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MITRE TECHNICAL REPORT

MITRE

Performance Management at R&D Organizations

Practices and Metrics from Case Examples

Carolyn Kahn
Sheila McGourty

In support of:

- *FY 2009 Sponsor Performance Management Investigations (POCs: K. Buck and M. Steinbach)*
- *FY 2009 CEM Stakeholder-Driven Performance Management MOIE (POCs: L. Oakley-Bogdewic and K. Buck)*

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Abstract

Performance management supports and enables achievement of an organization and/or program's strategic objectives. It connects activities to stakeholder and mission needs. Effective performance management focuses an organization or program to achieve optimal value from the resources that are allocated to achieving its objectives. It can be used to communicate management efficiencies and to show transparency of goal alignment and resource targeting, output effectiveness, and overall value of agency outcomes or progress toward those outcomes.

This paper investigates performance management from the perspective of research and development (R&D) organizations and programs. R&D organizations face unique performance management challenges, including difficulty in measuring performance, lack of timely data, and the many unknowns associated with R&D efforts including lack of clarity of the initial scope of many projects. The study team researched performance management for R&D organizations in the commercial and government sectors. The paper provides insight into performance management as it relates to R&D, science and technology (S&T), and intelligence communities. It examines practices of commercial and government R&D organizations and programs and presents eleven case studies, including five from commercial industry and six from government. Organizations are increasingly using both quantitative and qualitative measures to manage performance and improve sustainable value. The paper provides example metrics used by commercial and government R&D organizations and programs. Many view R&D as an essential means to achieving increased knowledge and innovation to provide a competitive advantage. Government organizations should choose a suite of performance metrics consistent with their specific missions and goals.

Performance management that is properly implemented with management support and active employee involvement is a powerful tool for the enterprise. Internally, it cultivates a holistic, long-term view of the organization. It helps an enterprise stay focused on attributes of success and failure to achieve the organization's goals and deliver meaningful results. Externally, it communicates management efficiencies, transparency of goal alignment and resource targeting, output effectiveness, and overall value of agency outcomes or progress toward those outcomes. R&D organizations should be allowed flexibility to design and implement a performance management process aligned with their mission, goals, and objectives that can be systematically implemented with management support and active employee involvement to convey the true value of performance to the enterprise.

Acknowledgements

The authors would like to thank Mary Przewlocki for her significant research investigations and Kevin Buck, Frank Dello Russo, Lisa Oakley-Bogdewic, and Michele Steinbach for their guidance and helpful reviews. Their efforts contributed to this study.

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1 Introduction

Performance management is conducted for many types of organizations. Yet programs differ by purpose, design, administration, budget, goals, performance, and type. One useful definition of R&D organizations comes from the Office of Management and Budget's (OMB's) Program Assessment Rating Tool (PART): R&D consists of "programs that focus on knowledge creation or its application to the creation of systems, methods, materials, or technologies."[1]

The MITRE Corporation (MITRE) conducted an investigation of performance management from the perspective of R&D organizations and programs. The study team researched performance management for R&D organizations in the commercial and government sectors. Following this introduction, Section 2 of the paper presents background information on performance management as it relates to R&D, science and technology (S&T), and intelligence communities. Section 3 describes practices of commercial and government R&D organizations and programs. Eleven case studies are presented, including five from commercial industry and six from government. Section 4 discusses example metrics for R&D organizations. Concluding remarks are provided in Section 5.

2 Performance Management[2]

Performance takes place at organizational, program, and individual (execution) levels.[3] Performance management must include, and link across, each of these interrelated levels. There are many reasons to manage performance in an organization, including the opportunity provided for creating or improving accountability and transparency, user choice, customer service, efficiency, results or effectiveness, an informed means for resource allocation, and a way for showing the creation of public value.[4] However, ineffective performance management can be riddled with imperfections and shortfalls,[5] including: incompleteness; over-complexity; high transaction costs; problems of attribution; unclear differentiation between quantity versus quality; opportunity for manipulation and deception; unintended distorted behavior and consequences; cyclical incompatibility; measurement degradation over time; and the inability to control for political pressures as drivers for the public programs.

[1] "Guide to the Program Assessment Rating Tool (PART)," Office of Management and Budget, January 2008.
[2] Dr. Oakley-Bogdewic, Lisa, Carolyn Kahn, and Kevin Buck, "Recommendations for the Program Assessment Rating Tool (PART)," The MITRE Corporation, Stakeholder-Driven Performance Management Mission Oriented Investigation and Experimentation (MOIE), April 2009.
[3] Colin Talbot, "Performance Management," The Oxford Handbook of Public Management," UK: Oxford University Press, 2005.
[4] Ibid.
[5] Ibid.

Most of these potential shortfalls with performance management can be characterized as barriers to productivity improvements that are pervasive in the public sector.[6] Effective performance management minimizes such potential shortfalls and also brings them to the attention of management so that the eventual indicators of results are meaningful to both the program and its stakeholders. Indeed, these shortfalls should not undermine the importance of performance evaluation at organizational, program, or individual levels.

Performance management supports and enables achievement of an organization and/or program's strategic objectives. It connects activities to stakeholder and mission needs. Effective performance management focuses an organization or program to achieve optimal value realized in public good outcomes from the resources and programs that support this value. It can be used to communicate management efficiencies and to show transparency of goal alignment and resource targeting, output effectiveness, and overall value of agency outcomes or progress toward those outcomes. The remainder of this section provides background information on performance management as it relates to R&D (Section 2.1), S&T (Section 2.2), and the Intelligence Community (Section 2.3).

2.1 Performance Management for Research and Development

Traditional performance measurement activities apply clearly defined measures to evaluate performance outcomes. They explain acceptable performance, and the data provides timely information on performance. An R&D environment poses particular challenges. First, in an R&D environment, performance is difficult to measure and the outcome of R&D activities often cannot be quantified in advance. Some benefits may be monetizable (i.e., measured in units of currency such as dollars), while others likely are not. Second, the timeliness of the data is a concern because of the often long time span (e.g., several decades) between starting an R&D effort and realization of those benefits. Third, in R&D there are many unknowns, which cannot be measured, as well as generally higher risks of failure.

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There is typically a tradeoff between near-term investment to fund operations and long-term investment important to developing capabilities to meet future challenges. A Defense Science Board Task Force surveyed industry in 1998 to learn more about their research investments. The

[6] Barriers may be characterized as environmental, organizational, or personal. David N. Ammons, "Productivity Barriers in the Public Sector," extracted from Marc Holzer, editor, Public Productivity Handbook, NY: Marcel Dekker, Inc., 1992, pp. 117-136. Environmental barriers include: absence of market pressures, political influence, public's dual impatience for results and resistance to change, short time horizons of politicians, productivity's lack of political appeal and subordination to secondary status, civil service and legal restrictions, unfunded mandates. Organizational barriers can include: bureaucratic socialization process, lack of accountability, unclear reward system, inadequate management commitment, union resistance and job security, ambiguous objectives, reluctance to abandon, insufficient skills, absence of cost accounting, inadequate performance data or evaluation processes, inadequate data sharing, fragmentation of government and authorities, requirements of large investments for productivity improvement efforts, performance myths from overselling productivity. Personal barriers can include: conceptual confusion, risk avoidance, and inadequate managerial control.

most successful industries invested about 15% of sales in R&D with about 3.5% of sales in research.[7]

R&D aims to grow capacity (i.e., mental abilities) and knowledge. From the macroeconomic point of view, when money is moved into certain areas of research, there is historically a secondary movement in the percentage of experts (e.g., PhD candidates) in those areas. Despite the longstanding interest in increasing accountability of R&D programs, there are relatively few models that program managers can follow to evaluate the effectiveness of R&D.

2.2 Performance Management for Science and Technology

The terms "R&D" and "S&T" are sometimes used interchangeably, but they refer to different budgetary classifications within the US federal government. R&D comprises creative work undertaken on a systematic basis to increase knowledge. S&T includes activities aimed at generating, advancing, disseminating, and applying scientific and technical knowledge in the fields of natural sciences, engineering, technology, medical sciences, agricultural sciences, social sciences, and humanities. S&T programs are vital to an R&D organization's development of technical capabilities.

> ***S&T programs are vital to an R&D organization's development of technical capabilities.***

S&T is difficult to measure in a meaningful way. Government S&T does not sell its products. There are long delays between when S&T shows feasibility and when a technology is actually used to enable an operational capability. Yet there is growing emphasis on applying rapid development and acquisition techniques to quickly field solutions developed in labs, and address the production, sustainment and supportability of these solutions later. S&T is responsible for enabling the warfighter and solving unanticipated problems quickly. How much S&T investment is enough? What S&T has transitioned to the warfighter lately? Answers to these questions help assess the return of the investment.

2.3 Performance Management and the Intelligence Community

The Intelligence Community (IC) is large, diverse, complex, and performs a broad range of activities. It is impractical for any management system to be equally applicable or useful to all of its organizations. The applicability of performance management to the IC is contentious. Many believe that IC failures are not the result of poor management practices. The output of an intelligence service is difficult to define, let alone quantify. Performance management is often mandated from above with limited or no involvement from organizations and personnel who perform the mission and are most knowledgeable about appropriate performance measures and outcomes. Therefore, performance management should not be applied indiscriminately across the IC; rather, it should be customized to fit, and benefit, a specific organization or program.

> ***Performance management should not be applied indiscriminately across the IC; rather, it should be customized to fit, and benefit, a specific organization or program.***

Within the IC, performance management is particularly valuable to Scientific and Technical Intelligence (S&TI). S&TI is critical to policy makers, warfighters, and the acquisition community, and it is important at the national strategic level as well as at the military strategic, operational, and tactical levels of war. Many of its characteristics and performance are

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[7] Harman, Wayne, and Robin Staton, "Science and Technology Metrics and Other Thoughts," Naval Surface Warfare Center, Dahlgren, Virginia, July 2006.

often quantifiable, and S&TI comprises many engineers and scientists comfortable with the processes and statistics required by performance management.

It can help create an environment where researchers and research can flourish. Performance management can benefit the IC by questioning current practices, identifying and optimizing processes, removing inefficiencies, and increasing employee motivation and collaboration. IC personnel are not rewarded by a truly merit-based compensation system. Daily activities and operational decisions can be linked to results. More effective and efficient outcomes that are aligned internally and externally can be selected, measured, and monitored. Without sufficient planning and effective communication of performance management requirements and delineation of roles/responsibilities, there is a real concern that performance management will be viewed as another reporting requirement and not a true management tool.

A performance management system that is properly implemented with management support and active employee involvement can potentially become a very powerful management tool.

3 Practices of R&D Organizations

MITRE investigated performance management practices of R&D organizations. Section 3.1 portrays commercial industry practices, and Section 3.2 describes government practices. Eleven case study examples are provided, including five from commercial industry and six from government. Additional information is available in Appendix A.

3.1 Commercial Industry Practices

A growing body of evidence suggests that just as companies are facing an ever increasing pace of technological change, their rate of investment in R&D is undergoing close scrutiny and firms may not respond effectively to the scrutiny.[8] In addition to this, the traditional performance metrics that have been used by commercial industry tend not to be the best fit for measuring or analyzing the work that is done by R&D business units. For example, oftentimes financial metrics are used to measure the value of investments made by a corporation over the short-term. Return on Investment (ROI) is the most common financial metric. However, the nature of R&D projects is such that the true value or return may not be realized for many years when planning, development, and roll-out phases are taken into account. Controversy also develops among management when decisions are being made about funding future projects. Since short-term projects have greater discounted cash returns on research investment costs, any R&D projects that may have a longer life could be ruled out due to cost concerns.[9]

This has led to an "apples to oranges" scenario where the performance metrics being used to measure the investment's progress may not be the best fit and, therefore, the true value of the R&D investments might not be correctly represented. Commercial companies are increasingly using non-financial measures to manage performance and improve sustainable business value, including such factors as engagement and leadership. In other cases, they are using different hurdle rates, or minimum acceptable rates of return, and creating separate budgets for R&D

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[8] Kirchhoff, Bruce, Steven Walsh, Matt Merges, and Joseph Morabito, "A Value Creation Model for Measuring and Managing the R&D Portfolio," Engineering Management Journal, March 2001.
[9] Ibid.

investments so that R&D projects do not compete directly with other business investments. What follows are several examples from commercial industry - Lucent Technologies, Xerox, Hewlett-Packard, and IBM - detailing new ways to measure and analyze performance in companies or business units whose sole focus is R&D.

3.1.1 Lucent Technologies

Lucent Technologies developed a decision support model called the Value Creation Model (VCM) in an attempt to better measure the operations of its Advanced Technologies (AT) Group's R&D Operations. At the time it was rolled out in 1997, Lucent had applied the model to a portfolio of over 500 research-driven innovation projects that required up to five years to transition from invention to commercialization. The projects were investment intensive, spanned numerous market settings and were composed of a wide array of differing, and often emerging, technologies.[10]

The major component of the VCM is the Portfolio Value Metric (PVM) which is defined as the ratio of the NPV of expected future cash flows resulting from the commercialization activities attributed to the NPV of the R&D expense. In addition to the PVM, a risk calculation can also be generated for individual projects or portfolios. The parameters for a triangular distribution[11] are created from three (pessimistic, realistic and optimistic) cash flow estimates for each project. The resulting calculation of risk is then displayed as a histogram projected by the VCM.[12]

Although the PVM could be categorized as a financial metric the VCM analysis includes six other qualitative, non-financial, attributes from the following four categories:

- Strategic Initiatives
    - e.g., an internal strategic initiative that dealt with broadband technology
- Market Categories
    - e.g., the market category of the investment itself, the life cycle stage of the market
- Intellectual Property
    - e.g., category of intellectual property, the life cycle stage
- Business Units
    - e.g., business units from Lucent's internal organizational structure that are supported by the particular R&D project

These additional qualitative metrics serve to create a more well-rounded measurement of the investment or portfolio performance. Analysis of the qualitative data, due diligence on multiple estimate scenarios (i.e. pessimistic, realistic and optimistic), and linkages of projects to other key initiatives and business units within the company all serve to provide Lucent management with much more data to base future decisions. It also allows the managers within Lucent's AT Group to better defend their past work and to make a stronger argument for why funding should continue in the future.

Lucent ties potential R&D investments to strategic initiatives at the outset.

3.1.2 Xerox

[10] Kirchhoff, Bruce, Steven Walsh, Matt Merges, and Joseph Morabito, "A Value Creation Model for Measuring and Managing the R&D Portfolio," Engineering Management Journal, March 2001.
[11] A triangular distribution is typically used as a subjective description of a population, often in cases when only limited data is available. It is a continuous probability distribution with a lower limit (minimum), upper limit (maximum), and modal (most likely) value.
[12] Walsh, Steven, "Portfolio Management for the Commercialization of Advanced Technologies," Engineering Management Journal, March 2001.

Like many large and mature technology-based firms, Xerox employs a budgeting process for R&D. Its internal process uses a key planning metric for the coming year, which it calls "R&D intensity." This metric is defined as the planned R&D investment divided by the anticipated revenue. The R&D intensity metric is periodically compared to competing firms, and it is kept relatively constant year over year.

Similar to other large technology firms, Xerox organizes its R&D budget into two main parts: product development and research laboratories. Approximately 80% of the total R&D budget is allocated to product development and managed by the business divisions. The remaining 20% is distributed to its research laboratories and is controlled at the corporate level.

Xerox makes tactical cost adjustments and reconsiders any strategic implications at the beginning of the next planning cycle.

The annual process for determining the next year's R&D budget coincides with the corporate-wide budget activities and is tightly aligned with projected revenues and profits. The specific R&D budget is created by categorizing those requests that fall under the scope of product development versus research laboratories, being sure to identify the number of years anticipated for the realization of the investments. Based on the current and anticipated economic environment, updated financial targets are established for the following year and costs across the corporation are adjusted to meet the new values. Unlike the model at Lucent which ties potential R&D investments to strategic initiatives at the outset, these cost adjustments at Xerox are tactical; any strategic implications are reconsidered at the beginning of the next planning cycle. Any decision to increase R&D spending is usually tied to next year's anticipated revenue, with revisions possible depending on short-term affordability. This approach implicitly assumes that the R&D budget followed revenue and profit growth, rather than driving it.[13]

3.1.3 Hewlett-Packard

At Hewlett-Packard, the continual investment in future product lines is a key activity that serves to establish a constant stream of revenue for the company even as older product lines are phased out

Hewlett-Packard is the focus of a study on new product revenue and the link between product innovation activities and revenue growth. The study defines the process by which a company converts internal resources (e.g., labor, materials) into products, the products are consumed by its customer base, the company earns revenue, and the revenue can then be reinvested into current operations as well as future R&D for innovative and new product lines. The continual investment in future product lines is a key activity that serves to establish a constant stream of revenue for the company even as older product lines are phased out of production.

A large company's revenue contributions of a particular new-product year (or vintage) fall into a regular pattern over time, which enables a company to determine mathematical relationships for revenue growth as a function of R&D investment and new product revenue growth.

Three factors are identified that drive revenue growth: the fraction of revenue invested in product innovation, new product revenue gain, and the behavior of revenue over time for a particular business. Using a graph called a product vintage chart, a large company's revenue contributions of a particular new-product year (or vintage) fall into a regular pattern over time, which enables a company to determine mathematical relationships for revenue growth as a function of R&D investment and new product revenue growth. In this way, senior managers can gain

[13] Hartmann, George, "Planning Your Firm's R&D Investment," Research Technology Management, March 2006.

clearer understanding of the interplay between product innovation, R&D investment, revenue growth, and profitability over time.[14]

3.1.4 IBM

Many companies believe there is a strong correlation between future revenue growth and internal investments made in R&D. Some argue that R&D should increase spending, regardless of the specific investment. However, there is some level of R&D spending that will not yield additional revenue return. John Armstrong, former Vice President of Research and Technology at IBM, claims "you can spend too much on R&D."[15]

John Armstrong, former Vice President of Research and Technology at IBM, claims "you can spend too much on R&D."

In an attempt to quantify the value of its e-business initiatives, IBM established the Risk and Opportunity Assessment process to assist in selecting and prioritizing e-business initiatives. Within this process, IBM uses the Value Chain Modeling Tool to analyze and model the value chain of its enterprise. This internal IBM approach has been successfully used to improve the financial and operating performance of several of its business units.[16]

The Risk and Opportunity Assessment process includes the following stages:

1. Collection of data about the R&D initiative: Includes any background information on the project as well as documented assumptions. This results in a data collection plan, definitions of data requirements, and the actual collection of data.
2. Modeling and Analysis: A baseline model is built, defining key financial and operational drivers for the initiative as well as highlighting various scenarios which could positively or negatively impact the success of the project.
3. Development: A cost-benefit analysis is performed, potential solutions are prioritized, and a final choice is made.

3.2 Government Experiences

As noted earlier, it is challenging to manage performance management in an R&D environment. Government R&D organizations could retrospectively measure the effects or outcomes of R&D activity. However, this approach may not be effective in a competitive environment (e.g., grant proposal) because a decision-maker may not want to base its investment decision on past performance.

This section highlights government experiences with performance management at R&D organizations. Six case examples - Army Research Laboratory, Office of Naval Research, Navy S&T, Department of Homeland Security, Department of Energy, and Federal Highway Administration - provide insight into performance management.

Government R&D organizations could retrospectively measure the effects or outcomes of R&D activity.

[14] Patterson, Marvin L., "From Experience: Linking Product Innovation to Business Growth," Journal of Product Innovation Management, 1998.
[15] Hartmann, George, "Planning Your Firm's R&D Investment," Research Technology Management, March 2006.
[16] Nassar, Ayman, "A System-Based Approach for Defining IT Operations Value Proposition," Management Science and Engineering, October 2006.

3.2.1 Army Research Laboratory[17]

The Army Research Laboratory (ARL) developed a performance measurement approach by asking the question, "What information does the stakeholder really want to know from a performance evaluation system, beyond what the ultimate outcomes and impacts of the research will be?" ARL determined that its stakeholders want information that will aid the in answering three questions:

1. **Is the work relevant?** *Does anyone care about the effort? Is there a target or a goal, no matter how distant, to which the sponsor can relate?*
2. **Is the program productive?** *Is the program moving toward a goal, or at least delivering a product to its customer in a timely manner?*
3. **Is the work of the highest quality**? *Can we backup the claim to be a world-class research organization doing world-class work?*

To answer these questions, ARL used a combination of peer review, customer evaluation, and performance measures.

ARL uses peer review, customer evaluations, and performance measures to answer stakeholder questions:
Is the work relevant?
Is the program productive?
Is the work of the highest quality?

3.2.1.1 Peer Review

According to the Organization of Economic Co-operation and development, peer review is the judgment of scientific merit by other scientists working in, or close to the field in question. It is premised upon the assumption that only an expert - with scientific knowledge about the cognitive development of the field, its research agenda, and the practitioners within it - is capable of making certain decisions.

ARL established a peer review group called the ARL Technical Assessment Board (TAB). TAB membership consists of 15 world renowned scientists and engineers. Under the TAB, ARL has size panels, each with six to seven members. The purposes of the TAB are three-fold: (1) to review the scientific and technical quality of ARL's program; (2) to make an assessment on the state of ARL's facilities and equipment; and (3) to appraise the preparedness of the technical staff. The TAB assesses one-third of the ARL program each year with results forwarded to senior management within the Army and the Department of Defense (DOD). The primary focus of the peer review process is in answering the question, "Is the work of the highest quality?" Data collection and analysis is in the form of an annual report based on the TAB review. The qualitative nature of the review and validation of the data are a concern, but the independence of the TAB from the ARL program minimizes any biases.

3.2.1.2 Customer Evaluation

ARL applies a stakeholder evaluation model for R&D firms developed by Dr. Edwards B. Roberts of MIT's Sloan School of Management. In this model, Dr. Roberts defines three groups of stakeholders: (1) the development and manufacturing groups which are directly dependent on the research results; (2) the customer of the company's finished product or service; and (3) the senior management of the company. For applied research, ARL gathers feedback from the first group of stakeholders via an annual questionnaire to determine if the ARL's products met

[17] "Performance Measurement of Research and Development (R&D) Activities, Oak Ridge Associated Universities, 2005.

expectations, if they were delivered in a timely fashion, and if the products performed as needed. For fundamental scientific research, in which the stakeholder is not clearly defined, the laboratory director provides the needed feedback. ARL does not obtain feedback from senior management since ARL does not deliver any tangible products to the Department of the Army senior management. Instead, a Stakeholders' Advisory Board (SAB) meets once each year to provide ARL with feedback needed to evaluate its performance. The SAB is chaired by the Commanding General, and it determines the degree to which the ARL program is effective along several dimensions (e.g., mission vs. customer funding, in-house vs. contractual work, and near-term vs. far-term emphasis).

3.2.1.3 Performance Measures

According to ARL, performance measures for evaluating the outcomes of R&D activities have limited utility, but can provide useful information on operational or functional health of an R&D organization. Example measures include maintenance backlog, workforce diversity, procurement cycle-time, papers published, and patents received.

3.2.1.4 Conclusion

The following graphic depicts the relative utility of peer review, customer evaluation, and performance measures in answering the three stakeholder questions for evaluating R&D performance.

Table 1. Relative Utility of Approaches - ARL Case Study

	Relevance	Productivity	Quality
Peer Review	-	*	+
Customer Evaluation	*	*	*
Performance Measures	+	+	*
+ = Very Useful * = Somewhat Useful - = Less Useful			

Overall, ARL gives performance measures the highest ratings, followed by customer evaluation, and peer review.

3.2.2 Office of Naval Research[18]

The Office of Naval Research (ONR) defines and sponsors R&D in support of current and future Navy and Marine Corp requirements. ONR makes its funding decisions in the presence of uncertainty. There is uncertainty in required capabilities, performance requirements, and the feasibility of a technology or R&D approach.

The Chief of Naval Research described ONR's basic research investment strategy as "planting a thousand flowers, to get 100 projects, three prototypes, and one profit-maker."

Figure 7 shows the basic research advances of ONR and others linked to Navy and Marine Corps user requirements that must be met to successfully transition technologies.

[18] Kostoff, Dr. Ronald N., "Science and Technology Metrics," Office of Naval Research.

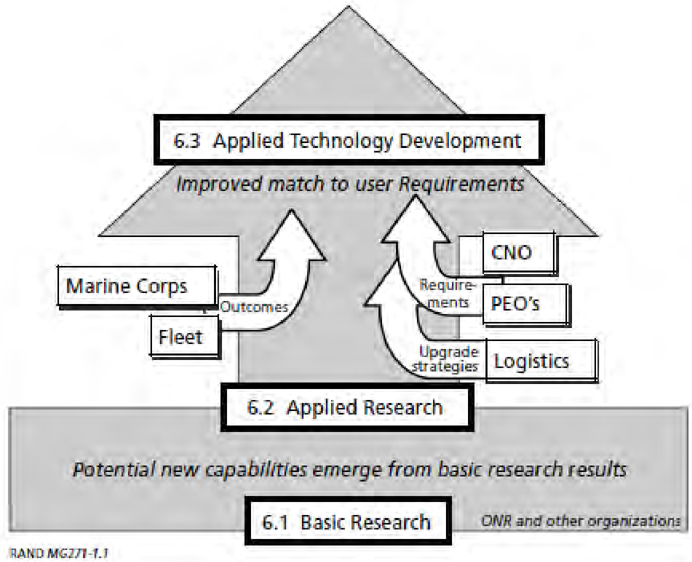

Figure 1. Transition from Basic Research to Meeting Requirements

The Chief of Naval Research in 2004, Rear Admiral Jay M. Cohen, described ONR's basic research investment strategy as "planting a thousand flowers, to get 100 projects, three prototypes, and one profit-maker."[19]

Figure 8 illustrates the Navy's process of matching the capabilities to be developed through R&D to those that meet end user requirements.

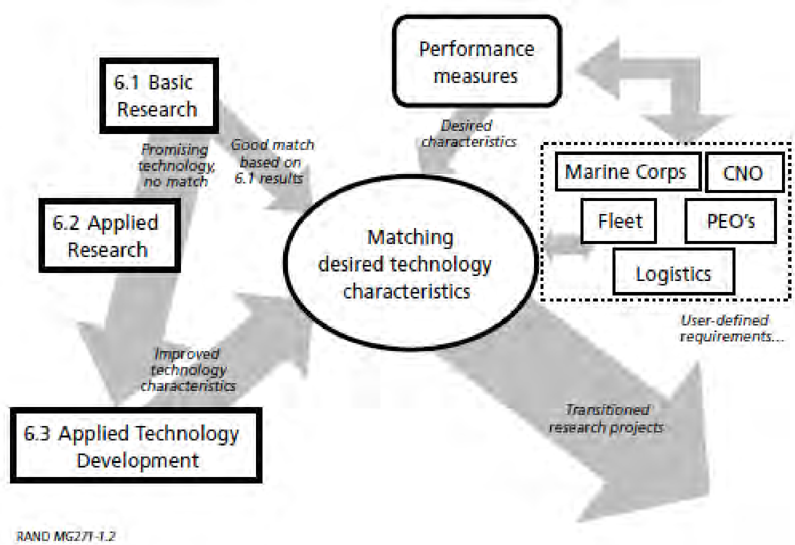

Figure 2. Navy R&D Process

[19] Interview quoted in Sea Power, February 2004, cited by Silberglitt, Richard, Lance Sherry, Carolyn Wong, Michael Tseng, Emile Ettedgui, Aaron Watts, Geoffrey Stothard, "Portfolio Analysis and Management for Naval Research and Development," RAND Corporation, 2004.

The RAND Corporation's PortMan R&D decision framework has been adapted to support ONR's R&D decision-making.[20] This tool computes the expected value of an R&D project as the product of three factors: value to the military of the capability sought through R&D, the extent to which the performance potential matches the level required to achieve the capability, and the project's transition probability. PortMan does not rely on the expected value as a point solution but, rather, includes an estimate of uncertainty and their estimated direction over time. Evaluation is based on best current information and tracking over time. PortMan has been used in a case study.

This approach incorporates anchored scales, which are scales that include explicit descriptions of the requirements or thresholds for assigning particular values. By requiring the evaluators to answer specific questions concerning capability, performance potential, and transition probability, the PortMan framework collects and records information needed to analyze the positive and negative aspects of each R&D project, and to facilitate discussion and analysis of possible investment strategies.

The approach also incorporates uncertainty to estimate expected value components, including capability, performance potential, and transition probability. R&D investment strategies attempt to balance the risk that R&D projects will fail to meet its objectives with their potential payoff.

3.2.3 Navy S&T[21]

The Dahlgren Division S&T Council collected information on S&T metrics as applied to Navy laboratories. The subject of S&T metrics was a frequent topic of interest in 2004, as the Naval Sea Systems Command (NAVSEA) restructuring plan was disclosed and Navy management tried to identify cost-savings investments. At this time, the Navy inquired about the value of its $2 billion per year investment in S&T.

S&T is dependent on what technologies are deployed and what might be needed in the future. The Navy desires the benefits of new S&T, at a reasonable cost. There are no "overnight" successes.

The study team asserted that in-house S&T has great value to the Navy. The level of S&T required to support the Navy is independent of the number of ships or sailors. Rather, it is dependent on what technologies are deployed and what might be needed in the future. The Navy desires the benefits of new S&T, at a reasonable cost. There are no "overnight" successes, i.e., low hanging fruit in S&T. For example, the Silver Fox has been recognized as a great S&T success story because it was delivered to Special Operations forces in only sixty days. Such reports typically do not mention that research on unmanned aerial vehicles began in 1918. Another example, the thermobaric bomb used in Afghanistan in 2002 was "delivered in less than six months," but was actually the result of over thirty years of research in basic explosive chemistry. Figure 9 shows the history of critical technology developments, including approximate dates of first demonstration and dates of first significant military application.

[20] The purpose of PortMan is to evaluate a defined group of actual or proposed projects and to provide a means for creating a portfolio from them that maximizes the value of R&D investments. It does not generate an absolute score for the total portfolio that could be used to compare to portfolios of other projects or to proportionally allocate funds between portfolios of different projects.

[21] Harman, Wayne, and Robin Staton, "Science and Technology Metrics and Other Thoughts," Naval Surface Warfare Center, Dahlgren, Virginia, July 2006.

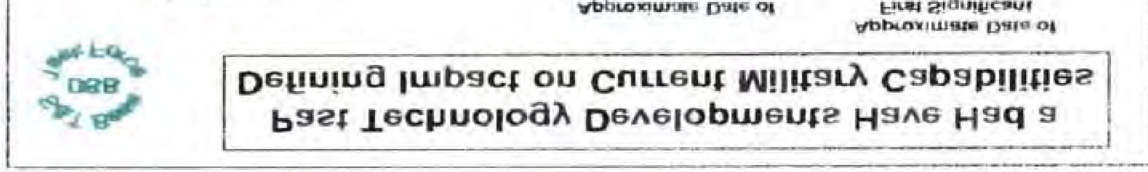

Figure 3. History of Military Critical Technology Developments

The remainder of this section discusses further findings of the Navy S&T study team.

The loss of institutional technical competence leads to failure. For instance, the Space Shuttle disaster has been attributed to the loss of technical in-house competence, which was contracted out due to budgetary reasons.

> ***According to Navy S&T:***
> - ***The loss of institutional technical competence leads to failure.***
> - ***S&T projects never go according to plan.***
> - ***An organization will likely get what it chooses to measure. If it chooses to measure the number of published papers, then there will surely be papers published, perhaps at the expense of other, more useful results.***

S&T projects never go according to plan. The results of research cannot be placed on a time schedule. Dollars invested in research in times of peace may mean the life of the nation when it goes to war. Acquisition and operational managers often focus on current issues, not what the future will need.

S&T metrics can be defined and collected in response to specific questions, but the program or organization will likely get what it chooses to measure. For example, if the program or organization chooses to measure the numbers of published papers and patent applications, then there will surely be papers published and patents applied for, perhaps at the expenses of other, more useful results.

The immediate ROI for Navy S&T is its contribution to the quality and development of its people, who will determine future success and failure. A competent government technical workforce requires significant tasking and responsibility in similar disciplines over multiple years. This supports in-house technical authority through continuity of core technical competencies. The availability of "hands-on" S&T projects helps attract, recruit, and retain the right talent. S&T experience is correlated with the probability that an individual is or will become a senior technical manager or leader. Military preparedness is a continuous function.

The intelligence gained from S&T investment is available on-demand. In-house S&T enables the recruiting, training, and retention of a technically competent scientific and engineering workforce. Real-time connections between S&T workforce and acquisition programs enable focused technology for the warfighter. The in-house workforce is highly responsive because of because of its ability to innovate and its knowledge of Naval systems. The S&T workforce tends to be agile and adaptive, bringing vision and innovation to future Naval capabilities. New and emerging S&T applications can be focused to support Navy fleet needs. The in-house S&T workforce can anticipate and provide capabilities to stay ahead of future threats and mitigate risk.

Transitions and speed of transition are not significant measures of S&T performance. They may be better measures of the entire Research, Development, Test, and Evaluation (RDT&E) acquisition process. S&T provides enabling technologies. It is a shopping list. Acquisition programs must provide funds for further development and integration of the technology into their systems. S&T programs do not have such funding and, therefore, cannot control transitions.

A better measure of S&T is how well the Navy is addressing current and future Navy needs, and how prepared the workforce is to address those needs. The size of the Navy S&T budget and in-house workforce should be determined by what it needs to do, i.e., what Navy capabilities need to be enabled.

The nature of the evaluation may change depending on organizational management. The Chief of Naval Operations wants to know the Navy's benefit from its investment. The S&T Director at Dahlgren Division, who manages the Division investments, is more concerned with the quality and appropriateness of the project selections.

The ability to learn faster than opponents may be the only sustainable competitive advantage.

Return on the Navy's S&T investment is frequently requested. However, the report concluded that ROI for S&T could not be quantified in fiscal terms because of the long delay between the S&T effort and when the technology is actually incorporated into a Navy system, which could be decades later. Furthermore, the Navy does not accrue a financial benefit for a successful S&T investment, unlike industry. Some may readily compare outcomes of S&T investments in a given year to the $2 billion cost. In actuality, the ROI is difficult to quantify. S&T capability acts as an additional form of deterrence against adversaries. The ability to learn faster than opponents may be the only sustainable competitive advantage. ROI must incorporate the resulting state of readiness of the technical workforce to respond to recognized capability gaps, solve specific technical problems, and create entirely new capabilities. It also should incorporate risk reduction throughout the acquisition process, including the following risks: technological surprise; acquiring expensive, unreliable, maintenance intensive systems; delaying program execution due to immature technologies; failing to recognize future threats or needed capabilities; and development risk. A competent workforce is the near-term Navy ROI for S&T. The Navy benefits from a robust S&T program through its vision to predict future Naval needs and risk reduction. As the Defense Advanced Research Projects Agency (DARPA) notes:

> *None of the most important weapons transforming warfare in the 20th century - the airplane, tank, radar, jet engine, helicopter, electronic computer, not even the atomic bomb [or unmanned systems, stealth, global positioning system, and Internet technologies] - owed its initial development to a doctrinal requirement or request of the military… If they don't know what to ask for then someone has to tell them what they need. This is ROI.*

3.2.4 Department of Homeland Security[22]

The S&T Directorate of the Department of Homeland Security (DHS) functions as the nation's homeland security research, development, test, and evaluation manager for S&T. The Directorate allocates 10% of its S&T funding to higher-risk innovation which, if successful, will provide potentially game-changing technologies and systems in one to five years - much quicker and with greater impact than incremental improvement typical in most programs. Within this portfolio it allocates about one-tenth (or 1% of its total S&T budget) to truly high-risk efforts, which are likely to fail. If successful, they will have profound impacts, and even projects that fail will often result in enhanced understanding to improve subsequent basic and applied research efforts to lead to breakthrough and leap-ahead capabilities. Another 50% of the S&T's Directorate is allocated to transition of lower-risk projects dedicated to satisfying DHS customer-defined capability needs, with spiral development, within three years. The remainder of the annual S&T program includes specially mandated programs and projects.

To help meet real-world requirements and deliver effective and affordable technologies, the Directorate developed a customer-focused and output-based risk analysis and requirements assessment architecture. The strategy-to-task framework directly links programs and initiatives to specific strategic goals and customer requirements. The Directorate’s management and oversight process tracks success of product transition in terms of three objective metrics: project cost, schedule and technological readiness.

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For cost, the Directorate aims to accurately estimate and track the RDT&E cost of a technology or system. It "weeds" out under-performing projects. For its schedule metric, the Directorate establishes detailed timelines, action plans, and milestones to monitor each project's progress. Frequent program reviews and internal assessments enable early on correction of problems. The Transition Office also formally elicits customer feedback from DHS components. For technology readiness, the Directorate uses Technology Readiness Levels (TRLs) for systematic measurement of periodic assessments of maturity of a specific technology or system, as shown in Figure 10. The TRLs also support determining whether a capability solution is ready to be transitioned to the field or should be modified or discarded.

It is critical to maintain outreach to scientists, engineers, and managers worldwide to help meet critical needs and support innovative S&T approaches.

[22] "Science and Technology for a Safer Nation," US Department of Homeland Security, March 2008.

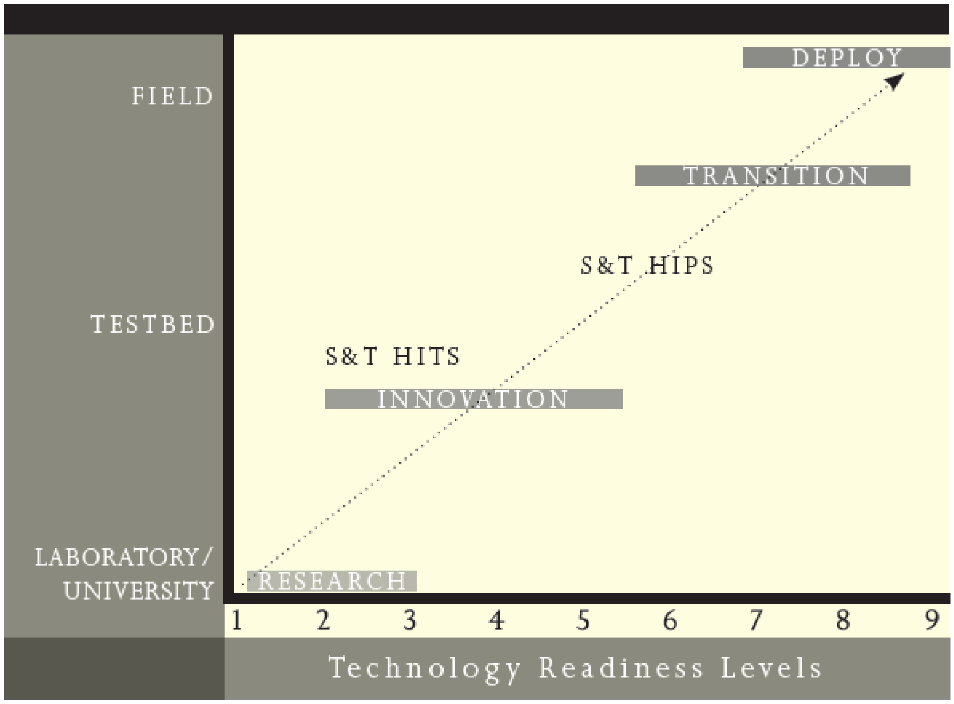


Figure 4. The TRL Vector

It is critical to maintain outreach to scientists, engineers, and managers worldwide to help meet critical needs and support innovative S&T approaches.

3.2.5 Department of Energy

The Office of Basic Energy Sciences (BES) of the Department of Energy published lessons learned of its research projects. They include:

Stable funding is invaluable to the field.

1. Stable funding is invaluable to the field
2. New organizational designs contribute to project effectiveness
3. Basic research often spills over, resulting in new directions
4. Interdisciplinary work requires a different management concept
5. Research projects can include those conducted at universities and/or federal labs

The R&D Value Mapping (RVM) approach attempts to track the flow of knowledge and specify possible outcomes of R&D projects. It is possible to develop predictive models of the factors related to project outcomes. RVM is an iterative process, and these models are revised and refined continuously during the project to add explanatory precision.

3.2.6 Federal Highway Administration[23]

'Different types of evaluation methods are appropriate for different types of research projects' and organizations.

The Federal Highway Administration (FHWA)'s Office of Research, Development, and Technology (RD&T) received the Quality Breakthrough Award, which recognizes organizations within FHWA that are making significant progress in developing clear plans, building sound processes, and achieving measurable results.

[23] "Performance Management," US Department of Transportation, Federal Highway Administration.

The National Cooperative Highway Research Program (NCHRP) concluded that "different types of evaluation methods are appropriate for different types of research projects" and organizations. The RD&T Performance Management Framework chart below identifies existing performance measures and assessment mechanisms used by unit managers. These measures and mechanisms are integrated across management function, enabling RD&T to manage, analyze, and integrate information obtained from a variety of sources. The RD&T Leadership Council uses the framework as a tool to assess unit performance measurement activities and to identify measurement gaps.

Table 2. RD&T Performance Management Framework

Corporate Management Strategies	**Definition**	**Related RD&T Performance Measures**	**Methodology**
Leadership	Leadership focuses on how senior leaders guide the organization. It describes how leaders set direction and high-performance expectations, project a strong customer focus, and communicate clear and visible values to employees.	• Leadership Effectiveness Inventory (LEI) results • Action items completed • Performance plan items fulfilled • Self-assessment score	• 360-degree feedback • Action agenda • Performance plans • Quality self-assessments
Strategic Planning	Strategic planning examines how the organization sets strategic goals and develops key action plans.	• Action items completed • Self-assessment score • Progress made on goals established	• Performance plans and action agenda • Quality self-assessment • Lab assessments
Customer/ Partner Focus	Customer and partner focus examines how the organization determines customer and market requirements and expectations.	• Percent of satisfaction with RD&T products and services • Number of technology facilitation plans in place • Self-assessment score • Lab assessment results (to be determined (TBD)) • RD&T customer survey results (TBD)	• American Customer Satisfaction Index (ACSI) • Technology Innovation Network (TIN) • Technology Facilitation Action Plan (TFAP) • Quality self-assessments • Lab assessments • Customer surveys
Information and Analysis	Information and analysis examines the management, effective use, and analysis of data and information to support key organization processes, to include the organization's objectives	• Performance measurement framework • Response level and content of feedback mechanisms • Self-assessment score • Lab Assessment results (TBD)	• Performance measurement framework • ACSI, TIN • Quality self-assessments • Lab Assessments
Human Resource Development	Human resource development and management examines how the organization enables its workforce to develop to its full potential and how the workforce is aligned with the organization's objectives	• Self-assessment score • Percent of employee satisfaction survey rating • Percent of payroll spent on training and development • Number of Individual Development Plans (IDPs) in place and in Learning and Development System (LAD)	• Quality self-assessments • Employee satisfaction survey • LADS

		• Number of “priority 1” training needs met • Number of vacancies filled • Number of days positions are vacant • Number of student interns (Number of Grant for Research Fellowships (GRF), Summer Transportation Intern Program for Diverse Groups (STIPDG), etc.) • Number of outreach activities	
Process Management	Process Management examines aspects of how key production, delivery, and support processes are designed, managed, and improved.	• Number of process improvements documented • Lab Assessment (TBD) • Number of contracts on time and on budget • TIN (TBD) • SBIR (TBD)	• Quality self-assessments • Lab assessments • Project tracking system • ACSI
Business Results	Business results show the organization's performance and improvement in its key business areas: customer satisfaction, financial and marketplace performance, human resources, supplier and partner performance, and operational performance. The category also examines how the organization performs relative to competitors.	• Percent of project completion • Number of success stories • Research benefit (TBD)	• Track project and services delivery • RD&T success stories • Pilot and case studies

RD&T benefit assessments are largely retrospective analyses and require data collection throughout the product development and delivery cycles to produce meaningful conclusions.

4 R&D Metrics

Section 4 provides example R&D metrics used by commercial industry and government organizations and programs.

4.1 Commercial Industry Practices

As mentioned in Section 3.1, a common industry practice is to categorize projects as either product development or research innovation, and funding is allocated at approximately 80% and 20%, respectively. However, the case examples show that many companies think about R&D budget allocation and spending trends in different ways. Metrics commonly used by commercial industry include:

Many organizations rely on metrics to measure R&D performance instead of relying on the traditional use of short-term financial metrics alone.

- Net Present Value (NPV)
- ROI
- Total Cost of Ownership (TCO)
- Discounted Cash Flow
- Budget variance (delivering on or below allocated budget)
- Quality measurements (meeting specifications/requirements)
- Risk

- Alignment with corporate strategies
- Cost
- Schedule
- Organizational flexibility
- Intellectual Property factors
- Market Lifecycle factors
- Fit with existing product portfolio
- Market Share

Since R&D projects are unique compared to other corporate spending projects, many firms have expanded the list of metrics used to measure R&D performance instead of relying on the traditional use of short-term financial metrics alone.

4.1.1 Example Efficiency Measures

For illustrative purposes, example efficiency measures developed by commercial organizations - Alcoa, Dow Chemical, IBM, and Procter & Gamble - are shown in the table below.[24]

Table 3. Commercial Industry Example Efficiency Measures

Agency or Organization	Efficiency Measure
Alcoa	Return-on-investment calculation:
	(FY 2005) Improve existing ARIS by converting its mainframe system into Web-based system designed by OAR and IC representatives in consultation with contractor Variable cost improvement Margin impact from organic growth Capital avoidance Cost avoidance
	Annual impact of these four metrics over 5-year period becomes numerator; denominator is total R&D budget Metric is used most often to evaluate overall value of R&D program and current budget focus (Atkins 2007)
Alcoa	Time (Atkins 2007)
Alcoa	Cost (Atkins 2007)
Alcoa	Customer demand (Atkins 2007)
Alcoa	Risk (Atkins 2007)
Alcoa	Impact on business (Atkins 2007)
Alcoa	Impact on customers (Atkins 2007)
Alcoa	Location (Atkins 2007)
Alcoa	Intellectual property (Atkins 2007)
Alcoa	Aggregate R&D expenditures by laboratory group or by identifiable programs and publish value capture or "success rate" for each on annual basis (Atkins 2007)
Alcoa	ROI on R&D spending; success rate of launched products (Atkins 2007)
Dow Chemical	Publications; participation and leadership in scientific community (collaborative research efforts; trade associations; ILSI-HESI; external workshops; adjunct faculty positions, journal or book editors, professional societies) (Bus 2007)

[24] "Evaluating Research Efficiency in the U.S. Environmental Protection Agency," National Research Council, 2008.

IBM	ROI on Summer Internship Program and Graduate Fellowship Program: what percentage return as regular IBM research employees?
IBM	"Bureaucracy Busters" Initiative to reduce bureaucracy in laboratory support, information-technology support, HR processes, and business processes (Kenney 2007)
IBM	Tracking of patent-evaluation process (Kenney 2007)
IBM	Customer-satisfaction surveys for support functions to evaluate effect of service reductions (Kenney 2007)
IBM	Measurement of response time and turnaround for external contracts (Kenney 2007)
IBM	Measurement of span of responsibility for secretarial support (Kenney 2007)
Procter & Gamble	Time saved in product development (Daston 2007)
Procter & Gamble	Increased confidence about safety (Daston 2007)
Procter & Gamble	External relations benefits (although not quantifiable) (Daston 2007)

4.2 Government Experiences

On the government side, R&D metrics support maximum acceleration of progress efficiently, consistent with the sponsor's mission and stakeholder goals. They quantify and help communicate progress toward R&D targets. For basic research, the goal is increased knowledge and understanding. Metrics selection should balance both quantitative and qualitative measures. MITRE has categorized example metrics used by government R&D organizations and programs as programmatic, organizational, workforce, activity, outcome, impact, and value. Example metrics for each of these categories are shown below.

Government R&D metrics support maximum acceleration of progress efficiently, consistent with the sponsor's mission and stakeholder goals. They quantify and help communicate progress toward R&D targets. Metrics selection should balance both quantitative and qualitative measures.

Programmatic

- Annual budget
- Budget request and budget appropriated
- Schedule
- Execution rates for obligation versus disbursement within 5% variance

Organizational

- Science and engineering demographics
- Number of proposals submitted and endorsed
- Number of new research agreements that leverage industry, academic, and/or other governmental and international partners/fiscal year (FY)
- Amount of special appropriations designated for research/FY
- Number of cooperative research and development agreements (CRADAs)
- Vision process for new starts
- Amount of funds leveraged
- Number and types of accreditation maintained at the organization
- Compliance with specified requirements

- Percent of DIACAP compliance
- Percent of buildings that receive "green" rating on installation report
- Number of work-related accidents
- Number of days for civilian recruitment actions to complete local approval
- Percent of divisions using a particular model
- Space requirements for all divisions captured and reconciled with availability
- Development and prioritization of top 10 unfunded requirements (UFRs)
- Reduction in dollar amount of lost accountable property
- Percent completion of monthly hand receipt inventory

Workforce

- Number of funded scientists and engineers
- Number of graduates/post graduates in programs
- Number of National Research Council (NRC) Fellows/FY
- Science and engineering attrition rates - total, by discipline, by training
- Workforce diversity
- Growth in employment of program participants
- Number of training students
- Percent of employees that complete specified training/FY
- Number of student hires
- Percent of military reenlistment goals met
- Percent of licensed professionals maintaining prescribed credentials
- Percent of employees that completed training
- Percent of military completing mandatory military education
- Percent of military completing acquisition training
- Percent of military completing training
- Percent of civilian supervisors completing advanced leadership training

Activity

- Number of patents, publications, and citations
- Number of licensing agreements issues for intellectual property
- Number of peer-reviewed publications (full articles or book chapters)
- Number of awards
- Percent of research proposals scored in the top 1/3 for scientific merit
- Number of conferences, exhibits, and associations at which program presents or exhibits
- Technical assistance to industry
- Production of algorithms

Outcome

- Customer assessments
- Percent that accomplish the objectives of the research proposals
- Number of developmental products funded by contributions from other organizations/FY
- Condition of technical base
- Acquisition funding applied
- Technology transition agreements
- Number of technologies transitioned

- Number of past transitions
- Increase in outside resources that support command-approved objectives
- Number of firms created
- Licensing revenues
- Maintenance backlog
- Procurement cycle-time

Impact

- Pillar alignment/alignment
- Capability gap coverage
- Warfighting capabilities achieved
- Progress toward goals
- Continued relevance to warfighting capabilities
- Cost avoided
- Lives saved
- Enhanced health/safety
- Improved system capability
- New capabilities enabled
- System improvements
- Reduced manning
- Percent that meet advanced development milestones
- Product area directorate needs addressed

Value

- Cost of risk reduction/cost of consequence
- ROI
- TRL
- Cost
- Costs avoided
- Potential payoff

While there are many measures that can be used, caution must be exercised in selecting measures that are helpful in determining the quality of S&T investments. As noted earlier, if you measure the number of peer-reviewed publications, you will get peer-reviewed publications (i.e., what you measure, is what you will get). Many of the above metrics do not necessarily show how the needs of the stakeholders (i.e., warfighter) are being met. There is no widely accepted approach for the federal government to make performance management decisions.

4.2.1 Peer Review

In addition to the example metrics shown above, peer review can also be used to help an R&D organization or program with performance management. Peer review is an unbiased review by knowledgeable experts. It can be applied to S&T programs and, of all the metrics, can reveal the most about the quality and appropriateness of S&T and other research projects. Peer review provides both an evaluation to S&T management as well as

Peer review is an unbiased review by knowledgeable experts. It can be applied to S&T programs and, of all the metrics, can reveal the most about the quality and appropriateness of S&T and other research projects. Peer review provides both an evaluation to S&T management as well as insights to the investigators, which can result in improvements to research methods and procedures.

insights to the investigators, which can result in improvements to research methods and procedures. It can take place on a regular basis, such as twice a year.

Some example metrics of peer review include:

- Scientific quality and uniqueness of ongoing and proposed efforts
- Scientific opportunities in areas of likely user importance
- Balance between revolutionary and evolutionary research
- Position of research relative to forefront of other scientific efforts
- Responsiveness to present and future user requirements
- Possibilities of follow-on programs in higher R&D categories
- Appropriateness of research for agency vice other Federal agencies.

4.2.2 Example Efficiency Measures

This section illustrates example efficiency measures developed by government agencies, including the Environmental Protection Agency (EPA), DOD, Department of Energy (DOE), Department of Interior (DOI), Department of Transportation (DOT), Department of Education, Department of Health and Human Services (DHHS), National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), National Science Foundation (NSF), and United States Department of Agriculture (USDA). These example metrics are shown in the table below.

Table 4. Example Efficiency Measures[25]

Agency or Organization	Program	Year	Efficiency Measure
EPA	Endocrine Disruptors (combined EPAPART)	2004	(OPPTS) Cost per labor hour of contracted validation studies (EPA, unpublished material, April 23, 2007)
EPA	EPA Human Health Research	2005	Average time (in days) to process research-grant proposals from RFA closure to submittal to EPA's Grants Administration Division while maintaining a credible and efficient competitive merit-review system (as evaluated by external expert review) (EPA, unpublished material, April 23, 2007)
EPA	Land Protection and Restoration Research	2006	Average time (in days) for technical support centers to process and respond to requests for technical document review, statistical analysis, and evaluation of characterization and treatability study plans (EPA, unpublished material, April 23, 2007)
EPA	Water Quality Research	2006	Number of peer reviewed publications per FTE (EPA, unpublished material, April 23, 2007)
EPA	Human Health Risk Assessment Program	2006	Average cost to produce Air Quality Criteria/Science Assessment documents (EPA, unpublished material, April 23, 2007)
EPA	EPA Ecological Research	2007	Percentage variance from planned cost and schedule (approved 3/13/07) (EPA, unpublished material, April 23, 2007)
EPA	Drinking Water Research	2007	Percentage variance from planned cost and schedule (approved 3/13/07) (EPA, unpublished material, April 23, 2007)

[25] "Evaluating Research Efficiency in the U.S. Environmental Protection Agency," National Research Council, 2008.

EPA	PM Research	2007	Percentage variance from planned cost and schedule (approved 3/13/07) (EPA, unpublished material, April 23, 2007)
EPA	Global Change Research	2007	Percentage variance from planned cost and schedule (approved 3/13/07) (EPA, unpublished material, April 23, 2007)
EPA	Pollution Prevention Research	2007	Percentage variance from planned cost and schedule (approved 3/13/07) (EPA, unpublished material, April 23, 2007)
DOD	Defense Basic Research	2002	Long-term measure: portion of funded research chosen on basis of merit review; reduce non-merit-reviewed and determined projects by half in 2 years (from 6.0% to 3.0%) (OMB 2007)
DOE	Advanced Simulation and Computing	2002	Annual average cost per teraflops of delivering, operating, and managing all Stockpile Stewardship Program (SSP) production systems in given fiscal year (OMB 2007)
DOE	Coal Energy Technology	2005	Administrative costs as percentage of total program costs (OMB 2007)
DOE	Advanced Fuel Cycle Initiative	2003	Program direction as percentage of total R&D program funding (OMB 2007)
DOE	Generation IV Nuclear Energy Systems Initiative	2003	Program direction as percentage of total R&D program funding (OMB 2007)
DOE	National Nuclear Security Administration: Nonproliferation and Verification Research and Development	2005	Cumulative percentage of active research projects for which independent R&D peer assessment of project's scientific quality and mission relevance has been completed during second year of effort (and again in each later 3-year period for projects found to be of merit) (OMB 2007)
DOE	Nuclear Power 2010	2003	Program direction as percentage of total R&D program funding (OMB 2007)
DOE	Basic Energy Sciences/ Biological and Environmental Research	2006	Average achieved operation time of scientific user facilities as percentage of total scheduled annual operation time; cost-weighted mean percentage variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects (cost variance listed first) (OMB 2007)
DOE	Hydrogen Program	2003	In 2003, EERE Hydrogen Program had about 130 fuel-cell and hydrogen production research projects that were subject to in-progress peer review by independent experts
Agency or Organization	Program	Year	Efficiency Measure
			For all reviewed projects, reviewers provided written comments and numerical ratings on a scale of 1-4, with 4 being highest with resulting scores ranging of 2.2-3.9 Program used review results to make important decisions to continue or discontinue projects Research efficiency = 1− [(no. of projects discontinued/(total no. of projects reviewed − no. of projects judged as completed − earmark projects)] (Beschen 2007)

DOI	U.S. Geological Survey – Biological Information Management and Delivery	2005	Average cost per gigabyte of data available through servers under program control (EPA, unpublished material, 2006)
DOI	U.S. Geological Survey – Biological Research & Monitoring	2005	Average cost per sample for selected high-priority environmentally available chemical analyses (EPA, unpublished material, 2006)
DOI	U.S. Geological Survey – Energy Resource Assessments	2007	Average cost of systematic analysis or investigation (dollars in millions) (EPA, unpublished material, 2006)
DOI	U.S. Geological Survey – Mineral Resource Assessment	2003	Average cost of systematic analysis or investigation; average cost per analysis allows comparisons among projects to determine how efficiencies can be achieved (EPA, unpublished material, 2006)
DOI	U.S. Geological Survey – Water Resources Research	2004	Average cost per analytic result, adjusted for inflation, is stable or declining over 5-year period (EPA, unpublished material, 2006)
DOI	U.S. Geological Survey – Water Information Collection and Dissemination	2004	Percentage of daily stream flow measurement sites with data that are converted from provisional to final status within 4 months of day of collection (EPA, unpublished material, 2006)
DOI	U.S. Geological Survey – Biological Research & Monitoring	2005	Percentage improvement in detectability limits for selected high-priority environmentally available chemical analytes (EPA, unpublished material, 2006)
DOI	U.S. Geological Survey – Geographic Research, Investigations, and Remote Sensing	2003	Percentage of total cost saved through partnering for data collection of high-resolution imagery (EPA, unpublished material, 2006)
DOI	Bureau of Reclamation – Science and Technology Program	2003	Each year, increase in R&D cost-sharing per reclamation R&D program dollar will contribute toward achieving long-term goal of 34% cumulative increase over 6-year period (OMB 2007)
DOT	Highway Research and Development/Intelligent Transportation Systems	2004	Annual percentage of all research projects completed within budget (OMB 2007)
DOT	Highway Research and Development/Intelligent Transportation Systems	2004	Annual percentage of research-project deliverables completed on time (OMB 2007)
DOT	Railroad Research and Development	2004	Organizational Excellence: Percentage of projects completed on time (OMB 2007)
Department of Education	National Assessment for Educational Progress	2003	Timeliness of NAEP data for Reading and Mathematics Assessment in support of President's No Child Left Behind initiative (time from end of data collection to initial public release of results for reading and mathematics assessments) (EPA, unpublished material, 2006)

Department of Education	National Center for Education Statistics	2003	NCES will release information from surveys within specified times; NCES collected baseline information in 2005, examining time-to-release for 31 recent surveys (National Assessment of Educational Progress releases not included in these figures) (EPA, unpublished material, 2006)
Agency or Organization	Program	Year	Efficiency Measure
DHHS	National Center for Health Statistics	2005	Number of months for release of data as measured by time from end of data collection to data release on Internet (OMB 2007)
DHHS	NIH Extramural Research Programs		By 2013, provide greater functionality and more streamlined processes in grant administration by continuing to develop NIH Electronic Research Administration System (eRA)
			(FY 2004) Develop plan to integrate OPDIVs into eRA (FY 2005) Integrate DHHS 50% of eligible DHHS OPDIVs as eRA users for administration of research grants (FY 2006) Integrate DHHS 100% of eligible DHHS OPDIVs as eRA users for administration of research grants Conversion of business processes (FY 2005) 25% of business processes done electronically (FY 2006) 40% (FY 2007) 55% (FY 2008) 80% (Duran 2007)
DHHS	NIH Intramural Research Program	2005	Reallocation of laboratory resources based on extramural reviews by Boards of Scientific Counselors (OMB 2007)
DHHS	Bioterrorism: CDC Intramural Research	2006	Decrease annual costs for personnel and materials development with development and continuous improvement of budget and performance integration information system tools (OMB 2007)
DHHS	NIOSH	2004	Percentage of grant award or funding decisions made available to applicants within 9 months of application receipt or deadline date while maintaining credible and efficient two-level peer-review system (OMB 2007)
DHHS	NIOSH	Not used currently	Determine future human capital resources needed to support programmatic strategic goals, focusing on workforce development or training and succession planning (Sinclair 2007)
DHHS	NIOSH	2007	Percentage of grant award or funding decisions made available to applicants within 9 months of application receipt or deadline date while maintaining credible and efficient two-level peer-review system (Sinclair 2007)

DHHS	Extramural Construction		By 2010, achieve average annual cost savings of managing construction grants by expanding use of electronic project-management tools that enhance oversight and 20-year use monitoring (Each FY) Achieve average annual cost of managing construction grants (Duran 2007)
DHHS	HIV/AIDS Research		By 2010, use enhanced AIDS Research Information System (ARIS) database to more efficiently conduct portfolio analysis to invest in priority AIDS research
			(FY 2005) Improve existing ARIS by converting its mainframe system into Web-based system designed by OAR and IC representatives in consultation with a contractor (FY 2006, FY 2007, FY 2008) Track, monitor, and budget for trans-NIH AIDS research, using enhanced ARIS database, to more efficiently conduct portfolio analysis of 100% of expiring grants to determine reallocation of resources for priority research (Duran 2007)
DHHS	Research Training Program	2006	By 2012, ensure that 100% of trainee appointment forms are processed electronically, to enhance program management (OMB 2007)
NASA	Human Systems Research and Technology	2005	Time between solicitation and selection in NASA Research Announcements (OMB 2007)
NASA	Solar System Exploration	2006	Percentage of budget for research projects allocated through open peer-reviewed competition (OMB 2007)
NASA	Solar System Exploration	2006	Number of days within which NASA Research Announcement research grants for program are awarded, from proposal due date to selection, with goal of 130 days (OMB 2007)
NASA	Original Uniform Measures		Complete all development projects within 110% of cost and schedule baseline Peer-review and competitively award at least 80%, by budget, of research projects Reduce time within which 80% of NRA research grants are awarded, from proposal due date to selection, by 5% per year, with goal of 130 days Deliver at least 90% of scheduled operating hours for all operations and research facilities (Pollitt 2007)
NASA		2007	Year-to-year reduction in Space Shuttle sustaining engineering workforce for flight hardware and software while maintaining safe flight Reduction in ground operations cost (through 2012) of Constellation Systems based on comparison with Space Shuttle Program Number of financial processing steps and time to perform year-end closing Number of hours required for NASA personnel to collect, combine, and reconcile data of contract-management type for external agency reporting purposes (Pollitt 2007)

NASA		2007	On-time availability and operation of Aeronautics Test Program ground test facilities in support of research, development, test, and engineering milestones of NASA and DOD programs from both schedule and cost perspectives Operational cost per minute of Space Network support of missions Ratio of Launch Services Program cost per mission to total spacecraft cost Number of people reached via e-education technologies per dollar invested (Pollitt 2007)
NOAA	Climate Program	2004	Volume of data taken in annually and placed into archive (terabytes) (EPA, unpublished material, 2006)
NOAA	Ecosystem Research	2005	Cost per site characterization (OMB 2007)
NOAA	Ecosystem Research	2005	Percentage of grants awarded on time (OMB 2007)
NSF	Fundamental Science and Engineering Research	2005	Percentage of award decisions made available to applicants within 6 months of proposal receipt or deadline date while maintaining credible and efficient competitive merit-review system as evaluated by external experts (OMB 2007)
NSF	Research on Biocomplexity in the Environment	2004	Percentage of award decisions made available to applicants within 6 months of proposal receipt or deadline date while maintaining credible and efficient competitive merit-review system as evaluated by external experts (OMB 2007)
NSF	Construction and Operations of Research Facilities	2003	Percentage of construction acquisition and upgrade projects with negative cost and schedule variances of less than 10% of approved project plan (EPA, unpublished material, 2006)
NSF	Polar Research Tools, Facilities and Logistics	2004	Percentage of construction cost and schedule variances of major projects as monitored by earned-value management (OMB 2007)
NSF	Support for Research Institutions	2004	Percentage of award decisions made available to applicants within 6 months of proposal receipt or deadline date while maintaining credible and efficient competitive merit-review system as evaluated by external experts (OMB 2007)
NSF	Support for Small Research Collaborations	2004	Percentage of award decisions made available to applicants within 6 months of proposal receipt or deadline date while maintaining credible and efficient competitive merit-review system as evaluated by external experts (OMB 2007)
NSF	Construction and Operations of Research Facilities	2003	Percentage of operational facilities that keep scheduled operating time lost to less than 10% (OMB 2007)
NSF	Federally Funded Research and Development Centers	2005	Percentage of operational facilities that keep scheduled operating time lost to less than 10% (OMB 2007)

NSF	Information Technology Research		Qualitative assessment by external experts that there have been significant research contributions to software design and quality, scalable information infrastructure, high-end computing, workforce, and socioeconomic impacts of IT (EPA, unpublished material, 2006)
NSF	Polar Research Tools, Facilities and Logistics		Percentage of person-days planned for Antarctic research for which program is able to provide necessary research support (EPA, unpublished material, 2006)
NSF	Polar Research Facilities and Support		Research facilities: keep construction cost and schedule variances of major polar facilities projects as monitored by earned-value management at 8% or less Research support: provide necessary research support for Antarctic researchers at least 90% of time (OMB 2007)
NSF	Support for Individual Researchers		External validation of "significant achievement" in attracting and preparing U.S. students to be highly qualified members of global S&E workforce (EPA, unpublished material, 2006)
NSF	Science and Engineering Centers Program	2006	Percentage of decisions on preproposals that are merit-reviewed and available to Centers Program applicants within 5 months of preproposal receipt or deadline date (OMB 2007)
NSF			Time to decision for proposals: for 70% of proposals submitted to National Science Foundation, inform applicants about funding decisions within 6 months of proposal receipt or deadline date or target date, whichever is later (Tsuchitani 2007)
NSF			Facilities cost, schedule, and operations: keep negative cost and schedule variances at less than 10% of approved project plan for 90% of facilities; keep loss of operating time due to unscheduled downtime to less than 10% of total scheduled operating time for 90% of operational facilities (Tsuchitani 2007)
USDA	USDA Research: Economic Opportunities for Producers		Percentage of construction acquisition and upgrade projects with negative cost variance of less than 10% of approved project plan (EPA, unpublished material, 2006)
USDA	Economic Opportunities for Producers	2004	Cumulative dollars saved for grant review (OMB 2007)
USDA	Economic Opportunities for Producers	2004	Proposal review time in days (OMB 2007)
USDA	Research on Protection and Safety of Agricultural Food Supply	2005	Additional research funds leveraged from external sources (OMB 2007)
USDA	Economic Research Service	2005	Index of ERS product releases per staff year (OMB 2007)

USDA	Grants for Economic Opportunities and Quality of Life for Rural America	2006	Cumulative dollars saved for grant review: dollars saved reflect average salary saved by calculating number of calendar days saved annually between receipt of proposal and date funding awarded for competitively reviewed proposals, then multiplied by average daily salary for CSREES employees (OMB 2007)
USDA	In-House Research for Natural Resource Base and Environment	2006	Relative increase in peer-reviewed publications (OMB 2007)
USDA	In-House Research for Nutrition and Health	2006	Relative increase in peer-reviewed publications (OMB 2007)

5 Conclusion

R&D organizations and programs face unique challenges in managing performance. An R&D environment generally supports more open-ended creativity, longer-term visions, and more exploratory work. In this type of environment, performance is generally harder to measure, available data is often less timely, and more unknowns exist.

However, R&D organizations and programs can establish a valuable performance management process. Organizations must look introspectively to identify measures of performance to help achieve their goals and meet stakeholder objectives. Example metrics from other organizations can provide a starting point for brainstorming. Those metrics that will best assess performance and motivate effectiveness and efficiency will be specific to each organization. Peer review will likely be a valuable process for offering performance feedback. Technical knowledge, flexibility in allowable outcomes and timeframes, ongoing support, and true integration within an organization's processes and culture are important attributes to performance management within an R&D organization.

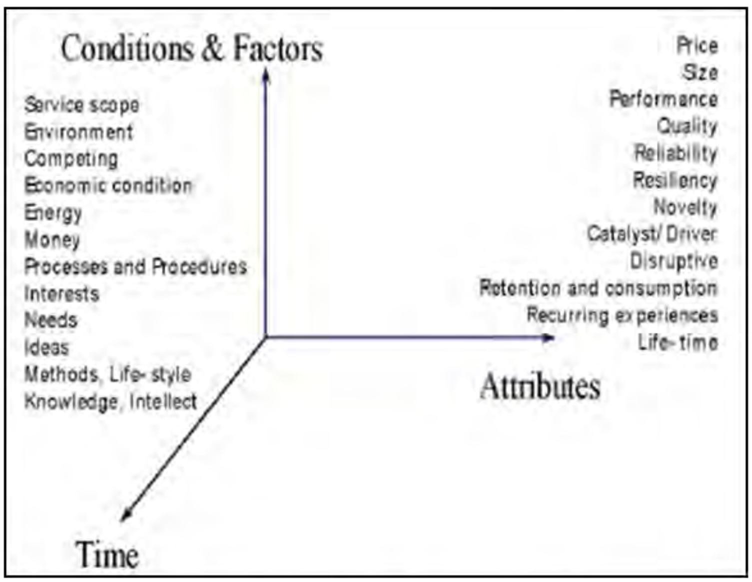
Based on the case studies examined in this report, organizations are increasingly using both quantitative and qualitative measures to manage performance and improve sustainable value. While some companies (e.g., Lucent, Hewlett-Packard) believe that R&D spending drives value and growth, others (e.g., Xerox) operate so that R&D spending lags value and growth creation. Yet other businesses (e.g., IBM) consider R&D spending uncorrelated to value and growth at some level. Government organizations have more multi-dimensional goals than commercial companies focused on profit. Therefore, a good performance management process is critical to assessing and driving value in the government sector. Government R&D organizations are evolving their own performance management processes based on goals and needs. Many (e.g., Navy S&T, DHS) view R&D as an essential means to achieving increased knowledge and innovation to provide a competitive advantage over adversaries. For-profit companies rely more heavily on financial metrics of performance, but are expanding to include other quantitative and qualitative metrics. Government organizations choose a suite of performance metrics (e.g., programmatic, organizational, workforce, activity, outcome, impact, value) consistent with their specific missions and goals.

Performance management that is properly implemented with management support and active employee involvement is a powerful tool for the enterprise. Internally, it cultivates a systematic, long-term view of the organization. It helps an enterprise stay focused on attributes of success and failure to achieve the organization's goals and deliver meaningful results. Externally, it communicates management efficiencies, transparency of goal alignment and resource targeting, output effectiveness, and overall value of agency outcomes or progress toward those outcomes. R&D organizations should be allowed flexibility to design and implement a performance management process aligned with their mission, goals, and objectives that can be systematically implemented with management support and active employee involvement to convey the true value of performance to the enterprise.

Appendix A The Three Dimensional Value Proposition Approach

The three dimensional value proposition (3DVP) approach provides a process for measuring the attributes of an IT operation organization, assessing the conditions under which it operates, and examining the time in which the value proposition is defined. The purely technical characteristics of the project (e.g., server uptime, network latency) and/or financial metrics (e.g. return on investment, total cost of ownership) do not convey the true value of the IT investment to the enterprise.[26]

As illustrated in Figure 11, the 3DVP approach is based on the idea that the value of any system is dependent on three main types of variables: internal variables (the attributes and characteristics) of the system, external variables (conditions and external factors) impacting the system, and the temporal effect represented in a varying time interval. It can be noted that the value of a system is a function of a set of measureable attributes of a system under different conditions at a specific point in time, and that these variables are only relevant to a certain group of stake-holders.[27]



The three dimensions of a system's value

Figure 5. 3DVP Approach

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[26] Nassar, Ayman, "A System-Based Approach for Defining IT Operations Value Proposition," Management Science and Engineering, October 2006.
[27] Ibid.

Appendix B Acronym List

3DVP	Three Dimensional Value Proposition
AAALAC	Association for Assessment and Accreditation of Laboratory Animal Care
ACSI	American Customer Satisfaction Index
ARIS	AIDS Research Information System
ARL	Army Research Laboratory
AT	Advanced Technologies
AT/FP	Anti-Terrorist/Force Protection
BES	Basic Energy Sciences
BRAC	Base Closure and Realignment Commission
CAP	College of American Pathologists
CDC	Center for Disease Control
CEM	Center for Enterprise Modernization
CNO	Chief of Naval Operations
CPT	Captain
COCOM	Combatant Command
CRADA	Cooperative Research and Development Agreement
CS	Customers and Stakeholders
CSDP	Chemical Stockpile Disposal Project
DARPA	Defense Advanced Research Projects Agency
DHHS	Department of Health and Human Services
DHP	Defense Health Program
DHS	Department of Homeland Security
DIACAP	DOD Information Assurance Certification and Accreditation Process
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of Interior
DOT	Department of Transportation
EPA	Environmental Protection Agency
ERS	Economic Research Service
FDA	Food and Drug Administration
eRA	Electronic Research Administration
FHWA	Federal Highway Administration
FTE	Full-time Technical Equivalent

FY	Fiscal Year
GRF	Grant for Research Fellowships
HIPS	Homeland Innovative Prototypical Solutions
HITS	High Impact Technology Solutions
IC	Intelligence Community
IDP	Individual Development Plans
IM/IT	Information Management and Information Technology
IP	Internal Process
LAD	Learning and Development System
LEI	Leadership Effectiveness Inventory
LG	Learning and Growth
OMB	Office of Management and Budget
MAJ	Major
MD	Maryland
MOIE	Mission Oriented Investigation and Experimentation
NASA	National Aeronautics and Space Administration
NAVSEA	Naval Sea Systems Command
NCES	National Center for Education Statistics
NCHRP	National Cooperative Highway Research Program
NOAA	National Oceanic and Atmospheric Administration
NPV	Net Present Value
NRC	National Research Council
NSF	National Science Foundation
OCONUS	Outside the Continental United States
OMB	Office of Management and Budget
ONR	Office of Naval Research
PART	Performance Assessment Rating Tool
PEO	Program Executive Office
PME	Professional Military Education
PVM	Portfolio Value Metric
R	Resources
R&D	Research and Development
RDT&E	Research, Development, Test, and Evaluation
ROI	Return on Investment
RVM	R&D Value Mapping

SBIR	Small Business Innovation Research
S&T	Science and Technology
S&TI	Science and Technical Intelligence
STIPDG	Summer Transportation Intern Program for Diverse Groups
TAB	Technical Assessment Board
TBD	To Be Determined
TCO	Total Cost of Ownership
TFAP	Technology Facilitation Action Plan
TIN	Technology Innovation Network
TRL	Technology Readiness Level
UFR	Unfunded Requirements
USDA	United States Department of Agriculture
VCM	Value Creation Model

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