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Crossing the Technology Valley of Death: The Case of the MDUSV

7 August 2018

Dr. David N. Ford, Associate Professor
COL John T. Dillard, USA (Ret), Senior Lecturer

Graduate School of Business & Public Policy

Naval Postgraduate School

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Abstract

Technology transition from research to “programs of record” (also known as “crossing the valley of death”) has often been challenging, especially when new capabilities emerge that weren’t originally envisioned, such as next generation aircraft, fighting vehicles, and so forth. The recent evolution of unmanned aerial systems (UASs) is a good example of extemporaneous proliferation of new capabilities. These technology-driven advances may not fit into conventional paradigms of warfighting concepts and may have organizational and infrastructure impacts. The Anti-Submarine Warfare Continuous Trail Unmanned Vessel (ACTUV) project by DARPA built a prototype surface ship, christened *Sea Hunter*, that was tested in San Diego and then transitioned to the Office of Naval Research (ONR) at the end of 2017. It endeavored 70-day missions of up to 7000nm without a manned crew aboard. To cross the valley of death and transition to a program of record, a validated requirement must exist, along with funding for development/procurement across the Future Years Defense Program. The current research proposes and applies a framework for planning successful crossing of the valley of death to the current version of the ACTUV program, MDUSV (Medium Displacement Unmanned Surface Vessel). Results include important specific challenges, behaviors, methods, recommendations, and impacts on practice and research.

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Context

Innovation is required to remain competitive in many domains, including commercial enterprises and national defense. Innovations are often classified as either incremental (e.g., increasing computer speed or sonar offset distance) or disruptive (e.g., smart phones, aircraft carriers). Disruptive innovations are distinguished from incremental innovations by their causing changes in the fundamental behavior of communities. Innovation of technologies is a knowledge development and technology application process that typically moves from understanding concepts and causal relationships in basic research through a series of discovery and development phases to a useful application of the technology.

Technology innovation is critical to the Department of Defense (DoD) fulfilling its mission "to provide the military forces needed to deter war and to protect the security of our country" (DoD, 2018) by keeping American warfighters armed with materiel solutions that maintain competitive advantage over adversaries. Maintaining a steady stream of innovative materiel solutions requires the effective and efficient design and management of the technology innovation process. The technology transition "valley of death" (referred to herein as "the valley") describes a particularly difficult part of the innovation process that lies near the middle of the journey from basic research to application.

The innovation process can be pulled forward by unmet needs, pushed forward by new technologies and capabilities, or both. In their study of innovation failure in the acquisition of the Unmanned Carrier-Launched Airborne Surveillance and Strike (UCLASS) system, Turner and Wickert (2016) described the three DoD offset strategies based on their needs and development of technologies:

- The First Offset Strategy (Eisenhower's New Look) was driven by technologies being pulled forward to meet nuclear deterrence needs. Requirements preceded and defined innovation.
- The Second Offset Strategy (Cold War era) was driven by technology push as technologies, such as in stealth and precision strike, were developed independently and then integrated into a strategy. Innovation preceded requirements.

- The current Third Offset Strategy (autonomy[1] and artificial intelligence) reflects both the need to address current emerging threats from near-peer adversaries and also the fast evolution of new technologies.

The remainder of this paper is organized as follows. The valley of death is introduced, followed by a description of the challenges it creates and relevant extant theories and recommendations for crossing the valley successfully in the form of a framework that will be used to analyze the Medium Displacement Unmanned Surface Vessel (MDUSV) program. The MDUSV program is then described as it relates to crossing the valley. The framework is applied to the program by specifying program challenges, behaviors, and methods. This leads to the recommendation of a new and unique organization which can address the MDUSV needs for crossing the valley. Finally, implications of the formation and use of the recommended organization are discussed.

[1] As defined by the DoD (2017, p. 15), autonomous vehicles and remotely controlled vehicles are mutually exclusive categories.

Background

The Valley of Death

The valley of death is a metaphor for the difficulty experienced by innovators in transitioning technologies that have been successfully researched and initially developed into successful applications. The valley most often includes a lack of funding and other forms of development support to progress from late research and pre-materiel decision-making, through technology development, to application (Pusateri, Macdonald, Given, Walter, & Prusaczyk, 2015). The metaphor is applied to the experiences of a wide range of products, including both incremental improvements and disruptive innovations, in many industrial and public settings. As a major developer and user of new technologies, the DoD suffers greatly from the valley of death (National Research Council, 2004).

Graphical descriptions of the valley of death abound. One example of a simple depiction is from a Canadian natural resources agency (Figure 1).

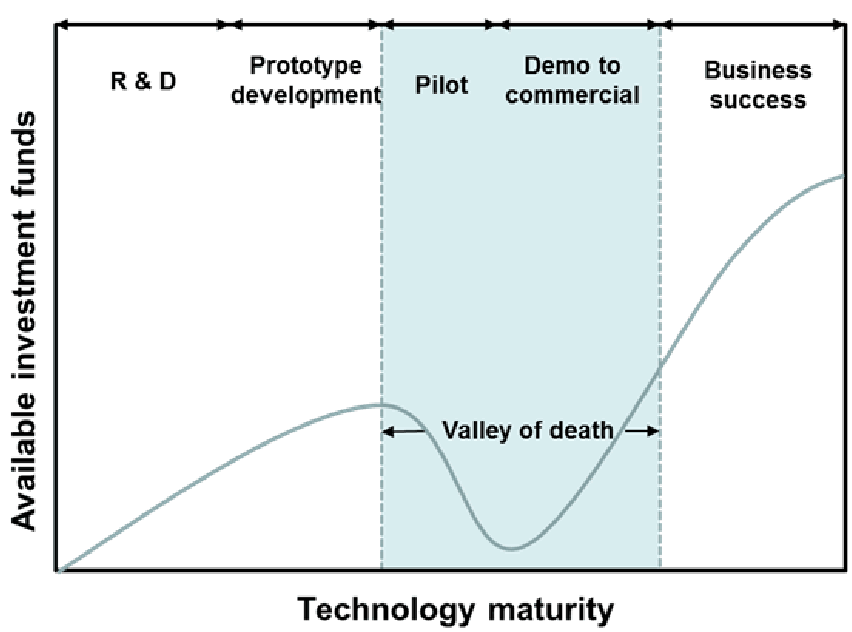

Figure 1: The Valley of Death in Technology Development
(https://cfs.nrcan.gc.ca/assets/image/2825)

Gunderson (2014) suggested that the “hype curves” developed by Gartner, Inc. also depict the valley. Generically, hype curves describe innovation life cycles with five phases: Innovation Trigger, Peak of Inflated Expectations, the Trough of Disillusionment (the valley of death), Slope of Enlightenment, and Plateau of Productivity. Figure 2 illustrates Gartner, Inc.’s hype cycle for emerging technologies.

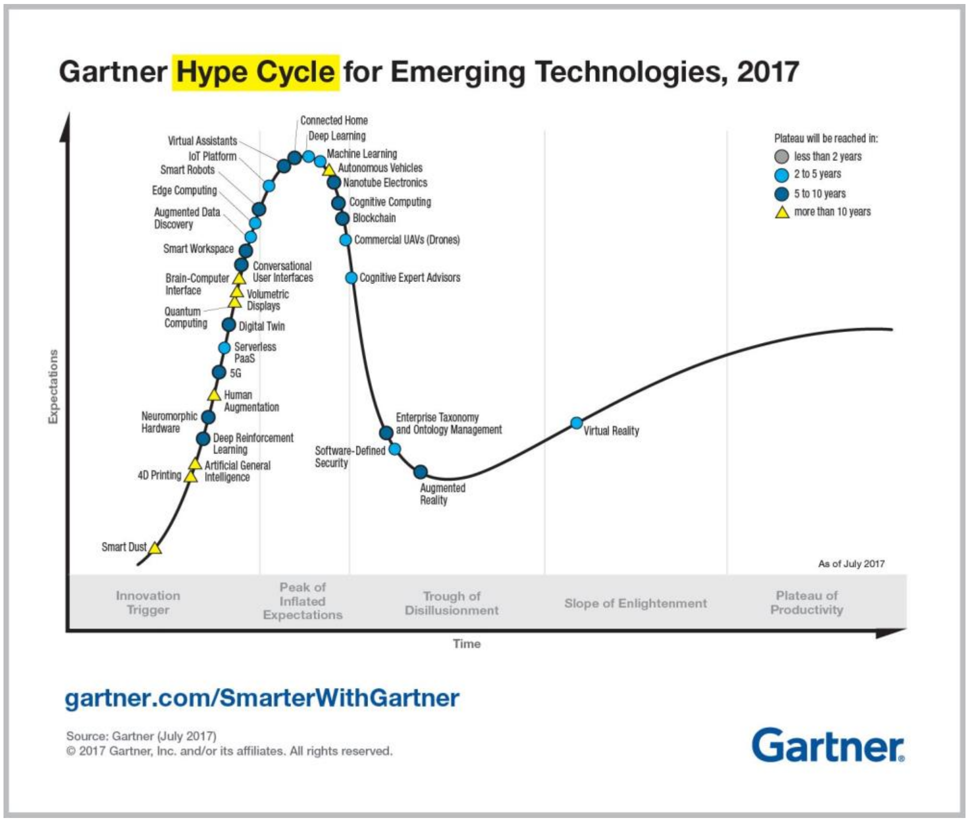

Figure 2: The Gartner Hype Curve for Emerging Technologies
(Panetta, 2017)

Much has also been written about the difficulties of technology transition in public (DoD) sectors, where successful transition is often elusive. The concept of a valley of death applies commercially as well, wherein products fail to be fully commercialized or adopted sufficiently by the marketplace. Products sometimes fail to successfully cross the valley of death to meet user needs. Newman (2018) noted that the iPad succeeded in 2010 only after the failure or much more limited success of the Microsoft Tablet PC in 2002, Microsoft Pocket PC 2000 in 2000, Intel Web Tablet in 1999, NewsPad in 1997, Palmpilot in 1996, Fujitsu Stylistic 1000 tablet in 1996, Apple Newton MessagePad in

1993, Compaq Concerto in 1993, EO Personal Communicator in 1991, GRIDPad tablet in 1989, Letterbug in1986, and others. Being able to describe the valley of death and efforts to facilitate crossing it is critical for Navy and DoD materiel acquisition. Recent operations in Iraq and Afghanistan have brought many capabilities to U.S. forces without going through the slow, disciplined, and burdened processes necessitated in peacetime. Developed and purchased with Overseas Contingency Operations funding, some of these discrete line items that are already distributed in the force are now having challenges getting fully authorized and resourced for sustainment as the DoD returns to normal peacetime operations. Similar challenges can face the development of new technologies and reuse of existing technologies in projects such as ACTUV/MDSUV.

The Medium Displacement Unmanned Surface Vehicle (MDUSV) Program

Program History

Medium Displacement Unmanned Surface Vessel (MDUSV) is the current moniker for the U.S. Navy's effort in autonomous technology demonstration, as it evolves toward a more fully defined set of capabilities. Formerly called the Anti-Submarine Warfare Continuous Trail Unmanned Vessel (ACTUV), implying early recognition for potential primary missions, it has completed its first phase of prototyping and experimentation as an outgrowth of a Defense Advanced Research Projects Agency (DARPA) project.

In 2016–2017, the Defense Advanced Research Projects Agency (DARPA) demonstrated autonomous operation of a naval surface vessel in the Anti-submarine Warfare Continuous Trail Unmanned Vessel (ACTUV) project. This project had three primary goals (Littlefield, 2017):

- Explore the performance potential of a surface platform conceived from concept to field demonstration under the premise that a human is never intended to step aboard at any point in its operating mission cycle.
- Advance unmanned maritime system autonomy to enable independently deploying systems capable of missions spanning thousands of kilometers of range and months of endurance under a sparse remote supervisory control model.

- Demonstrate the capability of the ACTUV system to use its unique characteristics to employ non-conventional sensor technologies that achieve robust continuous track of the quietest submarine targets over their entire operating envelope.

The project was also structured to explore and advance the potential of autonomous vessel performance, including independent multi-mission operations over time and distance with varying payloads. The prototype vessel DARPA produced, named *Sea Hunter*, was focused initially upon the anti-submarine (ASW) mission (thus its name). However, a wider range of missions and configurations came into view and are already envisioned for future experimentation and exploitation. Key questions to be answered going forward are not only within the business and technical realm of acquisition, but also the operational framework of future surface combatant operations, covering a myriad of missions and concepts of operations (CONOPS). Not at all (to date) deemed an “orphan technology” in search of utility, the capability and cost savings perceived as apparent from autonomy, both in the near and far term, have already given rise to strong OPNAV advocacy and resource sponsorship. This suggests that MDUSV’s successful crossing of the valley of death can make a significant contribution to naval surface warfare capabilities. In addition to the benefits of human life risk reduction and obvious life cycle cost savings, perhaps the most compelling aspects of the autonomy concepts that are at the heart of the MDUSV are the opportunities to contribute to the yet-to-be-fully-defined Third Offset Strategy. A shrinking U.S. military force structure with declining technological superiority faces a current era of near-peer threats and military power competition. How can autonomy, and the MDUSV specifically, help to deliver a large quantity of relatively inexpensive, though technologically advanced, surface vessels to better augment and distribute U.S. forces and maximize survivability?

The first vessel to emerge from the MDUSV program was designated as the *Sea Hunter*, a Class III vessel (displacement of approximately 145 tons) of several displacement size classes, launched in 2016. *Sea Hunter* has since been undergoing sea trials and experiments along the western U.S. coast and throughout areas of the Pacific Ocean. Transitioning in 2018 to the Office of Naval Research for two years of further tests, *Sea Hunter* has completed its demonstration of over-water speed and stability, with system reliability during extended operations throughout 2017. Perhaps chief among these was compliance with maritime collision regulations (COLREGS). Prior to and during this period, Office of the Chief of Naval Operations (OPNAV) staff began their analysis of required capabilities that might be performed by multiple classes of autonomous surface vessels.

MDUSV Approaches the Valley of Death

Like the recent history of unmanned aerial vehicles, there are organizational, cultural, doctrinal, and business and technological barriers to the acceptance and employment of new technologies such as *autonomy*. Autonomy actually represents a spectrum of unmanned systems spanning those under human remote control to systems with sparse or no human supervision. Having one prototype built for testing and experimentation, the ACTUV working group has successfully brought together the appropriate stakeholders to ensure a successful crossing of the technology transition "chasm," or valley of death. However, substantial uncertainty lies ahead for them and the larger naval force it seeks to serve.

In response to this need, the Naval Postgraduate School (NPS) hosted an ACTUV Workshop February 14–15, 2017, to host representatives from practically every community that might constitute stakeholders. Organizations represented were the Office of Naval Research, DARPA, Leidos Corporation (DARPA's ACTUV prime contractor), PEO Littoral Combat Ships, OPNAV N96, N9I, SPAWAR, and multiple departments of NPS. The workgroup was fortunate to have actual "owners" participate, as is necessary for successful technology transition. The resource sponsor, N96, is perhaps the most important of these. But also important are members of the science and technology (S&T) community, who must transition the outputs of the DARPA project seamlessly into an extended phase of testing, and then their eventual transfer to an existing program office structure such as PMS 406, Unmanned Maritime Systems. An author of this research served, along with N96, as co-leads of the acquisition breakout session, whose task it was to brief the 2017 workshop on progress made with identification of challenges for technology transition, that is, in crossing the valley of death. The acquisition strategy breakout session of the two-day work group sought to identify technical and business challenges associated with the technology transition of ACTUV from its current status as a DARPA project to become an official "program of record." (This term refers to a program with its own line of funding in the Future Years Defense Plan, a database of programmed funds, and denotes also that it has been formally initiated with a Milestone B decision, thus necessarily having a validated requirement in the form of a Capability Development Document.) History is replete with examples of promising technologies not being able to cross a mythical valley of death or technology transition or commercial marketing chasm. Over a dozen of these typical challenges were pulled from existing literature about DoD tech transfer and used for a group discussion on a later breakout session.

The first output of this breakout session's work was recognition that *a substantial number of accomplishments had occurred to date.* Not only has technology been demonstrated with obvious revolutionary capabilities, but opportunities are easily envisioned for cost savings as well within a mixed fleet of manned and unmanned naval service vessels. Significant is the amount of user interest and support already evident, extending to the highest levels of the Navy. Depending upon outputs from other working groups to further develop operational concepts, roles, and missions, it is already apparent that autonomous vessels such as ACTUV, now MDSUV, can become a force multiplier.

Developing capabilities is a critical part of crossing the valley of death. The initial configuration of ACTUV already allowed for multi-mission payloads. Besides anti-submarine warfare, other "dull and dirty" missions are emerging, such as mine/countermine operations, long-haul resupply, etc. During the 2017 workshop, a N96 representative revealed that the Navy staff had conducted Capabilities Based Analyses (CBA) to verify the need for unmanned and autonomous vessels, with follow-on analyses of alternatives (AoA) proceeding through Fiscal Year (FY) 19, and then development of an overarching Initial Capabilities Document (ICD) to follow. This formalization of a validated requirement document is key in establishing service needs, which drive the acquisition process and help establish programs of record. He also described plans for a "development squadron" (DEVRON) to be in place by FY20 to further demonstrate technologies for basic missions to at least levels of Technology Readiness Levels (TRL) 4–5.

Lastly, the resource sponsor assured that continued funding will be reflected in the Future Years Defense Plan (FYDP), Future Service Combatant (FSC) line. From an acquisition process point of view, intellectual property should not be a substantial issue when later development efforts are ready for competitive procurement, as the ACTUV source code and other technical data are believed to be either nonproprietary or otherwise in-house within the government.

Important results from this 2017 workshop were the introduction of key players and cementing of their partnerships and respective responsibilities for the near future. However, while technology transition was discussed, much remained, and still remains, to fully develop a technology transition plan. Challenges include the need for a validated Joint Capabilities Integration and Development System (JCIDS) requirement and full funding for development and procurement across the Future Years Defense Program (FYDP). Entering advanced development and low/full rate production will necessarily include potential paradigm shifts regarding system autonomy in the Navy as it ascertains missions and operational concepts for integration into a mixed fleet of future surface combatant vessels.

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A Framework for Crossing the Valley of Death

The proposed framework herein structures the relevant literature on the crossing of the valley of death into three perspectives: (1) challenges faced in crossing the valley, (2) behavior modes in crossing the valley, and (3) methods for crossing the valley. Specifying the components of the framework for individual technology transition programs can facilitate crossing the valley.

Challenges in Crossing the Valley of Death

Many challenges make crossing the valley of death difficult. In addition to the development of the underlying technologies, Newman (2018) identified the development of the technologies, manufacturing readiness (which addresses the feasibility and affordability of producing the technology at the required scale and rate), and the integration of the technology into other larger systems. Within the DoD, the *Manager's Guide to Technology Transition in an Evolutionary Acquisition Environment* (DoD, 2005) describes technology transition challenges, many that apply to crossing the valley of death. These challenges are organized around three types of problems: (1) technology transition, (2) cultural barriers, and (3) knowledge management. More specific challenges identified in the *Manager's Guide* (DoD, 2005) include the following:

- The technology may not develop rapidly enough to be ready when it is needed (p. 4-23).
- A focus on a preferred solution may prevent the adoption of better solutions.
- Designs may not adequately incorporate needed future upgrades (p. 4-6).
- A suboptimal technology may be chosen (pp. 4-11–4-12).
- Teaming is critical (p. 4-22).

Resistance from within innovating organizations can make also crossing the valley difficult. Established organizations and systems often tend to support retaining the status quo by opposing the development and adoption of disruptive technologies. For example, Turner and Wickert (2016) described the erosion of requirements of the Navy's

Unmanned Carrier-Launched Airborne Surveillance and Strike (UCLASS) system, a potentially-disruptive next-generation unmanned combat system, until the system was diluted into a tanker for traditional manned missions. Other challenges can include users not being ready for a mature-enough technology—for example, inline skates were available in 1972, but Rollerblades did not become popular until 15 years later (Newman, 2018)—or regulatory approvals lagging technology and demand, for example, UAV pizza delivery.

The proposed framework structures these challenges of crossing the valley of death into three potential bottlenecks:

- **Technology development**, including performance, speed of development, and phasing of development and costs
- **Application development**, including identifying and developing needs and uses and capabilities, individually and with other systems, and matching technologies to uses
- **Overcoming social resistance**, including addressing inertia and support of the status quo in users, sponsors, and regulators, providing adequate knowledge transfer communication and partnering to no constrain progress, and maintaining forward momentum

Identifying which of three types of challenges best describes a specific issue or need can assist in identifying what organization or persons has the knowledge, skills, capabilities, and capacity to best address the issue or need.

Behavior Modes of Crossing the Valley of Death

Gulbrandsen (2009) described two behavior modes of crossing the valley, a linear process and a social process. They refer to the linear approach as “Mode 1” and the social approach as “Mode 2.”

Crossing the Valley as a Linear Process

The linear behavior model of crossing the valley of death (Mode 1) is process-based and objective. In this behavior mode, the transition from research to application moves through a sequence of phases, evolving from basic science to applied science to “development” to production, as explained by Mirowski & Sent (as cited in Gulbrandsen, 2009, p. 20). Gulbrandsen (2009) quoted Gibbons et al.'s (1994) description of this behavior mode:

> Mode 1 is discipline-based and carries a distinction between what is fundamental and what is applied; this implies an operational distinction between a theoretical core and other areas of knowledge such as the engineering sciences, where the theoretical insights are translated into applications. (as cited in Gulbrandsen, 2009, p. 4)

Although the liner behavior mode includes negotiations about the evolution of solutions, participants are (in theory) objective and all participants are guided by meeting the goals of the project.

The successful use of the linear process for crossing the valley of death requires clear, specific, shared, and enforced methods and measures of how technologies will be developed and how other aspects of innovation will be managed.

Crossing the Valley as a Social Process

In contrast to the linear behavior mode, the social behavior mode (Mode 2) is a highly interactive process in which a trans-disciplinary team negotiates and renegotiates the technology. For example, an inter-disciplinary project team (IPT) may reconceptualize a solution, move to a different technology if progress on the first technology chosen stalls, or change how the technology will be used, thereby redefining the nature of the materiel solution. In the social process, knowledge production is characterized by a diffuse trans-disciplinarity that can blur the lines between disciplines and the traditional stages of acquisition. Progress within the social process can interrupt progress within the linear process. An example is if discussions with users were to identify a previously unidentified but very valuable potential use (the social process) that requires changes in the performance targets for technology development (the linear process).

Successful use of the social process for crossing the valley of death requires the socializing of ideas across the various and diverse organizational participants in the innovation effort. This requires the establishment and maintenance of linkages and relationships across organizational boundaries and between participants with differing local objectives and methods (e.g., cost control vs. speed of innovation vs. risk reduction). Social processes are notoriously challenging, and the failure to manage them can slow and stop momentum in innovation. Therefore, crossing the valley successfully using a social process is based on relationships within an IPT and others (e.g., contractors and research organizations) and collaboration among stakeholders who hold varied interests. According to Doheny-Farina (1992),

> At their core these processes involve individuals and groups negotiating their visions of technologies and applications, markets and users in what they all hope is a common enterprise. This means that the reality of a transfer does not exist apart from the perceptions of the participants. Instead, the reality—what the transfer means to the participants—is the result of continual conceptualizing, negotiating, and reconceptualizing. (as cited in Gulbrandsen, 2009)

Posen (1984) supported the need for a social process in military innovation by suggesting that it requires internal champions and pressure from commercial stakeholders. The *Manager's Guide* says that crossing the valley requires a partnership among communities such as S&T, R&D, PM, capability needs, T&E, sustainment, and financial (DoD, 2005, p. 4-5).

A superficial understanding of innovation reveals the need for a combination of linear and social processes to successfully cross the valley of death. The proposed framework describes the following aspects of behavior modes for crossing the valley of death:

- **The linear processes used for crossing the valley**, including identifying and describing actual practice vs. espoused processes and gaps between (resource constrained) practice and needed practices
- **The social processes used for crossing the valley,** including identifying and describing practice vs. espoused processes and gaps between social practices within the IPT and practices needed, and places where the social process is likely to interfere with linear process
- **Interactions of the linear and social processes in crossing the valley,** including identifying and describing places where the linear process is likely to interfere with social processes, identifying and describing places where the social process is likely to interfere with linear process, and means of managing those interfaces

Identifying which of three types of behavior modes best describes the actual or desired process for addressing a specific issue or need can assist in identifying which organization or persons has the knowledge, skills, capabilities, and capacity to best address the issue or need.

Methods for Crossing the Valley of Death

Many commercial and military innovation accomplishments demonstrate that innovative organizations can successfully cross the valley of death. See the DoD's *Manager's Guide to Technology Transition in an Evolutionary Acquisition Environment* (DoD, 2005), Pusateri et al. (2015), and "The Latest Unmanned Drone" (2017) for military examples. The literature also recommends how to do so.

Christensen (2003) recommended three strategies for crossing the valley in the case of disruptive technologies:

- Targeting underserved early adopters who are less committed to legacy systems, thereby gaining adoption without threatening the status quo. Williams and Gibson (1990) refered to this approach as "dissemination."
- Provide solutions that are superior to the status quo (the "better mousetrap" approach). Williams and Gibson (1990) refered to this approach as "appropriability."
- Introduce the innovation gradually, first through familiar methods and settings to accelerate adoption and reduce resistance from those defending the status quo.

In addition, Williams and Gibson (1990) observed facilitation of the interfaces among stakeholders through communication as a means of crossing the valley.

Tippens (2004) contrasted "high-velocity" technology firms that successfully cross the valley of death with those that hold onto technologies into obsolescence. The former had

- short, iterative processes
- collaborative concurrent development
- a passionate focus on user needs
- a willingness to take risks
- early and rapid prototyping

Within the DoD, Pusateri et al. (2015) developed a Joint Transition Planning Process with supporting meetings and a working group for crossing the valley in DoD medical development. Their process positions products in late-stage S&T for successful transition to AD, thereby facilitating, without replacing, current processes. Meetings structure and improve IPT communication, particularly awareness of progress and technology transition issues. The working group is like a temporary IPT that focuses on technology transition. Its activities can include assessments of status, analysis of alternatives, and program management. They emphasize communication across parts of the IPT and processes and document multiple successes using this joint transition planning.

Lewis (2017), in his analysis of the DoD's Third Offset Strategy, recommends that the DoD be a "fast follower" (of commercial efforts) instead of a first mover in acquiring autonomy and artificial intelligence (AI) technologies. First movers are organizations that initially invest in and develop a new technology. History has shown that first movers are often overtaken by fast followers, organizations that refine a technology based on the work of the first mover and quickly adapt them for application. Lewis provides examples of information technology (IT) products that became dominated by fast followers, including Google (fast follower) superseding AltaVista in search engines and Excel superseding Lotus 123 in spreadsheets. Fast followers are particularly likely to move past first movers in environments characterized by rapid innovation, such as autonomy and AI. Lewis suggests how the DoD can be an effective fast follower of autonomy and AI technology to accelerate acquisition, including crossing the valley of death. Critical acquisition capabilities for doing this include deep learning about specific technologies (effective following) and judiciously increasing government risk-taking to accelerate acquisition processes (move faster). The following are some of Lewis's specific recommendations that can help in crossing the valley:

- Develop internal autonomy and AI expertise
- Track and use specific commercial technologies
- Track technology developed by others
- Learn from other related DoD efforts
- Build interoperability into autonomous and AI systems

Although the need to be a leader in the application of autonomy and AI in the MDUSV program may preclude the adoption of a fast follower strategy, some of Lewis's recommendations may be effectively applied to MDUSV crossing the valley of death.

The proposed framework structures the recommended methods for successfully crossing the valley of death described previously according to how they address the three types of challenges also described previously:

Technology Development

- Provide better solutions
- Collaborate and facilitate stakeholder interfaces
- Iterate early and fast
- Be willing to take risks
- Hold and keep deep knowledge of technologies

Application Development

- Target underserved users and needs
- Collaborate and facilitate stakeholder interfaces
- Iterate early and fast
- Focus on user needs
- Be willing to take risks

Overcoming Social Resistance

- Introduce innovations gradually
- Focus on user needs

Identifying which type of method can best address a specific issue or need can assist in identifying which organization or persons has the knowledge, skills, capabilities, and capacity to best address the issue or need. In addition, recommendations can be further disaggregated for analysis into those that apply the linear behavior mode, the social behavior mode, or are at an interface between the linear and social behavior modes, thereby integrating the first and second part of the framework.

Summary of Proposed Framework for Crossing the Valley of Death

Challenges of crossing the valley of death:

- Technology development
- Application development
- Overcoming social resistance

Behavior modes for crossing the valley of death:

- The linear processes used
- The social processes used
- Interactions of the linear and social processes in crossing the valley

Methods for crossing the valley of death

Technology Development

- Provide better solutions
- Collaborate and facilitate stakeholder interfaces
- Iterate early and fast
- Be willing to take risks
- Hold and keep deep knowledge of technologies

Application Development

- Target underserved users and needs
- Collaborate and facilitate stakeholder interfaces
- Iterate early and fast
- Focus on user needs
- Be willing to take risks

Overcoming Social Resistance

- Introduce innovations gradually
- Focus on user needs

Disaggregate recommended actions into those aspects that apply the linear behavior mode, social behavior mode, or interface between those modes.

Application of the Framework to the MDUSV Program

MDUSV Challenges in Crossing the Valley of Death

The previously described 2017 ACTUV workshop and the successive interdisciplinary MDSUV working group series of sessions at NPS in 2018 continues to identify what these authors see as eight primary groups of challenges, incomplete work, or simply important things that needed to be accomplished. They are summarized and further disaggregated into 14 more challenges in our framework of categorization:

Technology Development

Processes:

- Four different milestone decision documents need to be produced along with a Navy roadmap for future surface combatants.
- Upon completion of S&T activities, the PMO will construct a full acquisition strategy for what will probably be a traditional acquisition approach to development. If technology enablers have not at that point been demonstrated to TRL 6–7, a Technology Maturation and Risk Reduction phase may be needed before Engineering and Manufacturing Development.
- Moving to a common test and evaluation “scorecard” is a challenge with regards to safety, etc.
- Traditional acquisition strategies contain a myriad of elements including lifecycle cost estimate, contractual competition, cyber security, etc. This all feeds into the contractual scope and type of transaction vehicle for continued industry efforts.
- Quantities of initial and final on buys for full operational capability must be planned and programmed.
- Specific feature sets for a completely configured system are needed to drive technical specifications and requirements.
- There was no way to ascertain even a rough order of magnitude for the cost of follow-on prototypes, but it could be presumed that at least initial buys would be analogous to the first vessel of $20 million, with an added payload of $3 million, spanning 24 months of time to produce.
- Future costs will rise with complexity, but production quantities and production schedules should certainly achieve some economies of scale commensurate with what we see across other systems/platforms.

Products:

- Autonomous tactics and behaviors are still conceptual and not fully mature.
- Endurance and reliability of autonomous vessels, amounts of corrective maintenance actions, etc. are yet to be proven.
- Several more years of development is needed for the maturation of autonomous technologies, especially for more complex missions.
- The resource sponsor should avoid a hiatus or loss of momentum by providing continuous funding for FY18 and beyond.

Application Development

- Four different milestone decision documents need to be produced along with a Navy roadmap for future surface combatants.
- A documented and validated requirement must be developed with missions and operational concepts fully identified.
- The need for interoperability with other systems and platforms demand that some top-level requirements emerge for common command and control.
- The resource sponsor should avoid a hiatus or loss of momentum by providing continuous funding for FY18 and beyond.
- Moving to a common test and evaluation "scorecard" is a challenge with regards to safety, etc.

Overcoming Social Resistance

- Key to the development of the four different milestone decision documents is the maintenance of dialogue among key players previously mentioned. The idea of a Tech Transfer Agreement (TTA) might facilitate this as a formal memorandum of sorts.
- The need for interoperability with other systems and platforms demand that some top-level requirements emerge for common command and control.

MDUSV Innovation Behavior Modes

The MDUSV program is next described based on the three portions of the "behavior modes for crossing the valley of death" portion of the framework: (1) a linear innovation process, (2) a social innovation process, and (3) interactions between linear and social innovation processes.

The Linear Innovation Behavior Mode Used in the MDUSV Program

The DoD acquisition process (Figure 3) is an example of a linear behavior mode of innovation. In this process, work is done to add knowledge about materiel solutions to move those solutions from S&T and Major Decision A, through Technology Maturation & Risk Reduction, Major Decision B, Engineering & Manufacturing Development, and into Production.

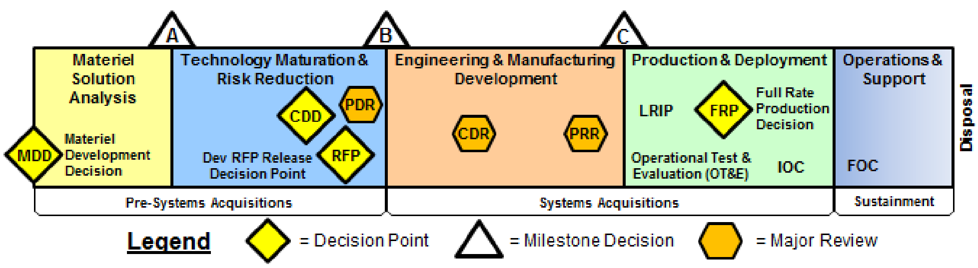

Figure 3: The DoD Acquisition Process (AcqNotes, 2018)

The MDUSV program will implement the DoD acquisition process and thereby be deeply embedded in a linear behavior mode. Comments at the 2017 workshop and the 2018 series of working group sessions that have continued at NPS also strongly support the use of a linear process in MDUSV innovation, primarily in discussions of the design and management of the DoD acquisition process for the MDUSV program. These addressed milestone decision-making, the development of an acquisition strategy and requirements, metrics (the "scorecard"), and purchase quantities.

The Social Innovation Behavior Mode Used in MDUSV Program

The NPS working group sessions have provided an important means of exploiting social innovation in the MDUSV by introducing the key players to each other and providing a setting within which they could openly discuss program issues, including crossing the valley of death. Products from the 2017 workshop described the need for and role of a social innovation process in the MDUSV program. For example, the considerations included the following questions:

- Any joint or interoperability/interdependency aspects of the system?
- Who is the likely Navy sponsor of ACTUV?
- Where should the JCIDS CDD/CPD be initiated?
- Risk areas (programmatic/technical, need, funding)?

These are areas where decisions will be based largely on discussions among program stakeholders, making the social processes critical to program success. Some of these have emergent resolutions underway already.

Interactions of the Linear and Social Innovation Behavior Modes in the MDUSV Program

Interactions between the linear and social innovation processes will likely be one of the most critical requirements for MDUSV successfully crossing the valley of death. Participants have noted that “key to the development of the four different milestone decision documents is the maintenance of dialogue amongst key players previously mentioned” and suggested a solution in “the idea of a Tech Transfer Agreement (TTA) might facilitate this as a formal memorandum of sorts.” This illustrates that participating stakeholders understand and appreciate the importance and challenges of designing and managing the interfaces between linear and social innovation in MDUSV. Notwithstanding the necessary adherence to *linear* processes inherent in the DoD acquisition management structure, it will be the *social* communication and coordination among stakeholders that, if maintained, will ensure safe passage across the valley of death.

MDUSV Methods for Crossing the Valley of Death

The 2017 workshop and follow-on sessions have also generated recommendations, including the following:

- Leverage the S&T community's time and efforts as much as possible to flesh out requirements and doctrinal concepts and to perhaps resolve other legal and ethical concerns.
- Use this time to explore innovative contracting methods (such as the use of development/production options) and anything else that will alleviate bureaucracy and allow development to continue.
- Manufacturing Readiness Levels (MRL) are also an aspect to be considered, given the relative certainty about the type of vessel this will be.
- Prepare for the use of prudent business practices, commensurate with an investment of this size, which will be required under the DOD 5000 series instructions and Federal Acquisition Regulation, etc., due to the program becoming a Major Defense Acquisition Program (MDAP).
- Address where such vessels will fit within the operational architecture of doctrinal war fighting. These vessels have great potential for lower unit cost, huge savings during their operation and support phase, and the saving of lives that aren't placed into harm's way for missions performed by them.
- Legislative changes in acquisition reform over the past year afford several new areas of relief to challenges identified.
    - **Investment Decision Authority**—Lowest level Milestone Decision Authority is another recent legislative change that can speed the attainment of autonomous surface vessel capability. Service-level Decision Reviews can be minimized, along with the costly multi-level and adjacent agency preparatory briefings that have added off-core scope activities to program managers and hindered timely progress in the past.
    - **Abbreviated Documentation**—Along with a lowered threshold for decision-making, the dozens of bureaucratic documents traditionally required for milestone review should be consolidated and abbreviated where possible to fulfill the steps necessary for sensible but pragmatic satisfaction of information needs for decision-making.
    - **Simplified Contracting**—Recent legislation now allows Other Transaction Authority (OTA) in lieu of Federal Acquisition Regulation contracting instruments from prototyping through production phases of acquisition. However, care must be taken

in the exercise of prudence for legal compliance regarding competition, rewards, and incentives structuring, scope of work specification, performance measurement, etc., to avoid pitfalls already being seen in acquisitions attempting to exploit this method of shortening transaction timelines. Cautions are in the areas of proprietary hardware and software from the selected industry partner. Modular Open Systems Architecture should be emphasized in both business as well as technological functions.

  - **Tailored Acquisition Strategy**—Leveraging of the DARPA project results, along with ONR's experimentation and sea trials should alleviate the necessity for a Technology Maturation and Risk Reduction Phase in the traditional model of acquisition. With validated need statement (CDD) and FYDP funding programmed, transition directly into Engineering and Manufacturing Development Phase, with concurrent Low Rate Initial Production should be approved by Milestone Decision Authority, given a match exists between requirements and resources, and finalized designs giving assurance of capability attainment.
  - **Streamlined Test and Evaluation**—As with contracting instruments, a balance must be struck among elements of good prudence and due diligence versus testing to the point of unnecessary extremes. That MDUSV is unmanned, except for occasional maintenance and back-up functions that may become necessary, justifies a lesser expenditure of resources for suitability factors such as safety and survivability, while nonetheless stressing system performance and reliability.

Notwithstanding these changes that could facilitate crossing the valley, a few acquisition imperatives remain. The following are recommendations for activities to be conducted in parallel, as the remaining months of sea trials and experimentation continue under the auspices of ONR before the hand-off to PMS 406:

- **Requirements Capture and Refinement**—Requirements definition should be better informed from experimentation efforts, with evolutionary growth of capabilities planned for the technology enablers that are identified as not yet fully mature, especially when such are defined along a range or spectrum (versus binary attainment) of performance. The *Sea Hunter* now afloat will give insights into multiple capability payload packages for various missions and concepts of operations (CONOPS). Prototyping and sea trials that are now moving along in parallel with JCIDS efforts for Initial Capability Development documentation and formal validation already constitute a large advantage in the transitioning of technology across the valley of death.

- **Maximize Modeling and Simulation**—For early requirements and product realization ranging from Force-on-Force simulations to computerized design and platform integration, M&S efforts will pay dividends along the entire path of MDUSV development for operational employment utility, anomaly discovery, and test scope or sample size reduction.
- **Disciplined Systems Engineering**—There are seldom shortcuts with regard to the necessarily disciplined engineering efforts at system and sub-system level. Systems engineering processes have proven their value for issue discovery venues, risk management, configuration control, and technical performance measurement along the iterative development path that attacks complexity and resolves uncertainty. However, such need not impede progress in technology transition.

To apply the framework, these recommendations and other characteristics of the program and acquisition process were organized into a two-dimensional matrix that aggregates recommendations from the literature according to the type of challenge addressed and identifies which behavior mode is used to apply specific recommendations for MDUSV (Table 1). The result facilitates analysis of the program plan for crossing the valley and the identification of methods and behavior modes that may not be being applied but could facilitate crossing the valley.

Table 1: Application of Crossing the Valley Framework to MDUSV Recommendations

Methods for Crossing the Valley of Death	Behavior Modes for Crossing the Valley of Death: Linear Behavior Mode	Social Behavior Mode	Linear and Social Behavior Modes
Technology Development			
Provide better solutions	Analysis of Alternatives	Maintain dialogue among key players	Tech Transfer Agreement among key players, Maintain dialogue
Collaborate and facilitate stakeholder interfaces	**Explore innovative contracting methods**	***Use S&T time to develop requirements, concepts, etc.***	Tech Transfer Agreement among key players, Maintain dialogue
Iterate early and fast	**Use S&T time to develop requirements etc. Prepare for MDAP**	Introduce users (DEVRON) to prototypes	
Be willing to take risks	Develop full acquisition strategy Analysis of Alternatives	Maintain dialogue among key players	Tech Transfer Agreement among key players, Maintain dialogue
Hold and keep deep knowledge of technologies	Rapid and iterative prototyping; Fast follower of commercial efforts	Collaborate with industry to become "Fast follower" of commercial efforts	
Application Development			
Target underserved users and needs	Develop requirements for interoperability, command, and control.	***Consider operations with other vessels***	
Collaborate and facilitate stakeholder interfaces		Maintain dialogue among key players	Tech Transfer Agreement among key players, Maintain dialogue
Iterate early and fast	**"Fast follower" of commercial efforts**	Common Test and evaluation scorecard	
Focus on user needs	Develop CONOPS, requirements, & features	Maintain dialogue among key players	Tech Transfer Agreement among key players, Maintain dialogue
Be willing to take risks	Develop full acquisition strategy Analysis of Alternatives	Maintain dialogue among key players	Tech Transfer Agreement among key players, Maintain dialogue
Overcoming Social Resistance			
Introduce innovations gradually	Evolutionary acquisition as increments of desired capability emerge	Introduce users (DEVRON) to prototypes	Modeling and simulation efforts for operational scenarios as well as technical parameters
Focus on user needs	Develop requirements for interoperability, command, and control.	Maintain dialogue among key players	Tech Transfer Agreement among key players, Maintain dialogue

The matrix provides a starting point for the analysis and design of the MDUSV program’s preparation for crossing the valley of death. Through review and revision, key players can improve the description by adding information. Blank cells can be used to identify methods (rows) and means (columns) that are not currently being used to consider additional efforts to accelerate innovation. Descriptions within specific cells can be the basis of discussions among relevant program participants about challenges, behavior modes, and methods of crossing the valley of death.

Recommendations for MDUSV Crossing the Valley of Death

The application of the framework to the MDUSV program suggests several aspects of the program's crossing of the valley of death that may be improved, including those discussed in this section.

These improvements could take many forms. Typically, they will cross the process categories of linear, social, and interfaces between linear and social innovation processes. As an example, Gallup, Trask, MacKinnon, and Wood (2018) proposed a specific method for managing the critical interfaces during innovation of MDUSV under the title "Coordinating a Multi-Organization Research and Development Program to Enable MDUSV Acquisition." After describing the program and the roles of its primary organizations in general, they describe a coordination challenge that threatens to prevent the program from crossing the valley of death and provide an illustration:

> All {primary organizations} agree with the need to incorporate unmanned systems in the future naval force but no one office is in charge of putting all the pieces together to provide a solution at a known point in time. Because the operational community has not documented and validated specific mission requirements for the design parameters of MDUSV, the acquisition community is not yet able to initiate a program to acquire MDUSV. The overall effort lacks organization, strategic alignment and an understanding of the inherent roles each organization must play to bring the MDUSV concept to fruition.
>
> These complexities are illustrated by the recent investment of $120M by the Special Capabilities Office (SCO) in Project Overlord, with the intention of creating one ship that will demonstrate some autonomy. This objective has already been proven and is being tested through the DARPA ACTUV/ONR MDUSV program which is being further enhanced by the commitment to build a second hull for testing and development. Expending resources on Project Overlord provides the illusion of progress while treading ground already covered. More could have been accomplished if SCO had invested these funds in the MDUSV program. (Gallup et al., 2018)

Gallup et al. (2018) then proposed a realistic means of overcoming this challenge:

> The solution proposed is to create a SECNAV approved consortium of organizations, cross-functionally responsible for conducting research and development activities so that each is solving an essential element necessary to make MDUSV operational at the earliest possible date. The organizational structure should be headed by a SECNAV level office with the following organizations participating:
>
> - N96, N2/N6, ONR, SPAWAR, NPS, Naval War College, NRL, SCO, and universities funded to pursue technical, operational, and acquisition research as directed.
> - The coordinating office at SECNAV would grant authority to member organizations to use "other transaction authority" to secure contracts with commercial vendors such as Boeing, Leidos, IBM and others.[2]
> - SECNAV office would take responsibility for coordinating the effort and protecting/adding funds as necessary to achieve goals and stay on schedule (p. 17).

Tools and methods such as the one proposed by Gallup et al. can greatly facilitate crossing the valley of death by creating and maintaining linkages across diverse parts of the innovation effort (users, developers, funders; challenges, behaviors, and solutions; technology development, application development, and social resistance). Such a method would facilitate the purposeful and planned incorporation of platform flexibility that would allow fast adoption of existing technologies, near adoption (10–15 years) of developing technologies, and the adoption of currently-unknown technologies in out years. Doing so would provide the justification for continued development and a realistic basis for forecasted cost savings and operational improvements in the future.

[2] "Other transactions" is the term commonly used to refer to the 10 U.S.C. 2371 authority to enter into transactions other than contracts, grants, or cooperative agreements. The DoD currently has temporary authority to award "other transactions" (OTs) in certain circumstances for prototype projects that are directly relevant to weapons or weapon systems proposed to be acquired or developed by the Department" (Under Secretary of Defense for Acquisition, Technology, and Logistics, 2000, p. 7). OT is used by DARPA to speed contracting necessary for rapid prototyping.

Conclusions

The current work describes the technology transition valley of death and the challenges in crossing it based on the literature and background on the ACTUV/MDUSV program as relative to same. A three-part framework for the analysis and design of crossing the valley is proposed and then applied to the current MDUSV program. Potential uses of the framework products are described. A specific example of a recommendation, as viewed through the lens of the framework, is provided, and how it can facilitate the program crossing the valley. Additional development of the framework for describing, analyzing, and designing the program's crossing of the valley of death is recommended.

The current work can impact practice through the MDUSV program. It provides an initial evaluation of the MDUSV plan for crossing the valley of death. This predicts where the program may encounter challenges and suggests underlying causes such as coordination across linear and social innovation behavior modes. Those challenges and underlying causes can be used by program leaders to identify, design, and implement solutions, thereby speeding the crossing of the valley.

The current work impacts research on the crossing of the valley of death by proposing and initially testing a framework for analyzing and designing a Department of Navy program's crossing of the valley of death. This framework can be expanded and improved based on other programs and tested through application to other programs. By doing so, a valuable tool for acquisition can be developed and applied.

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Acquisition Research Program
Graduate School of Business & Public Policy
Naval Postgraduate School
555 Dyer Road, Ingersoll Hall
Monterey, CA 93943

www.acquisitionresearch.net