16th ICCRTS

"Collective C2 in Multinational Civil-Military Operations"

Innovation Patterns in Some Successful C2 Technologies

Topics:
(1): Concepts, Theory and Policy
(2): Approaches and Organizations

M. S. Vassiliou
Institute for Defense Analyses
4850 Mark Center Drive
Alexandria, VA 22311
USA
+1-703-845-4385
mvassili@ida.org

S. O. Davis
Institute for Defense Analyses
4850 Mark Center Drive
Alexandria, VA 22311
USA
+1-520-320-3750
dfam13@aol.com

Jonathan Agre
Institute for Defense Analyses
4850 Mark Center Drive
Alexandria, VA 22311
USA
+1-703-933-6522
jagre@ida.org

Point of Contact:

M. S. Vassiliou
Institute for Defense Analyses
4850 Mark Center Drive
Alexandria, VA 22311
USA
+1-703-845-4385
mvassili@ida.org

Abstract

In a world of rapidly advancing commercial technology, the U.S. military often still struggles to deliver state-of-the art information technologies for C2 to warfighters and commanders. Some recent success stories include the Tactical Ground Reporting (TIGR) system, the Command Post of the Future (CPOF), and the Combined Information Data Network Exchange (CIDNE). These cases can be characterized using a Kline chain-linked model of innovation, with very strong iterative links between R&D and "markets" (military end users in this context). These initiatives also made effective use of available commercial technology, and displayed "edge innovation" by end users. The initiatives identified pressing needs with a minimum of process formalism, and then filled those needs quickly, with dedicated development teams for continual refinement. They often temporarily bypassed normal procurement channels. Initial deployments were often limited, with "at-risk" adoption by commanders, allowing crucial in-theater experimentation and feedback loops in the development process. As the technologies proved useful, deployment expanded. Despite potential problems in interoperability and security, and conflicts with the military bureaucracy, such "Kline-like" innovation shows promise for some C2 technologies.

Introduction

A number of successful information technology (IT) developments related to U.S. military command and control (C2), including the Tactical Ground Reporting (TIGR) system, the Command Post of the Future (CPOF), and the Combined Information Data Network Exchange (CIDNE) have displayed some common characteristics in their development processes. Among these are strong iterative links between end users and personnel in research, development and engineering, and a relatively high degree of innovation by end users themselves. The development of these technologies can be characterized using a Kline "Chain-Linked" model of innovation,[1] as we discuss below. The technologies were also characterized by relatively rapid deployment to fill pressing user needs, and were often initially deployed "at risk," temporarily bypassing the normal U.S. military acquisition process.

The Linear Innovation Model

A simple linear model of innovation holds that fundamental scientific research leads to new ideas that can ultimately form the basis for new products. In this model, scientific research creates new knowledge; applied research and development focuses and applies the knowledge; development and engineering functions create products based on the knowledge; and manufacturing and production departments then take over and make the products. There is an implied unidirectional chain of causality between science and

[1] Kline (1985), Kline and Rosenberg (1986)

technology, and between technology and production[2]. Fig. 1 depicts a simple linear model.

Although rarely enunciated explicitly, a mindset similar to the linear model was prevalent during the post-war era of "Big Science." Discussions of the linear model frequently make reference[3] to a famous report produced by Vannevar Bush at the end of the Second World War,[4] in response to a letter from President Truman. Bush argued that the way to create truly new products and entirely new industries, and thereby ensure a long-term increase in the standard of living, was to discover new scientific knowledge, which would seed future developments. The Bush report was a well-reasoned and successful attempt to argue that scientific research is a public good deserving public support. It should be noted, however, that Bush did not draw a diagram like the one in Fig. 1, nor did he use the phrase "linear model," in his report.[5] The "linear model" may have been in the back of many people's minds for decades, but it was not until the 1980s that it was explicitly written down as such[6], and then only as a straw man to be refined and improved.[7]

The linear model is not "wrong." It tells part of the story of how successful innovation can occur, but not always the whole story. Innovation is generally a more complex process, with considerable feedback between science, technology, manufacturing, and marketing.

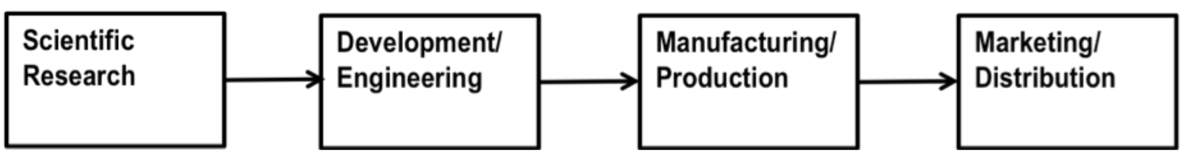

Figure 1. The so-called "Linear" model of innovation (adapted from Kline and Rosenberg[8]). In this model, fundamental scientific research leads to development, then engineering and production, and finally marketing and distribution of new products. While scientific research can certainly provide the knowledge required to create new classes of products, the innovation process is often more complex and involves more feedback than indicated by the simple linear model.

---

[2] Caraça et al. (2009)
[3] E.g. Caraça et al. (2009)
[4] Bush (1945)
[5] There is also no evidence that Mr. Bush was unaware of the true complexity of the innovation process.
[6] E.g. by Kline (1985), Kline and Rosenberg (1986).
[7] Edgerton (2004); Godin (2005a,b); Godin (2006); Gulbrandsen (2008)
[8] Kline and Rosenberg (1986)

The Kline "Chain-Linked" Model of Innovation

The Model

The Kline Chain-Linked model of innovation,[9] depicted in Fig. 2, recognizes a number of complexities in the innovation process. While it is possible for the innovation chain to proceed sequentially (*C* in the figure), this is not necessarily or generally the case. In addition, new knowledge is not typically the driver for initiating the process; rather, the driver is the identification of an unfulfilled market need. There are numerous feedback loops (*f* and *F* in the figure) between the various sequential stages. Questions raised in production, for example, may stimulate new design and testing. Issues raised in design and test may necessitate new analysis and invention. A particularly important feedback loop (*F*) is between marketing, the final stage of the main chain, and the first conceptual stage—the identification of the unfulfilled need. The market helps refine the conception of the need, and hence to guide the innovation and invention.

When a problem arises at any stage in the process, and feedback loops to earlier stages cannot solve it, the practitioners may query the world's base of scientific knowledge (path *K* in the figure) for a solution. If the knowledge base does not yield a solution, new research may be performed or commissioned (*R*). Occasionally, fundamental research may give rise directly to an innovation chain (path *D*) as in the linear model. It is also possible for the products of an innovation chain, for example scientific instruments, to be used by practitioners performing basic research (path *I*).

Overall, the Kline model recognizes that technology can move backwards as well as forwards in the innovation process, and that science can contribute to every stage. The model also recognizes the importance of direct and indirect links between research and marketing. Implicit in the model is the crucial importance of feedback from end users. Research may set the course directly for subsequent innovation stages, but it will not always do so. Unfulfilled needs (marketing) often set the course, and research contributes to resolving problems, both because previous research has added to the accumulated store of knowledge and because new research may answer questions directly and uncover new ones.

Cautions in Applying the Model to Military Systems

The Kline model probably applies best in a commercial industrial context. One must exercise some caution when using it to describe developments in the United States Department of Defense (DoD). What, after all, constitutes a "market" in the case of the DoD? How are "market signals" generated and perceived? This question is difficult to answer in the case of long-term, multibillion-dollar procurement programs. The DoD, after all, is a monopsony, with a limited supplier base.

---

[9] Kline (1985); Kline and Rosenberg (1986); variations and extensions of the model are discussed e.g. by Kameoka and Kobayashi (2001).

However, in the case of individual IT capabilities with identifiable end users in the field, the analogy is more apt. To an important extent, the *end users*, rather than the acquisition establishment, constitute the "market." The feedback from those users can serve as the basis for Kline-like iteration. IT capabilities of the kind discussed in this paper have at least some of the character of commercial packages. They are developed to fill perceived needs of users who may then accept or reject them, and whose experiences may modify them.

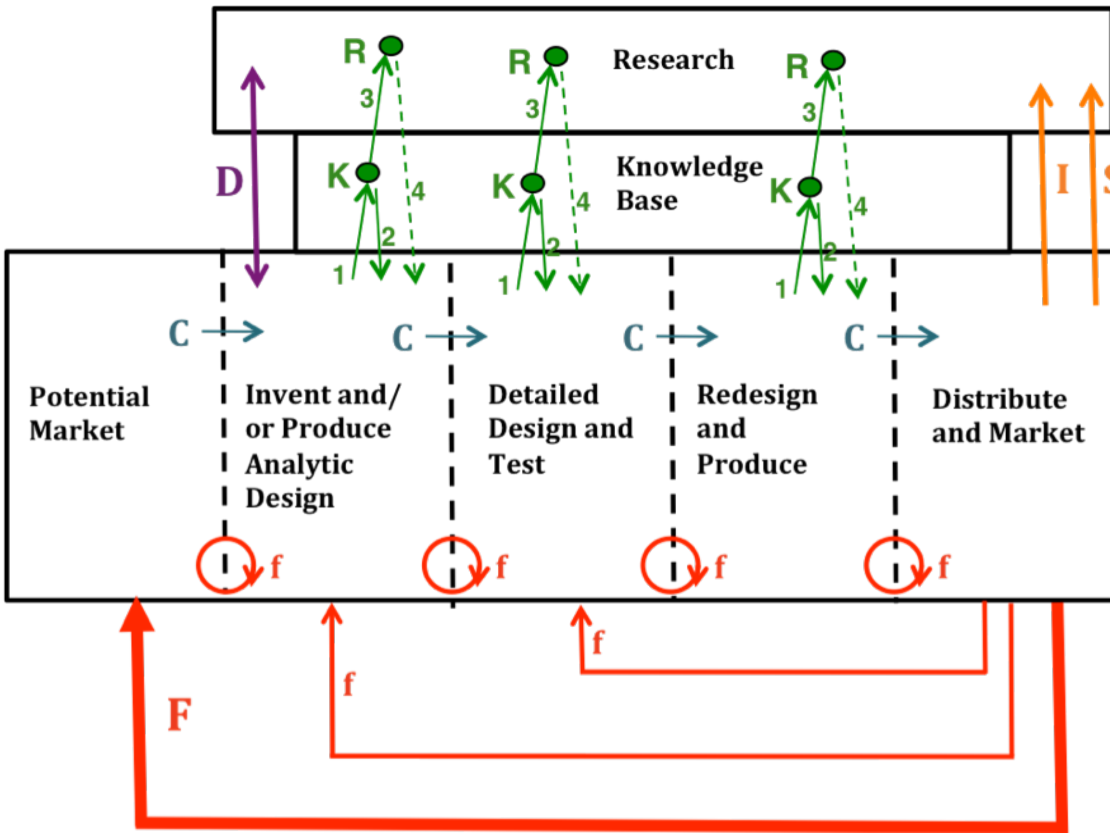

Figure 2. The Kline ("Chain-Linked") Model of Innovation (adapted from Kline and Rosenberg[10]). The model depicts innovation as a complex process in which science and technology may make important contributions at several different points. The main chain of innovation is indicated by *C*, and proceeds from an initial perceived need ("potential market") through the various technical stages culminating in a product. However, C is not the only possible path. There are feedback loops *f* between the technical stages, as well as between marketing and the technical stages. A particularly important feedback loop *F* is the one between marketing and the initial conceptual stage. Another path (*K* and *R*) involves interaction with the existing base of scientific knowledge (*K*) to solve problems and obtain new ideas, or, if necessary, the performance of new scientific research (*R*). *K* and/or *R* may occur at any of the stages leading to a product—or may not. Path *D* represents a potential direct link between scientific research and the invention and design stage, as in the linear model. Path *I* indicates feedback to scientific research by the products of innovation, for example the telescope aiding Galileo's fundamental work in astronomy. *S* indicates the stimulation of new research in sciences underlying the product area of the particular innovation process in question.

[10] Kline and Rosenberg (1986)

Cases

Case 1: Tactical Ground Reporting (TIGR) System

Introduction and Features

The Tactical Ground Reporting (TIGR) System is a tactical situational awareness system developed by the U.S. Defense Advanced Research Projects Agency (DARPA).[11] It allows operators to share facts, issues, suppositions, and lessons learned via map-referenced multimedia. It enables troops heading out on new assignments to benefit from the knowledge gained by their predecessors. TIGR's graphical, map-based user interface is highly intuitive and allows data such as voice recordings, digital photos, and GPS tracks to be easily collected and searched. The system also features a purpose-built data distribution architecture that minimizes the load on sparse-bandwidth, intermittent tactical networks while allowing digital imagery and other multimedia data to be exchanged.[12] This network science and engineering content distinguishes TIGR from typical commercial products that are not designed for the harsh tactical environment. Initial evaluations of TIGR took place in 2006; by 2010 it was being used by all U.S. Army Brigade Combat Teams in Iraq and Afghanistan.[13]

Using TIGR, patrol leaders can conduct company- and patrol-level intelligence preparation of the battlefield (IPB) both before and after missions. By clicking on icons and lists, they can see the locations of key buildings (such as mosques, schools, and hospitals) and retrieve information (such as location data on past attacks, geo-tagged photos of houses and other buildings, and photos of suspected insurgents and neighborhood leaders). They can listen to civilian interviews and watch videos of past maneuvers. TIGR was expressly created to support horizontal information sharing at relatively low echelons of U.S. ground force operations. As a staff officer from the First Brigade Combat Team put it, “It is a bit revolutionary from a military perspective when you think about it, using peer- based information to drive the next move.... Normally we are used to our higher headquarters telling the patrol leader what he needs to think.”[14] TIGR ran initially on laptop computers at fixed sites to which soldiers would return after a patrol. Work has been underway to increase mobility, and also to increase integration of information from new sources such as unmanned aerial vehicles (UAVs).

[11] Ewy et al. (2009); Corrin (2010); Maeda (2010)
[12] Ewy et al. (2009)
[13] Maeda (2010)
[14] Quoted by Talbot (2008)

Development

An important TIGR predecessor was CavNet, a local system developed internally by the U.S. Army 1st Cavalry—a true case of "edge innovation."[15] CavNet was a collection of blogs and forums that allowed junior leaders down to the squad level to share information with one another across the entire division. In one well-publicized use of the network, a patrol leader in Baghdad learned that insurgents were wiring posters of Moqtada al-Sadr to explode when U.S. soldiers took them down, and posted the information. Another officer elsewhere in the city read the information and alerted his soldiers, who discovered some of the rigged posters and safely removed them.[16]

Although CavNet improved information sharing, it did not have a friendly, well-integrated human-machine interface, or a reliable database for multimedia and reports.[17] To fill these needs and others, soldiers from the 1st Cavalry teamed with DARPA to work on what would be later called TIGR. A DARPA program manager (PM) began interacting directly with soldiers returning from Iraq and was able to refine her appreciation of the operational need. She was also able to confirm the willingness of battalion-level leaders to accept new tools to fill that need.

A team of programmers was assigned to work directly with soldiers in developing specific TIGR features in prioritized categories. First Cavalry personnel tested the system in exercises at the unit's home station and at Army training centers. Working directly with soldiers who would actually use the software on deployment accelerated the development process, and also enabled developers to focus on the most crucial features and capabilities. The PM has been quoted as saying "the functionality in TIGR has changed and increased in various ways based on feedback from the troops."[18] One result was an extremely intuitive and effective user interface, similar to that found in Google Maps and in social networking sites—familiar paradigms for young soldiers. The system made creative and effective use of available commercial technologies, initially using a Microsoft infrastructure and a graphical user interface provided by Internet Explorer.[19]

TIGR did not begin as a formal program of record, and did not have time to go through all the usual military acquisition channels. Compelling operational needs demanded its presence in theater, and commanders in the field made the decision to employ it. The Army did not provide formal acquisition support for fielding. The Army also did not initially approve TIGR's use over wireless tactical networks. In an initial compromise agreement, the system would only be used within the 1st Cavalry. Funding was also limited. However, the 1st Cavalry found the capability valuable enough that it provided

[15] Teamey (2008)
[16] Baum (2005)
[17] Teamey (2008)
[18] Turner (2009)
[19] Turner (2009)

some of its own funding. DARPA also teamed with the Rapid Equipping Force (REF), which sent a training and engineering team.

TIGR gained support fairly quickly from troops in the field, but somewhat slower from the larger Army establishment. Some of the same capabilities that make it useful can also cause problems with Army business and operational practices. For example, the ability to share data across all echelons can conflict with Army rules for handling classified information. In addition, TIGR did not always interoperate easily with the mainline C2 systems at the battalion level and above. Continuing collaborative development and refinement were needed. This work was facilitated by in-theater teams of field service representatives and system engineers responsible for fielding and maintaining TIGR instances throughout Afghanistan and Iraq. The program manager also ensured the availability of training in support of theater operations, and the maintenance of a help desk.

From the foregoing we can see that TIGR development showed many features associated with a complex and tightly coupled innovation process, of the kind described by the Kline Model. TIGR originated not from an initial discovery but from a set of pressing needs. Its development process was iterative and exhibited considerable feedback loops between stages. There was a particularly important feedback loop between the end user (the "market") and the first conceptual stage driving the development. The program manager on the contractor side described TIGR as "something completely unique, a living, breathing system."[20] While much of the work on TIGR can be characterized as experimental development and engineering, the innovation process also exhibited paths into the global scientific knowledge base, and initiated some new research in a number of areas. One such area, as we have mentioned, involved the creation of a distributed architecture with policy-based data dissemination to keep the bandwidth load on the tactical network low and hence minimize the impact of network outages.

Case 2: Combined Information Data Network Exchange (CIDNE)

Introduction and Features

The Combined Information and Data Network Exchange (CIDNE) is a Web-based database system used by the U.S. military, generally at brigade level or above, to record and manage information related to improvised explosive devices (IEDs)[21]. CIDNE offers a capability for tracking three types of entities—people, facilities, and organizations—that influence operations in a region. CIDNE's Web-enabled Temporal Analysis System (WebTAS) is a suite of analytical tools that allows users to combine, visualize, and interpret information from various sources. Using WebTAS to explore the CIDNE

[20] Corrin (2010)
[21] ISS (2010); Grace (2010); Wojciechowski (2006); Borgman et al. (2009)

database, users may obtain associated data on explosive hazard events throughout the theater in near real time.[22]

Development

CIDNE was developed by a small team of software engineers working directly with troops in the field to fulfill pressing operational needs. The development process was tightly coupled and exhibited Kline-like feedback loops between stages. CIDNE was developed by the Army's III Corps, with the encouragement of Central Command. CIDNE has had four major releases since fall 2006[23]. By 2009 it was the standard IED activity reporting system in Iraq.[24]

CIDNE did not begin as a counter-IED system, but evolved and was repurposed into that role. CIDNE began operational life as a local C2 capability at a division command center and several brigade headquarters in Iraq to enable information management and sharing, as well as storage for access by replacement units.[25] Its initial focus was on managing brigade-and-above contacts and coordination efforts with the Sons of Iraq (SoI).[26] The 445th Civilian Affairs Battalion gave the technology to their deploying troops and encouraged its use in SoI engagements. By providing a standardized reporting framework across the intelligence and operations disciplines, CIDNE brought together a number of disparate communities.[27] Its role expanded, and its capability to track people, facilities, and organizations proved to be critical in the burgeoning effort to counter IEDs. CIDNE thus provides an excellent example of a flexible innovation and development process with a very strong responsiveness to evolving market signals.

Case 3: Command Post of the Future (CPOF)

Introduction and Features

The Command Post of the Future (CPOF) is a real-time collaboration technology with powerful military mapping capabilities.[28] It constitutes a virtual "sand box" where commanders can publicly depict situations, plan potential courses of action, offer ideas, refine tasking, and synchronize plans. Its users are flag officers, unit commanders, and senior staff at several echelons. The tool enables commanders in dispersed geographic locations to visualize the battlefield, obtain recent information about operations, and make annotations. Users can communicate and collaborate without leaving their

---

[22] Brady (2009)
[23] Teamey (2008)
[24] Walsh et al. (2010)
[25] Walsh et al. (2010)
[26] The Sons of Iraq, also known as the Sunni Awakening Movement, are coalitions of tribal sheikhs that have taken on the task of maintaining security in their communities.
[27] ISS (2010)
[28] Croser (2006); Ebbutt (2007); Schachtman (2009)

operations centers, synchronizing tactical and strategic activities while avoiding the hazards of travel. CPOF was originally a DARPA technology demonstration in the late 1990s, and became part of an Army Program of Record in 2006. It has been federated with the Army's Maneuver Control System (MCS) and consumes data from the Global Command and Control System (GCCS).[29] By 2009, 6,000 CPOF systems had been fielded in Iraq and Afghanistan.[30]

CPOF's main human interface is a virtual workspace in which all content is a shared piece of data in a networked repository. There are visual representations of units, events, tasks, and the like. These appear, for example, on maps or schedule charts. In addition there are representations of whiteboard-like hand annotation, such as brush-marks, highlighting, and notes. Users can edit data values, such as locations on a map or tasks on a schedule, by dragging and dropping. The results of such editing are visible to all participants in a visualization session. When one user moves an event on a map, for example, that event icon moves on all maps and shared views.

Development

Before the Iraq War, DARPA development of CPOF concentrated on creating the most intuitive possible human-computer interface to support C2. For operational use in a tactical environment, other improvements were needed. The system would need to be hardened significantly and made more stable. It also needed to be made scalable to hundreds of users. As the Army's First Cavalry Division began deploying to Iraq, DARPA began a serious collaboration with the Army to make the necessary enhancements. General Peter Chiarelli understood the technical issues and allowed deployment of CPOF at risk.[31]

This deployment at risk meant that invaluable experimentation, with Kline-like feedback loops, could be conducted in-theater to guide the development. DARPA and the Army signed a Memorandum of Agreement (MOA) in 2004. DARPA would continue to fund advanced technology research required to harden the system and exploit lessons learned, while the Army would fund continued fielding. The experimentation in theater allowed a disciplined and integrated development process with constant feedback. Software developers were not the only ones who participated in this process; some very high-level research scientists spent some time in theater as well.[32] As in the case of TIGR, CPOF had field service representatives on location to help manage the process and collect user feedback. As new capabilities were added, users and field service representatives provided more impressions. This allowed software developers to focus on the most important problems. Since resources were not expended on an enhancement until it was

[29] Walsh et al. (2010)
[30] Walker (2009)
[31] Greene et al. (2010)
[32] Gershon and Kolojejchick (2005)

justified as a valid real-world need, the feedback loops served not only to reduce risk but also to reduce cost.

Not only has CPOF had its development guided by user feedback, but the system's very structure and functionality also encourages user experimentation and edge innovation. CPOF users at any level can assemble their own local workspaces out of smaller "tool-and-appliance" capabilities. They can create their own quick applications for purposes that the developers of the software might not have anticipated, and do so without disrupting other users. In addition, CPOF repositories have become a rich source of empirical data on the nature and specific content of C2 business processes. This is a powerful requirements definition and validation mechanism that can augment anecdotal evidence.[33]

Although CPOF was becoming a successful deployed system before 2006, it had still not gone through the usual requirements and acquisition channels, and was not a formal program of record. During the period between 2004 and 2006, there was an overlap in DARPA and Army leadership of the effort. Among other things, this allowed time for a rationale to be developed to turn CPOF from a research and development program deployed at risk to a formal program conforming to all acquisition regulations. In 2006 CPOF was integrated into the Army's Maneuver Control System program.[34]

Discussion

Rapid Innovation and Fielding in the Context of U.S. Military Acquisition Rules

One can argue that current formal DoD acquisition processes are already based on the concept of identifying and fulfilling operational needs.[35] One could also argue that the various feedback processes in the Kline Model of innovation are fully compatible with DoD acquisition regulations. The problem is one of time scale. For the types of capabilities discussed in this paper, the feedback loops operate best when they do so often and fast, with a minimum of formalism and with as few bureaucratic middlemen as possible. We live in a world where young soldiers are used to seeing new generations of cellular phones and media players appear over a time span of several months, and non-state adversaries can easily and cheaply acquire advanced information technologies that make them nimble and effective. In such a world, formal DoD processes for identifying and validating operational needs can take longer than development timelines for new IT capabilities, and the resulting technologies can significantly lag the operational need.[36] In addition, as a recent report by the National Research Council put it, "Success as

[33] Walsh et al. (2010)
[34] Greene et al. (2010)
[35] e.g., Matthews (2004)
[36] Teamey (2008); NRC (2010)

determined by process metrics in acquisition does not necessarily align with success metrics based on the timely delivery of end-user capability."[37]

U.S. Army Procedures to Accelerate Fielding of New IT

The U.S. Army has developed some standard operating procedures (SOPs) to support wartime fielding of new information technologies. Requirements are documented as an Urgent Operational Need (UON), which may be joint or Service-specific. In some cases, the UON can describe some proposed IT to fill the gap. Once a UON is validated by Army G-3,[38] resources can be allocated. The process up to this point can take 60 days or more, depending on the priority of the requirement. The next step is to determine if the UON will become a Program of Record, or be adopted by an existing Program of Record. For IT, both Army G-3 and Army G-6[39] are involved in the process. IT used on networks must be certified for interoperability with existing infrastructure and systems. This can take a year or more. In the past, requests from units in actual combat did not appear to receive special priority, either.[40] Thus, even the accelerated Army pathway for IT can be long and involved. The transition to Program-of-Record status is not automatic, nor is it assured to take place within a given time frame, even for very useful technologies.

At-Risk Adoption and Bureaucratic Resistance

In order for effective development of the types of C2 IT we have been considering, in-theater experimentation and iteration are almost essential. It is difficult to conduct such experimentation and development within the Army's usual time scale for acquisition—even its accelerated process for IT. However, commanders are sometimes empowered to assume risks and allow the use of uncertified systems in theater, generally with approval of the relevant Combatant Command (COCOM). In such a case, the operational chain of command authority is effectively trumping the usual formal acquisition rules.[41] For all three of the cases discussed in this paper, commanders approved "at risk" operation at some point.

Although TIGR and CIDNE could be deployed because commanders approved at-risk operation, both continued to be subject to process demands for further certifications, recommendations, and validations. The DARPA PM in charge of TIGR was quoted in 2010 as saying that the system received "a lot of bureaucratic pushback" when it first began deploying in 2006. She also said "…every six months or so we still get push back because we are not a PoR [Program of Record]."[42] In 2008 the U.S. Army Vice Chief of

[37] NRC (2010)
[38] The U.S. Army staff organization for Operations and Training
[39] The U.S. Army staff organization for Communications and Electronics
[40] Teamey (2008)
[41] Resource constraints often prevent wider adoption of a technology outside of the initial theater.
[42] Magnuson (2010)

Staff, General Peter Chiarelli, made much stronger statements. He characterized TIGR as a technology that "forever changed our Army," but he said it succeeded "in spite of everything the Army could do to stop it."[43]

The Army, and most of the DoD, still find it very difficult to strike a balance between the importance of protecting networks, enabling IT platforms to share information, and rapidly supplying units in combat with capabilities they need.[44]

<u>Interoperability</u>

It is easy to criticize the DoD's acquisition rules as cumbersome and inappropriate for the information age. It is also easy to advocate that all IT development be allowed to follow Kline-like innovation paths with more of a commercial industrial character. However, this type of innovation can, sometimes unwittingly, have downsides. One problem that might be aggravated when technologies are developed rapidly and somewhat independently to fill pressing battlefield needs is that of interoperability. This is not to say that DoD systems developed according the letter of all the acquisition rules are always interoperable. It is also not to say that the more freewheeling development we have discussed here must necessary lead to systems that are not interoperable. However, this type of development perhaps introduces more of that risk. Interoperability with mainline C2 systems has been a continuing problem for CPOF, for example. A recent study has also found low levels of semantic interoperability between CIDNE, TIGR, and CPOF.[45]

<u>Security</u>

Security is another important concern. We have already mentioned the conflict between TIGR's widespread horizontal sharing of information and Army procedures for safeguarding classified information, for example. It is also conjectured that one of the main unauthorized releases of classified information to the *Wikileaks* web site in 2010 originated in Central Command's CIDNE. It is possible that the alleged leaker used CIDNE's "Export to Excel" feature to capture the information that he later illegally transmitted.[46] Using this feature apparently did not leave a signature that was easily noticed as being dangerous, because the process is used routinely for legitimate data exchange. We should emphasize, in fairness, that such an insider attack could foil many systems, including ones that were procured following all formal procedures. Perhaps, though, it is possible that rapid, Kline-like, quasi-independent development of an IT could introduce more such vulnerabilities. Is it possible that a more deliberately planned

[43] Clark (2008)
[44] It is worth noting that the U.S. Marines and Special Forces have been somewhat more successful with their processes for rapid certification for information technologies.
[45] Lichtblau and Bleach (2010)
[46] Dubaz (2010)

and more robust CIDNE could have thrown up more flags when it detected large data exports under certain conditions?

Development in a War Zone

The rapid, iterative development of new military IT capabilities, with considerable guidance from user feedback, almost necessitates in-theater experimentation. Thus development is occurring, at least to some extent, in a war zone. This raises a number of unique challenges and issues. For one thing, soldiers are very busy, and do not necessarily have large amounts of time to devote to the process. For another thing, developers, engineers, and scientists are not generally soldiers, and it may be difficult to deploy them to such an environment. This does not make the process impossible, but it does make it very difficult and risky for all concerned. Kline-like in-theater development is thus hardly an innovation process that can be considered routine.

Summary and Conclusions

In a world of rapidly advancing commercial technology, the U.S. military often still struggles to deliver state-of-the art information technologies for C2 to warfighters and commanders. Some recent success stories include the Tactical Ground Reporting (TIGR) system, the Command Post of the Future (CPOF), and the Combined Information Data Network Exchange (CIDNE). These shared some important characteristics in their development:

- They were driven by the need to solve immediate and pressing battlefield problems. Sometimes they existed first as research programs, but it was only after the battlefield driver was added that they achieved their true and current form.
- The development process acted to fill the battlefield needs as quickly as possible, by taking advantage of what users were already doing, or trying to do; by using commercially available technology when appropriate; and by allowing users scope to innovate (edge innovation).
- The systems were developed with constant and considerable user feedback, enabled by in-theater experimentation.
- The combination of forward engineering development and user feedback sometimes led to new technology being required, thus driving a more basic level of R&D, or a more fundamental interaction with the base of stored scientific knowledge.

The development processes of these systems can be characterized using a Kline chain-linked model of innovation, involving feedback loops between the various stages of the innovation process, with a particularly important feedback loop between market signals and the early conceptual stages of development. The Kline Model may not be generally applicable to large defense acquisition programs, but can be useful in the case of an individual IT capability being developed for end users. Although the analogy with commercial industry is not exact, the end users constitute the "market."

A number of consequences flow from the application of such an innovation process in a military IT system:

- The need for in-theater experimentation, combined with the need for rapid results, means that development may depend on "at risk" adoption by commanders, temporarily trumping the normal, lengthy military requirements and acquisition process. Considerable support from at least some people at high levels in the hierarchy may be necessary for this to happen.
- The necessity of achieving rapid usefulness, and meeting the needs of a particular constituency, can lead to development of systems with some "stand-alone" character, forming the basis for future interoperability problems.
- The same necessities can also lead to potential security problems. Systems designed for broad use and enabling a large amount of information sharing can conflict with regulations and practices for handling sensitive information.
- The need for considerable user feedback to perfect the system and make it relevant can place a burden on end users who are busy with life-and-death decisions and operations. It can also place a burden on scientists and engineers who are not accustomed to working in a war zone.

Overall, the U.S. Army, and most of the DoD, still find it very difficult to strike a balance between the importance of protecting networks, enabling IT platforms to share information, and rapidly supplying units in combat with capabilities they need. However, despite the many problems they encounter, "Kline-like" iterative innovation processes for new IT capabilities have shown promise.

The formal acquisition system emphasizes a carefully planned, controlled, and centralized approach. A more or less uniform environment is implicitly assumed and often fails to recognize that (1) bursts of innovation do occur, and are critically important to successful operations, and (2) conditions that foster innovation can be defined in advance and recognized by authorities in the chain of command. Commanders should more easily and quickly be able to invoke a set of special acquisition rules that support innovation. This often happens anyway, in an *ad hoc* manner, as in the cases we have studied. The process should be simpler and more transparent.

Acknowledgements

This work was performed under Institute for Defense Analyses Contract No. DASW01-04-C-0003, task order AK-2-2701. We thank David Jakubek for helpful discussions. We also thank the paper's reviewers for their valuable suggestions.

Disclaimer

The views expressed are those of the authors and do not reflect the official policy or position of the Defense Advanced Research Projects Agency, the Department of Defense, or the United States Government.

References

Baum, Dan (2005). "Battle Lessons." *The New Yorker*, 17 January.

Borgman, Alicia, Phil Smith, and Dustin Johnson (2009). *Tools for Enhancing Distributed, Asynchronous Collaboration in Army Operations. Proc. 2009 IEEE International Conference on Systems, Man, and Cybernetics*. San Antonio, Texas, Oct. 2009, 3528-3533.

Brady, Matthew (2009). "The 766th Explosive Hazards Coordination Cell Leads the Way into Afghanistan." *Engineer: The Professional Bulletin for Army Engineers* Vol. 39 No. 1, 42-45.

Bush, Vannevar (1945). *Science the Endless Frontier*. Report to the President by Vannevar Bush, Director of the Office of Scientific Research and Development. United States Government Printing Office, Washington, 1945.

Caraça, João, Bengt-Åke Lundvall, and Sandro Mendonça (2009). "The changing role of science in the innovation process: From Queen to Cinderella?" *Technological Forecasting & Social Change* 76, 861–867.

Clark, Colin (2008). "Army Vice Touts TIGR; Success 'in Spite of' System." *DoD Buzz—Online Defense and Acquisition Journal*, 2 December 2008. http://www.dodbuzz.com/2008/12/02/army-vice-touts-tigr-success-in-spite-of-system/, last retrieved 27 January 2011.

Corrin, Amber (2010). "TIGR Keeps Troops in the Field Safer." http://defensesystems.com/articles/2010/03/11/defense-it-1-tigr-system-gaining-rapid-adoption.aspx Last retrieved 19 January, 2011.

Croser, Caroline (2006). "Commanding the Future: Command and Control in a Networked Environment." *Defense & Security Analysis* Vol. 22, No. 2, 197-202.

Dubaz, Nick (2010). "How Manning Stole the Cables." *Conflict Health* website, 30 November 2010. http://conflicthealth.com/how-did-manning-steal-the-cables/, last retrieved 27 January 2011.

Ebbutt, Giles (2007). "US Future Command Post Comes of Age." *Jane's International Defense Review*, Vol. 40, 15.

Edgerton, David (2004). “The Linear Model did not Exist: Reflections on the History and Historiography of Science and Research in Industry in the Twentieth Century.” In Karl Grandin, Nina Wombs, and Sven Widmalm (eds.), *The Science-Industry Nexus: History, Policy, Implications: Nobel Symposium 123*. Sagamore Beach, Massachusetts: Science History Publications, pp. 31-57.

Ewy, Benjamin J., Michael T. Swink, Steven G. Pennington, Joseph B. Evans, Jin M. Kim, Chun (Steve) Ling, Samuel L. Earp, and Mari Maeda (2009). “TIGR in Iraq and Afghanistan: Network-Adaptive Distribution of Media Rich Tactical Data.” *Proc. IEEE Military Communications Conference (MILCOM 2009)*, 1-7.

Gershon, Nahum, and Jake Kolojejchick (2005). “From the Lab to the Field.” *IEEE Computer Graphics and Applications* Vol. 25 No. 5, 6-7.

Godin, Benoît (2005a). *Measurement and Statistics on Science and Technology: 1920 to the Present*. London: Routledge.

Godin, Benoît (2005b). *The Linear Model of Innovation: The Historical Construction of an Analytical Framework*. Montreal, Quebec: Project on the History and Sociology of S&T Statistics, Working Paper No. 30. Available at: http://www.csiic.ca/PDF/Godin_30.pdf , last retrieved 18 December 2010.

Godin, Benoît (2006). “The linear model.” *Sci. Technol. Human Value*s 31 (6) 639–667.

Greene, Harry, Larry Stotts, Ryan Paterson, and Janet Greenberg (2010). “Command Post of the Future: Successful Transition of a Science and Technology Initiative to a Program of Record.” *Defense Acquisition Review Journal*, Vol. 17 No. 1, 3-26.

Gulbrandsen, Magnus (2008). “The Role of Basic Research in Innovation.” In Willy Østreng, editor, Confluence: *Interdisciplinary Communications 2007/2008*. Oslo, Norway: Norwegian Academy of Science and Letters, Center for Advanced Studies, pp. 55-58.

ISS (2010). *CIDNE*. Intelligent Software Solutions. http://www.issinc.com/solutions/cidne.html. Last Retrieved 17 December 2010.

Jean, Grace (2010). “Culture Maps Becoming Essential Tools of War.” *National Defense*, February 2010.

Kameoka, A., D. Ito, and K. Kobayashi (2001). “A Cross-Generation Framework for Deriving Next-Generation Innovation Model.” *Change Management and the New Industrial Revolution*, *IEMC ‘01 Proceedings*, Albany, NY.

Kline (1985). *Research, Invention, Innovation and Production: Models and Reality*, Report INN-1, March 1985, Mechanical Engineering Department, Stanford University.

Kline, S.J. & N. Rosenberg (1986). "An overview of innovation." In R. Landau & N. Rosenberg (eds.), *The Positive Sum Strategy: Harnessing Technology for Economic Growth.* Washington, D.C.: National Academy Press, pp. 275–305.

Lichtblau, Dale E., and Richard D. Bleach (2010). *U.S. and Coalition Forces Data (Semantic) Interoperability Study*. Alexandria, Virginia: Institute for Defense Analyses, Report No. D-4018.

Maeda, Mari (2010). *TIGR: An Introduction*. Arlington, Virginia: Defense Advanced Research Projects Agency.

Magnuson, Stew (2007). "Army Wants to Make 'Every Soldier a Sensor.'" *National Defense* Vol. 91, Issue 642, 44-47.

Magnuson, Strew (2010). "DARPA Apps Program Generates 'Overwhelming' Response." Posting to *National Defense* Blog, 3 November 2010. http://www.nationaldefensemagazine.org/blog/Lists/Posts/Post.aspx?List=7c996cd7%2Dcbb4%2D4018%2Dbaf8%2D8825eada7aa2&ID=239, last retrieved 27 January 2011.

Matthews, David M. (2004). *The New Joint Capabilities Integration Development System (JCIDS) and its Potential Impacts upon Defense Program Managers*. Monterey, California: Naval Postgraduate School, Report No. NPS-PM-04-017.

Matthews, William (2008). "Helping Info Flow Freely." *Defense News*, 28 January 2008.

NRC [National Research Council] (2010). *Achieving Effective Acquisition of Information Technology in the Department of Defense*. Washington, DC: National Academies Press.

Saito (2007). "'Application-Specific Research': A New Concept Representing 'Mode-Conversion' from 'Research' Mode to 'Development' Mode." *PICMET 2007 Proceedings*, 5-9 August, Portland, Oregon

Schachtman, Noah (2009). "'Command Posts of the Future' Readied for Afghan Surge." http://www.wired.com/dangerroom/2009/12/command-posts-of-the-future-readied-for-afghan-surge/#more-20035, last retrieved 17 December 2010.

Talbot, David (2008). "A Technology Surges." *Technology Review*, March/April 2008.

Teamey, Kyle (2008). "A Tale of Four IT Programs." *Armed Forces Journal*, Nov. 2008.

Turner, John (2009). "DARPA's TIGR Project Helps Platoons Stay Alive." O'Reilly Radar. http://radar.oreilly.com/2009/04/where-20-preview---darpas-tige.html, last retrieved 27 January 2011.

Walker, Amy (2009). "Command Post of the Future Program Nears Fielding of 6,000th Unit." *Fort Hood Sentinel*, 16 July 2009. http://www.forthoodsentinel.com/story.php?id=1386, Last retrieved 17 December 2010.

Walsh, P.J., S.O. Davis, M. Kiefer, K.A. Morrison, J.W. Piper and H.G. Potrykus (2010). *DoD Net-Centric Services Strategy Implementation in the C2 Domain*. Alexandria, Virginia: Institute for Defense Analyses, Paper P-4549.

Wojciechowski, Mark (2006). "CIDNE Empowers Theater-wide Communications." http://newsblaze.com/story/20060213070727nnnn.nb/topstory.html Last Retrieved 17 December 2010.