decreasing trend line with the period of the oscillations increasing with time.

It is clear from figures 1 and 6 that the total DOD civilian workforce that supports the DOD program has been decreasing relative to the program size since WWII. A measure of the average reduction can be gained by taking the ratio of the workforce trend line to the program trend line. This is shown in figure 7, where the ratio has been normalized by setting the 1940 ratio value to be one.

Figure 6. Defense Civilian Workforce 1940-2006



Source: U.S. Budget FY 01, available at < <http://www.gpoaccess.gov/usbudget/fy01/browse.html>>.

**Figure 7. Trend of Total DOD Civilian Workforce Relative to Program Size
Normalized to 1940**

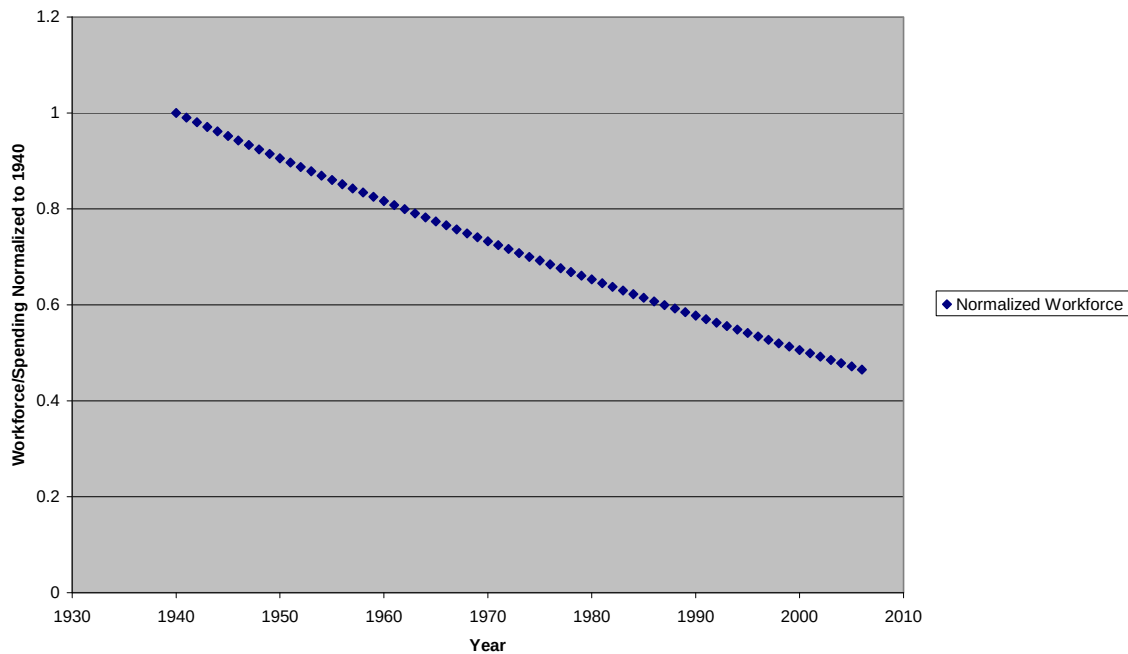


Figure 7 shows that, relative to the size of the defense program, the DOD 2005 trend line total civilian workforce is 46 percent of what it was in 1940 and 56 percent of what it was in 1960. While there undoubtedly have been some efficiency and effectiveness benefits associated with the reduction shown in figure 7, a continued progression along this trend raises concerns relative to proper stewardship of public funds. To make this point, a simple extrapolation of this long-term trend results in DOD civilian employment reaching zero in 2089. While it is unlikely that this point will ever be reached, the trend does suggest that some serious re-thinking of the defense program and its public sector workforce may be in order.

The DOD S&E workforce is included in figures 6 and 7, representing about 10 percent of the total. The S&E workforce, however, has shown a different behavior from the total DOD civilian workforce. This is seen in figure 8.

Unlike the total civilian workforce, the S&E workforce trend line has a positive slope since 1958 (when specific S&E data becomes available). If one takes the ratio of the DOD S&E workforce to the defense program and normalizes it to one in 1958, one obtains figure 9.

Figure 8. Defense S&E Workforce 1958-2005

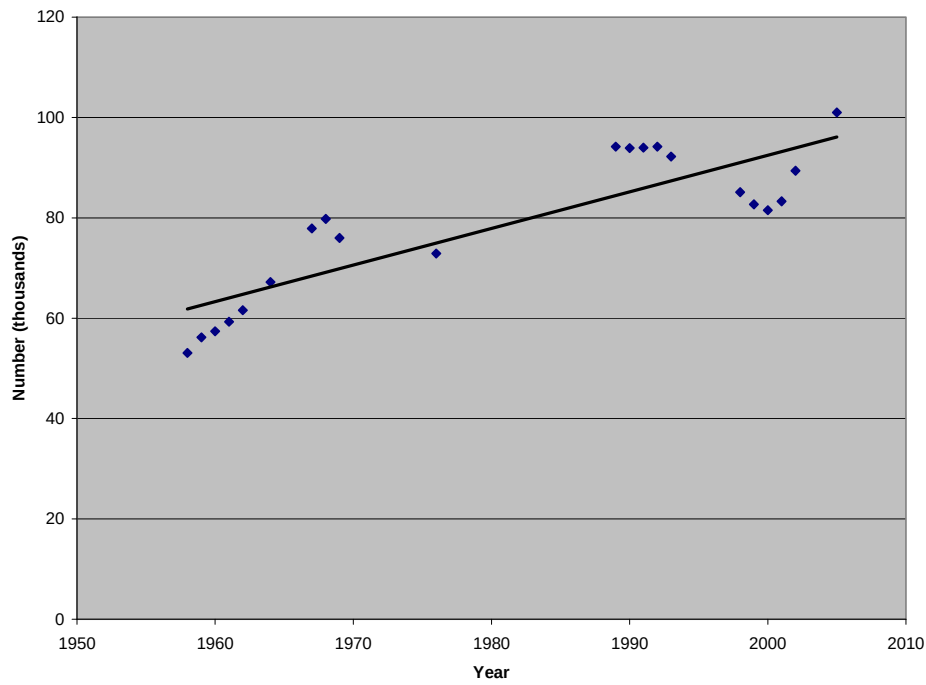
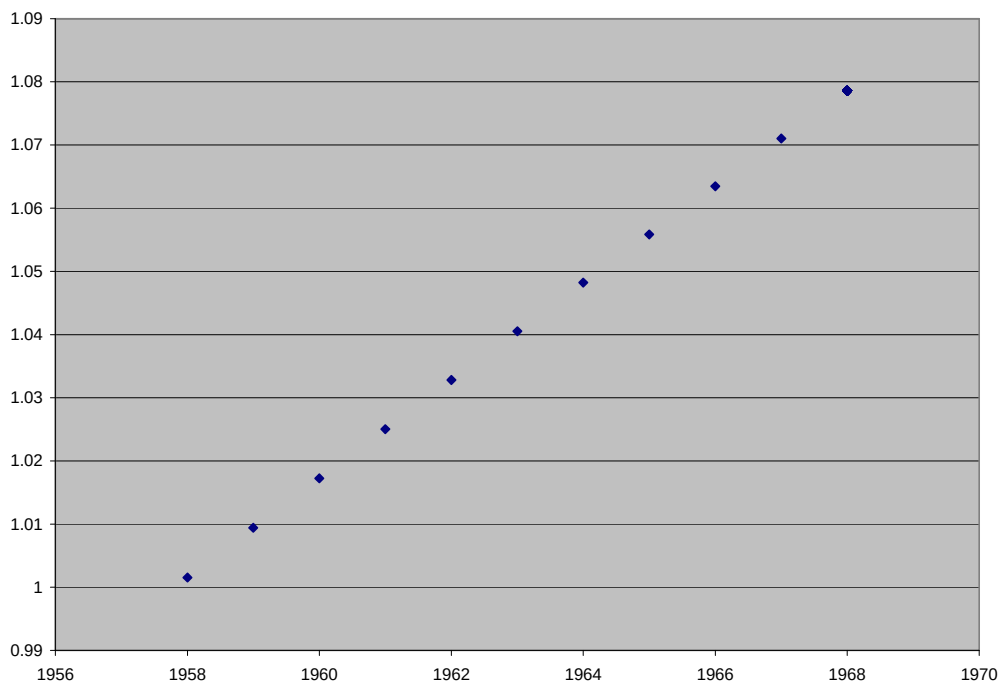


Figure 9. Ratio of Defense S&E workforce to Defense Program 1958-2005 Normalized to 1958



It is seen that the trend line DOD S&E workforce has increased, on average, slightly faster than the trend line defense base program but is basically tracking the program. It seems reasonable that the size of the DOD S&E workforce should track the defense program that it exists to support. However, this does not mean that all is well with the DOD S&E workforce. This becomes evident when one compares the evolution of the national S&E workforce with the DOD S&E workforce. Figure 10 summarizes the evolution of the U.S. S&E workforce from 1950 to 2000 and compares that with the DOD S&E workforce in 1960 and 2005. The chart categorizes occupations as Life Sciences, Physical Sciences, Engineering, Math and Information Technology (IT), and Social Sciences.

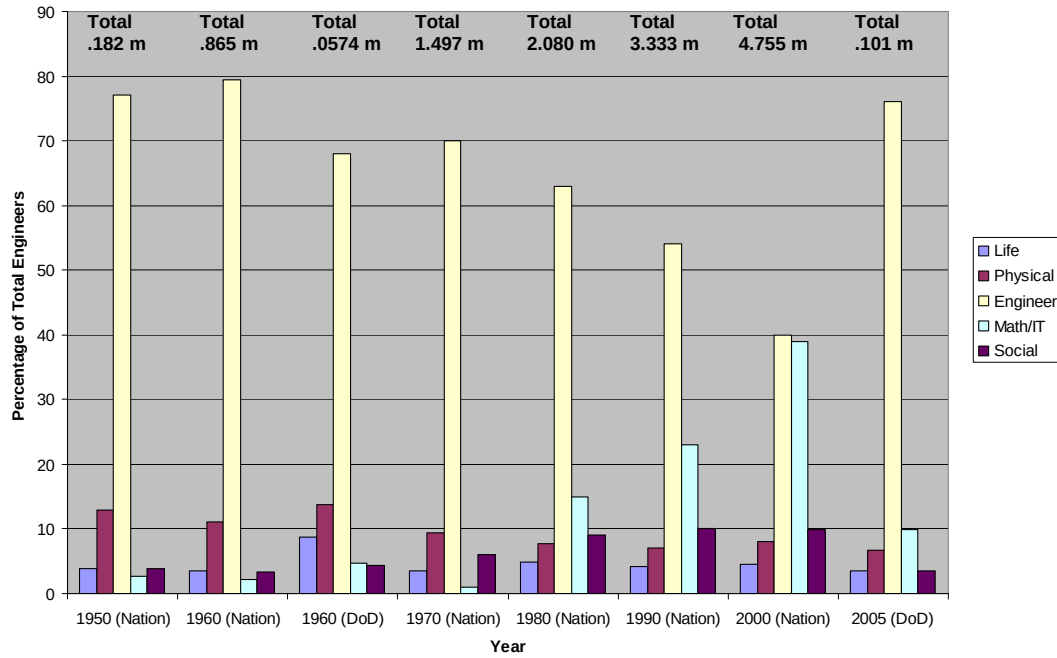
In 1960, the DOD S&E workforce was representative of the 1960 national S&E workforce. However, it can be seen from figure 10 that the DOD 2005 S&E workforce is more representative of the 1960 national workforce than it is of today's national workforce. The difference is especially noteworthy when one compares the engineering components and the math/IT components of DOD and the Nation. It should be recalled that IT was fledgling in 1960. From 1960 to 2000, the Nation roughly tripled its engineering workforce and increased its IT workforce by a factor of 100, resulting in about as many IT professionals as engineers by 2000. The Nation was able to exploit a growing economy to continue to grow its engineering workforce while radically increasing its IT workforce. The Nation increased its total S&E workforce over this period by a factor of 5.5. DOD was unable to do this, because its S&E workforce, on average, increased by a factor of 1.4 during this period. Since DOD has been a hardware/engineering focused organization, decisions were clearly made to accommodate the workforce constraints by predominately outsourcing its growing IT workforce needs. This resulted in an imbalance between engineers and IT professionals in DOD compared to the Nation. As a result, DOD now finds itself poorly positioned to understand the "art of the possible" in IT, an area that is having a rapidly growing impact on DOD programs. Recent studies have shown that a growing number of major DOD acquisition program problems are now IT-related. For example, it is estimated that 55 percent of military large software projects (100,000 FP size range) are terminated prior to completion.⁷ Some of this may be related to the imbalance regarding IT professionals in the DOD civilian workforce. In support of a possible connection to the lack of adequate IT expertise in the DOD S&E workforce, we note that the GAO has reported that IT programs with unrealistic objectives are established, requirements are poorly specified, and management and oversight of the programs are deficient.⁸ The GAO attributes the problem to management deficiencies. Another possible explanation is that it is due to lack of adequate DOD expertise in the appropriate scientific and technical disciplines that form the foundation of IT. This can result in bad technical decisions regarding which IT projects should be approved in the first place. When this happens, even the best managed programs will fail.

Historically, one of the important roles that the DOD civilian S&E workforce played was that of maintaining awareness of and developing competence regarding developments in the national and international S&E workforces. It appears that continuing that role is becoming increasingly problematic. The national S&T workforce grew at an annual rate of about 3.8 percent from 1970 to 2000. This is slightly faster than GDP growth during this period. However, the DOD S&E workforce followed the trend shown in figure 8. This means that the DOD S&E workforce has been declining exponentially with a negative growth rate of about 3.8 percent relative to the national S&E workforce. It is informative to extrapolate this trend to the 2040 time frame considered in this paper. To do this, we assume that the national S&E workforce will continue its past trend (i.e. growing slightly faster than the expected GDP), and the DOD S&E workforce will continue its historical trend. The result is shown in figure 11, which projects the DOD S&E workforce as a percentage of the national S&E workforce.

⁷ *Project Management Tools and Software Failures and Successes*, Capers Jones, Software Productivity Research, Inc., available at <<http://www.stsc.hill.af.mil/crosstalk/1998/07/tools.asp>>.

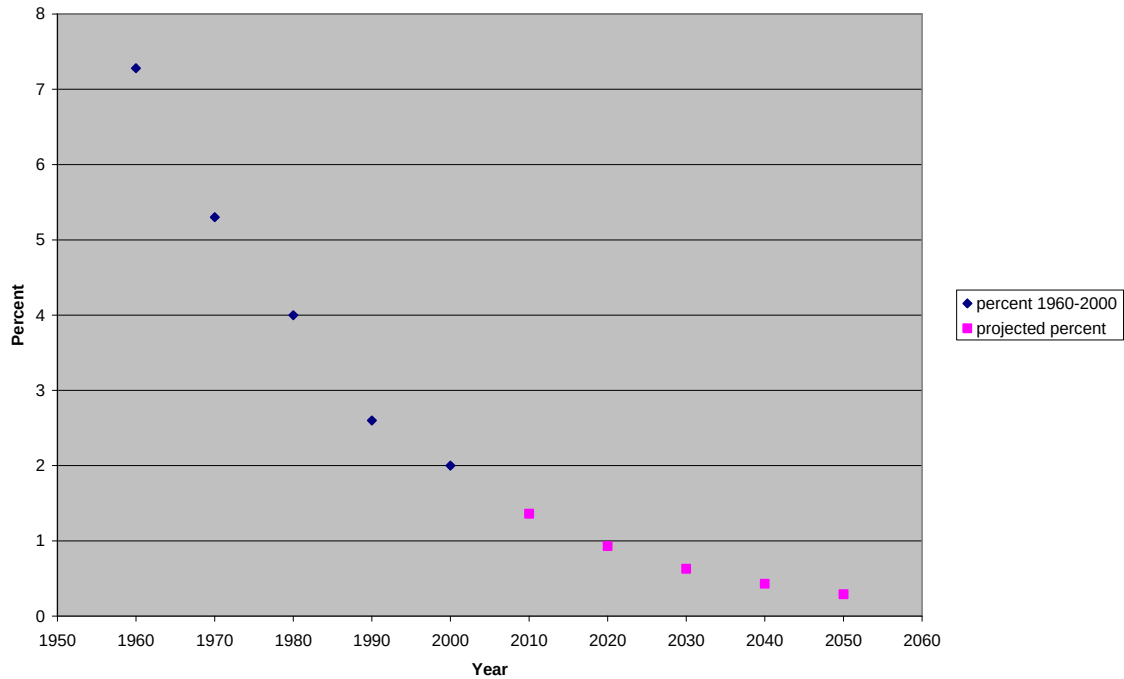
⁸ "Defense Acquisitions: Stronger Management Practices Are Needed to Improve DOD's Software-Intensive Management Acquisitions", GAO report to the Committee on Armed Services, 2004.

Figure 10. Scientist and Engineers by Occupational Group
(as percent of total)
Nation 1950 - 2000, DoD 1960 and 2005



Source: NSF, DOD-CPMS (for DOD 2005)

Figure 11. DOD S&Es as Percent of National S&Es



It is clear from figure 11 that, if past DOD practices continue, then the DOD S&E workforce will exponentially approach zero relative to the national S&E workforce. By 2040, the ratio will be about .5 percent. This has profound and disturbing implications regarding the ability of DOD to remain current in S&T developments and thereby to be able to predict and prepare for the impact of those developments on national security. It also has significant implications regarding DOD's ability to judge the merit of proposed scientific and technical work and to properly oversee work once it is funded.

The current situation regarding DOD civilian S&Es is analogous to placing an arbitrary, fixed cap on the number of scientists and engineers in the United States, and then expecting that the country will remain competitive in the global economy. Under such constraints, it would not be long before the United States lost touch with the state of the art in science and technology. It is a simple fact that, in S&T, one must be a serious player if one is to be taken seriously. This requires that the S&E workforce grows as S&T grows. DOD is no exception to this rule. An obvious question arises regarding how much of that DOD S&E workforce needs to be inside the Federal Government. On that question, analysis tends to give way to political, ideological, and marketing considerations. Politically, it has been very difficult to justify growing the DOD Federal workforce, even though the S&T that DOD depends upon has grown exponentially over the past 50 years. This growth has been accommodated by contracting so that the associated workforce growth would not show in the Federal workforce. As a short-term strategy this has been reasonable. However, the exponential behavior discussed above makes this a very worrisome long-term strategy. A point is eventually reached where no one is left "minding the store." Determining when this point is reached is difficult and is largely dependent on one's view of the proper role of government. At one extreme is a view that the government's role is primarily to move appropriated dollars to contract. In this view, the government adds no value to programs other than providing the administrative and accounting functions required by law. This view expects that the real value will be added outside of government where it asserts the competence to reside. It takes the position that the government cannot add serious scientific and technical value, because it cannot attract the required scientific and technical talent due to non-competitive salaries, stifling bureaucracy, etc. At the other extreme is a view that would have the government workforce bring defense systems to the point where they are ready to go into production, at which time the appropriate private sector contractors would be awarded "build to print" contracts.

The first extreme above is representative of contemporary trends, while the second extreme is more representative of the pre-WWII situation. Neither extreme is representative of the period from WWII through the mid 80s when most of the technology and systems that we now use were developed. DOD emerged from WWII with a very powerful and technically respected S&E workforce. That workforce resided primarily in the DOD laboratory system and in the various system commands. It understood how the government worked and the needs of defense organizations. It provided advocacy within government for the needed S&T efforts. It was also well integrated into the national S&T communities that, during most of that period, were important to DOD. It provided the government S&T "brain cells" for a national and international undertaking that became known as the defense-industrial complex. This complex, while often characterized in negative terms, was very effective in providing for the national defense. However, problems were evident as early as 1960, especially regarding the Federal Government's ability play its role in the complex. In 1962, these early concerns were captured in what became known as The "Bell Report."⁹ The panel included Director Bureau of the Budget David Bell; Secretary of Defense Robert McNamara; NASA Administrator James Webb; Chairman of the Atomic Energy Commission; Glenn Seaborg; and the Science Adviser to the President, Jerome Wiesner.

⁹ *Report to the President on Government Contracting for Research and Development* (Washington, DC: Bureau of the Budget, April 30, 1962).

Several of the Bell Report observations relevant to this discussion are:

- “...the developments of recent years have inevitably blurred the traditional dividing lines between the public and private sectors of our nation. A number of profound questions affecting the structure of our society are raised by our inability to apply the classical distinctions between what is public and what is private.”
- “We need to be particularly sensitive to the cumulative effects of contracting out Government work. A series of actions to contract out important activities, each wholly justified when considered on its own merits, may when taken together begin to erode the Government’s ability to manage its research and development programs... No matter how heavily the government relies on private contracting, it should never lose a strong internal competence in research and development.”
- “...the decisions which seem to us to be essential to be taken by government officials, rather than being contracted out to private bodies of any kind, are the decisions on what work is to be done, what objectives are to be set for the work, what time period and what costs are to be associated with the work, what results expected are to be, and the evaluation, and the responsibilities for knowing whether the work has gone as it was supposed to go, and if it has not, what went wrong and why, and how it can be corrected on subsequent occasions.”
- The Bell Report was not directed exclusively at scientists and engineers; however, it did recommend that government should “have on its staff exceptionally strong and able executives, scientists, and engineers fully qualified to weigh the views and advice of technical specialists,” and noted “a serious trend toward eroding the competence of the government’s research and development establishment—in part owing to the keen competition for scarce talent which has come from government contractors.”

The Rise of the “Shadow Government Workforce”

In the years since the Bell Report, there have been perhaps 100 blue ribbon reports that have repeated the concerns identified by the Bell Report. The trends identified by Bell have, however, continued unimpeded. Since DOD work must get done, a private sector workforce has assumed an increasing portion of the work that was traditionally performed by a government workforce. We will refer to this new workforce as the “shadow government workforce.” This shadow workforce is to be distinguished from the much larger private sector component of the defense-industrial complex that provides traditional goods (e.g., radar systems) and services (e.g., studies and analysis).¹⁰

The nature of the shadow workforce is different for the total DOD civilian workforce than it is for the subject matter expert DOD S&E workforce. We note from figure 7 that, for the 30 years from 1940 to 1970, the normalized ratio of the total DOD government civilian workforce to the DOD program remained above 70 percent. This suggests that the government workforce during this time was rational with respect to the DOD program, i.e., there was legitimate and necessary work being done by the government. The initial growth of the shadow workforce was a natural outcome of the decision to hold constant or decrease the total government workforce relative to the defense program. Since the work had to get done, contracts were let to provide support to the government workforce. Many of these early contracts manifest as Systems Engineering and Technical Assistance (SETA) contracts and as Technical

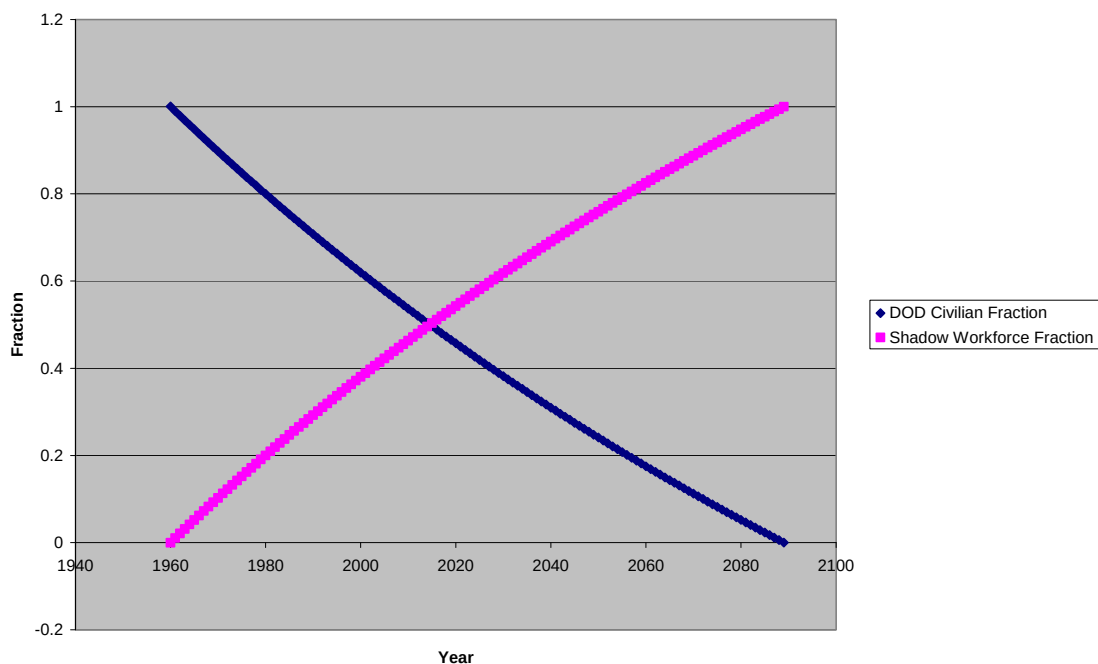
¹⁰ Paul C. Light, in *The True Size of Government* (Washington, DC: Brookings Institution Press, 1999) applies the term *shadow workforce* more expansively to all those employed by the government but not on the Civil Service rolls.

Engineering/Management Support (TEMS) contracts. Under these contracts, the contractor employees worked very closely with the Federal Government. These contracts were not to be personal services contracts, which would be illegal. However, the contractors often were co-mingled with government employees.

As the defense program grew and the government workforce declined, the support contractors necessarily assumed more functions and developed more expertise, and the government became more dependent on the support contracts to get its job done. By the mid 90s, the shadow workforce in defense had grown to a point where legal concerns arose regarding the co-mingling of the government and the shadow workforce. This resulted in an effort to physically separate the two workforces. When the shadow workforces moved to separate locations, the work they were performing still had to be done, so they took it with them thereby creating a “life of its own” for the shadow workforce independent of the government workforce it was initially created to support.

Since it is not accounted for explicitly, no one actually knows the present size of the shadow workforce. However, one can obtain a rough estimate by taking the ratio of the workforce trend line in figure 6 to the defense spending trend line in figure 1. If one normalizes that ratio to one in 1960 (when the issues raised by the Bell report began to become evident) then the resulting curve is indicative of the government workforce fraction of the total or de facto workforce. In this simple model the shadow workforce fraction is 1 minus the government workforce fraction. Figure 12 illustrates a crude estimate of the evolution of the government and shadow fractions of the DOD de facto civilian workforce.

Figure 12. DOD Total Civilian Workforce Fraction and Shadow Workforce Fraction



Since the trend line DOD government workforce is now about 752,000 (see figure 6), figure 12 suggests that the trend line shadow workforce is about 565,000 (i.e., 43 percent of the total) and is growing, while the government trend line workforce is declining. Within this model, the crossover point occurs in 2015. While the model used here is oversimplified, it is probably a reasonable approximation of the developing situation. In this regard, it is interesting to note that the GAO report on Selected Weapon Programs found that “About 48 percent of the DOD program office staff for programs GAO collected

data from is composed of personnel outside of the government.”¹¹ This development presents a potentially serious problem and has led to a growing concern regarding whether or not the government is any longer in charge of the defense program.

There is no mathematically rigorous way to determine the optimum fractions for the government and shadow workforces. This is ultimately a management and policy decision. DOD can, and as appropriate should, outsource as necessary to get its traditional government work done. This, however, does not provide DOD with a certificate of non-responsibility for the consequence of such a solution. The government remains responsible for the decisions and their consequences. This responsibility cannot be passed to the private sector. This suggests that the government should remain properly sized and competent to exercise the stewardship with which it is entrusted. The trends do not look encouraging in this regard.

The discussion above deals with the total DOD government workforce. The situation with respect to the DOD S&E workforce is more subtle than for the total workforce. It was shown above that the DOD S&E workforce has, on average, tracked the average defense program. Hence, the arguments earlier in this section do not apply. However, it is clear that a shadow S&E workforce must also have emerged due to the rapid growth in S&T in the national S&E workforce whose parallel did not occur in the DOD civilian workforce. The defense program is impacted by these national and international developments. A subset of the DOD S&E workforce should be responsible and positioned to provide the internal brain cells to permit DOD to remain aware of and develop competence in new S&T developments. To the extent that DOD does not develop the internal brain cells to deal with these developments, then it must rely upon external brain cells. This would result in a shadow S&E workforce whose size should be related to the results shown in figure 11.

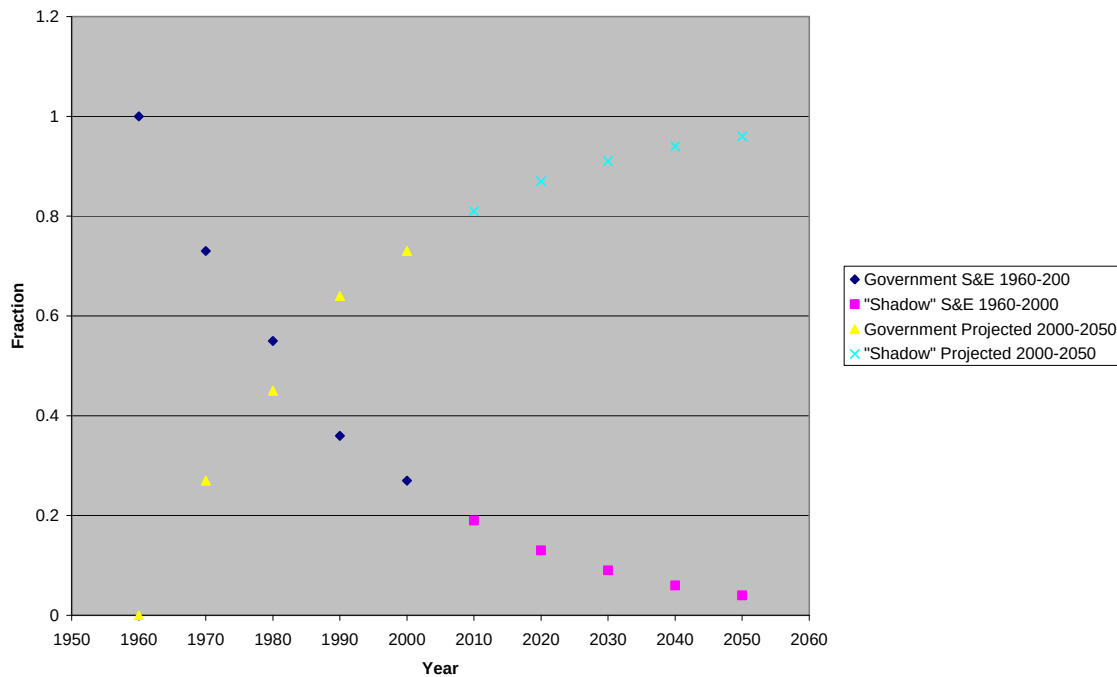
As the breadth and depth of science and technology grew relative to the internal expertise of DOD, then DOD must have become more dependent on external expertise, even in planning its program. If we assume that the subset of the DOD S&E workforce responsible for tracking emerging S&T remained a fixed fraction of the total DOD S&E workforce, then a simple estimate of the growing dependence on external expertise can be obtained just by normalizing the data in figure 11 to unity in 1960 and calling that the government S&E fraction and defining the shadow fraction to be one minus the government S&E fraction. The result is shown in figure 13. The fraction shown in figure 13 applies only to the subset mentioned above and not necessarily to the total DOD S&E workforce.

This simple estimate suggests that the shadow S&E workforce is far more advanced in its take-over of government decision making than is the shadow workforce associated with the total civilian DOD workforce. This unsurprising conclusion has to do with the very rapid rise of new technologies since 1960. Figure 13 suggests that the crossover point for the S&E workforce occurred in the 1980's. Figure 13 may overestimate the shadow S&E fraction. Nevertheless, figure 13 probably gives a reasonable picture of what is happening. DOD is simply not developing the government brain cells needed to keep up with the rapid advances in science and technology. It must, therefore, become more dependent on external brain cells in the formulation, selection and oversight of its S&T programs.

This has a direct bearing on the matter of the future DOD S&E workforce. It is likely that the development of emerging technologies will be rapid over the next 30 years, as was IT development over the past 30 years. It is also likely that these emerging technologies will significantly impact defense systems in the coming years, as did IT. If DOD manages its S&T workforce over the next 30 years as it did over the past 30 years, then it is quite likely that DOD will find itself in 2040 once again poorly positioned to exercise stewardship over areas of increasing importance to DOD missions.

¹¹ See, for example, “Is U.S. Government 'Outsourcing Its Brain?',” *Wall Street Journal*, March 30, 2007, and Dan Guttman, “The Shadow Pentagon: Private contractors play a huge role in basic government work—mostly out of public view” (Washington, DC: The Center for Public, February 2007).

Figure 13. Estimate of Defense Civilian S&E Fraction and "Shadow" S&E Fraction 1960-2050



This developing situation has serious implications for the DOD workforce (military and civilian), and for those in government (executive and legislative departments) who plan for this workforce. In particular, it is necessary to confront realistically the growth in the de facto government workforce. As the economy grows and the population grows, the demand for government services grows. That includes defense services. In a practical sense this means that, even after accounting for productivity improvements, the de facto government workforce grows. That growth can occur in the government workforce, in the shadow workforce, or in some combination of both. The approach of attempting to contain government growth by capping or reducing the government workforce is unrealistic. More importantly, it is irresponsible. Since the de facto government will grow as the economy and population grows, the current approach inevitably leads to a situation that places de facto control with those who are not accountable to the public. The government workforce is where the responsibility and accountability legally reside. That workforce requires sufficient numbers with sufficient competence and authority to undertake the planning, execution, oversight, and stewardship that the public deserves and should demand. On the other hand the shadow workforce is a practical reality. It is necessary to meet the government's obligations to citizens. What is needed is to establish the proper balance between the two workforces in both numbers and in the nature of the work that each performs. In this regard, some rules need to be established. Since the government is ultimately responsible and accountable, the shadow workforce should work in support of the government workforce rather than the other way around. Decisions regarding government programs and government directions should be government decisions. Therefore, while it is reasonable that the government should be as small as possible, it should also be no smaller than possible.

A Simple Strategy for the DOD S&E Workforce

The data and analysis presented above suggests that a strategy regarding the DOD S&E workforce is needed. Like the Nation, DOD needs to maintain and grow competence in areas of continuing interest and to make room to introduce competence in important emerging areas of science and technology and other areas. Figure 6 suggests that the DOD civilian workforce, like the defense program, can be viewed as a base program and a transient program. In a planned program it seems reasonable that the DOD civilian base workforce should track the defense base program, which is just the product of $P_b(t)$ and GDP (times 100). If one introduced such a model and chose, for example, FY 2003 as the year from which the future DOD civilian base workforce would evolve, then figure 4 would also represent the future DOD civilian base workforce when normalized to the number of employees in 2003. The actual size of the future workforce under such a model will depend on the value chosen for steady state value P_{ss} . In all cases, the DOD civilian base workforce would grow or shrink with the defense base program. The shadow workforce would do the same, but its fraction of the de facto government would asymptote over time to a value determined by P_{ss} .

Under the model suggested above, the DOD S&E base workforce would also track the defense base program. If a non-zero value of P_{ss} were chosen, this would, at some point in time, result, in the ratio of the DOD S&E base workforce to the national S&E workforce remaining constant. That ratio would be determined by the choice of P_{ss} . This would have the benefit of allowing the DOD S&T workforce to maintain competence in areas of long term interest and to direct some of the workforce growth to developing new competence in emerging areas of long term importance to DOD. The value selected for P_{ss} would determine the public sector, private sector mix of the de facto government.

Even in the case where $P_{ss} = 0$, it is still necessary for DOD to maintain a balance between competence in areas of long term interest and competence in areas of emerging interest. This will be difficult because, when $P_{ss} = 0$, it must be done in what is likely to be a fixed or even declining workforce. To date, DOD has allowed the size of its S&E workforce to track, on average, the defense program. However, the S&T discipline makeup of that workforce has not remained representative of the national workforce. Some scheme should be considered that could systematically remedy that problem. The organizations in DOD that are best positioned to remain current in their scientific and technical disciplines are the in-house performing activities. These include the warfare centers, the R&D Centers, and the Service corporate laboratories (Army Research Laboratory, Naval Research Laboratory, and Air Force Research Laboratory). About 40–50 percent of the DOD S&Es are employed by the in-house performing activities. On average, this amounts to about 50,000 S&Es. Of that number, about 13,000 are funded by S&T funds (i.e., funding categories 6.1 basic research, 6.2 applied research, 6.3 advanced technology development). Those employed to perform S&T would be best positioned to remain current on newly emerging S&T. In this regard, the Service corporate laboratories would seem best positioned to maintain awareness of the truly long term S&T. Collectively, they employ about 5,000 S&Es who are funded by S&T funds.

It appears from the above that the pieces are already in place to provide for a systematic, long-term renewal of the DOD S&E workforce. That renewal should have the objective of ensuring that the required expertise is in place across the RDT&E spectrum. At the acquisition end of the process, there should be available to the buying commands the technical expertise to prepare realistic technical specifications, to evaluate authoritatively those proposals that are being submitted in response to military needs at any time and to competently oversee those programs that are funded. Similarly, at the early emerging science and technology end of the process there should be in place an S&E workforce that has the expertise and competence to contribute to and maintain awareness of those early developments and is positioned such that those insights become part of the DOD long-range S&T planning process. Some of the required renewal can occur through normal turnover of personnel. Some renewal should occur as S&Es move from one part of the process to another. Some renewal may need to be imposed. One would expect that a

significant number of the S&Es employed at the acquisition end would come from the in-house RDT&E activities.

It would seem that maintaining adequate numbers, breadth, competence, and influence in the DOD in-house S&E workforce is in the best interest of DOD and the Nation. The trends that have emerged over the past 50 years indicate that a strategy needs to be put in place to achieve this objective. The strategy should include several tenets, among which are: maintain an adequate base level of S&Es that, on average, tracks the DOD program; evolve the S&T discipline makeup of the DOD S&E workforce over time such that it reflects the S&T discipline makeup of the national S&E workforce; task the Service corporate laboratories with the responsibility of maintaining awareness of and competence in newly emerging S&T disciplines; for newly emerging S&T disciplines that show promise for significant DOD application, grow competence in the performing activities beyond the Service corporate laboratories; expect that technical competence in new disciplines will migrate from the S&T (6.1, 6.2, 6.3) performing activities to the buying commands as these disciplines mature; establish a philosophy and introduce practices that bring the broad S&T competence of the DOD S&T workforce to bear on assessing the realism of proposed programs.

It has been said many times that there is no knowing without doing. This is especially true in science and engineering. If DOD is to maintain a competent and motivated internal S&E workforce, then a substantial fraction of that workforce must be involved in the actual practice of science and engineering in concert with the larger scientific and technical community. Otherwise, the needed expertise will not be sustainable. Those DOD S&Es who are not practicing S&Es should be well coupled to those who are. Furthermore, the funding of the DOD S&E workforce should be such that it does not create a potential conflict of interest regarding the scientific and technical advice that is sought from the workforce. The workforce should not be a potential direct beneficiary of the advice that it provides. In this regard, the growing tendency to view the in-house S&E performers as just another set of performers is troublesome, in that it potentially compromises the objectivity expected of the in-house S&E workforce. It undercuts the reason for having an in-house S&E workforce. There is a sound strategic reason for maintaining a competent cadre of practicing S&Es in DOD. The funding of that cadre should be a strategic decision rather than a byproduct of the market place. While there are various means available to fund the in-house S&E workforce (e.g. direct appropriation, Working Capital Fund, hybrid schemes), these various means should be used to account for funding and expenditures rather than as tools to manage the in-house S&E workforce. The growing tendency to view the in-house S&E workforce as just another set of performers suggests the absence of an understanding of why DOD (or the government) maintains in-house competence in science and engineering. In the absence of such an understanding, the competitive model provides a means to determine what the in-house workforce will do and at what level it will be funded. While the competitive model is very effective at making such determinations, it is not well suited as a tool for running the government. It hopelessly blurs the distinction between what is public and what is private, it puts the government in the awkward position of being in direct competition with its citizens, and it compromises the objectivity that the public should expect and demand of its government.

Stature of the Federal S&E Workforce

For the approach suggested above to be successful, it will be necessary for the DOD S&E workforce to be highly competent, properly positioned, and empowered to meet its responsibilities. This statement applies to the entire government workforce, but the particular interest here is the DOD S&E workforce. It is often asserted that the government cannot attract the talent necessary to be taken seriously and, therefore, that one must contract with parties outside government to obtain the needed talent. This assertion is often especially vigorous with respect to scientific and technical talent. It is certainly true that most S&Es are outside of government. That is as it should be. This situation, however, does not automatically result in the government's being unable to attract high quality S&E talent.

In this regard, it is interesting to inquire as to how those S&Es currently in government compare in stature and competence to similarly situated S&Es outside of government. While there is no rigorous answer to this question, there are, in science and engineering, indicators of stature and competence. These include, among others, publications in refereed journals and memberships in the National Academies [Academy of Science (NAS), Academy of Engineering (NAE) and Institute of Medicine (IOM)]. It is informative to look at how S&Es in and out of government compare with respect to these indicators. Tables 1 and 2 provide a comparison of three research institutions staffed by Federal Government scientists and engineers with several highly regarded research institutions staffed by non-Federal scientists and engineers. The three federally staffed institutions are the National Institutes of Health (NIH), the National Institute of Standards and Technology (NIST) and the Naval Research Laboratory (NRL). These organizations represent three separate Departments of the Executive Branch. The other institutions are Argonne National Laboratory (ANL), Brookhaven National Laboratory (BNL), Jet Propulsion Laboratory (JPL), Lincoln Laboratory (LL), Los Alamos National Laboratory (LANL), Lawrence Livermore National Laboratory (LLNL), and IBM Watson and Almaden Laboratories (IBM). The National laboratories have been chosen because their missions are similar to the three Federal labs, but they are not staffed by government employees. The IBM laboratories have been selected because of their high standing within the S&T community. Most of the institutions considered are comparable in size (within a factor of two), except NIH, which is much larger than the others.

Table 1 provides data regarding National Academies memberships held by these organizations. This table indicates that the institutions staffed by Federal Government scientists and engineers account for themselves quite well by this metric.

Table 2 provides data regarding the peer-reviewed open literature publications of several of the institutions and again indicates that Federal Government scientists and engineers account for themselves quite well.

Tables 1 and 2 suggest that today's Federal Government can and does employ government scientists and engineers who measure well against their non-Federal peer groups. While the three Federal Government organizations mentioned above may not be typical of all Federal Government institutions, they do prove the point that the Federal Government, under proper circumstances, can attract and retain the very best S&E talent. It is quite likely that the same is true in fields other than science and engineering. While not all S&Es are suitable for Federal employment, the three Federal organizations discussed above demonstrate that there is a sub-set of the Nation's best S&Es who, under the right circumstances, will flourish in government employment. The challenge is to find and recruit from that sub-set and to provide the proper "circumstances."

Table 1. National Academy Membership of Selected Federal Laboratories

Academy	ANL	BNL	JPL	LANL	LL	LLNL	IBM	NIH	NIST	NRL
NAE	3	2	6	4	1	3	17	0	10	5
NAS	3	9	0	5	0	0	11	50	5	3
IOM	0	0	0	0	0	0	0	87	0	0
Total	6	11	6	9	1	3	28	137	15	8

Source: National Academies Website

Table 2. Peer-Reviewed Publications 2003

Organization	ANL	BNL	JPL	LANL	LLNL	NIH	NIST	NRL
Articles	1023	761	705	1526	1038	4305	350	957

Source: Science Citation Index Search

Part of the success of the three Federal institutions mentioned above lies in their recognition that the income that motivates people comes in two forms: real income and psychic income. Real income deals with items such as pay and benefits. Psychic income deals with items such as importance and potential impact of program, resources available to program, quality of colleagues, quality and capability of facilities and quality of life. The government has always been, and will always be, at a disadvantage regarding real income. However, Federal pay and benefits can and have remained above the minimum level necessary to attract and retain the needed talent. Once that minimum level is achieved, then psychic income plays an increasingly important role in attracting and retaining scientific and technical talent. It is clear that the Federal Government, if it chooses, can be very competitive in the area of psychic income because the work it can offer is important and it can provide significant resources and excellent facilities to accomplish that work. These are key attributes for attracting first class S&Es. Another contributing factor in the success of the three Federal institutions was that the agencies to which these institutions report have historically valued their work and have drawn upon their scientific and technical expertise and advice in the exercise of agency stewardship. This is the way that it should be. An organization will not retain first rate S&Es if their advice, expertise and insights are not valued.

Historically, these government institutions and others like them have been a source of scientific and technical talent for filling agency leadership positions such as senior acquisition program managers. This was a useful practice since it provided program managers who had hands on scientific, engineering and government experience and positioned those program managers to easily draw upon the technical talent and advice of the institutions from which they came. This arrangement provided the government's scientific and technical brain cells with regard to acquisition programs. Unfortunately, this situation has changed as the events described earlier unfolded. A recent independent review noted that "Increasingly Pentagon leadership is losing its ability to tell the difference between sound and unsound decisions on innovative technology and is outsourcing key decision-making as well."¹² The review went on to note that in 1974 over half of those managing the acquisition of Air Force systems held engineering degrees while in 2001 that percentage had dropped to 14 percent.

It is interesting to note that failed or troubled DOD and other government programs are often attributed to bad management when, in fact, in many cases the decisions to enter the programs in the first place were simply bad technical decisions. The responsibility for these technical decisions is the government's rather than that of the private parties that sold the programs to the government. DOD should develop, sustain, and listen to a DOD S&E workforce that has the "ability to tell the difference between sound and unsound decisions on innovative technology." This will be especially important regarding emerging fields of S&T.

The 2040 S&E Workforce

The previous sections of this paper have provided some background on the evolution of the national and DOD S&E workforces. They also discussed several scenarios for projecting the defense program and the related workforce into the future. This section will build upon those discussions to provide estimates of the 2040 S&E workforce and issues associated with developing that workforce. In this regard it is helpful

¹² *Missile Defense, the Space Relationship, and the Twenty-First Century* (Cambridge, MA: Institute for Foreign Policy Analysis, 2006), available at <<http://www.ifpa.org/publications/TWGReport.htm>>.

to examine the past evolution of this workforce. Figure 10 indicates that, during the period 1970-2000, the total number of scientist and engineers supporting the US GDP underwent an annual growth rate of about 3.85 percent. This is slightly faster than the typical GDP growth rate. In a mature, technically advanced economy, it seems reasonable that the S&E workforce would roughly track GDP, because that workforce exists to support that GDP. If one assumes that the future S&E workforce will roughly follow GDP, then figure 10 suggests that the S&E workforce of 2040 will employ about 18 million scientists and engineers. During the 1970–2000 period, the total number of scientists (Life plus Physical) remained relatively stable at about 13 percent of the S&E workforce. Based on this data we will assume that this trend will continue. The major change that occurred during this period was the rapid growth in the Math/IT category. This occurred mainly at the expense of the engineering category. It seems unlikely that this trend can continue much longer. Indeed, if the Math/IT category continues to grow as it has over the past 30 years then it will employ about 52 million people by 2040. This exceeds by nearly a factor of three the projected number for all S&Es in 2040. This suggests that the current growth rate for the Math/IT category is not sustainable. The mix of engineers and math/IT professionals must come into equilibrium soon. Therefore, for the purpose of this projection at the S&T category level of description it is assumed that there will be no radical changes beyond the 2000 relative percentages of scientists and engineers employed in the workforce at large over the next 30 years. Under this assumption one can construct table 3 to estimate the makeup of the 2040 S&E workforce for the Nation.

Table 3. Projection of all S&Es employed in scientific and engineering work in 2040 using the 2000 percentages shown in figure 4

S&E Category	2000 (millions)	Number	% of Total	2040 (millions)	Projection
Scientists (Life & Physical)	.61		13	2.34	
Engineers	1.92		40	7.2	
Math/Information	1.88		40	7.2	
Social Scientists	.347		7	1.26	
Total	4.757		100	18	

The 18-million-person total is reasonable based on historical GDP growth. The split among the S&E categories is likely to be much less accurate but nevertheless does give some indication of the number of individuals that must be educated over the next 30 years. The next step is to construct a similar table for the 2040 DOD S&E workforce.

The DOD civilian 2040 S&E workforce will depend on how DOD manages its S&E workforce over the next 30 years. There are several scenarios that could develop. For illustrative purposes, we will consider three scenarios. In the first scenario DOD and the Congress allow the S&E trend shown in figure 8 to continue over this period. In this scenario the total DOD civilian base S&E workforce in 2040 will be about 107,000. This would be about one half of one percent of the expected national S&E workforce at that time. We will call this the “Status Quo” projection. The actual number would be greater or less depending on what the transient contribution was at that time.

In the second scenario DOD and the Congress maintain the ratio of the total DOD civilian base S&E workforce to the national S&E workforce at its present value of two percent. In this scenario the 2040 DOD civilian base S&E workforce would be about 321,000. We will call this the “Two Percent for all S&Es” projection. Again the actual value would depend on the transients in effect at the time. The two-percent solution as calculated would make sense only if the DOD base program remained fixed at two percent of GDP. Otherwise the DOD S&E workforce would get out of balance with the DOD program.

In the third scenario we allow the 13,000 S&E workforce funded on S&T to maintain its 2005 percentage of the national S&E workforce. This would result in 2040 DOD S&E workforce of about 140,000. In all scenarios, we will assume that DOD will strive to achieve an S&E category breakdown

that is representative of the national breakdown shown in table 1. Under these assumptions the 2040 DOD civilian base S&E workforce category breakdown for each scenario is shown in table 4.

Table 4. Projection of S&Es in the DOD civilian base workforce of 2040 under the “Status Quo,” “2% all S&Es” and “2% S&T Only” scenarios and that the DOD S&E workforce is representative of the 2040 national S&E workforce breakdown projected in table 3

S&E Category	2005 Number (thousands)	2040 “Status Quo Projection (thousands)	2040 “2% Projection All S&E (thousands)	2040 “2% Projection S&T Only (thousands)
Scientists	10.6	14	41.7	18.2
Engineers	77	42.8	128	56
Math/IT	10	42.8	128	56
Social Science	3.7	7.4	22.5	9.8
Total	101	107	321	140

The difference between the “Status Quo” approach and the “Two Percent for all S&Es” approach is somewhat startling when looked at after 30 years. It would require tripling the current DOD S&E base workforce. This would be difficult to justify, unless the DOD base program grew by the same amount. The S&T only scenario would result in about a 30 percent increase in the S&E base workforce which, while substantial, would be more manageable. These required increases illustrate the problem that DOD faces regarding maintaining technological superiority in a world in which science and technology will advance rapidly. While the problem may be difficult, it is not one that DOD can afford to neglect. It is unlikely that the science and technology of interest to DOD will suddenly stagnate. A strategy needs to be put in place that provides DOD with the ability to independently, objectively and authoritatively identify important emerging science and technology, to independently, objectively and authoritatively assess the realism of proposed programs and to independently, objectively and authoritatively oversee those programs that are funded.

A large number of DOD S&E vacancies will occur over the coming years due to the much discussed retirement of the “baby boom” generation. This creates an excellent opportunity to renew the DOD S&E workforce (and the DOD workforce in general). Recent studies indicate that a significant number of young people would seriously consider Federal jobs.¹³ This interest is especially high regarding jobs that provide intellectual challenges and the opportunity to innovate and exercise creativity. These are criteria against which DOD S&E positions should fare very well.

Conclusions

Since WWII, the U.S. defense program, on average, has shown slow but real growth while the total DOD civilian workforce, on average, has shown a significant decline. This has led to the emergence of a shadow workforce in the private sector to compensate for the government workforce draw down. There is a growing concern that the size of the shadow workforce may soon dominate the government workforce thereby raising questions about whether or not the government is in charge of its own program. During the same period, the DOD S&E workforce, on average, has shown real growth similar to the real growth in the average defense program. However, an examination of the DOD S&E workforce indicates that its makeup in terms of scientific and technical disciplines is not representative of today’s national S&T

¹³ See, for example, <www.avuetechnology.com/young-people-do-want-be-feds-only-certain-agencies>.

workforce. This raises concerns about DOD's ability to judge the "art of the possible" regarding the new technologies that have emerged over the past few decades.

There are several additional and disturbing trends evident at this time. For example, on average, the defense program is approaching zero exponentially when measured relative to GDP while total Federal outlays, on average, have been increasing relative to GDP. Furthermore the DOD civilian S&E workforce is approaching zero exponentially relative to the national S&E workforce. As a result of this there has emerged a significant shadow S&T workforce that is providing DOD brain cells regarding new developments in science and technology and thereby new directions for defense.

Most of these developments are simply the result of the various tradeoffs needed to get the government's business done. However, there are a number of significant potential negative consequences of allowing these trends to continue indefinitely. For example, if the growth in total Federal outlays should accelerate due to problems in areas such as Medicare, Social Security or servicing the national debt, then it could become difficult under the current trends to maintain defense readiness. Furthermore, if the DOD civilian S&T workforce continues to decline relative to the national workforce, a point will be reached where it becomes irrelevant. It will not be able to renew itself. It will not be able to maintain competence in newly developing fields of science and technology while at the same time maintaining competence in the traditional fields which will still be important to DOD. This could result in the government not being able to distinguish a good S&T proposal from a bad one or to competently oversee S&T work that has been funded. In addition, the DOD S&T workforce will not be able to provide compelling advocacy within the government for important new S&T initiatives that are derivative of newly emerging fields.

At some point these trends need to be addressed such that DOD does not reach a subcritical state in its program, its total civilian workforce, and its S&T civilian workforce. Since defense outlays are becoming such a small fraction of the national economy, dealing with these trends appears to be more of a political issue than an economic issue. One method of addressing some of the concerns would be to establish a floor for the average defense program when measured relative to GDP. This floor would need to be small enough to be acceptable to the economy and large enough that it can maintain readiness. If this is done then many of the concerns become resolved. The total DOD workforce and the shadow workforce can, on average, be maintained in a desired balance. The DOD S&T workforce, on average, can be maintained at a fixed percentage of the national S&T workforce thereby allowing opportunities to grow government competence in emerging fields of S&T while maintaining the necessary competence in existing fields of S&T. However, for this to happen, the current practice of appearing to control government growth by artificially constraining the DOD workforce would need to be abandoned and replaced by a strategy that controls the size of the average DOD workforce in accordance with the size of the average defense program. Under this approach the total defense program (and workforce) at a particular time would be the sum of the average plus the transient terms (which will be positive or negative) associated with dealing with particular transient events in play at that time.

In addition to ensuring that there are adequate numbers of DOD S&Es, it is equally important that the scientific and engineering discipline makeup of that workforce is representative of the scientific and engineering makeup of the national S&E workforce. This is especially true for that component of the DOD S&E workforce that is responsible for tracking and developing competence in areas of emerging science and technology.