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Application of Logic Models to Facilitate DoD Laboratory Technology Transfer

Eric Landree and Richard Silberglitt

Key findings

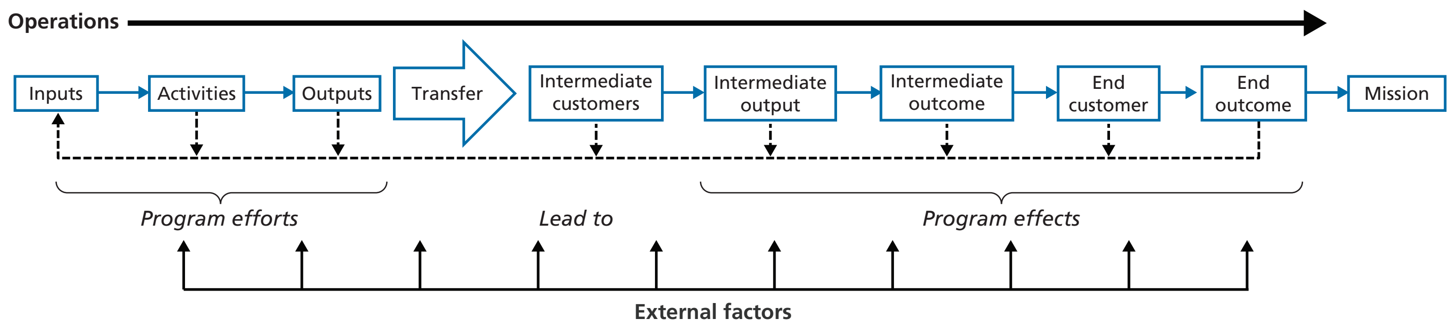
- The key element of successful technology transfer is that program efforts must lead to a product that could lead to new military operations, changes in existing operations or procedures, or direct use by the warfighter.
- Logic models can help the Department of Defense monitor and track technology transfer from laboratories to customers and assess efforts that may lead to capability improvements.
- Our method describes the laboratory operations to help create a definition of "successful technology transfer" that may be applied across the Defense Laboratory Enterprise.

SUMMARY ■ The Department of Defense (DoD) laboratories are sources of new ideas and technologies that can provide military and capability advantages to the warfighter over U.S. adversaries. However, for that advantage to be realized, these new ideas and technologies almost always must be transferred from the laboratory to industry or other organizations capable of developing products or services. Over the years, federal organizations have made efforts—including creating offices dedicated to technology transfer—to accelerate the transfer of research findings and outputs to companies or other organizations. Still, there is not a universally accepted definition of successful technology transfer or guidance for monitoring transfer that can be applied across multiple laboratories or research organizations.

This report describes a method that can be used to help the DoD monitor and track technology transfer from laboratories to customers and assess the success of efforts that may lead to capability improvements. Our method maps efforts associated with technology transfer into a logic model framework that describes the laboratory operations and can be used to create a definition of "successful technology transfer" that may be applied across the Defense Laboratory Enterprise (DLE). Our method also provides guidance for developing measures for monitoring successful technology transfer.

Figure S.1 shows the elements of a generic logic model. The logic model is a framework that can be used to characterize and connect aspects of a research organization, beginning with the inputs that drive the day-to-day operations of the organization and continuing all the way through to its stated mission. Components on the left-hand side of the model are program efforts— elements under the direct control of the organization. Inputs include money, formal requirements, technical performance or capability specifications, staff, research equipment, and facilities. Activities include the conduct of research and development (R&D), the presentation of findings, and the registration of patents. Outputs may include scientific papers, reports, patents, and prototypes. Transfer activi-

Figure S.1. Elements of a Logic Model



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ties might include the circulation of fact sheets, discussions with industry, and the licensing of patents. An example of intermediate customers would be other research laboratories or companies. Generally, program efforts lead to program effects, which are elements of the model that are outside the laboratory's direct control but are necessary to achieving the laboratory's and the DoD's mission. A company that uses licensed patents to create their own commercial product would be an example of an intermediate output. The acquisition and use of that new product which results in a change in procedure or practice would be an intermediate outcome. The ultimate end customer from the perspective of the DLE is the warfighter. It is possible that some of a laboratory's outputs reach the warfighter directly. However, generally laboratory outputs go through an intermediate customer, in some cases multiple intermediate customers, before reaching the warfighter.

Using the framework shown in Figure S.1, we propose a definition of successful technology transfer as having the following elements:

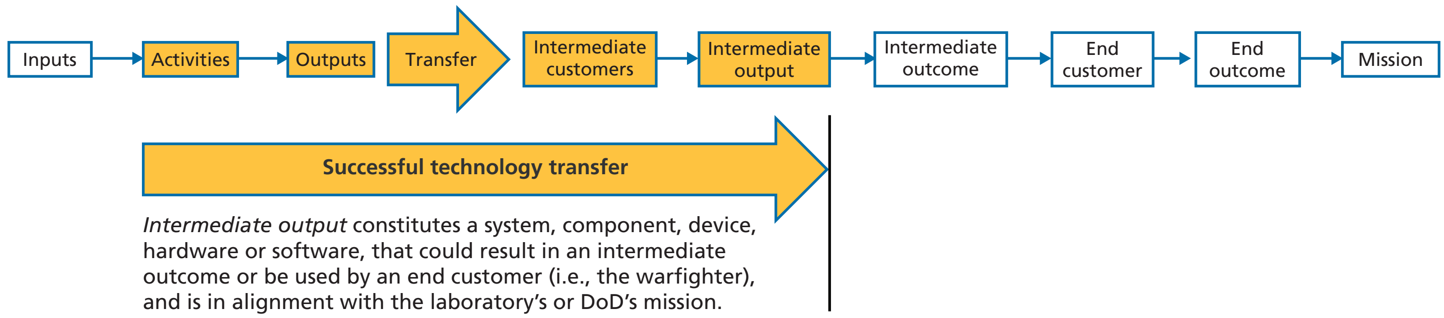
- *activities* that lead to
- *outputs* that are then
- *transferred* to one or more
- *intermediate customers* who in turn produce an
- *intermediate output*—a product (e.g., system, component, device, hardware, software) that could result in an *intermediate outcome* (e.g, a new military operation, a change in an existing operation or procedure) or direct use by an *end customer* (the warfighter) to achieve an *end outcome* in alignment with the laboratory's or DoD's mission.

This definition is illustrated in Figure S.2.

The key element of successful technology transfer is that the laboratory's program efforts must lead to an intermediate output that could lead to either an intermediate outcome or direct use by the warfighter. Absent direct warfighter use, an intermediate customer must use the laboratory's output to create or modify a product;[1] that product must be consistent with the laboratory's mission and have the potential to provide a warfighting advantage. This does not have to be a linear process and may require multiple iterations of intermediate customers creating intermediate outputs that are used by other intermediate customers. For example, a laboratory journal article or prototype leads to research by an outside organization, and that research is then used by a weapon-systems contractor to produce an improved component or system.

Regardless of the pathway or number of steps required, the framework described above can be used to describe and document successful technology transfer. Measures can be developed that correspond to the logic model elements associated with the successful technology transfer definition. In this way, the progress of laboratory activities into outputs and

Figure S.2. Definition of Successful Technology Transfer



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the technology transfer activities associated with these outputs can be monitored and measured, and the occurrence of and reasons for successful and unsuccessful technology transfer can be analyzed. Table S.1 lists some notional measures for each of the logic model elements that can be used for monitoring successful technology transfer

Using this framework, DoD laboratory management can assess and evaluate their various technology transfer activities and determine which have been most effective in leading to successful transfers of technology to intermediate customers, and (with further effort) to determine the ultimate outcomes for the end customer. In a later section, we provide an illustrative example that describes the tracking of a specific successful technology transfer involving U.S. Army research on battery technology. The example is intended to be neither comprehensive nor detailed, but instead is meant to highlight the types of questions and data that a laboratory might use to track and monitor technology transfer and judge success. Applied more broadly, this method has the potential to help the DLE track and monitor how research efforts are transferred and fielded; it supports the objective of Defense Innovation Initiative to sustain our military dominance in the 21st century.

Table S.1. Notional Measures for Monitoring Successful Technology Transfer

Logic Model Element	Notional Measures
Activities	What research is being done? What engagements are occurring with (potential) intermediate customers or end customers?
Outputs	How many prototypes are developed? How many patents are filed? How many papers or reports are written?
Transfer	How many prototype demonstrations are done? How many patents are licensed? How many papers or reports are published as articles and in which journals?
Intermediate Customer	Who has attended prototype or product demonstrations? Who has licensed which patents? Who cited a particular paper, report, or article?
Intermediate Output	What and how many new products or capabilities have been developed by specific intermediate customers? What and how many new procedures or changes in practice have been developed by specific intermediate customers? What and how many reports, scientific articles, or documents have been developed by intermediate customers that cite specific outputs? Which of these led to further activities or outputs by the laboratory or were used by intermediate customers to generate a system, component, device, hardware or software with the potential to be used by an end customer?

MOTIVATION AND APPROACH

According to the American Association for the Advancement of Science's report and analysis on trends in federal research and development (R&D), U.S. federal government investment across the major federal R&D departments and agencies peaked around 2009–2010 at approximately $160 billion (2014 dollars). Since then, federal R&D investment has declined slightly to $140 billion. A similar trend is observed in Department of Defense (DoD) R&D investment, which peaked at approximately $16 billion in 2005 and in 2010, and now has declined to approximately $12 billion.[2] While this is still a considerable amount, trends suggest that R&D dollars for DoD (as well as other federal R&D agencies) are likely to remain flat. Shifting priorities within and among federal departments and agencies will continue to pressure research organizations to justify their R&D budgets. Consequently, there is growing interest in describing the relevance and impact of R&D investment and research outputs and how they support agency missions. Transferring outputs from federal research to customers is an important step in achieving organizational mission or purpose.

DoD laboratories are sources of ideas and capabilities that support DoD's mission to provide the military forces needed to deter war and protect U.S. security. The transfer of technologies and capabilities from DoD laboratories to customers enables continuous improvement of U.S. warfighting capabilities, but technology transfer is a *contact sport* (i.e., it requires active engagement and participation on both sides). In essence, technology transfer is a *matching game*—laboratories' developments in science and technology need to be aligned with customers' performance or capability needs. This matching can be challenging, as requirement developers and science and technology researchers often speak different "languages" and sometimes lack contact with each other.[3] To assess the potential of a match, researchers need to understand user needs in ways that relate to their own work, and users and requirements developers need detailed descriptions of science and technology capabilities that they can relate to their own needs.

Tracking and evaluating successful technology transfers can also be difficult because transfer can occur via multiple different paths. In addition, researchers are incentivized to create research outputs, such as papers and patents, and advance new discoveries. However, these same individuals generally are not incentivized to track how those discoveries are used and whether they are contributing to their intended purpose or mission.

Federal government agencies have made multiple efforts to measure and track the progress of technology transfer from federally funded research efforts and programs.[4] One example is the Department of Commerce's development of measures and goals in response to the 2011 Presidential memorandum on accelerating technology transfer and commercialization of federal research in support of high-growth businesses. The U.S. Department of Energy also recently stood up a new office, the Office of Technology Transition, to "expand the commercial impact of [the Department of Energy's] portfolio" of research activities. This office conducts periodic data collection and analyses to understand the department's impact on the commercial sector.[5] Emphasizing the importance of technology transfer in the DoD, the then–director of the Defense Laboratories Office described the department's technology transfer program at the 2014 National Defense Industrial Association's Annual Science and Engineering Technology/Defense Tech Exposition. The presentation described the department's efforts and measures to accelerate and track technology transfer.[6]

To help improve the DoD's ability to monitor and track technology transfer from the DoD Laboratory Enterprise to its customers and judge the success of that transfer, RAND has mapped technology transfer activities into a logic model. Our technology transfer approach is based on the matching concept described above and has been used previously as part of RAND's technology foresight and R&D prioritization work for the Department of Energy, the Army, the Navy, the National Institute of Justice, and the National Academies Transportation Research Board.[7] A schematic illustration of the technology transfer activities and of correctly matching requirements developer's needs with the discoveries and products derived from the efforts of researchers is shown in Figure 1.

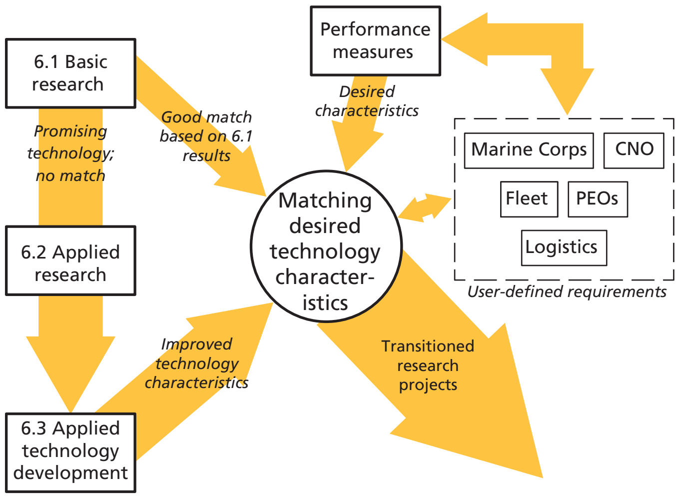
As described in Silberglitt et al.,

> [our] principal objective in this work is to provide a means for evaluating R&D investments in terms of their ability to facilitate this matching and thus close the gap between [basic] research and Navy and Marine Corps requirements.[8]

This approach uses a detailed description of the desired performance or capability that a technology should fulfill and detailed evaluations of science and technology developments to match promising areas that can lead to effective technology transfer.

We sought to build on this approach and develop a generalizable definition of successful technology transfer by mapping the activities described in Silberglitt et al. into a logic model framework. An illustration of the key elements of a generic

Figure 1. Schematic View of Navy R&D Process



SOURCE: Silberglitt et al., 2004, p. 4.
NOTE: CNO = Chief of Naval Operations; PEO = Program Executive Office.
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logic model is shown in Figure 2. Logic models provide a framework for characterizing and tracing the operations of an organization, beginning from inputs (i.e., factors that influence day-to-day operations) through to desired end outcomes. The desired outcomes generally are gauged for their alignment with and support of the organization's mission.

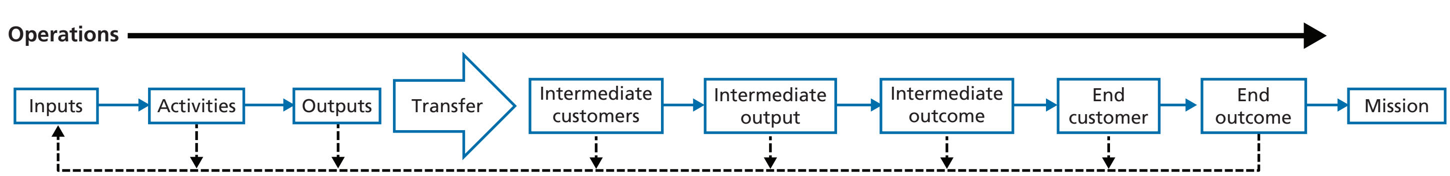
In the case of a research laboratory, *inputs* that would influence day-to-day operations include factors such as money, staff, and formal requirements; performance needs; and capabilities statements. Examples of the types of *activities* one would expect to occur within a laboratory would include R&D; presenting findings; registering patents; and engaging with customers and other organizations, including technology and systems developers or users. The *outputs* from those activities would include new technologies, prototypes, journal articles, papers, reports, and patents. *Transfer* refers to purposefully moving research outputs beyond the laboratory into the hands of organizations or individuals; this includes publishing reports, circulating fact sheets among customers and potential customers, holding technical exchanges with industry, and patent licensing.

Intermediate customers include companies, nonprofit organizations, other researchers, and other research organizations. If an intermediate customer does something with the transferred output, it is referred to as an *intermediate output*. Examples of an intermediate output include new technologies, modifications to existing technologies, and systems that incorporate insights or aspects of the research outputs. If those intermediate outputs are used they can lead to changes in practice, referred to as *intermediate outcomes*. Intermediate outputs and outcomes can be adopted by the end customer; for most DoD laboratories, this is the warfighter. The use and adoption of intermediate outcomes or new products and capabilities that result in changes in practices or benefits for the *end customer* (i.e., the warfighter) are referred to as *end outcomes*. It is worth noting that each element has the potential to provide feedback to previous elements. Research outputs (or the lack thereof) may influence or result in new inputs, such as changes in research funding or revisions to strategic guidance. In some cases, research outputs may move directly to end customers, such as when a technology prototype is provided to soldiers in theater for testing in operational conditions. However, in most cases, the research findings will make their way to the end customer through one or more intermediate customers. A more complete description of logic models and general definitions for the individual logic model elements are provided in the next section.

Visually representing the elements of these operations as chains of events within a logic model framework can be useful for understanding and articulating an organization's mission contributions and for evaluating performance.[9]

RAND has applied logic models to examine and assess programs (including other research laboratories) and organizations across multiple federal agencies and organizations. Starting in 2005, RAND helped National Institute for Occupational Safety and Health (NIOSH), a federal R&D organization within the Department of Health and Human Service's Centers for Disease Control and Prevention, prepare for a National Academies evaluation of the impact and relevance of its R&D programs.[10] Logic models were used as a framework

Figure 2. Elements for a Generic Logic Model



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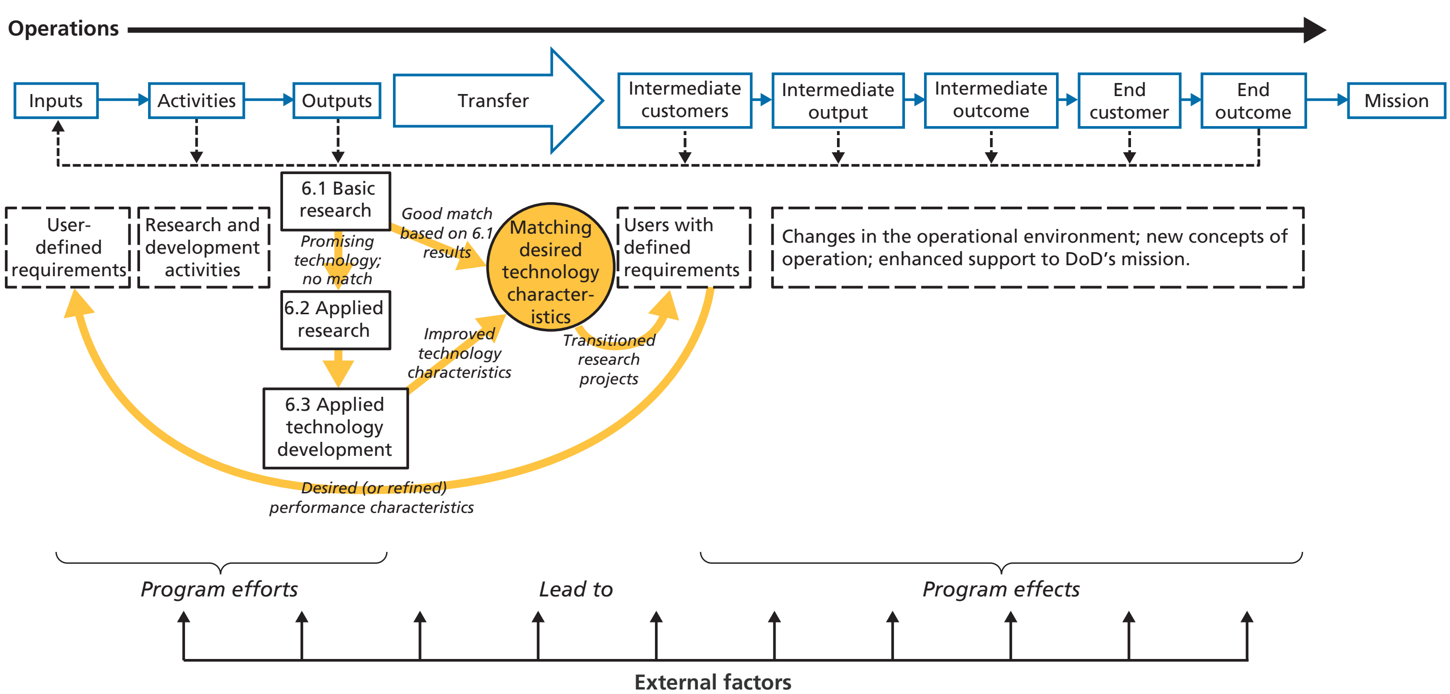
to guide the collection of evidence and compose a narrative to describe how each of the program's efforts contributed to outcomes that supported NIOSH's stated mission (to reduce injuries, illness, fatalities and risk exposures in the workplace). RAND's efforts focused on analyzing each of the NIOSH programs, developing a corresponding logic model, and guiding the development of evidence packages to support the program's evaluation by the National Academies.[11]

In this report, we combine aspects of the technology-transfer approach described in Silberglitt et al. with the logic-model framework to (1) establish a general definition of "successful technology transfer" that may be applied across the Defense Laboratory Enterprise (DLE) and (2) provide guidance for developing measures to monitor technology transfer. While there has been considerable interest in improving the effectiveness of technology transfer, including recommendations to increase the use of logic models in measuring technology transfer effectiveness,[12] to our knowledge no one has combined these concepts in this manner to develop a generalizable definition that can be applied across a broad set of organizations with differing missions and operations.

These methods will be joined at the juncture in the logic model between outputs and customers, which is often referred to in such models as the "transfer." Figure 3, which encapsulates our approach, shows how combining these two methods enables a more detailed and nuanced description and analysis of the transfer process by identifying and characterizing the myriad pathways by which the matching of desired technology characteristics to user needs can be accomplished. We especially note that this matching can occur at any of the science and technology research levels and that the user requirements can be important inputs to R&D activities in DoD laboratories.

For the purpose of our study, we focus our discussion on the research, development, test, and evaluation activities defined as "Basic Research," "Applied Research," and "Advanced Technology Development," also referred to as the Defense Science and Technology (S&T) program.[13] When we use the term S&T, we are specifically referring to the DoD S&T program. When discussing issues or topics related to R&D more broadly, we will refer to it as research or R&D. It should also be noted that this method is most appropriate for capturing the successful transfer of technologies that emerge from applied research and advanced technology development. As will be discussed later in the report, it may also be used for capturing successful technology transfer from basic research. However, capturing successful technology transfer from basic research can be difficult because of the generally longer timelines and more varied paths basic research may travel between discovery and usable technology relative to more applied R&D.

Figure 3. Schematic of Connection Between Logic Model Elements and Technology Transfer



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INTRODUCTION TO LOGIC MODELS

Our framework uses what is referred to in program evaluation literature as a *program logic model* to serve as a blueprint for describing a program's operational path. In this section, we provide a very brief introduction to logic models, including the primary elements of a logic model and how it may be used for activities like developing measures and helping guide strategic planning. For a more comprehensive description of logic models, including their use in program evaluation, readers are encouraged to review the documents listed in the notes.[14]

As a blueprint, the logic model lays out the program's plan for how resources, activities, and outputs lead to outcomes. We also describe some issues that may arise with describing complex organizations and processes within the boundaries of the logic model and provide suggestions and recommendations for addressing those issues and representing contextual nuances within the logic model structure.

Elements of a Logic Model

Logic models serve multiple purposes, including communicating the operation and function of an organization to internal and external audiences. They can also help in identifying a critical path or paths to achieving a set of desired outcomes that support an organization's mission (see Figure 2 for a generic version). A simple, blank logic model that shows the key components described below is provided in Figure 4.

While the amount of detail in logic models can vary, most include the following elements.

Inputs refer to the resources (e.g., staff, money, research equipment, facilities) and information (e.g., strategic guidance, surveillance data, formal requirements, technical performance or capability specifications, user needs or performance capabilities) that drive the day-to-day operations of an organization.

Activities represent what an organization does on a daily basis. Depending on the size and complexity of the organization, the range of activities can be narrow or broad and may include R&D, presenting research findings, and engaging with the customer.

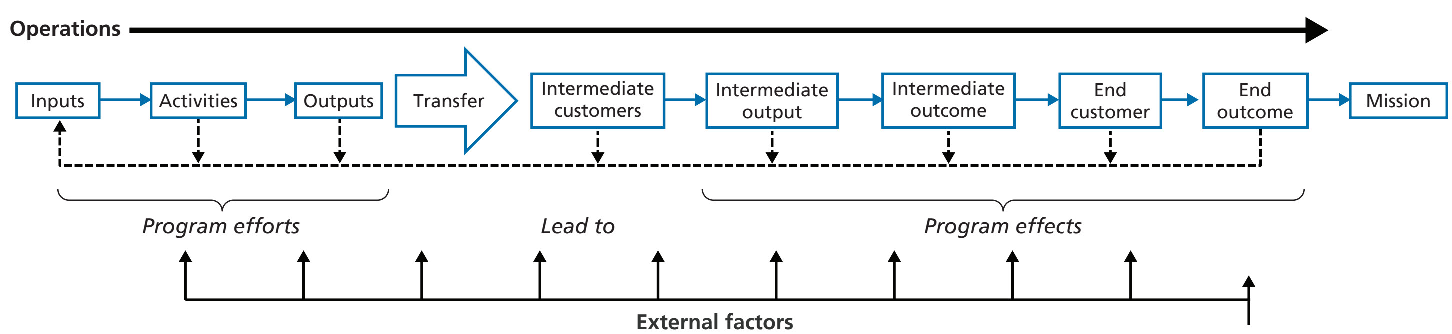
Outputs are the direct products (e.g., guidance documents, prototypes, scientific journal articles, papers, reports, patents) that the organization's activities generate.

Customers are the intended users or target of an organization's outputs. Intermediate customers are individuals or entities that use and transform an organization's outputs to produce an intermediate product. Products or outputs created by an intermediate customer are referred to as intermediate outputs, and can be used either by other intermediate customers or by end customers. End customers are the final target population that the organization is seeking to affect and are associated most closely with the organization's mission.

Outcomes are the changes that occur and the benefits that result from the use of an organization's outputs or the use of an intermediate customer's intermediate outputs. Generally they involve changes in knowledge, attitudes, and behaviors and yield changes in an environment or practice. Intermediate outcomes can be changes in practice (e.g., the adoption of a new technology, capability, or procedure) that lead to desired results (e.g., a more effective military operation or better-protected facility) or end outcomes. End outcomes typically are connected to a program's strategic goals or stated mission and are associated with a societal benefit (e.g., reductions in injuries and fatalities).

External factors are circumstances or events that are exogenous to the program and that positively or negatively affect an organization's ability to achieve outcomes.

Figure 4. Blank Logic Model Highlighting Program Efforts and Effects



SOURCE: Adapted from Greenfield, Williams, and Eiseman, 2006, and Williams, Eiseman, Landree, and Adamson, 2009.

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Typically, an organization's program efforts (i.e., the left-hand portion of the logic model), which consist of its inputs, activities, outputs, and transfer, should lead to or contribute to its program effects, which include intermediate outputs, intermediate outcomes, and end outcomes (i.e., the right-hand portion of the logic model).

Tracking contributions to intermediate and end outcomes is challenging for many research organizations and collecting the information to show progress towards outcomes can be difficult. Outcomes involve the actions or changes on the part of intermediate or end customers. Precisely how particular research outputs contributed to a specific outcome is difficult to quantify. Research organizations also generally prefer being held accountable for things that they have direct control over, including their use of inputs, conduct of activities, and generation of outputs, and are less comfortable being held accountable for that which is outside their direct control.[15] Research organizations may have the ability to influence their customers' actions, but typically cannot control whether or how their research outputs are used.

Also, in some cases the path between outputs and end customers or end outcome will travel through multiple intermediate customers and intermediate outputs. The number of iterations of intermediate customer and intermediate outputs before an end customer is reached or an end outcome is achieved is difficult to predict. In addition, the time between the generation of an output and an intermediate (or end) outcome is difficult to anticipate.

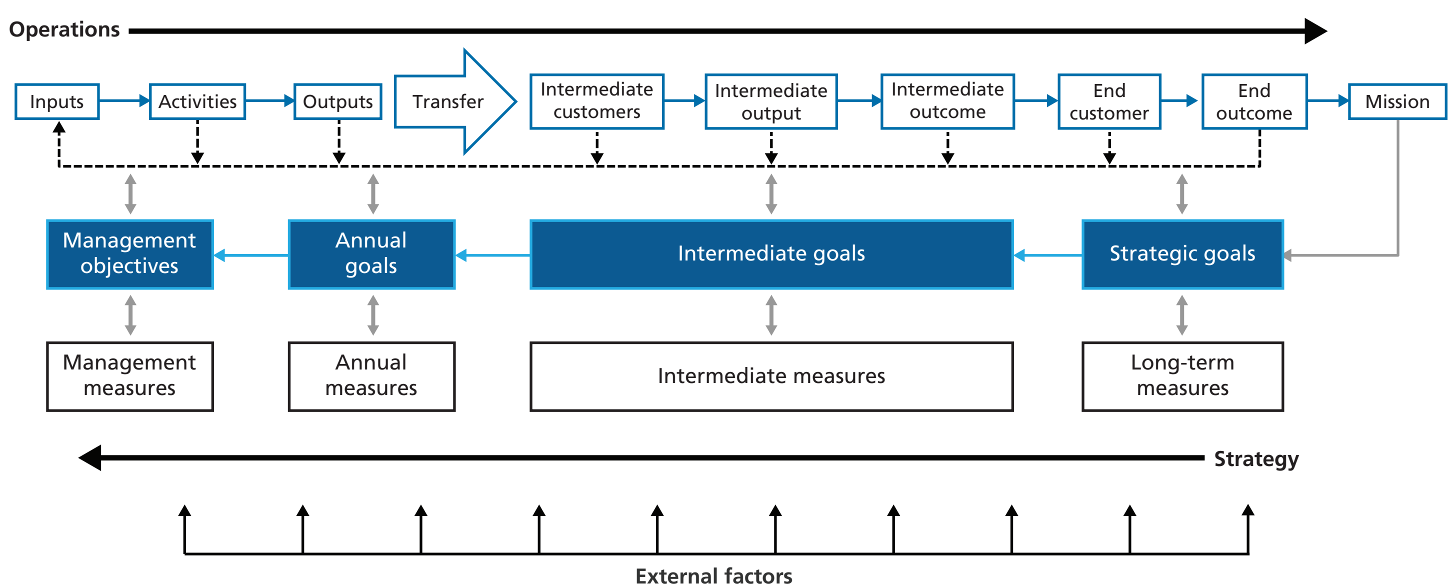
Finally, developing data collection methods and the corresponding infrastructure for assessing how customers are using research outputs beyond the laboratory can be labor and resource-intensive. It also may require expertise that does not reside within the organization and will necessitate investing resources to collect information from intermediate customers. Assuming that the organization does not have an endless supply of employees or funding, these efforts will inevitably require tradeoffs with other laboratory priorities.

Linking Program Operation to Program Strategy and Measures

An important feature of logic models is their ability to link standard elements of the model (i.e. inputs, activities, outputs and outcomes) to the mission and goals of the program, as illustrated in Figure 5 below. We refer to the standard elements of the logic model as depicting the program operations (the top row in Figure 5) and the program goals (i.e. strategic, intermediate, and annual, the middle row in Figure 5) as depicting the program strategy (the bottom row in Figure 5).

In contrast to a program's operations, which flow from left to right in a logic model, an organization's strategy elements flow from right to left. Strategic goals are derived from

Figure 5. Depiction of Alignment of Program Operations with Goals and Measures



SOURCE: Adapted from Greenfield, Williams, and Eisman, 2006.
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or linked to the program or organization mission. The strategic goals then lead to intermediate goals, which in turn should lead to annual goals, which lead to management objectives. Technology or capability requirements may emerge from or be associated with an organization's intermediate or strategic goals and feed into the operational logic model as inputs. The vertical alignment between strategy and operations in Figure 5 is deliberate and highlights the relationship between the vertical components of the figure. In other words, a program's strategy and operations should make sense as a package and "line up" as the vertical double arrows in Figure 5 indicate. The desired end outcomes should align with the strategic goals; intermediate customers, outputs, and outcomes should align with intermediate goals; program activities and outputs should align with annual goals; and program inputs and activities should align with management objectives. The logic model is important in that it not only describes how a program achieves its goals, but also defines the path that it may take.

Similarly, the measures posited for each stage should enable programs to gauge progress in meeting the corresponding goals and objectives. Annual measures for a research organization's output goals might include the numbers of scientific articles, prototypes developed, patents filed, etc.; annual measures for research transfer might include the numbers of presentations, licenses acquired for a particular patent, or demonstrations made of a particular prototype or capability. The relationships between operations, goals, and measures should be direct, transparent, and supportable with evidence.

It may be possible to establish quantitative measures at each step along the path of the logic model; however, the interpretability of those measures can become increasingly problematic the closer one moves toward outcomes, and might benefit from augmentation with qualitative information. Also, the closer one gets to outcomes, the more difficult it can be to identify the distinct contributions of the organization under consideration given the intervening actions of others.

Also, an organization might be able to develop a quantitative measure, but have difficulty establishing its significance for measuring progress toward the desired end outcome absent further examination. For instance, a research laboratory may know how many new products an intermediate customer generates from a particular research output. However, knowing whether that number is significant may depend on qualitative information about the intermediate outputs that were generated. For example, what are the capabilities of the intermediate outputs and how do they benefit the end customer? Another example could be an academic scientist's journal article that cites a report generated by a laboratory, and a product produced by a company that cites the same report. Both count as examples of an intermediate output. However the academic article may need to pass through several more intermediate customers and require more time before a physical device or capability is generated compared to the company that produces a product that has the potential to impact the end customer much sooner. While both examples are countable, their qualitative significance could be very different.

Long-term measures align with strategic goals and end customers and end outcomes, which are connected with an organization's intended mission, and may be entirely qualitative measures. An organization whose mission is to "empower, unburden, sustain and protect the Warfighter to enable the dominance of the Army,"[16] may include measures such as, how has the warfighter (i.e., the final customer) been protected, or how has the warfighter's protection been enhanced? What new ways has the warfighter been empowered or what enhanced capabilities has he or she acquired?

SUCCESSFUL TECHNOLOGY TRANSFER

Tracking and measuring the contribution of activities all the way to outcomes is difficult for most organizations for all the reasons noted in the previous section. In addition, different research organizations, even those under a common parent organization, may have different mission statements that imply different corresponding end outcomes. Consider the mission statements for the research institutions under the DLE. While each laboratory is affiliated with and supports the DoD, each characterizes its mission differently. In some cases, the mission statements focus on the laboratory's activities and outputs, while in others they focus on desired outcomes. The mission statements for several laboratories within the DLE are listed in Table 1. Portions of the mission statements that address program efforts are highlighted in italics. Portions of the mission statements that suggest or refer to program effects are highlighted in bold text.

Table 1 reveals two important observations. First, even though all of the defense laboratories are part of the DLE and are focused on supporting DoD's overall mission, which is to "deter war and to protect the security of our country," the individual mission statements are generally different. This is due in

Table 1. Example Defense Laboratory Mission Statements with Program Efforts and Program Effects Highlighted

Defense Laboratory	Mission Statement
Air Force Research Laboratory (AFRL)	AFRL's mission is *leading the discovery, development, and integration* of warfighting technologies for our air, space and cyberspace forces.[a]
Air Force Office of Scientific Research (AFOSR)	AFOSR continues to *expand the horizon of scientific knowledge through its leadership and management of the Air Force's basic research program.* As a vital component of the AFRL, AFOSR's mission is *to support Air Force goals* of **control and maximum utilization of air, space, and cyberspace**.[b]
Army Research Laboratory (ARL)	Discover, innovate, and *transition* science and technology to ensure **dominant strategic land power**.[c]
U.S. Army Medical Research and Materiel Command Walter Reed Army Institute of Research (WRAIR)	The WRAIR aims to *conduct biomedical research* that is responsive to Department of Defense and U.S. Army requirements and *delivers life saving products* including knowledge, technology and medical material that **sustain the combat effectiveness of the Warfighter**.[d]
U.S. Army Medical Research Institute of Infectious Diseases	To *provide leading edge medical capabilities* t**o deter and defend against current and emerging biological threat agents**[e] (U.S. Army, 2014).
[excerpt from] Naval Research Laboratory (NRL)	NRL *operates* as the Navy's full-spectrum corporate laboratory, *conducting* a broadly based multidisciplinary program of scientific research and advanced technological development directed toward maritime applications of *new and improved materials, techniques, equipment, systems and ocean, atmospheric, and space sciences and related technologies.* In fulfillment of this mission, NRL: • *Initiates and conducts broad scientific research* of a basic and long-range nature in scientific areas of interest to the Navy. • *Conducts exploratory and advanced technological development* deriving from or appropriate to the scientific program areas. • Within areas of technological expertise, *develops prototype systems* applicable to specific projects. • *Assumes responsibility* as the Navy's principal R&D activity in areas of unique professional competence upon designation from appropriate Navy or DoD authority. • *Performs scientific R&D* for other Navy activities and, where specifically qualified, for other agencies of the DoD and, in defense-related efforts, for other government agencies. • *Serves as the lead Navy activity for space technology and space systems development and support.* • *Serves as the lead Navy activity for mapping, charting, and geodesy R&D* for the National Geospatial-Intelligence Agency (NGA).[f]
Navy Surface Warfare Center Dahlgren Division	*Provide research, development, test and evaluation, analysis, systems engineering, integration and certification of complex naval warfare systems* related to surface warfare, strategic systems, combat and weapons systems associated with surface warfare. *Provide system integration and certification* for weapons, combat systems and warfare systems. *Execute other responsibilities as assigned* by the Commander, Naval Surface Warfare Center.[g]
Space and Naval Warfare Systems Command Systems Center Pacific	*Conduct research, development, delivery, and support* of integrated command, control, communications, computers, intelligence, surveillance, and reconnaissance, cyber, and space systems across all warfighting domains.[h]

[a] U.S. Air Force, "Fact Sheet: Air Force Research Laboratory," December 15, 2014.
[b] U.S. Air Force, "Air Force Office of Scientific Research," undated.
[c] U.S. Army, "About ARL," March 1, 2011.
[d] U.S. Army, "U.S. Army Medical Research and Materiel Command Walter Reed Army Institute of Research: Mission," October 15, 2015.
[e] U.S. Army, "U.S. Army Medical Department U.S. Army Medical Research Institute of Infectious Diseases: About USAMRIID," December 4, 2014.
[f] U.S. Naval Research Laboratory, "Mission," undated.
[g] Naval Sea Systems Command, "Warfare Centers: NSWC Dahlgren Division," undated.
[h] U.S. Navy, "SPAWAR Systems Center Pacific (SSC Pacific)," undated.
NOTE: Examples of program efforts are in *italic* text. Examples of program effects are in **bold** text.

part to the laboratories' focus on program activities, which are unique to each of the different laboratories.

Second, the laboratory mission statements tend to focus on program efforts (i.e., what an organization does or what it generates) as opposed to program effects (i.e., the desired changes in practices or the environment that result from those efforts). This is not unique to DoD research laboratories. A laboratory's program efforts include things over which it has direct influence and control. A laboratory's program effects typically require customers or others to use the laboratory's outputs to achieve some desired outcome. At best, most laboratories have direct influence over their customers, and typically only indirect influence over how their outputs are used to contribute to outcomes.

Based on this small sample of the laboratories' mission statements, there is not an obvious single logic model, with a coherent set of end outcomes, under which all of the defense laboratories could be aligned or evaluated. However, what is true and consistent for all research laboratories is that in order for an organization's activities and outputs to ultimately contribute to intermediate and end outcomes, that laboratory must successfully transfer their output to an intermediate customer that uses it or produces something from it. A laboratory discovery, prototype, or capability that does not leave the laboratory and is never delivered to a customer might be intrinsically valuable, but it is incapable of contributing to an outcome. It also should be emphasized that "transfer," albeit essential, is not a surrogate for "outcome."

Using the framework and logic model components and vocabulary that we introduced in the previous section, we define successful technology transfer as having the following elements:

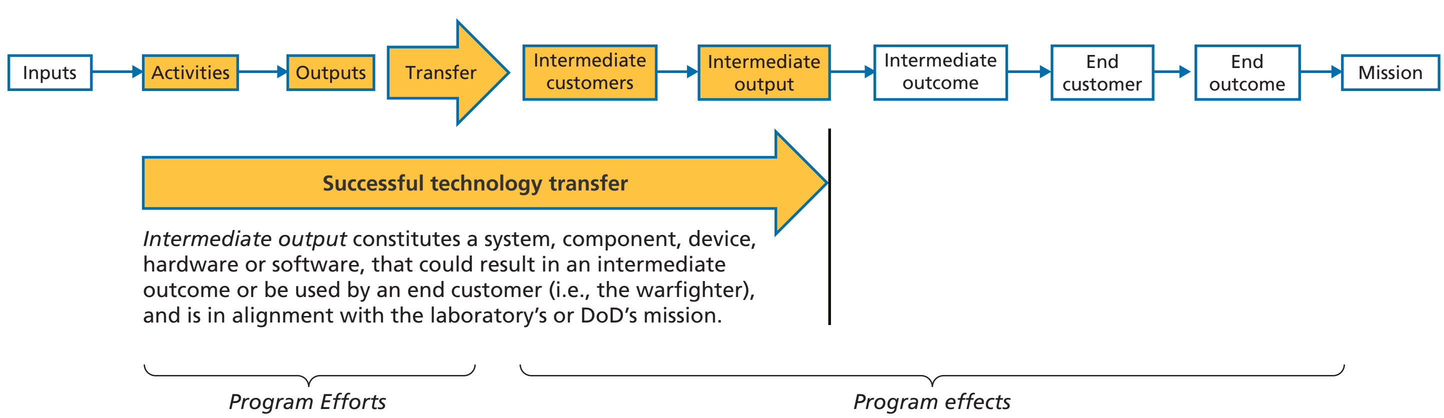
- *activities* that lead to
- *outputs* that are then
- *transferred* to one or more
- *intermediate customers* who in turn produce an
- *intermediate output*—a product (e.g., system, component, device, hardware, software) that could result in an *intermediate outcome* (e.g, a new military operation, a change in an existing operation or procedure) or direct use by an *end customer* (the warfighter) to achieve an *end outcome* in alignment with the laboratory's or DoD's mission.

This definition requires the production of a product[17] that an intermediate or end customer could employ to achieve a specific outcome, depicted graphically in the operational logic model shown in Figure 6 below.

The exact nature of the intermediate outputs that are generated will depend on the specific output that is produced by the laboratory and the intermediate customer to which it is transferred. A commercial entity (i.e., Company A) might use a laboratory's outputs (e.g., a technology) to produce new products or change an industrial process that affects existing or new products and can yield an outcome. This would be an example of a successful technology transfer.

Alternatively, a research organization (i.e., Organization B) might use research outputs (e.g., a scientific article) to produce new scientific findings, journal articles, or other publications. This would not constitute a successful technology transfer. Although both Company A and Organization B have produced "intermediate outputs," they are different types of intermediate outputs. Successful technology transfer would not occur unless Organization B's findings, articles, or other publications are used by it or another intermediate customer to produce a product such as a system, component, device, hardware or software that could result in an intermediate outcome.

Figure 6. Logic Model Description of Successful Technology Transfer



RAND *RR2122-3.1*

There is the potential for multiple iterations of intermediate customers creating intermediate outputs that are then used by other intermediate customers before they produce an intermediate output that could result in an intermediate outcome that constitutes a successful technology transfer, as illustrated in Figure 7.

Using the previous examples, the intermediate output generated by Organization B (e.g., a journal article) may be used by Company A to produce a new product (e.g., a commercial entity generates a commercial product that is influenced by the research organization's journal article that was originally influenced by the defense laboratory's output). In this simplified example, there were two intermediate customers between the original outputs and the development of an intermediate output that could produce an intermediate outcome of relevance to the laboratory's mission or DoD's mission. As mentioned in the section introducing logic models, the number of iterations between intermediate customers required to achieve intermediate outputs that meet the criteria described above is both variable and difficult to predict. In addition, the time it will take between the generation of an output and an intermediate (or end) outcome is difficult to anticipate in advance.

In order to claim having a successful technology transfer, it is the organization's responsibility to document and describe the contribution at each step (i.e., activity, output, transfer mechanism, intermediate customer, intermediate output) and to make a case for contributing to outcomes or having "impact." Although there can be multiple iterations of steps between an output or outputs and an intermediate outcome, these steps can be described and their results can be measured, as indicated in Figure 8.

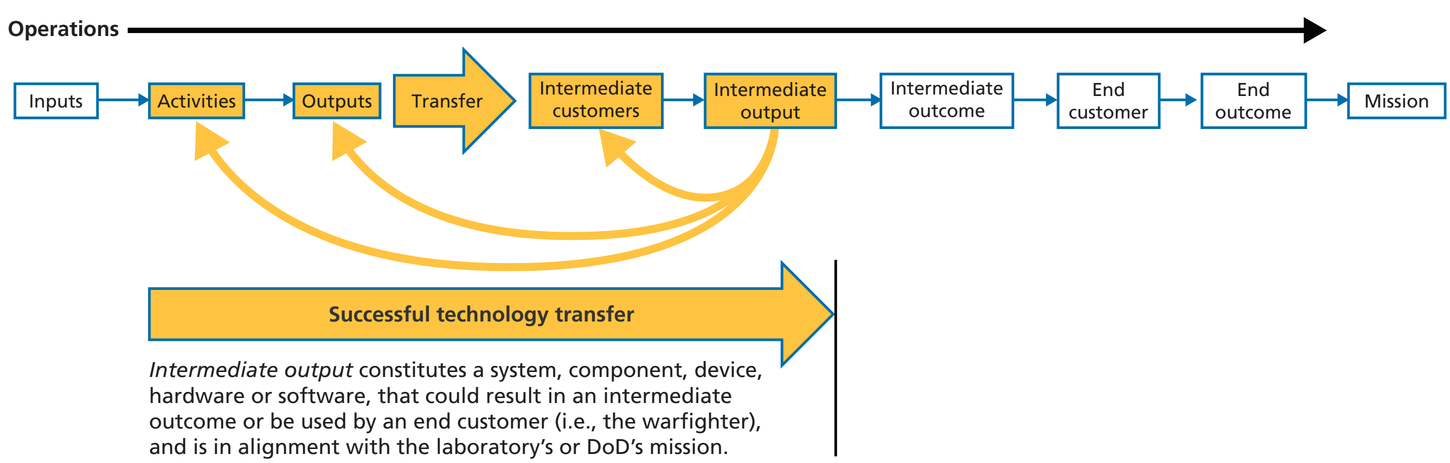
Examples of measures that might be used to monitor successful technology transfer are listed in Table 2. Because each research laboratory or organization contributes to outcomes differently, the measures that would be appropriate for a specific laboratory or research organization would need to be tailored to that particular organization's operations.

The next section provides an example of how our method might be used to describe and highlight the tracking of successful technology transfer. We note however, that this example represents but a small thread in a large tapestry of R&D. It is intended to be neither comprehensive nor detailed, but rather to point out the types of questions and data that a laboratory might use to track and monitor the successful transfer of its technologies.

EXAMPLE: DOCUMENTING SUCCESSFUL TECHNOLOGY TRANSFER OF ARMY BATTERY RESEARCH

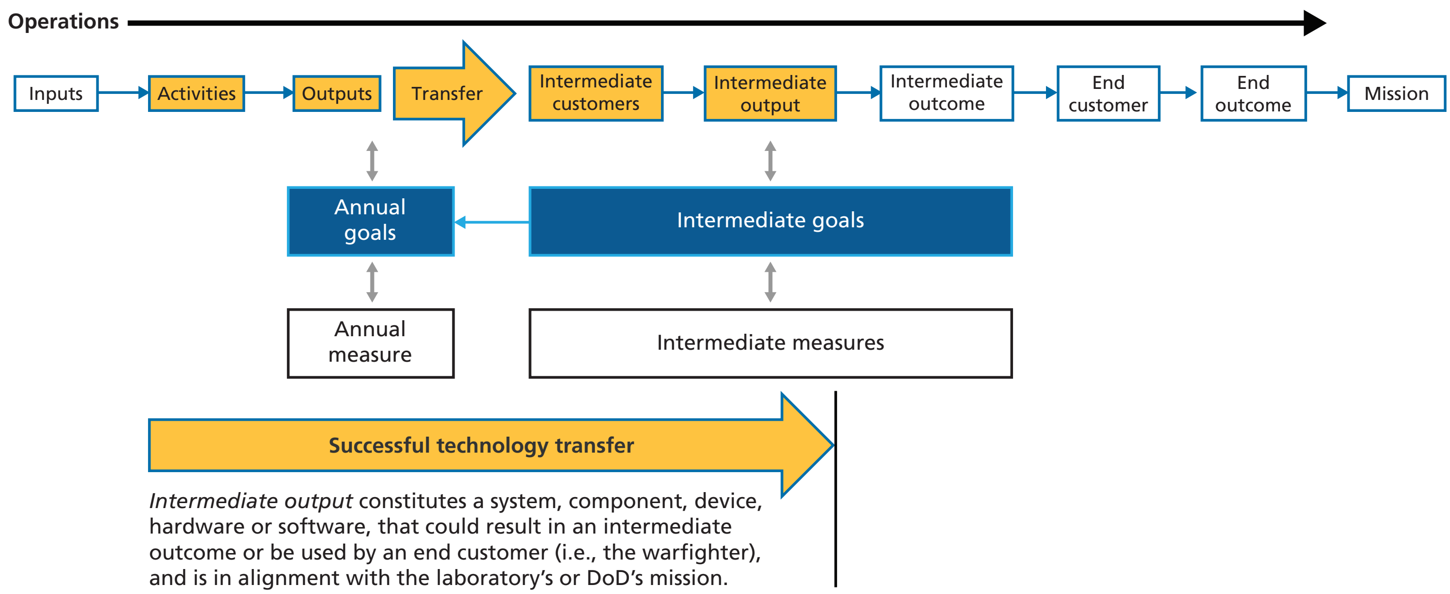
In this section, we provide an example of how one might use our method to monitor whether a specific research organization's program efforts are contributing to desired program effects—specifically, a successful technology transfer based on the definition provided in the previous section. The example we use is an ARL battery technology to power the equipment used by warfighters. We chose this example based on our knowledge of recent developments in electrochemistry at ARL and discussions in the literature of how these developments might be used by intermediate and end customers. This allowed us to explain our approach and illustrate the logic model using actual data.

Figure 7. Successful Technology Transfer Through Multiple Intermediate Customers



RAND *RR2122-3.2*

Figure 8. Successful Technology Transfer and Corresponding Measures



RAND *RR2122-3.3*

Table 2. Notional Measures for Monitoring Successful Technology Transfer

Logic Model Element	Notional Measures
Activities	What research is being done? What engagements are occurring with (potential) intermediate customers or end customers?
Outputs	How many prototypes are developed? How many patents are filed? How many papers or reports are written?
Transfer	How many prototype demonstrations are done? How many patents are licensed? How many papers or reports are published as articles and in which journals?
Intermediate Customer	Who has attended prototype or product demonstrations? Who has licensed which patents? Who cited a particular paper, report, or article?
Intermediate Output	What and how many new products or capabilities have been developed by specific intermediate customers? What and how many new procedures or changes in practice have been developed by specific intermediate customers? What and how many reports, scientific articles, or documents have been developed by intermediate customers that cite specific outputs? Which of these led to further activities or outputs by the laboratory or were used by intermediate customers to generate a system, component, device, hardware or software with the potential to be used by an end customer?

We stress, however, that this example is presented solely for the purpose of illustrating the method and is not a reflection of the broader ARL program.

In the sections below we suggest possible entries under the corresponding logic model elements and then discuss how they may constitute an example of a successful technology transfer as previously defined.

Example Input

In this initial example (see Figure 9), ARL inputs could include requirements for better performance from batteries that soldiers use for everything from radios to unmanned aerial vehicles. Requirements can be formally derived from rigorous requirements processes[18] or informally acquired through interaction with technology users and end customers (i.e., the warfighter). Other inputs that might influence and affect laboratory research activities could include the availability and expertise of the laboratory's researchers and technical staff, as well as funds to conduct the research and the necessary equipment. In this example, expertise and experience in electrochemistry (particularly the design and operation of lithium-ion batteries and the determinants of their performance and lifetime) were important inputs to the research. Other examples of inputs that will affect research activities explicit in Figure 9 include research articles, publications, patents, information from other researchers and other research institutions, feedback from industry or battery manufacturers (e.g., design specifications), as well as other types of information.

Although not a part of the definition of successful technology transfer that we developed, inputs have a direct influence on the activities undertaken within a research laboratory such as ARL. Consequently, they are worth considering as one looks to develop measures and check for examples of successful technology transfer.

Example Activities

The ensuing laboratory activities (see Figure 10) would then include research into alternative battery electrolytes, as one example of research into means to improve battery performance. Activities could include the research, development, and testing of various electrolyte chemistries and systems, as a means to improve the electrode stability at higher voltages, increase the number of charging cycles, and expand the battery's operating temperatures, as well as research on creating propane-powered fuel cells. Analysis would include evaluating the experimental data and determining how the performance characteristics of the batteries using the new battery electrolyte compared to those of conventional electrolytes (or other research efforts). Documenting the research findings, including the writing of journal articles, creation of conference presentations, or drafting of patent applications, would be other activities that contribute to the development of research outputs.[19]

Another important activity from the prospective of the laboratory with regards to technology transfer would be arranging and participating in technical exchanges among the laboratory researchers and representatives from industry that could potentially use these technologies.

Example Outputs

Corresponding research outputs (see Figure 11) could include the design for the improved electrolyte material, scientific

Figure 9. Illustrative Example: Army Battery Research Inputs

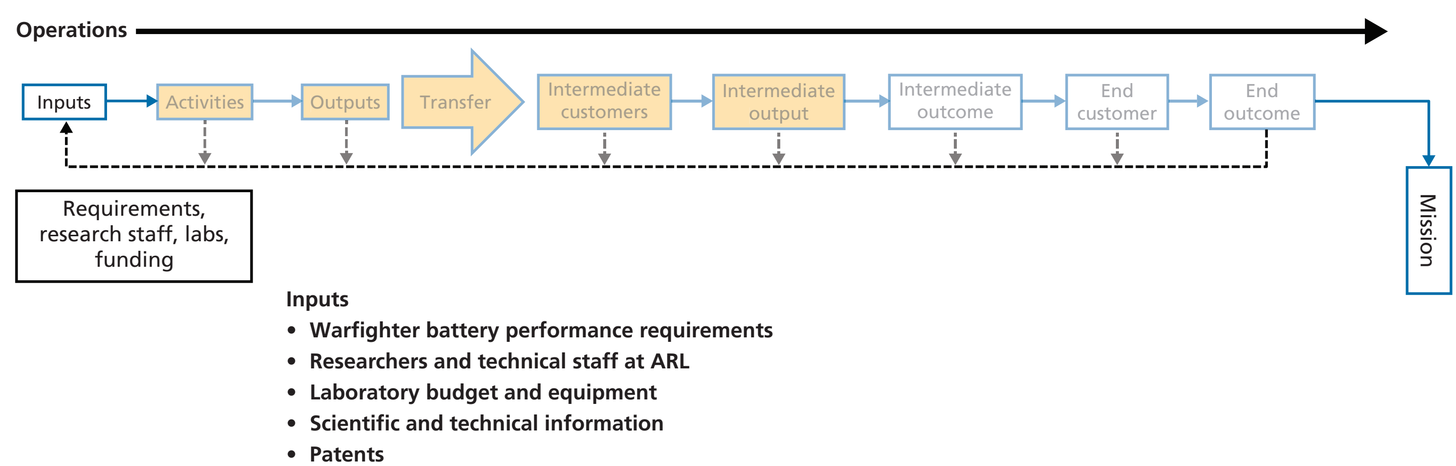


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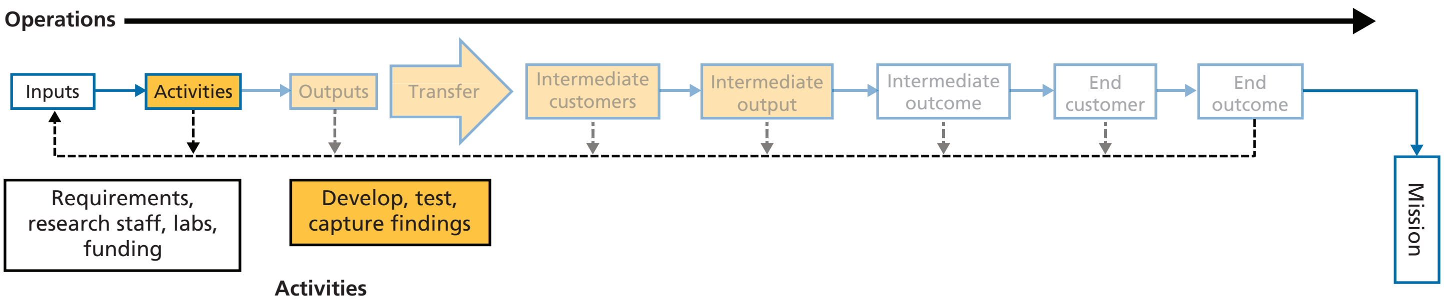
Figure 10. Illustrative Example: Army Battery Research Activities



Activities

- **Develop and test alternative battery electrolytes ($LiBF_3Cl$)**
- **Data analysis**
- **Document findings and researcher results**
- **ARL researchers engage with manufacturers**

RAND *RR2122-4.2*

articles, prototype electrolyte materials, and prototype batteries. Other outputs can include methods for commercial manufacturing of the electrolytes, fuel cell development, and batteries that would be suitable for industrial use.[20]

Other examples of outputs that focus on transferring technologies may include a planned technical exchange meeting with other researchers or representatives from industry, along with any presentation materials or demonstrations that have been prepared to be part of that technical exchange.

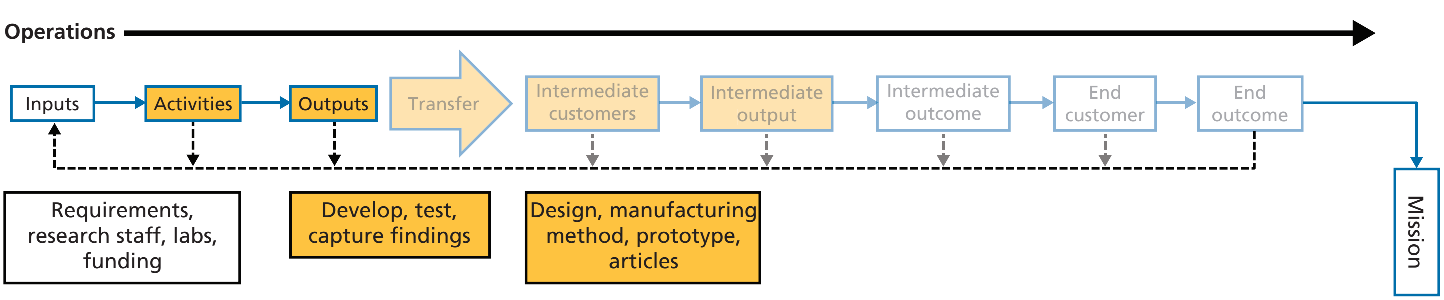
As discussed earlier, research organizations tend to focus on program efforts, which are under their direct control, and develop measures that are geared to countable items (e.g., numbers of patents, articles, and citations). All of these are important for identifying progress along the path to outcomes, but none is sufficient to demonstrate that an organization's outputs are contributing to its mission or desired end outcomes.

Transfer and Customers

Transfer refers to the ways that the research laboratory's outputs are provided or transferred to the various customers. In this example (see Figure 12), it might include the exchange of new knowledge or best practices or advice to companies manufacturing the propane-based fuel cell that ARL developed.

Other examples of transfer can be the downloading of factsheets about specific discoveries or technology innovations, such as the U.S. Army Research, Development and Engineering Command factsheet on the ARL-developed improved electrolyte. Recalling our earlier discussion of technology transfer as a contact sport, direct engagement between laboratory and industry researchers and staff can provide more utility as a transfer mechanism than engagement via factsheets. Nonetheless, factsheets represent a vehicle that other intermediate custom-

Figure 11. Illustrative Example: Army Battery Research Outputs and Program Efforts



Outputs

- **Design for improved electrolyte**
- **Method for improved commercial manufacturing**
- **Prototype**
- **Scientific articles**

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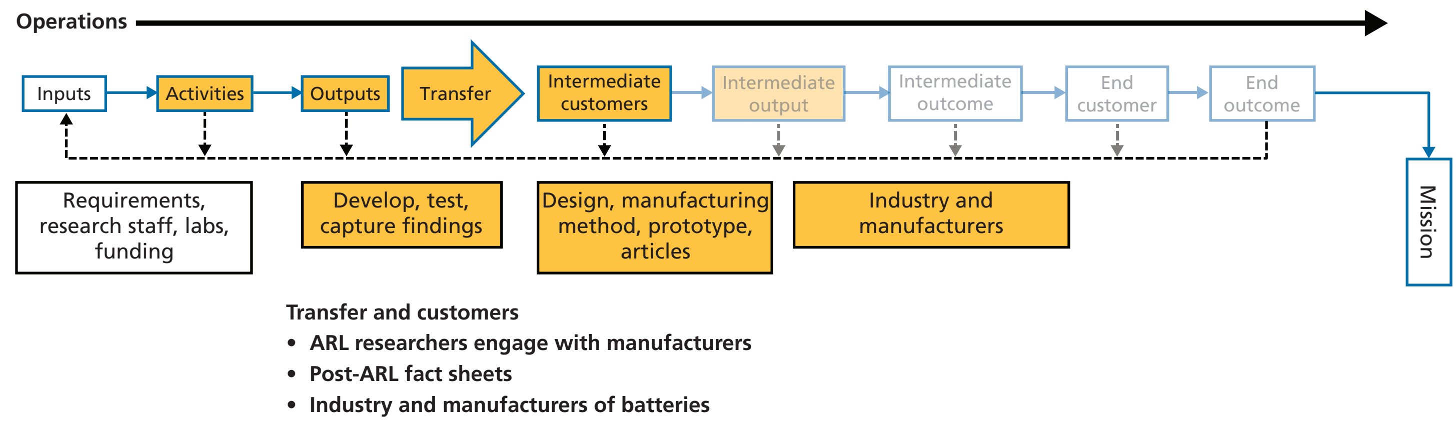
Figure 12. Illustrative Example: Army Battery Research Transfer and Customers



RAND *RR2122-4.4*

ers, including researchers, as well as other manufacturers and developers of battery technologies can use to receive information about ARL's outputs.

Intermediate Outputs

For purposes of this example, a successful technology transfer would occur when an intermediate customer has created or enhanced a product (e.g., hardware, software, device, manufacturing process) or a service based on outputs that had been transferred to it from ARL (see Figure 13). As mentioned earlier, it does require additional efforts on the part of ARL to monitor and document examples of how its outputs are used by intermediate customers. However, these efforts (such as engagements with manufacturers) provide an ideal opportunity to both provide information to industry and other intermediate customers, as well as to capture information about how its outputs are being used by intermediate customers. In the case of the propane-based fuel cell, it was reported that the technology had been transferred to Protonex, which was

> in its early phases of selling to PEO Soldier its "Power Manager," which combines energy drawn from a fuel cell and a solar blanket to provide power in some of the most remote places in the world.[21]

Once a laboratory has successfully transferred its research outputs to its intermediate customers (e.g., manufacturers, industry, other research organizations and researchers), they can then be used to create other intermediate outputs (e.g., new batteries, new patents, new devices that incorporate those batteries or new research findings). Intermediate outputs may then be used by other intermediate customers or (less frequently) immediately by end customers (i.e., U.S. Army soldiers and other warfighters), directly resulting in new or enhanced solider capabilities or reduced burden. Referring back to our definition, the production of a commercial battery that can be used by other industries and researchers or by the warfighter would constitute an example of a successful technology transfer.

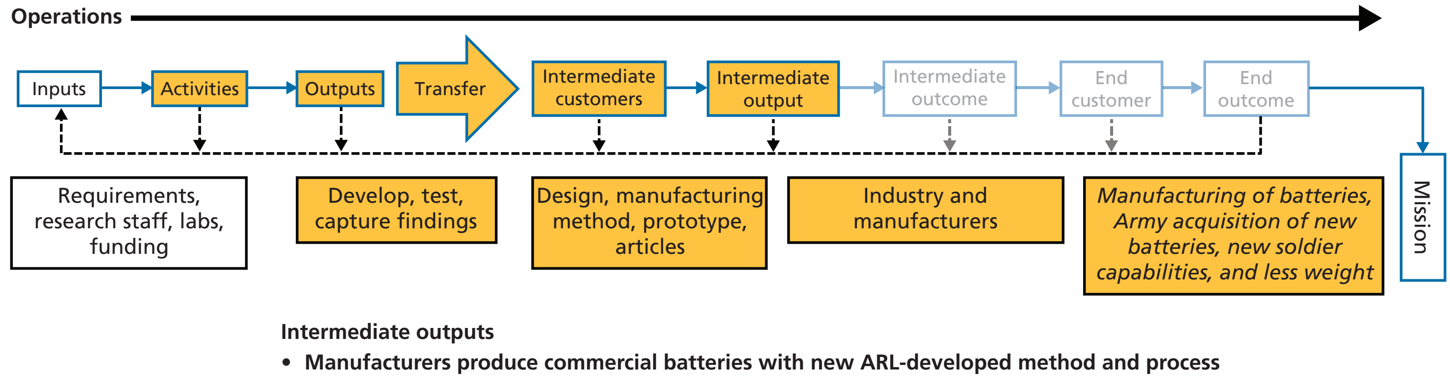
Intermediate outputs are not always directly related to the original target application. For example, in the fuel-cell case described above, the ultimate application was remote power in combination with a solar blanket, rather than powering an unmanned aerial vehicle.

After the successful technology transfer has been documented, additional information could be collected to document how the research outputs may have contributed to specific intermediate outcomes (what new military operations were enabled due to enhanced battery performance) or end outcomes—in the context of the ARL mission, how the transfer has enabled the warfighter to "dominate strategic land power."

INSIGHTS AND IMPLICATIONS FOR MONITORING SUCCESSFUL TECHNOLOGY TRANSFER

Given the enormous variation in scope and mission across the DLE, it is unrealistic to establish a single model and corresponding set of measures for every laboratory that contributes to the DoD. Nonetheless, it is generally true that in order for a discovery or new technology to enhance the capabilities or reduce the burden of the U.S. soldier, it must be successfully transferred to an intermediate or end customer that then uses the discovery or technology. Successful technology transfer is thus a necessary, but not sufficient, step toward achieving mission objectives (i.e., outcomes). Applying our definition

Figure 13. Illustrative Example: Army Battery Research Intermediate Outputs



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of successful technology transfer across the DLE, as well as applying the resources to capture the data necessary to document successful technology transfer, could provide DoD with important insights into the existing and potential contributions of its research investment to enhancing warfighter capabilities. It would also move the laboratories a major step beyond merely counting research outputs, such as the number of patents, the number of journal articles, and the number of presentations, as measures of impact.

Generally speaking, the more applied the research the easier it becomes to measure successful technology transfer. The more basic the research, the more iterations between the laboratory and other intermediate customers may be needed before it contributes to the creation or enhancement of a product, service, or capability that could impact the warfighter. This method may be applied to all S&T programs; however, it can be more difficult to trace the successful technology transfers that stem from basic research relative to research that is more applied. Most laboratories within the DLE conduct a range of research activities. While the amount of basic research varies among the different DoD laboratories, the majority of effort generally is focused on applied research, advanced technology development, and similar activities.[22] Therefore, linking the majority of research activities and outputs of the DLE laboratories to potential users or monitoring them for evidence of successful technology transfer should be achievable.

This monitoring would also be helpful in understanding the reasons why particular research program efforts are not contributing to the stated mission. For example, the absence of a robust or mature manufacturing or industry customer to receive the research outputs would inhibit successful technology transfer and perhaps even preclude the achievement of desired intermediate or end outcomes. If this is the case, then it is valid to ask whether it makes sense to continue the same level of effort if the research has limited potential to eventually contribute to outcomes. Monitoring and analyzing successful technology transfer and analyzing why successful technology transfer does not occur could provide greater insights and information for DLE and DoD leadership to strategically manage R&D resources.

Our proposed method is an approach to capture and document which science, technology, and research discoveries and developments are (or are not) resulting in potentially new capabilities for our warfighters. Having information on successful technology transfers can assist decisionmakers prioritize and focus on research investments that maximally enhance our military's advantage over our adversaries.

Notes

[1] For the purposes of this report, we consider products to include processes as well as tangible items, a consideration consistent with U.S. Patent and Trademark Office practice. See U.S. Patent and Trademark Office, "Patent FAQs," 2016.

[2] A description of current and historical trends is available online at American Association for the Advancement of Science, "Historical Trends in Federal R&D," June 22, 2017.

[3] The technology that is being transferred is embedded in a product that results from applied research. Basic or fundamental research likely will have preceded the development of the technology, as we describe in the following sections.

[4] White House, Office of the Press Secretary, "Presidential Memorandum—Accelerating Technology Transfer and Commercialization of Federal Research in Support of High-Growth Businesses," October 28, 2011. For more information, see U.S. Department of Commerce, *Accelerating Technology Transfer and Commercialization of Federal Research in Support of High-Growth Businesses*, Washington, D.C., September 2012; and Interagency Working Group on Technology Transfer, Revised Technology Transfer Metrics in Response to the October 28, 2011 Presidential Memorandum: Accelerating Technology Transfer and Commercialization of Federal Research in Support of High-Growth Businesses, November 2012.

[5] See U.S. Department of Energy, Office of Technology Transitions, "Mission," undated; and U.S. Department of Energy, "Energy Department Announces New Office of Technology Transitions," February 11, 2015.

[6] John Fischer, "Department of Defense Technology Transfer (T2) Program," presented at the NDIA 15th Annual Science & Engineering Technology/Defense Tech Exposition, April 8, 2014.

[7] For example, see Figure 1.2 on p. 4 of Richard Silberglitt, Lance Sherry, Carolyn Wong, Michael Tseng, Emile Ettedgui, Aaron Watts, and Geoffrey Stothard, *Portfolio Analysis and Management for Naval Research and Development*, Santa Monica, Calif.: RAND Corporation, MG-271-NAVY, 2004; or Figure 2-1 on p. 9 of Steven W. Popper, Nidhi Kalra, Richard Silberglitt, Edmundo Melina-Perez, Youngbok Ryu, and Michael Scarpati, NCHRP Report 750, *Strategic Issues Facing Transportation, Vol. 3: Expediting Future Technologies for Enhancing Transportation System Performance*, Washington, D.C.: Transportation Research Board of the National Academies, 2013.

[8] Silberglitt et al., 2004, p. 3. In the figure and throughout this report, we use DoD research category definitions. See J. D. Moteff, *Defense Research: A Primer on the Department of Defense's Research, Development, Test and Evaluation (RDT&E) Program*, Congressional Research Service, Washington, D.C., 97-316 SPR, May 1998.

[9] For example, see W. K. Kellogg Foundation, *W. K. Kellogg Foundation Logic Model Development Guide*, Battle Creek, Mich., January 2004.

[10] Centers for Disease Control and Prevention, "The National Academies Evaluation of NIOSH Programs," February 7, 2013.

[11] Valerie L. Williams, Elisa Eiseman, Eric Landree, and David M. Adamson, *Demonstrating and Communicating Research Impact: Preparing NIOSH Program for External Review*, Santa Monica, Calif.: RAND Corporation, MG-809-NIOSH, 2009. Additional discussions of applications can be found in Victoria A. Greenfield, Valerie L. Williams, and Elisa Eiseman, *Using Logic Models for Strategic Planning and Evaluation*, Santa Monica, Calif.: RAND Corporation, TR-370-NCIPC, 2006.

[12] Barry Bozeman, Heather Rimes, and Jan Youltie, "The Evolving State-of-the-Art in Technology Transfer Research: Revisiting the Contingent Effectiveness Model," *Research Policy*, Vol. 44, No. 1, 2015, pp. 34–49.

[13] J. D. Moteff, *Defense Research: A Primer on the Department of Defense's Research, Development, Test and Evaluation (RDT&E) Program*, Congressional Research Service, Washington, D.C., 97-316 SPR, May 1998.

[14] A more comprehensive description of the elements of the logic model is available in Williams, Eiseman, Landree, and Adamson, 2009. Additional discussions of applications can be found in Greenfield, Williams, and Eiseman, 2006; and Victoria A. Greenfield, Henry H. Willis, and Tom LaTourette, *Assessing the Benefits of U.S. Customs and Border Protection Regulatory Actions to Reduce Terrorism Risks*, Santa Monica, Calif.: RAND Corporation, CF-301-INDEC, 2012. For further background reading, we suggest J.A. McLaughlin and G. B. Jordan, "Logic Models: A Tool for Telling Your Program's Performance Story," *Evaluation and Program Planning*, Vol. 22, No. 1, pp. 65–72, 1999; Ellen Taylor-Powell and Ellen Henert, *Developing a Logic Model: Teaching and Training Guide*, Madison, Wisc.: University of Wisconsin—Extension: Cooperative Extension, 2008; Joseph S. Wholey, Harry P. Hatry, and Kathryn E. Newcomer, eds., *Handbook of Practical Program Evaluation*, San Francisco: John Wiley & Sons, Inc., 2010.; and W.K. Kellogg Foundation, 2004.

[15] The authors recognize that this is a broad generalization, but it is consistent with their experience working with other federal agencies on program evaluations.

[16] U.S. Army, "RDECOM: U.S. Army Research Development and Engineering Command," undated.

[17] For the purposes of this report, we consider products to include both tangible products and software as well as processes, which is consistent with the U.S. Patent and Trademark Office practice of conferring patents on processes. See U.S. Patent and Trademark Office, "Patent FAQs," 2016.

[18] See U.S. Army Communications Electronics Command, Department of the Army, "Batteries, Rechargeable, Sealed, General Specification for," MIL-PRF-32052, December 7, 1999.

[19] For example, see U.S. Army Research Development and Engineering Command, "Technology Fact Sheet: Improving Low Temperature Operability of Lithium-Ion Batteries," undated; and Lindsey Boerma, "Army Scientists Max Out Battery Power to Save Soldiers' Lives," *CBS News*, August 31, 2013.

[20] For example, the development of a fuel cell that runs on propane to power unmanned aerial vehicles (Boerma, 2013).

[21] Boerma, 2013.

[22] According to the American Association for the Advancement of Science, the total science and technology budget is $12,266 million, of which only $2,089 million is categorized as basic research. This means that about 83 percent is considered applied research or advanced technology development. For more details, see Melissa Vetterkind, "The President's FY 2016 Budget: Agency Budgets: Chapter 11, Department of Defense," *American Association for the Advancement of Science*, July 29, 2015.

About This Report

This report describes a proposed method for improving the ability of the Department of Defense (DoD) to monitor and track the transfer of technology from the Defense Laboratory Enterprise to its customers. The proposed method is based upon mapping aspects of technology transfer activities into a logic model framework to develop a definition of technology transfer "success" that can be applied to laboratory research and development (R&D). Using this approach, measures can be developed to monitor and track successful technology transfers. An illustrative example of the method for documenting technology transfer is provided. The example is not intended to be comprehensive or detailed, but rather to point out the types of questions and data that a laboratory might use to track and monitor the transfer of its technologies and judge its success.

This method should be of interest to those who manage or oversee DoD laboratories and to others who manage R&D enterprises both in the federal government and in the private sector. The report might also be of interest to R&D customers, such as technology and system developers, and providers of deployable military capabilities who seek to better understand and improve their relationships with the enterprises that they rely on for R&D innovations. The report may also provide motivation and guidance for laboratory managers and researchers to collect and analyze the data for documenting their technology transfer successes and to engage in continuous improvement of their technology transfer processes.

The authors thank Cynthia Cook for her suggestion of and continued support for this project. We would also like to thank Michael Barrett, John Fischer, Robert Gamble, Jessica Hart, and John Thorne for participating in a workshop at the RAND Corporation that provided direct experience with the application of the logic model for the example of successful technology transfer of U.S. Army battery research.

Finally, we would like to thank Chris Pernin, a RAND adjunct physical scientist, and Victoria Greenfield, a visiting scholar in the Department of Criminology, Law, and Society at George Mason University, for their thorough and thoughtful review of the document.

This work was funded through RAND's National Defense Research Institute (NDRI) Research Support and sponsored by the director of Acquisition Resources and Analysis, Office of the Undersecretary of Defense for Acquisitions, Technology, and Logistics. These concept development funds are used to strengthen NDRI capabilities to support the federally funded research and development center's (FFRDC's) sponsor needs over time. Research Support projects may address emerging topics, provide proof-of-concept for new policy initiatives, further the reach of prior analysis, or enable other activities relevant to NDRI sponsor interests but not otherwise funded.

This research was conducted within the Acquisition Technology Policy Center of the NDRI, an FFRDC sponsored by the Office of the Secretary of Defense, the Joint Staff, the Unified Combatant Commands, the Navy, the Marine Corps, the defense agencies, and the defense Intelligence Community.

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