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on

21st Century Strategic Technology Vectors

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February 2007

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OFFICE OF THE SECRETARY OF DEFENSE
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WASHINGTON, DC 20301-3140

DEFENSE SCIENCE BOARD

February 1, 2007

MEMORANDUM FOR: Under Secretary of Defense for Acquisition, Technology, and Logistics

SUBJECT: Final Report of the Defense Science Board 2006 Summer Study on 21st Century Strategic Technology Vectors (Volume I)

I am pleased to forward Volume I of the final report of the Defense Science Board 2006 Summer Study on 21st Century Strategic Technology Vectors. Volumes 2–4, reports of the task force's panels, will follow shortly.

The task force identified the enabling technologies for a set of capabilities that, taken together, are crucial to meeting the diverse set of challenging missions our military forces will face. To a large extent, the capabilities and technologies discussed in this report are not coupled to the major systems so important during the Cold War. Instead the report highlights enhanced training and continuous education, automated language processing, close-in sensor systems, the soldier as a collector in a network, rapid extraction of information hidden in massive amounts of data, and non-kinetic operations. The report also points to the potential of models from the social and behavioral sciences to better understand how individuals, groups, societies, and nations are likely to act in response to changing circumstances.

The task force also addressed issues associated with the continuing globalization of technology. The report recommends ways to more effectively incorporate a deeper understanding of technology into DOD's strategic planning and concept development and to promote more rapid transition of technology into fielded capability.

I endorse all of the study's recommendations and encourage you to forward the report to the Secretary of Defense.

Dr. William Schnieder, Jr.
Chairman
Defense Science Board

OFFICE OF THE SECRETARY OF DEFENSE
3140 DEFENSE PENTAGON
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DEFENSE SCIENCE BOARD

February 1, 2007

MEMORANDUM TO THE CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Report of the Defense Science Board 2006 Summer Study on 21st Century Science and Technology Vectors (Volume I)

Unlike during the Cold War when the United States focused on one major, relatively slow-changing but individually formidable adversary, in the current era and for the foreseeable future, U.S. military forces will be called upon to perform a wide range of missions. These include major combat, counter insurgency, stability and reconstruction, countering weapons of mass destruction, homeland defense, and disaster relief. These varied missions present different challenges calling for highly adaptive military forces. One common feature of these missions is the increased responsibility placed on junior leaders and the small teams they lead.

This report of the Defense Science Board 2006 Summer Study on 21st Century Strategic Technology Vectors identifies a set of four operational capabilities and their enabling technologies that can support the range of future military missions. In identifying these capabilities, the report defined technology broadly, to include tools enabled by the social sciences as well as the physical and life sciences.

- Perhaps most central is to gain deeper understanding of how individuals, groups, societies and nations behave and then use this information to (1) improve the performance of U.S. forces through continuous education and training and (2) shape behaviors of others in pre-, intra- and post-conflict situations. Key enablers include immersive gaming environments, automated language processing and human, social, cultural and behavior modeling.

- The second is greatly enhanced capabilities to observe people, things, and activities in urban and other tough terrains and to record and recall the data. This will reduce sanctuaries where adversaries hide and draw support for their operations, and reduce their ability as irregular forces to "hide in plain sight." Needed are new suites of close-in sensors and the soldier on the ground empowered to be a powerful collector.

- The third is extracting actionable information hidden in massive data much more rapidly than is done today. This capability would be critically important to commanders at all levels, intelligence analysts, and soldiers and marines on patrol.

- Last is producing effects—offensive and defensive, kinetic and non-kinetic, lethal and non-lethal—tailored rapidly to the circumstances in order to achieve the desired and avoid the counterproductive.

A key enabler to all of these capabilities is the availability of ubiquitous, secure, reliable, rapid connectivity among all the sources and users of information.

Another major change from the Cold War is that the U.S. government and its defense industry partners no longer are at the leading edge of most of the militarily relevant technologies, having been displaced by international commercial industries and markets. Thus the DOD must further modify its processes and practices for technology planning and transitioning technology into capabilities.

This report recommends ways that DOD can (1) reestablish a tighter integration between DOD's user and technology communities, (2) enrich its capacity to recognize and exploit technology opportunities, (3) establish robust processes to insert new capabilities into ongoing operations to meet an expected long term need, and (4) cut in half the time it nominally takes to field major systems. The report also identifies steps to broaden and deepen DOD's in-house technical expertise, search globally for technologies that may become important to DOD and/or its adversaries, provide budget flexibility, lower barriers to commercial firms working with DOD, and revitalize internal research and development investments in the defense industry.

We speak for the members of the task force in expressing appreciation for the contributions of the government advisors; Beth Foster, ODDR&E, our executive secretary; CDR Cliff Phillips, the DSB Office representative; and Brian Hughes, Executive Director of the DSB Secretariat. Last but not least, we acknowledge the invaluable role of Julie Evans, Barbara Bicksler, Kevin Gates, Stacy Zelenski O'Mara, and the other the members of the staff.

Dr. Theodore S. Gold
Task Force Co-Chair

Dr. William R. Graham
Task Force Co-Chair

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Volume II. Critical Capabilities and Enabling Technologies
Volume III. Strategic Technology Planning
Volume IV. Accelerating the Transition of Technologies into U.S. Capabilities

Major Themes

This report identifies a set of four operational capabilities and their enabling technologies that can support the range of future military missions:

- mapping the "human terrain"
- ubiquitous observation and data recording in difficult terrain
- rapidly extracting actionable information hidden in massive clutter
- producing effects rapidly and tailored to the circumstances

A tighter integration between the Department of Defense (DOD) user and technology communities should be reestablished so that:

- DOD's mission solutions are inspired by a deeper understanding of technology opportunities
- DOD's science and technology activities are more directly informed by DOD's strategic goals and top-level missions

DOD needs to enrich its capacity to recognize and exploit such technology opportunities through:

- more "prospecting" of commercial, non–DOD, and foreign technologies for good ideas and products
- more "speculating" through investing in truly disruptive opportunities
- a more coherent and comprehensive approach to anticipating how adversaries might exploit technology

DOD should prepare for the long-term need to insert new capabilities into ongoing operations by turning current improvised approaches into processes and practices robust enough for a long war characterized by many diverse conflicts, cooperative activities with individuals and groups from a wide range of cultures, and other actions.

A disciplined spiral development process can allow DOD to cut in half the time it nominally takes to field a major system and thus avoid technological obsolescence and reduce risk.

This report offers recommendations to do all of the above

Summary

This study had two broad tasks. The first was to identify a set of operational capabilities and their enabling technologies (strategic technology vectors) that are the successors to the Cold War's speed; stealth; precision; and tactical intelligence, surveillance, and reconnaissance (ISR). The second was to recommend how DOD should conduct strategic technology planning and speed the transition of technology into fielded capability.

The United States faces a complex set of security challenges with greater uncertainty than during the Cold War and an extraordinary pace of technological advance. However, there is a tendency to forget the uncertainties faced in the Cold War and that technology was changing rapidly during that war as well: in explosives, propulsion, rocketry, satellites, electronics, and communication.

One feature of the security landscape has changed fundamentally. The DOD and its government and industry partners are no longer at the leading edge of most technologies. The globalization of multi-purpose technology provides opportunities for U.S. adversaries to exploit that did not exist during the Cold War. Time to market has become the competitive advantage.

Critical Capabilities and Enabling Technologies

The Cold War strategic vectors were succinct descriptors of capabilities that would make a big difference in U.S. military operations. Precision provided a means to go from the many sorties needed to destroy a single target to a single sortie being able to destroy multiple targets. Stealth would provide the means to negate the Soviet Union's massive investment in air defense and increase the element of surprise. Tactical ISR provided the means to see targets deep beyond the front lines. Speed shortened the sensor-to-shooter times so that targets could be engaged as they were detected.

Those vectors did not operate in a vacuum. They supported a strategy that looked to technology to offset the numerical advantages held by the Soviet Union and Warsaw Pact, and reduce NATO's reliance on nuclear weapons to deter an attack. They complemented an evolving concept—the Air-Land Battle—that provided an operational context. These vectors focused on one scenario, holding at risk the follow-on forces of the Warsaw Pact so that any attack on NATO could not be sustained.

This report offers a set of four capabilities and their enabling technologies that are critical to meeting the range of DOD's 21st century missions. These four do not match the succinctness or transparency of those of the Cold War. But multiple threats now present different challenges and uncertainties that cannot be captured by a single scenario. An overarching strategic vision has not yet emerged and operational concepts are still relatively immature. Nevertheless, the critical capabilities and enabling technologies identified in this report provide a coherent starting point for a science and technology (S&T) strategy that will address 21st century security challenges.

Methodology

This study took a systematic, although not scenario-based or quantitative, approach driven by five top-level missions derived from the 2006 Quadrennial Defense Review: (1) defeating terrorist networks; (2) preventing acquisition and use of weapons of mass destruction (WMD); (3) defending the homeland; (4) shaping nations at strategic crossroads; and (5) conducting stability, security, transition, and reconstruction operations.

Using these five missions as the basis, the task force identified contributing capabilities needed to accomplish these missions and, in turn, the technologies that enable these capabilities. The task force then judged the relative importance of the capabilities to these missions. All missions were deemed equally significant; thus capabilities and technologies with broad applicability were considered more critical. This process yielded a set of four high-level capabilities, a dozen enabling technology areas, and over forty constituent technologies. Technologies were categorized according to their relative maturity and whether progress to further mature these technologies lay within DOD or elsewhere. Knowledge of where the action is for a given technology is essential to craft an effective science and technology strategy.

Four Critical Capabilities

The four Cold War "vectors" remain important, but have evolved against the demands of today's missions. Speed remains critical, but it is not about just getting there fast, but about adapting, understanding, deciding, and acting. Counter-stealth has supplanted stealth as a critical need, since it is U.S. adversaries who are able to operate hidden underground and hidden in plain sight among civilians. The capabilities needed for such counter-stealth operations are ubiquitous observation, recording, and archiving of difficult target data and being able to rapidly extract useful information hidden in massive clutter. Precision has expanded from "hitting what you aim at" into tailoring effects to the circumstance, including minimizing counterproductive effects. Lastly, tactical ISR—seeing deep—can be viewed now as the much broader challenge of mapping the human terrain, including foes, ourselves, and others.

The four critical capabilities thus are: human terrain preparation, ubiquitous observation and recording, contextual exploitation, and rapidly tailored effects (with speed implicit in all). Why these four? Because together they constitute a capability vital for success across all the missions and against adaptive adversaries. In particular, they provide the means for U.S. forces to operate within an adversary's decision cycle. In that sense, as illustrated in figure 1, they can be considered an expansion to an operational-level version of the tactical OODA loop: observe, orient, decide, and act.

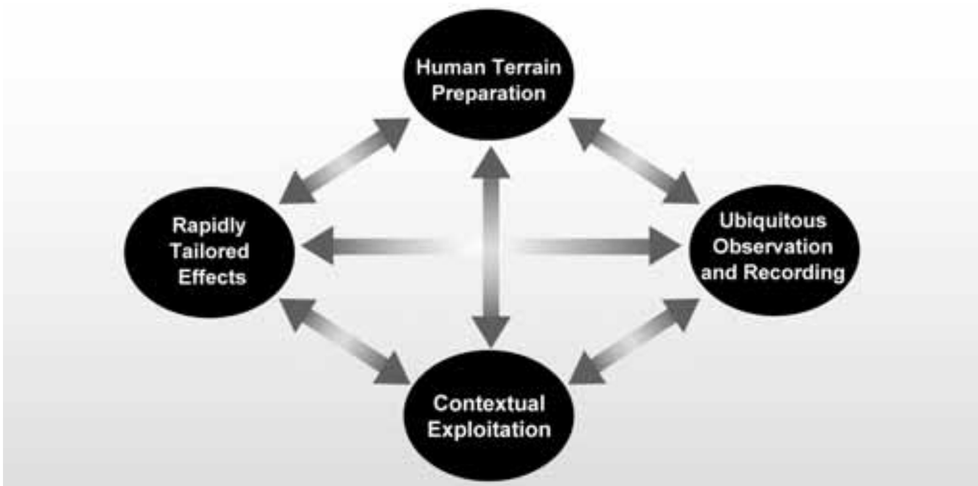

Figure 1. Four Critical Capabilities—an OODA-like Loop for the 21st Century

Human terrain preparation will enable U.S. forces to better understand how individuals, groups, societies, and nations behave, and then use this information to (1) improve the performance of U.S. forces and (2) understand and shape behaviors of others in pre-, intra-, and post-conflict situations. The enabling technology areas are:

- **Rapid training and continuous learning,** particularly aimed at junior leaders and small units whose performance is so critical to success across the mission space. Increasingly, they are called upon to make rapid decisions under duress in complex circumstances and when the outcome can have strategic consequences. Constituent technologies include high fidelity immersive gaming/simulation, cultural and leadership tutoring tools, and measurement of individual and team performance carried out in a continuum of activities extending from the classroom into actual operations and through post-action evaluations. Cognitive science research could lead to dramatic advances. Training has been a major asymmetrical advantage for U.S. forces. This advantage could be threatened if adversaries adopt new training regimes enabled by simulation technology or biotechnically-induced performance enhancement.

- **Automated language processing** (speech and text translation), where a vigorous technology effort will sustain continuous improvement in foreign-to-English translation in non-romance languages, speech-to-text transcription, and two-way translation devices able to convey the meaning of language as well as the words being used.
- **Human, social, cultural, and behavior modeling** would help in understanding how individuals, groups, societies, and nations behave. One place to start is to supplement the more familiar physical network modeling with human and group behavioral models. Such models push the boundaries of DOD's S&T experience. DOD needs to become more familiar with the theories, methods, and models from psychology, sociology, political science, economics, and cultural anthropology in order to identify those with potential to add value. Coupling these to simulation environments and computational modeling methods would lead to valuable new tools. This will not happen overnight; it will take time to develop the skills and understanding needed. A major challenge is collecting relevant data. Another is validating that a model does in fact add value by providing insight into extremely complex systems.

Ubiquitous observation and recording will help reduce sanctuaries where adversaries hide and draw support for their operations. A substantially increased ability to record, retain, and archive large amounts of data and extract information rapidly can have a major influence at tactical and operational levels across all missions. Key enabling technology areas are:

- **Day/night all-weather wide area surveillance** in areas where it is not done well today (urban areas and under foliage). Constituent technologies include sensors (triple canopy foliage penetration, large format optical imaging framing, active and passive hyper-spectral imaging) and survivable satellite and unmanned platforms.
- **Close-in sensor and "tagging" systems** would need a variety of sensors (chemical, biological, radiological, acoustic, seismic, optical, and infrared) with integrated command and control,

data exfiltration links, precision delivery, and long-term energy sources. The tagging could be accomplished through data embedded in the recorded observation as well as by physical devices placed on an object.

- **Soldiers-as-collectors within a network** require a broad range of sensors, efficient energy storage and power generation, body-borne flexible displays, soldier-centric communications and networking technology, interactive automated debriefing tools, and all-domain precision geolocation.

Contextual exploitation tools are needed to extract, much more rapidly than today, actionable information that is hidden in sometimes massive amounts of data. Potential practitioners include commanders at all levels, intelligence analysts, and soldiers and marines on patrol. Because data management and information extraction will be increasingly done in a networked environment, S&T research in how to assure the availability, confidentiality, and integrity of the data is vital. Data, information, and knowledge must be able to flow rapidly and securely from all sources to all users. Enabling technology areas are:

- **Megascale data management** to link disparate information sources and provide robust knowledge management to support very short decision timelines. Constituent technologies include knowledge management and fusion from diverse sources, entity relationship and pattern recognition analysis, and multi-level security and accreditation.

- **Situation-dependent information extraction,** using Bayesian networks, statistical analyses, and hidden Markov models to extract meaning and context from complex and cluttered data streams drawn from very disparate sensors that are not temporally or spatially matched.

- **Human/system collaboration** that results in dramatic reduction in workload for operators under stress and in time to conduct complex analyses characterized by uncertainty and ambiguity. Technologies that will enable computers to assist in tasks that today can be done only by humans include natural man-machine interfaces, knowledge representation, and human-guided algorithms.

Advances in these areas are being driven by the commercial market, and fundamental transformation over 10–20 years is possible. Issues of privacy and potential for tension over public and political perceptions exist and must be addressed and mitigated as an integral part of the research.

Rapidly tailored effects will result from the three capabilities already described and will enhance the ability of U.S. forces to act, apply force, and cause effects in any circumstance. Understanding the human terrain, ubiquitous observation, and rapid extraction and interpretation of data will facilitate actions that produce desired effects and avoid the counterproductive. The actions could be defensive as well as offensive, non-lethal as well as lethal.

The study identified three areas not well covered by the current tool kit of action options. These are: (1) enhancing the ability of U.S. forces to conduct non-kinetic operations aimed at influencing the local populace, (2) delivering conventional strikes with great precision and timeliness from afar, and (3) mitigating the effects of WMD attacks. The first is in recognition of the growing importance of non-kinetic operations, the second is in order to provide new strike options when local access is denied, and the third is to address the most devastating attacks.

- **Influence operations.** This is strategic communication at the operational and tactical levels—the soldier as a transmitter of the U.S. message through both words and deeds. DOD needs to be better able to predict and measure the effects of these operations and to anticipate the non-kinetic effects of kinetic actions. Technologies include non-lethal as well as lethal weapon employment, kinetic and non-kinetic cause-effect models; campaign planning/targeting/shaping tools; storytelling and advanced visualization technologies; and decision support tools to deal with complexity and uncertainty.
- **Time-critical strike from afar.** Enabling technologies include directed energy, high-energy lasers, ballistic missile propulsion and guidance, scalable warheads, and hypersonic flight of either transport or launch vehicle.

- **WMD protection and mitigation.** Technology areas include: rapid threat detection and exposure screening of individuals (in minutes) and environments (within a few hours); broad spectrum medical countermeasures that can be deployed within hours to one or two days; rapid recovery and restoration measures in the course of hours to a few days; standoff detection of biological, chemical, and nuclear materials; and nuclear survivability of critical military equipment and functions.

DOD must also keep abreast of the most rapidly changing and emerging technologies as a necessary complement to the mission-driven perspective that is the focus of this report. Today these include bio-, info-, and nano-technologies. Synergistic combinations of these could produce truly revolutionary capabilities in human performance enhancement, medical treatment and prophylaxis, miniaturization, life extension, robotics, and machine intelligence, to name a few of the more promising areas for research.

Strategic Technology Planning

Strategic technology planning encompasses how technology should play in the wider arena of DOD planning and should not be limited to just guiding S&T investments. Current DOD practices and processes fall short of what is needed. The substantial documentation about S&T goals and activities serve less to guide than to describe what is happening. The busy office of the Director of Defense Research and Engineering (DDR&E) finds little time for strategic planning. There is not an aggressive enough effort to identify and evaluate opportunities from the global technology marketplace. Future joint concepts and capability needs are developed without an informed understanding of the technological possibilities.

The study's recommendations in this area neither fine tune existing processes nor invent new ones. Instead they introduce "forcing functions" into existing processes to strengthen both mission pull and technology push. Both are needed.

DOD needs to achieve tighter integration between its user and technology communities so that mission solutions are inspired by a deeper understanding of technology opportunities (for the United States and its adversaries) and S&T activities are more directly informed by DOD's strategic goals and top-level missions.

Recommendation: Reestablish a mission-oriented mindset within the office of the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD [AT&L]) by creating a few small, dedicated groups of mission-oriented portfolio strategists. Each group would address a top-level DOD mission, such as a long war against terrorists, and advise the USD (AT&L) and the Vice Chairman, Joint Chiefs of Staff, by providing an integrated enterprise-wide view of technology and capability opportunities. The groups, interacting with the combatant commands, force providers, and technology providers, would lay out hedging strategies, anticipating measures and countermeasures from the near to far term, and develop metrics to measure progress. They would make investment and divestment recommendations, but not be responsible for preparing a detailed budget plan. Their products would be used both to develop a mission-oriented strategic technology plan and to inform concept development and capability opportunities.

A mission-focused approach was used with considerable success in the 1960s and 1970s within the offices of the DDR&E. Its strategic and tactical offices played leading roles in devising and overseeing portfolios based on a wide, end-to-end perspective of the whole mission in at least two of the major DOD missions at that time: deterrence of nuclear strikes by the Soviet Union and assurance of U.S. commitment to Europe.

Technology Opportunities

Complementing this mission-oriented mindset, DOD's technology community must increase its capacity to recognize and exploit technology opportunities, especially those that exist outside of DOD's domain.

Technology can enable disruptive capabilities, developed either by the United States to gain asymmetrical advantage, or by its foes, to thwart U.S. objectives and put the United States at an asymmetrical disadvantage. The

DOD needs to get much better at fostering the former and anticipating the latter. Often the very technology that can provide the United States with a disruptive advantage is itself disruptive to DOD's culture and antibodies rapidly and reflexively form to reject it.

Recommendation: In order to enrich DOD's capacity to understand and exploit technology opportunities:

- **Create an organized function to "prospect"** commercial, non–DOD, and foreign technologies for good ideas and products for use by DOD, other U.S. government agencies, and its international friends and partners**.**
- **Increase and protect the "speculators" operating on the frontiers**, looking for the truly disruptive opportunities that the United States could exploit.
- **Establish a more comprehensive approach to "anticipating" how adversaries might exploit technology**. This function involves increased S&T intelligence to understand what adversaries are doing and more red teaming and net assessment to anticipate what they could do.

Rapid Transition of Technology into Capability

Failure to speed the transition of technology into capabilities has severe consequences. U.S. forces do not get the capabilities they need to anticipate and respond to adaptive adversaries. Major systems are fielded with obsolete technology and unnecessarily high cost. Delay encourages "requirements creep," leading to further delay. Opportunities to exploit disruptive and other technologies are missed. DOD's current processes and practices of transitioning technology, largely a legacy of the Cold War, are not adequate for today's new security challenges.

This study addresses both (1) rapid fielding of new capabilities into ongoing operations and (2) major system acquisition. The challenges are different for each. The task force assumed there will be a continuing, long-term need for rapid fielding into ongoing operations and, thus, the challenge here is to turn the current improvised approaches into processes and practices robust for a long war without creating a new bureaucracy. For major system acquisition, the challenge is to transform long established practices into a process that will cut in half the time it normally takes to field a system. The reasons why it takes so long to field major systems are well documented by the Defense Science Board and other studies, as are proposed solutions.[1]

Rapidly fielding new capabilities into ongoing operations was not a major priority during much of the Cold War. The exception was Viet Nam, but practices invented during that war to facilitate speedy introduction were abandoned when the war ended. To meet the new demand from war fighters, the DOD has set up a variety of organizations and processes. While there have been successes, the DOD must become much more adroit at rapid insertion, must constantly learn how to get better at it, and must be prepared to do it for a long time. It is no easy task, not the least because of the need for extraordinary collaboration among war fighters, trainers, technologists, operational analysts, systems engineers, and testers.

Recommendation: Configure most of the current "rapid" programs into a new "expeditor," a Rapid Fielding Organization (RFO). The RFO would provide a joint institutional focus, with memory and knowledge-transfer, on achieving very rapid response (less than two years, but as short as weeks). It would have the leadership, staff, authorities, and budgets to become an agile, results-oriented organization accountable to the joint war fighter. It would also be tightly coupled to testing and training, so that new materiel could be introduced concurrently with doctrinal adaptation to realize new capabilities as units prepare for deployment. Current operations are fostering a culture of experimentation and continuous learning in parts of the DOD; this opportunity to promulgate and embed such a culture must not be missed.

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1. One such study is the *Defense Science Board 2001 Summer Study on Defense Science and Technology*, May 2002.

Recommendation: Implement a spiral development process—to cut in half the time to field militarily useful blocks of a system and conduct a vigorous S&T and experimentation effort in parallel to create options for future block improvements. Implementation requires:

- considering technology and cost issues earlier in the requirements process, before deciding what to buy
- assuring technology and manufacturing readiness by Milestone B by placing greater attention on the technology development phase than currently accorded
- strengthening systems analysis and engineering in DOD and industry
- controlling appetites for performance in each block and making timely decisions, if necessary, to relax requirements during each block to protect cost and schedule while still delivering a militarily useful system

DOD appears to be implementing some of these steps but robust processes are not yet in place.

This report also recommends additional steps to broaden and deepen DOD's in-house technical expertise, provide budget flexibility, lower barriers to commercial firms working with DOD, revitalize internal research and development investments in industry, foster competition, and create incentives for rapid technology transition.

Conclusion

Our focus is technology. But the human dimensions still dominate, especially in the irregular challenges facing the nation today. Technology still can be a powerful enabler of new capabilities, but must be closely coupled to evolving concepts, doctrine, training, and organizational structures. DOD's mastery in applying technology helped win the Cold War. However, the processes and practices of that era must be reshaped to deal with new security challenges today and in the future.

The 2006 Quadrennial Defense Review states the "imperative to work with other government agencies, allies and partners and, where appropriate, to help them increase their capacities and capabilities and the ability to work together." One of the goals of DOD's S&T activities and processes should be to provide that help.

This report describes the findings and recommendations of the study in further detail. The chapters in Part I identify and describe the "handful" of key 21st century capabilities and enabling technologies—those most critical to achieving DOD future missions. Part II examines the topics of strategic technology planning, technology transition—for ongoing military operations and in major system acquisition—and cross-cutting enablers. The report concludes, in Part III, with a summary of recommendations.

More detail on all these topics is provided in three supporting reports, one from each of the three study panels:

- Volume II. Critical Capabilities and Enabling Technologies
- Volume III. Strategic Technology Planning
- Volume IV. Accelerating the Transition of Technologies into U.S. Capabilities

Part I

A Set of Critical Capabilities and Enabling Technologies for the 21st Century

Chapter 1.
Identifying Operational Capabilities

Methodology

The process of identifying a set of operational capabilities and their enabling technologies, depicted in figure 2, began with five top-level missions derived from the 2006 Quadrennial Defense Review (QDR):

- defeating terrorist networks
- preventing acquisition and use of weapons of mass destruction (WMD)
- defending the homeland
- shaping nations at strategic crossroads
- conducting stability, security, transition, and reconstruction operations

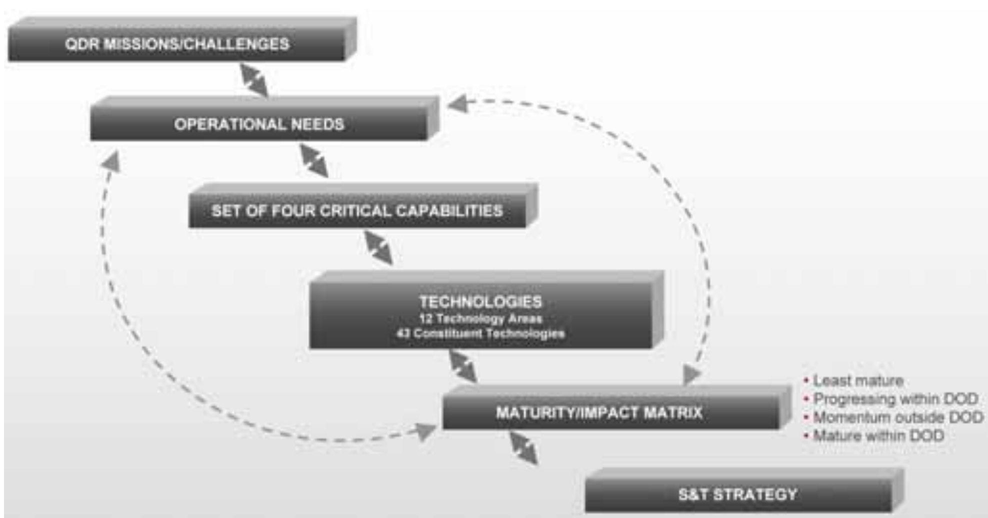

Figure 2. Strategic Planning Framework

With these missions as the starting point, the study identified the needed capabilities and the enabling technologies required to develop the capabilities. Next, a judgment was made as to the relative importance of these capabilities and technologies to achieving the missions. The study assumed all missions equally significant; thus, capabilities and technologies with broad applicability were judged more critical.

This process yielded a set of four high-level capabilities, a dozen enabling technology areas, and over forty constituent technologies. These technologies were further categorized according to their relative maturity and whether or not the main action to mature the technology would be conducted within the Department of Defense (DOD) or elsewhere. This categorization helps inform a science and technology strategy.

The set of four capabilities are:

- **Human terrain preparation** to gain better understanding of how individuals, groups, societies and nations behave in order to improve the performance of U.S. forces and to understand and shape behaviors of adversaries and others in pre-, intra-, and post-conflict situations.
- **Ubiquitous observation, recording, and long-term archiving of data** to reduce sanctuaries where adversaries hide and operate and to understand the patterns of their activities.
- **Contextual exploitation** to extract, much more rapidly than today, actionable information hidden in sometimes massive amounts of data.
- **Rapidly tailored effects,** achieving the desirable and avoiding the counterproductive.

Data, information, and knowledge must be able to flow rapidly and securely from all sources to all users. See the companion *Defense Science Board 2006 Summer Study on Information Management for Net-Centric Operations* for an in-depth discussion of this subject.

Collectively, these capabilities provide the means for U.S. forces to operate within an adversary's decision cycle across the range of missions and circumstances. In a sense, as illustrated in figure 3, they can be considered an expansion, to an operational-level, of the tactical OODA loop: observe, orient, decide, and act.

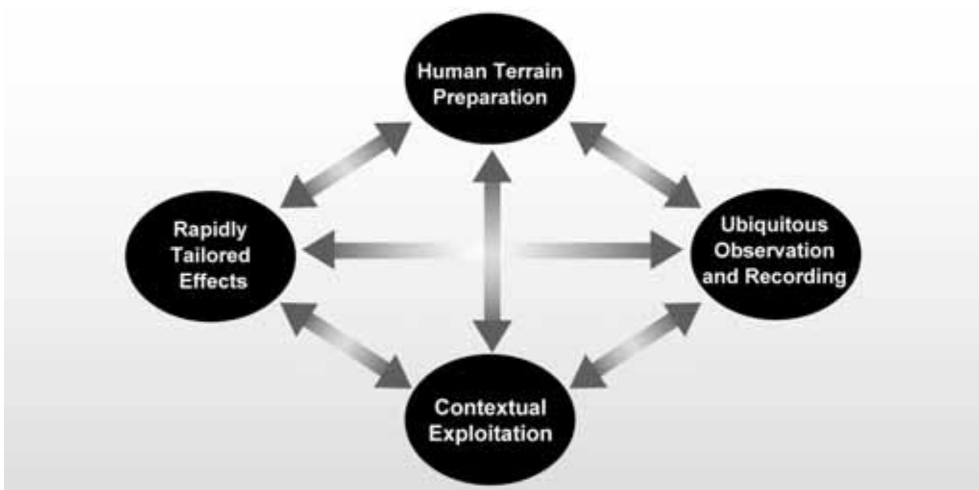

Figure 3. Four Critical Capabilities: An OODA-like Loop for the 21st Century

The aim of the study, in identifying a small set of capabilities, was to avoid the tendency to generate large lists without prioritization. The 2005 National Defense Strategy, for example, identifies eight desired operational capabilities not unlike the ones presented in this report. On the other hand, the QDR lists more than 50 desired capabilities. In addition, there are 22 tier one joint capability areas and over 100 tier two joint capability areas.

The next four chapters will describe in more detail these four capabilities and associated technology area enablers, an overview of which is shown in table 1. For each of these 12 technology area enablers, the report identifies a set of constituent technologies, which are discussed in more detail in Volume II. Appendix D contains an assessment of the relative maturity of these technologies.

Table 1. Twelve Key Technology Area Enablers

Critical Capability	Technology Area
Human Terrain Preparation	• Rapid Training and Continuous Learning • Automated Language Processing • Human, Social, Cultural, and Behavior Modeling
Ubiquitous Observation and Recording	• Day/Night All-weather Wide Area Surveillance • Close-in Sensors and Tagging Systems • Soldier as a Collector
Contextual Exploitation	• Mega-scale Data Management • Situation-dependent Information Extraction • Human/System Collaboration
Rapidly Tailored Effects	• Influence Operations • Time-critical Conventional Strike • WMD Protection and Mitigation

Chapter 2.
Human Terrain Preparation

U.S. forces need to be better prepared to operate in new battlefields where knowing the local cultural, societal, religious, ethnic, tribal, and other related dimensions is essential. The goals for this critical capability are to better understand how individuals, groups, societies, and nations behave, including adversaries, allies, others, and even the United States itself. This understanding can then be used to improve the performance of U.S. forces (individuals, as well as small and large units) and to understand and shape behaviors of adversaries, allies, and others in pre-, intra-, and post-conflict situations.

Three technology areas enabling this capability are highlighted in this chapter: rapid training and continuous learning; automated language and content translation for both speech and text; and human, social, cultural, and behavior modeling.

Rapid Training and Continuous Learning

Training and continuous learning are core enablers for every joint war fighting capability and are most successful when tools and methods embrace the cognitive complexities of how people learn. The training and continuous learning enhancements should pay special attention to the needs of junior leaders (officers and noncommissioned officers) and small units. Increasingly, these leaders and the soldiers they lead are called upon to make rapid decisions, in complex circumstances, under duress, and when the outcome can have strategic consequences. Thus, a major goal of the learning tools and methods is to recognize and accelerate the development of critical thinking and decision-making skills in such circumstances. Enabling technologies include high fidelity immersive gaming and simulation, cultural and leadership tutoring tools, and measurement of individual and team performance. Research in the cognitive sciences could lead to dramatic advances.

High-fidelity, immersive games and training, and mission-rehearsal tools should serve as one of the cornerstones of a flexible, user-tailored training and learning program. Design should integrate the most advanced displays and techniques from the gaming industry, Hollywood, and academia while incorporating natural language dialogue, cognitive models, and learner models to maximize the learning opportunity and determine a learner's progress. Authoring tools that allow users to rapidly manipulate relevant scenarios are an important and necessary characteristic of future tools. The proliferation of massive, multi-player games suggests promise in this area.

Language, culture, and leadership tutoring tools are an integral dimension of training. Technologies that will more rapidly prepare junior leaders and small units for the unique cultural dimensions of the future battle space will help speed the learning process. Training and learning tools must adequately represent culture and language nuances and must provide trainees with an opportunity to experience the second and third order effects associated with decision making in this fluid environment. Intelligent tutors designed into immersive training tools should reduce the need for personal mentors and allow for more immediate and tailored feedback to the trainee, thereby expediting the learning process.

Human and team performance measurement represents an important dimension of effective learning tools and methods. After-action reviews currently provide a level of feedback to trainees on performance, but often lack metrics that could clearly define future individual training needs. Measuring performance, particularly in high stress environments experienced on the battlefield, including the complex urban environment and stability and support operations, requires additional study.

Several current programs and research efforts offer promise in achieving these goals. Examples include:

- The Army's Combat Leader's Environment tool recently underwent a proof of concept. This virtual simulation tool placed battalion and brigade level leaders in an immersive environment designed from live experiences. It provides each learner with an opportunity to "think about how they think" in a cognitively authentic context.

- Another tool under development is Learning with Adaptive Simulation and Training. This tool seeks to deliver effective and engaging training simulations that incorporate realistic political/cultural effects of the environment and behaviors of an adaptive, asymmetrical enemy force.
- The Enhanced Learning Environment with Creative Technologies incorporates techniques of Hollywood and the gaming industry. It seeks to combine enhanced interactive simulation technology in training with a better understanding of the learner model and cognitive readiness on soldier performance to increase soldier engagement in the training experience, thereby increasing retention and decreasing the burden of re-training.
- The Defense Advanced Research Projects Agency (DARPA) has developed a training tool—DARWARS Ambush—using a multi-payer commercial computer game that allows the user to make changes in tactics, techniques, and procedures. This flexible training tool, originally created to deal with attacks on convoys, is being used for a wider range of training missions. There are plans to expand DARWARS into non-kinetic training to hone trainee mental agility, interpersonal communication, and cultural acumen.
- Another game-based training tool, the Adaptive Thinking and Leadership Training application, has been in use at the JFK Special Warfare Center and School for special forces, civil affairs, and psychological operations soldiers. It was designed to hone trainee critical thinking, negotiation, adaptability, and cultural awareness. This multi-user training system supports players connecting from laptops with roles for host nationals, soldiers, and observer controllers.

Training has been a major asymmetrical advantage for U.S. forces. This advantage could be threatened if adversaries adopt new training regimes enabled by simulation technology or drug-induced performance enhancement.

Automated Language Processing

Foreign language speech and text are indispensable sources of intelligence, but only a small fraction of the massive amount of available data is examined, in part due to the labor-intensive nature of the task. Success in many missions will depend on the ability of U.S. forces to communicate effectively with the local populace. New and powerful foreign language technology is needed to allow English-speaking analysts to exploit and understand vastly more foreign speech and text than is currently possible today. A vigorous technology effort is needed to sustain continuous improvement in foreign-to-English translation (especially in the non-romance languages), in speech-to-text transcription, and in two-way translation devices.

The enabling technologies, in addition to foreign-to-English translation and speech-to-text transcription, include information management and text processing. The goals are very ambitious: to allow automated processes and English-speaking users to examine and analyze all multi-lingual speech / text that is available in the information space; allow any user—whether tactical, operational, strategic planner, analyst, or decision maker—to acquire basic language proficiency (for any language) in days and expert language proficiency in months and to continue improvements in word error rate, precision and recall, and usability measures such as effectiveness, efficiency, and user satisfaction. Pursuit of these ambitious goals should not detract from the need for the department to enlarge and sustain a skilled workforce of translators and listeners in key languages and lingua franca

Foreign-to-English translation seeks to provide high accuracy machine translation and structural metadata annotation from multilingual text document and speech transcription input at all stages of processing and across multiple sources (such as the Web, news, blogs, signals intelligence, and databases). Challenges include resolving semantic differences, duplications, inconsistencies, and ambiguities across words, passages, and documents; providing enriched translation output that is clear and meaningful to decision-makers; and eliminating the need for human intervention.

Automatic speech-to-text transcription attempts to produce rich, readable transcripts of foreign news broadcasts and conversations despite widely-varying pronunciations, speaking styles, and subject matter. There are two basic approaches to speech-to-text transcription: differing in whether their vocabularies are constrained.[2] Challenges include extracting "meaning" out of spoken language by resolving jargon, slang, code-speak, cultural nuances, and language ambiguities; and dynamically adapting to (noisy) acoustics, speakers, topics, new names, speaking-styles, and dialects. Recent achievements (2004) include word error rates of about 20–25 percent at processing speeds of 7 to 8 times slower than real-time on Arabic and Chinese news broadcasts.

Information management and text processing involves many techniques, including information retrieval, entity extraction, the much more difficult relationship extraction, summarization, graphical representations, link discovery, and pattern learning. A recent DARPA experiment used a multi-lingual information retrieval front-end system comprised of various information management and text processing technologies to "automatically" ingest, transform, and translate massive amounts of open-source text data. Then model-relevant data is extracted and used to auto-populate a back-end analytical human, social, cultural, behavior model of the type discussed later in this report. The data—drawn from over 1.2 million English and foreign documents—were analyzed in less than one man year (the bulk of which is a one-time cost) using the automated system, as compared to the 117 man years it would have taken for a human to perform the same task.

One research and development (R&D) program that integrates the automated language processing constituent technologies is DARPA's GALE (Global Autonomous Language Exploitation) program. The GALE program is developing and applying computer software technologies to absorb, analyze, and interpret huge volumes of speech and text in multiple languages, eliminating the need for linguists and analysts. It is also developing the ability to automatically provide relevant, distilled, actionable information to military command and personnel in a timely fashion. Automatic processing "engines" convert

2. The Phraselator is an example of a vocabulary constrained speech translator.

and distill the data, delivering pertinent, consolidated information in easy-to-understand forms to military personnel and monolingual English-speaking analysts in response to direct or implicit requests.

Human, Social, Cultural, and Behavior Modeling

The third of the human terrain enabling technology areas—human, social, cultural, and behavior (HSCB) modeling—is the one that pushes the boundaries of DOD's comfort zone the farthest. However, it is an area that DOD cannot afford to ignore. The DOD needs to become much more familiar with the theories, methods, and models from psychology, sociology, cultural anthropology, cognitive science, political science, and economics in order to be able to identify those with real potential to add value to DOD's tool kit. Coupling these to quantitative and computational modeling and simulation techniques from mathematics, physics, statistics, operations research, and computer science could lead to powerful new tools that represent complex human and social systems and will better enable U.S. forces to understand, assess, anticipate, and shape new battlefields.

One promising starting point for the application of HSCB models is to complement the more familiar physical network modeling with human/group behavioral models.

For purposes of this report, HSCB modeling refers to tools to investigate human social phenomena (cognition, conflict, decision making, cooperation) at various levels of data aggregation (individual, group, societal, global). There are numerous computer-based tools and models in academia and industry today that have shown varying degrees of promise and utility for social applications and artificial societal environments at small and large scales. Examples of limited but promising successes in coupling social science methods with quantitative/computational techniques have emerged in marketing research to project sales of consumer goods, and in politics to forecast election results based on polling and other data.

HSCB models are designed to help understand the structure, interconnections, dependencies, behavior, and trends associated with organizational entities. Macro HSCB models address nation states, socio-cultural regions, economies, and political systems. Micro HSCB models deal with religious and ethnic tribes, militias, insurgent and terrorist networks, and military units at the tactical level. Integrated models try to tie together the macro and micro models. A formidable challenge in modeling social and behavioral phenomena is to integrate and make coherent micro-macro models at multiple levels of data, granularity, and analysis, and across multiple disciplines of the social sciences, and to acquire and structure data that can be used to guide and test the models. An example of integrated micro-macro HSCB modeling is found in the work done at the Center for Army Analysis to forecast country instability.

The challenges in developing practical HSCB models are formidable. They include: (1) advancing the accuracy and reliability of HSCB models for assessment, prediction, and forecasting purposes (while recognizing the limits to HSCB modeling for prediction and forecasting); (2) collecting reliable data at the "right" level and unit of analysis (e.g., tribal, provincial, district, regional, transnational); (3) creating controlled experiments, and defining associated metrics, for which HSCB models can be validated with extensive human-subject trials; and (4) utilizing legitimate approaches to validate HSCB models that may in fact be different from the methods used in the physical sciences, and getting the DOD science and technology (S&T) community to recognize that, absent such rigor, these models are still valuable in provoking thought.

Recommendations: Human Terrain Preparation

Increase the priority and accelerate the creation of a continuous learning environment for training and professional military education. It is especially needed when the operational tempo is high and the traditional reliance on attendance at institutions for training and professional military education is most strained. Steps include the following:

- more exploitation of commercially developed distance learning tools and more experiments on alternative approaches
- creating a DOD program linking Service efforts to design training tools and processes to develop cognitive decision making skills in junior leaders

- rewarding service members for pursuing less structured but equally compelling professional military programs of study that develop their skills in human terrain preparation
- assigning higher priority and more resources to the development of immersive games, simulators, training, and mission rehearsal tools to develop multi-cultural interpersonal skills supporting small unit operations

Plan to sustain a long-term commitment and robust effort to develop and adapt automated language processing technologies. This will involve tapping into and leveraging commercial R&D work and investments, but will also require focused investments for those particular languages and dialects to which the military may be uniquely exposed.

Develop an S&T roadmap for HSCB in response to the Director of Defense Research and Engineering's (DDR&E) Strategic Planning Guidance (FY08–13) and create an S&T portfolio for such modeling that would

- attract the best and brightest from the HSCB community to work on DOD problems; this could involve expanding the Defense Science Study Group program to include social scientists
- establish HSCB modeling benchmarks, metrics, experimentation, and validation techniques
- be closely connected to the combatant commands and other potential users

Chapter 3. Ubiquitous Observation and Recording

This capability is not about pursuing the fantasy of eliminating the fog of war. Rather, it is about reducing significantly the sanctuaries where adversaries can hide and operate. The emerging new threat environment has fundamentally challenged U.S. traditional surveillance systems' ability to detect, track, and identify adversaries. The tanks, submarines, and aircraft of previous conflicts are being augmented or replaced with small and dispersed teams and individuals. Adversaries are employing what might be considered the ultimate of stealth: individuals hiding in plain sight. Today's surveillance systems often provide either episodic observation with exquisite detail or very course resolution with higher temporal sampling rates.

To counter these new threats, technology exists, or could be developed, to provide new levels of spatial, temporal, and spectral resolution and diversity. Furthermore, the ability to record terabyte and larger databases will provide an omnipresent knowledge of the present and the past that can be used to rewind battle space observations in TiVo-like fashion and to run recorded time backwards to help identify and locate even low-level enemy forces. For example, after a car bomb detonates, one would have the ability to play high-resolution data backward in time to follow the vehicle back to the source, and then use that knowledge to focus collection and gain additional information by organizing and searching through archived data.

An integrated system of diverse sensors and platforms could provide both surveillance of large areas and close-access surveillance of individuals and small groups. Such systems would include VHF imaging radars that can penetrate foliage; high-frequency radars that can provide high-resolution day/night images and moving-target tracking in all weather conditions; and optical systems that can detect, locate, and track systems with very high resolution in very low light conditions. These persistent sensors will be complemented with prolific use of hand-emplaced or autonomously-delivered unattended networked sensors and tags. The sensors and tags will enable detailed quantitative tracking and measurement of individuals, vehicles, small groups, and other dispersed assets of value to the enemy. A vital element in an integrated system will be the information collected by the soldiers and Marines on the ground in intimate contact with both the enemy and noncombatant population.

Thus, the task force identified three key technology areas: day / night all-weather wide area surveillance where it is not done well today (namely in urban areas and under foliage); close-in sensor and tagging systems; and soldiers-as-collectors within a network.

Day / Night All-weather Wide Area Surveillance

Ubiquitous observation starts with broad area surveillance and "birth-to-death" tracking and identification of critical targets. Surveillance is provided over the entire field of operations or smaller areas of particular interest to forces in close contact. The outputs from this system will target regions of interest for examination by systems with higher resolution in both space and time and by mid-tier sensors capable of target identification.

The goals are to cover regions of tens of thousands of square kilometers with constant surveillance that can detect and track moving targets and image stationary targets at resolutions measured in feet to meters. In addition, temporal sampling, measured in tens of seconds, will be coupled to a capability to focus on areas of hundreds of square kilometers continuously at a resolution of less than a meter and a sampling time of one second.

The elements that will enable such broad area video surveillance capability would include arrays of small, low cost unmanned aerial vehicles (UAVs) for under-the-clouds optical surveillance and tracking; ultra long-endurance, high altitude UAVs, whose endurance is measured in weeks for large focus areas; and space-based radar surveillance systems to provide a broad synoptic integrating view.

Enabling technologies to achieve this capability include: hydrogen fuel-based light-weight power for long endurance UAVs; ultra-light weight sensor systems (radar, infrared, and optical); light weight optics;

large area (one billion pixel) focal plane sensors; active and passive hyper-spectral imaging sensors with on-board compression and automatic target recognition; triple canopy foliage penetration sensors; radiation-hard digital electronics for space transmit and receive modules; and 50 percent efficient space solar power. Advances in radar technology will also be needed to provide both high update rates with high resolution and, at the same time, provide wide area coverage.

Future collection concepts, like ultra high 2-D spatial resolution and vector measurement of target velocity via multi-static range-range bilateration of ground moving target radar data from two separate platforms, offer potential enhancements to target location and identification.[3] These new system collection opportunities will require the ability to task both airborne and space-based sensors in a tightly integrated manner.

Close-in Sensors and Tagging Systems

Today's national intelligence, surveillance, and reconnaissance (ISR) systems were developed largely to provide indications and warning against the military forces of a peer competitor. In the past, the critical threats to the United States and its allies were ballistic missiles, submarines, and massed conventional military forces. The threats described in the QDR are different. The diffuse nature and low signature of future threats make close-in ISR increasingly important. Close-in sensing will include traditional human intelligence as well as a new set of sensors positioned very close to the target.

The task force envisions a broad spectrum of such sensors (chemical, biological, radiation, acoustic, seismic, optical, and infrared, for example) with integrated command and control (tasking) and data exfiltration links. Their small size and innovative camouflage/deception for the sensors and their means of communication will make detection difficult. The size could be smaller than a shirt button or as large as a soda can (with < 1

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3. The use of different, synchronous views from multiple platforms allows for much higher target resolution and tracking prediction of moving targets on the ground.

cm^3 as a nominal goal). Precision delivery is needed as well as energy sources to permit the sensors to operate for weeks to months.

A variety of technologies can support this vision. There have been dramatic advances in high-density electronic packaging, largely driven by the handheld consumer electronics industry. This same industry has also fostered advances in some sensor technologies such as microphones and video cameras. However, DOD cannot rely on industry to produce other military-specific sensors, in particular chemical, biological, and radiation sensors. A continuing effort is needed to build on recent DOD progress in this area.

High-performance and efficient signal processors are needed to process sensor data and reduce data bandwidth prior to data exfiltration. Bandwidth compression helps to reduce detectability as well as to conserve power for the communications hardware. The need for extremely low-power signal processors (1-10 mW desirable) warrants continued DOD interest in following the development of commercial low-power signal processors.

The energy source and communications system antenna make it difficult to reduce the observability of close-in sensors. Battery technology has advanced substantially in recent years. However, a further 10 to 100 fold increase in energy storage density could be critically important to realizing the potential of close-access sensor systems.[4] Specialty materials (that morph, change color, or have unusual visual or electronic properties) for antennas, energy sources, and structures will also be needed. Another challenge is stealthy emplacement of the sensors which could be by low-observable, autonomous, air, land, and sea vehicles specifically designed for precision (<1 meter circular error of probability) sensor emplacement across a broad region.

Additional emphasis needs to be directed toward exfiltration of data from remote locations and autonomous control of sensors, including

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4. Energy scavenging systems could increase battery lifetimes by supplementing the power supply with environmental energy, such as solar, thermal, kinetic, and vibration energy. These energy sources may eventually play a role, but with the exception of solar cells, are not likely within the next decade.

movement based on sensed information. S&T investment increases currently planned in this area should be supported, with potentially added funding as the projects demonstrate progress. DOD and the intelligence community should also support efforts to maintain awareness of non–U.S. research and development in these areas and potential threats to U.S. forces and critical national infrastructure.

Current R&D programs for clandestine tagging, tracking, and locating should be enhanced to provide capability to deploy and use tags, taggants, and sensors for close observation in areas where access is dangerous, difficult, or denied. Nanotechnology, in particular, offers potential for devices that can endure for very long periods of time in close proximity to targets of interest and that can be delivered by clandestine means. Biology and chemistry can be exploited to enable the ability to track and identify people and materiel that move from locations of interest to other locations. A combination of nanotechnology, biology, and chemistry promises to provide significant increases in capability to conduct pervasive surveillance on a global basis—with minimized personnel exposure and minimized probability that deployed assets will be compromised.

Soldier as a Collector

In the new missions, much of the needed intelligence is only available to the soldier on the ground. The challenge is to train and outfit soldiers to be more comprehensive and discerning intelligence collectors without unduly affecting their other tasks. The vision here is to create networks of sensors using the individual troop both as the sensors itself and as a platform to carry and/or distribute sensor systems. The goal is to create networks of soldiers who are capable of collecting information within their sphere of influence and who can share this information with other members of the net in a timely fashion. Such information, collected at the tactical (and even interpersonal) level, will contribute to better operational decisions at all levels.

A variety of sensor technologies (many of them similar or identical to those discussed in the previous section) have size, weight, power, and other logistics attributes that make them suitable for employment on the soldier without adding a significant burden.

Several technologies must be developed and/or integrated to achieve the goal of a seamlessly integrated network of sensors capable of collecting and recording data that is in each soldier's sphere of influence. Many front-end sensors (especially small digital/video cameras, audio recorders, and Global Positioning System [GPS] receivers) are already ready for integration. The consumer electronics industry has driven these technologies to an attractive regime of size, weight, power, performance, and cost.

Other sensor technologies are at lower readiness levels and will require development to make them compatible with being soldier-borne. Examples of these technologies include chemical and biological detectors, small multispectral sensors, mobile ad hoc communication networks, and geo-location systems that will work in GPS-denied areas (such as in buildings). There are also some interesting technologies under development that can aid soldiers when interacting with local civilians. These include automatic language translators and technologies to automatically detect intentional deception of people being interviewed by soldiers.

Automated and interactive debriefing tools will also be needed. These tools will allow the soldier to quickly and efficiently collect personal observations and deliver them to the network with minimal effort.

Energy sources will also be a key enabling technology. Batteries appear to be the only currently viable source of energy for soldier-borne equipment. As with close-in emplaced sensors, a 10-fold improvement in current energy storage per unit of weight would be extremely useful. Although industry is pushing these technologies hard, the extreme needs of DOD users warrant continued R&D monitoring and possibly investment in ultra-high-density energy storage technologies.

Observations and Recommendations: Ubiquitous Observation and Recording

Outside of energy storage technologies, which are today being driven largely by commercial electronics, the priority technologies for ubiquitous observation and recording are more specialized for DOD and intelligence community purposes, and will therefore require both sustained investment and monitoring commercial technologies to advance. Such has been the case for hyperspectral and foliage penetration sensors. These particular technologies are ready for operational fielding. More speculative domains such as microsensors, bio-inspired and bio-electronic tags and sensors, devices in the micro to nano domains, molecular-scaled taggants, and micro delivery platforms, deserve investment.

The vision for ubiquitous observation cross-cuts combatant commands, military services, defense agencies, and the intelligence community. As such, cross-cutting programming, management, and oversight are needed to achieve substantial progress toward this vision.

Recommendations are as follows:

- **The Army, Marines and DARPA should partner in an effort to accelerate the maturation of the "soldier-as-sensor" concept.** The program should also include monitoring and developing relevant miniature sensor technologies and automated debriefing tools.
- **A sustained series of advanced technology demonstrations (ATDs) and advanced concept technology demonstrations (ACTDs) should be supported through DARPA and DDR&E to develop and demonstrate the ability to task and integrate local collection with wide area assets.** U.S Strategic Command and U.S. Southern Command should be major participants in these activities because of their global ISR responsibilities.
- **DARPA and related R&D agencies should sustain a focused program to develop energy efficient microsensors and the platforms to deliver them, along with development of the systems network concepts to enable close-in sensing.**

Chapter 4. Contextual Exploitation

A new set of information-rich exploitation and collaboration tools are needed to bridge the functional capabilities of ubiquitous observation and rapidly tailored delivery of scaled effects. Three enabling technology areas are mega-scale data management, situation-dependent information extraction, and human/system collaboration.

The combination of these technologies will open new opportunities to automate the intersection of apparently independent events, actions, things, or people, masked by military and civilian clutter. These tools will be used to extract related features, to enable time-critical targeting and intent recognition of evolving threats. Their development is being driven by the commercial sector and fueled by rapid innovations in underlying technologies such as computation, data storage, and software architecture.

Fundamental transformation over 10–20 years is possible, with significant investments in architecture development coupled with increasing computation and data storage capabilities, and advances in cognitive science. There are also issues of privacy and potential for tension over public and political perceptions.

Because the data management and information extraction will be increasingly done in a networked environment, science and technology investment in how to assure the availability, confidentiality, and integrity of the data is vital. Data integrity is especially important, not only due to the damage done by the use of deliberately corrupted data, but from the loss of trust in the network. Networks are covered in more detail in the companion *Defense Science Board 2006 Summer Study on Information Management for Net-Centric Operations*.

Mega-scale Data Management

As the threat base evolves, there will be greater dependence on integrated multiple-domain sensors with much greater dynamic range, spatial reach, sample rate, and temporal history. Mega-scale data management implies integrated, federated, and scaleable data frameworks to link disparate information sources and provide robust knowledge management to permit conclusions based on contextual relationships. The goals are to archive, organize, search, and use exabytes of data at transfer rates of terabytes per second with decision timelines in seconds to minutes.

Enabling technologies include knowledge management (including data storage and transport) and fusion from diverse sources, entity relationship and pattern recognition analysis, and multi-level security and accreditation.

Situation-dependent information extraction will use advanced algorithms to support situation-associative processing and improved human systems collaboration. Advanced automated decision tools will increase the war fighter's ability to make timely decisions with an explicit evidential basis and reduce the level of information overload often experienced in answering prioritized information requests. User-defined knowledge sharing minimizes catastrophic errors due to cognitive biases and other limitations.

Within DOD, efforts to manage and exploit large data sets, and conduct mission planning and contingency management, have had limited success. These technologies have been applied with considerable success in the commercial world, in applications such as marketing analysis, energy exploration, and financial forecasting.

Situation-dependent Information Extraction

Contemporary and projected operational environments are characterized by extraordinarily complex and demanding terrains: of geography; social and cultural identity; state and non-state political association; interweaving adversary activity with everyday commerce and civil life; communications; and much-increased expectation of mission effectiveness and avoidance of collateral damage. Additionally, target identification and location and decision-making remain central elements of combat. The concept of "target" has expanded and now includes complex and often ambiguous entities, such as subsets of indigenous populations. In this increasingly demanding operating environment, the war fighter needs target-discrimination tools that provide effects that are rapid, accurate, and contextually relevant.

Intelligence analysts need to be able to find the needles of actionable intelligence buried in massive haystacks of data. Joint commanders need to be able to discern patterns of adversary behavior from the increasing amount of ISR output now available. Tactical commanders need to be able to identify time-critical targets. Soldiers in the street need to be able to recognize linkages among actions and people from the bits and pieces of information they gather. Technology can help all of them.

Tools are needed to go beyond static data filtering and template matching. Early work has shown that Bayesian networks, statistical analysis, and hidden Markov models can be used to extract meaning and context from complex and cluttered data streams.[5] Application of these techniques for very disparate sensors that are not temporally or spatially matched will enable DOD to detect, discern, analyze, and understand the actions of stealthy adversaries embedded in complex domains.

Effective implementation and utilization of these tools and improved understanding of the operational environment and adversary activities will improve performance of U.S. forces across the decision-making spectrum, from tactical to strategic. It will provide a new ability to shape the behaviors of adversaries and potential adversaries, and will be useful before conflict, during combat, and post-conflict to achieve

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5. A Bayesian network represents "beliefs" or relationships of principal actors (or nodes) in a model and connects them in pairs that reflect how common the belief is held between the two actors of the pair. The network is then built using these pairings, allowing a complex system to be modeled and its behavior analyzed based on testing the simple relationship between the pairs. Hidden Markov models extend this idea in ways that let the analyst discover relationships among the nodes that are not readily evident.

national objectives. It will improve link analysis and intent inference, resulting in faster and more complete understanding of options leading to better decisions.

Human/System Collaboration

The current state of the art for humans interacting with computer systems is largely characterized by data filtering and graphical user interfaces. The long-term objective in this technology area is to transform the interactions between humans and systems from an "interface" to true "collaboration." By creating the capability for computers to assist in tasks that today can be done only by humans, the goals are at least an order of magnitude reduction in workload for operators under stress and two or more orders of magnitude reduction in time for complex analyses characterized by uncertainty and ambiguity. Three constituent technologies—natural man-machine interfaces, knowledge representation, and human-guided algorithms—are briefly discussed below.

Natural Man-Machine Interfaces

Effective interfaces between the user/operator and the computer is needed whether it is for a soldier in combat or an analyst confronted with a "haystack" of data within which he/she is searching for the proverbial "needle." An understanding of how humans interpret and understand data to create useful information in both time-pressured and life-threatening environments is essential for progress. The interface should be transparent and intuitive to the human and be supported by context-sensitive cues or some other reach-back knowledge management capability so that only the most relevant and timely data are presented. The modalities for interaction will expand beyond the visual, to include voice and speech, tactical, and other concepts (e.g., psychophysical context or physiological measurements of operator "state"). Thus, the mode of interaction could be keyed in part by the physiological state. There is significant activity outside DOD in gaming, weather forecasting, financial analysis, and energy exploration that can contribute to developing these interfaces.

Knowledge Representation

To allow the human and computer to truly collaborate, it is necessary to improve the ability to represent human knowledge in a manner that a computer can both store and use. Knowledge representation has been recognized for decades as a key enabler for the tractability of machine reasoning including decision-making, data mining, hypothesis generation/affirmation/negation, and search. There has been significant research in this area for a number of years, largely directed at trying to model/replicate human cognitive tasks in computer hardware. The field of artificial intelligence has been one of the prime drivers. There is still much to be done, and, as with the man-machine interface area, there is significant activity outside the DOD. For military applications, knowledge representation challenges include representing commander's intent and tactics and representing political, military, economic, cultural, and religious characteristics of an operational environment and the relationships among them.

Human-Guided Algorithms

Automated (purely algorithmic) solutions to complex, large-scale problems such as image analysis and understanding for exploitation, connecting the dots for higher levels of fusion, and generating real-time plans for command and control applications (including tasking exploitation resources) often fall short. The primary reasons are (1) the inability of algorithm designers to build-in the broad set of models required to capture the richness of real-world problems, and (2) the heuristics required to trim the huge search spaces involved.[6]

A traditional approach to addressing these shortcomings has been to model the way that operators (humans) solve these problems through cognitive task analysis and to build software that embodies and/or supports those human-centric approaches. This approach often falls short due to the difficulty of building software that mimics complex human decision-making strategies.

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6. Heuristics are the "rules of thumb" that can be applied to a data set based on what the operator is looking for and the nature of the database (s).

An alternative approach—referred to here as "human-guided algorithms"—is to augment algorithmic approaches with operator insight into models and heuristics that are highly context-dependent. That is, in developing algorithmic approaches it is nearly impossible for the algorithm designer to anticipate and build in models and heuristics for all possible contexts—though designers are often able to build many that are broadly applicable across contexts and to build-in a finite set of context-specific algorithms.

Human-guided algorithms—that is, algorithms that can adjust based on human operator requests—have "hooks" built in and associated human-system interface (aka GUI) mechanisms that allow operators to participate in decision-making. The software for these solutions must be designed to accommodate these interactions. Furthermore, the solution must be "instrumented" with additional data structures to tag the solution in order to indicate which models and heuristics were employed in developing the solution. This information will give the operator insight as to why and how a specific solution was developed.

This area is in the very early stages of development and falls into the high-risk category. However, success with this technology is likely to pay significant dividends in reducing analysis and decision times in uncertain and ambiguous circumstances.

Observations and Recommendations: Contextual Exploitation

More so than any of the other capabilities, contextual exploitation will benefit from advances in the commercial sector. Current networking technology will continue to evolve rapidly based on market demands and worldwide competition. Development of business intelligence and network-searching algorithms will continue to respond to marketplace demands. The imminent appearance (in the 2010 timeframe) of key technologies opens many new paths. Exabyte storage will enable collection of data approaching that of the human brain. Terabyte-per-second data transport rates will enable rapid collection of data to support new algorithms and advanced analysis. Petabyte processing will enable rapid computation and association of disparate data.

The current programming and management of contextual exploitation within DOD are not well focused despite the many, but scattered efforts in the military services and defense agencies. There exists no structured governance or coherent planning across the department. One formidable challenge is how to account for and address issues of protecting privacy and other civil rights. Also, the potential for new threats based on technology surprise is significant, especially since adversaries can operate in an environment where they are less constrained by legal or moral scruples yet enjoy wide access to advanced information technologies.

Rapid improvement requires establishing effective new connections between communities that do not easily communicate—the soldier and a new discipline of scientist. A related challenge is how to identify quality practitioners and deliver the potential their expertise can bring to the effort.

Recommendations to DOD include the following:

- Conduct a major review of ongoing efforts to prioritize, integrate as necessary, and identify areas where additional funding can accelerate maturation of key technologies.
- Establish goals and metrics to monitor progress; such as exabyte storage, terabyte-per-second data transfer, seconds-to-minutes analysis/decision cycle time.
- Relax restrictive rules for obtaining access to new sources of technology coming from outside DOD and often outside of the United States.
- Recruit non–DOD partners—the Departments of Health and Human Services, Homeland Security, Transportation, Justice, State, and Commerce, as well as private entities—as sources, developers, and users.

Chapter 5. Rapidly Tailored Effects

The three capabilities already described will enhance the ability of U.S. forces in the coming years to act, apply force, and cause effects in nearly any circumstance. Understanding the human terrain, ubiquitous observation, and rapid extraction and interpretation of data will facilitate actions that will produce desired effects and avoid the counterproductive. The actions could be defensive as well as offensive, non-lethal as well as lethal.

During the Cold War, DOD focused on a “greatest threat” capability directed against a well-known adversary. To address the emergence of an expanded class of adversary, and the challenges of asymmetric warfare, DOD is currently in the fledgling stages of building a broader range of action options applicable to an uncertain future.

The complexities of the 21st century and the challenges in countering a wide range of adversaries operating within an equally wide range of societal and political environments demands an extensive “tool kit” of action options. The desired, enriched set of options should be instantaneously deliverable, scalable in scope and effect, applicable from tactical to strategic, useable by a broad range of friendly forces, and feasible and affordable in a long war environment (from pre- through post-conflict).

The study identified three areas not well covered by the current toolkit of action options. These are (1) enhancing the ability of U.S. forces to conduct non-kinetic operations aimed at influencing the local populace, (2) delivering conventional strikes with great precision and timeliness from afar, and (3) mitigating the effects of WMD attacks. The first is in recognition of the growing importance of non-kinetic operations, the second is in order to provide new strike options when local access is denied, and the third is to address the most potentially devastating attacks.

Influence Operations

U.S. military forces (and other U.S. government agencies) must become more proficient in the so-called non-kinetic operations, and integrate these with the more traditional combat operations. Non-kinetic operations include information operations, defined as "The integrated employment of the core capabilities of Electronic Warfare, Computer Network Operations, Psychological Operations, Military Deception, and Operations Security, in concert with specified supporting and related capabilities, to influence, disrupt, corrupt, or usurp adversarial human and automated decision-making while protecting our own."[7] This definition, and the definition found in the Joint Information Operations Publication 3-13, both focus on operations directed against the adversary.

However, non-kinetic operations involve much more than operations directed at the adversary. To a great extent they are aimed at the indigenous population at large in the theater of operations. The intent is to win respect and trust, and eventually hearts and minds, in order to isolate the adversary from the populace. In conducting these non-kinetic operations, U.S. forces on the ground are the face of America to the local populace, serving multiple and diverse roles such as policemen, health and civil service providers, trainers, negotiators, consensus builders, mayors, intelligence collectors, and spokespersons. In this sense, these non-kinetic operations (called influence operations in this report) can be considered strategic communications at the tactical and operational levels. DOD should be working very closely with other U.S. government agencies and allies in this area.

Training and continuous learning at all levels, as discussed in chapter 2, is critically important in order to make each soldier a "transmitter" of the desired messages, through both words and deeds. While the tools that are normally part of psychological operations (pamphlets, loud speakers, press releases) are likely to support future influence operations, new tools are needed. Goals are to be better able to predict and measure the effects of these operations and to anticipate the non-kinetic effects of kinetic actions.

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7. Department of Defense Information Operations Roadmap, 30 October 2003.

An ensemble of methods and models must be integrated within a decision support framework to help commanders at all levels plan for, conduct, and assess the results of these influence operations. Technologies include kinetic and non-kinetic cause-effect models; campaign planning/targeting/shaping tools; storytelling, gisting and advanced visualization technologies; and decision support tools to deal with complexity and uncertainty

Time-critical Conventional Strike

The challenges of anti-terrorism, counter insurgency, shaping the choices of emerging powers, and countering the acquisition or use of WMD drive the need to quickly deliver a conventional strike against time-critical targets. In many cases this need may arise when U.S. forces are not deployed to any significant degree in the required area of operations, thus adding the requirement that such a strike has to be able to be delivered from afar, while still maintaining the required timeline and precision. What is required is the ability to reach out with a rapidly delivered, precise conventional strike against a person, vehicle, building, or facility when allied forces may not be in the region of interest or when entry has been denied. Useful metrics for such a capability would be:

- response time of less than a half hour (total time to impact, including decision time)
- standoff range greater than 1,000 kilometers
- delivery accuracy in meters or less
- no local support requirements
- highly discriminating control and minimization of counterproductive effects

Response options include land- or sea-based ballistic missiles, air- or surface-launched hypervelocity cruise missiles, space- or terrestrial-based directed energy, and long-range (intercontinental) guns. In some cases the technology is mature (ballistic missiles) and in others more development is needed (hypervelocity and directed energy).

Enabling technologies include directed energy, high energy lasers, ballistic missile propulsion and guidance, scalable warheads, and hypersonic flight of either transport or launch vehicle.

If the timeliness of the weapon is going to be useful, then the timeliness of decision-making also needs to be addressed. The use of technology to aid in difficult decision-making in complex multi-dimensional situations must accompany any effort to develop the weapon component of rapid conventional strike.

WMD Protection and Mitigation

The accelerating global proliferation of WMD and associated delivery technologies requires a comprehensive approach to war fighter and system protection, consequence management, and continuity of operations. Proficiency in these areas contributes to deterring adversaries, and can also be applied in responses to natural catastrophes for which DOD has a critical supporting role.

The task force's assessments of critical constituent technologies benefited from the comprehensive *Defense Science Board 2005 Summer Study on Reducing Vulnerability to Weapons of Mass Destruction.* One of that report's conclusions was that effective and rapid restoration and recovery are the cross-cutting capabilities needed with respect to all four modalities of attack addressed in the study (chemical, biological, radiological, and nuclear). Another concern, which has emerged in other recent studies, is the possibility of massive disruption of communication and other functions caused by an electromagnetic pulse (EMP). Attaining the needed capabilities will require the development of rapid diagnostics and environmental assessment, the application of broad-spectrum medical countermeasures (for pre- and post-exposure), rapid decontamination protocols, and a renewed focus on maintaining or restoring functionality after a nuclear attack.

Rapid Diagnostic and Environmental Monitoring Tools

Effective crisis management during a WMD attack requires knowledge of the nature and extent of the attack. Needed are methods and procedures for rapid, minimally invasive screening of biological, chemical, or radiological exposure. The performance goals are to have test results from individuals available within minutes and of the environment within hours. Furthermore, such screening should be simple enough to be performed by non-professionals.

Broad Spectrum Medical Countermeasures

As illustrated by the anthrax attack of 2001, post-event treatment for a biological attack currently requires weeks to months of active medical intervention for each victim. The goal is to substantially shorten the time to respond with medical countermeasures—to hours and days. Broad-spectrum, active, and passive countermeasures (drugs and vaccines) for protection from exposure to chemical and biological agents are needed, but in many cases the fundamental knowledge is lacking.

Technological and process advances are needed in the areas of drug testing, approval, simulation, and modeling tools to speed and better inform scientific investigations. Future progress will depend on active collaboration with researchers in academia and the biomedical industry. It may also be possible to develop countermeasures that reduce radiation exposure deaths substantially. Preliminary medical science investigations have shown some promise.

Rapid Decontamination

Restoring operations in a timely and safe manner is crucial to minimizing the impact of a WMD event or similar crisis. Directed research, development, and technology transition should aim to improve decontamination activities to reconstitute operations within 15 minutes to one hour, with 99 percent assurance. In using a layered approach to rapid reconstitution, methods and procedures should include isolation through early warning as well as integrated design features to actively and passively protect and/or decontaminate areas, people, systems, surfaces, and infrastructures. Decontamination processes are different for chemical or biological exposures than for radiological or nuclear exposure. There is a pressing need for additional work to define standards and processes for cleanup for each modality using currently available technologies.

Maintaining or Restoring Functionality after a Nuclear Attack

A nuclear attack has the capacity to inflict substantially greater damage than other means of attack. Potential and declared nation state adversaries have an incentive to pursue nuclear weapons in order to counter U.S. conventional military superiority, much the same as the United States had during the Cold War to counter the Soviet Union.

The destructiveness of a nuclear weapon places a high premium on detecting nuclear weapons and material from a distance so that they can be intercepted and disarmed before they detonate. While such detection is challenging, nuclear materials have unique properties that can be exploited for remote detection.

Mitigation and recovery of the effects of a nuclear attack were studied during the Cold War, but much of that expertise has been lost. Since the end of the Cold War, inadequate attention has been paid to nuclear and electromagnetic radiation hardening and operational workarounds. Over the past decade, investments at the Department of Energy have advanced the state-of-the-art in simulating both a nuclear event and the impact on critical electronics important to U.S. nuclear weapons capabilities. However, the expert community and the supporting test facilities in this area are proving unsustainable because of the lack of "user pull."

Both the Congressionally mandated Electromagnetic Pulse Commission[8] and a recent Defense Science Board (DSB) study[9] have taken DOD to task for its neglect of nuclear survivability. Recommendations for remedying the situation have been made and some concurring actions regarding EMP have recently been initiated by the Office of the Secretary of Defense. But the spectrum of concerns extends beyond EMP and needs to be addressed more thoroughly.

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8. *Report of the Commission to Assess the Threat to the United States of Electromagnetic Pulse (EMP) Attack*, July 2004.
9. *Nuclear Weapon Effects Test, Evaluation, and Simulation*, Defense Science Board Report, April 2005

Recommendations: Rapidly Tailored Effects

The task force's recommendations for influence operations are closely related to those in chapter 2. Specifically:

- **DOD should undertake a major research and tool development effort** to understand and enhance the training and execution (including assessing results) of influence and related non-kinetic operations. This should include developing credible "cause-effect" models.
- **DARPA and the service laboratories, working with U.S. Strategic Command and other combatant commanders, should expand emphasis for dealing with uncertainty and ambiguity in decision support tool development and for providing credible "cause-effect" models.** Good use should be made of advances in the commercial sector.

For time-critical conventional strike the next step is for DOD to develop a comprehensive plan to evolve this capability. The plan should encompass both nearer term options and radically new potential capabilities that could result from R&D in directed energy or other technologies. The plan should be supported by a careful systems analysis of the various options, using quantitative measures of effectiveness and spanning all of the critical issues including the requisite real-time decision-making.

The task force recommends the following for improving WMD protection and mitigation:

- Building on the modalities panel report in Volume II of the *Defense Science Board 2005 Summer Study on Reducing Vulnerabilities to Weapons of Mass Destruction* (which provides more detail on each recommendation), DOD, in partnership with other key federal agencies, should:
  - **Increase medical surge capabilities** through coordinating existing assets, broadening the cadre of trained personnel, and developing rapid diagnostics and broad spectrum treatments.

- **Increase preparedness for crisis communications** by preplanning content and improving regional communication systems.
- **Institute multi-level planning** to prepare regional response assets and enable rapid integration of federal support.
- **Reassess restoration processes and cleanup standards** for a range of WMD attack scenarios.

▪ **DOD leadership should re-instate nuclear survivability as a security requirement in critical war fighting and support functions**.

Chapter 6.
Game-Changing Technology Push

The history of advances in military capabilities is filled with examples of technical "game changers" whose impact was not—and most often, could not be—anticipated. The fission bomb produced an increase of about 10^3 in explosive yield compared with the largest conventional bombs at the time. The fusion secondary produced another increase of 10^3 beyond fission bombs. Each of those increases was large enough to change the existing strategic military paradigm.

Over the last three decades, the capital cost per computer operation per second has decreased by something on the order of 10^9, as has the cost per bit of data storage, while the speed of operations has increased by at least 10^3. These increases in computing performance will eventually lead to paradigm-changing uses of computers. But as yet, computers are still being used largely as substitutes for existing capabilities, and only just starting to be used for entirely new capabilities.

Thus, a balanced S&T strategy should maintain a healthy "technology push" component, as well as the operational or capability pull. A focus on technology push can discover game-changing capabilities enabled by technology advances—both to exploit new technology opportunities for use by U.S. forces and, equally important, to assure that the United States is not surprised by its adversaries.

As a necessary complement to the mission-driven perspective that is the focus of this report, DOD must keep abreast of the most rapidly changing and emerging technologies. Today these technologies include biology (where DOD also lags behind other government organizations and the private sector), nanotechnology, and information technology (that continues to expand in spite of decades of advances). Synergistic combinations of these technologies might someday produce truly revolutionary capabilities, in areas such as human performance enhancement, medical treatment and prophylaxis, miniaturization, life extension, robotics, and machine intelligence.

Figure 4 provides an example of the bio-nano-info opportunity space. The rectangles indicate the individual technology area with an example military capability that might be developed using that particular technology. The ovals represent capabilities that derive from the synergy of two or three of these high-rate-of-change technologies.

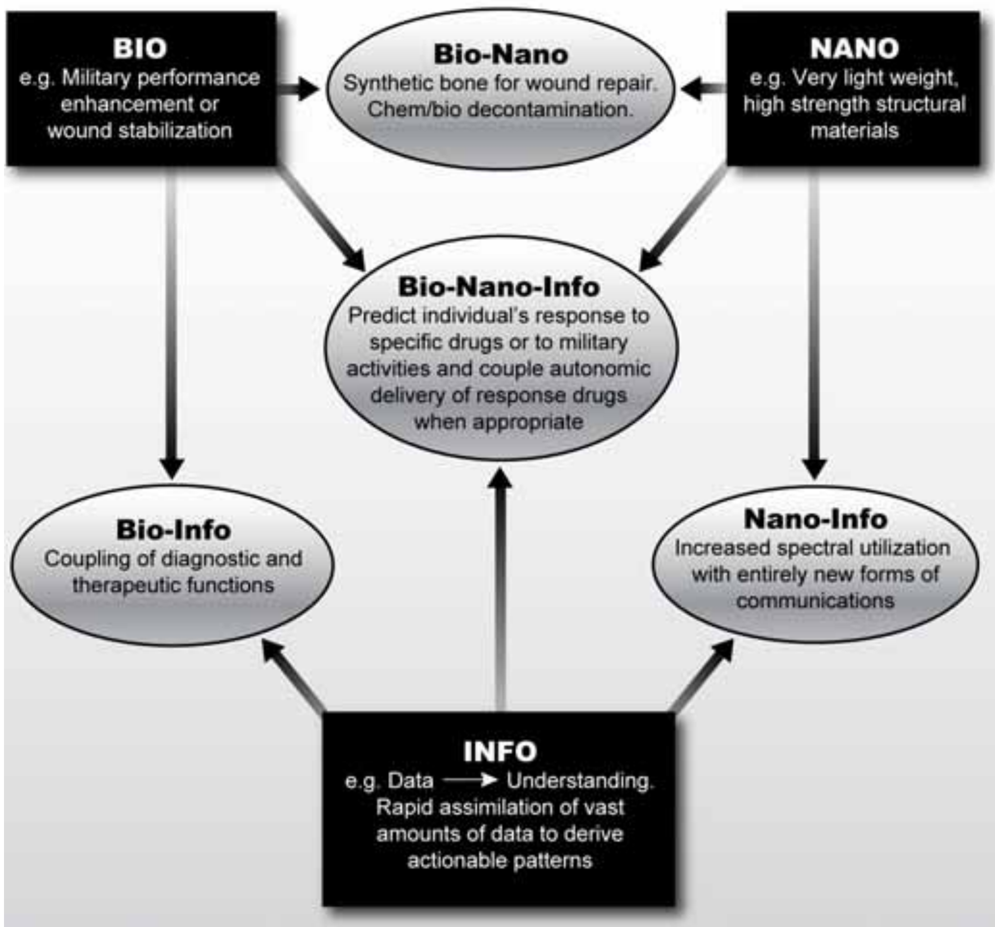

Figure 4. "Technology Push" Examples in the Bio-Nano-Info Nexus

Part II

Strategic Technology Planning and Rapid Technology Transition

Chapter 7.
Strategic Technology Planning

—bringing technologists and users closer together—

This study interpreted strategic technology planning broadly, not limiting this function merely to developing a plan to guide S&T investments. Rather, it encompasses how technology should play in the wider arena of DOD planning. Today, DOD has numerous processes in place to shepherd the S&T process, but current practices and processes are not adequate to meet 21st century operational challenges. Problems and concerns include the following:

> The Secretary of Defense has stated a goal of "technological superiority and no technical surprises," but there is no supporting vision for technology developed below this top-most conceptualization.
>
> There is relevant and valuable S&T activity, but no over-arching DOD-wide strategic technology plan with assigned responsibility, accountability, and metrics.
>
> There is a plethora of published DOD guidance and documentation of S&T goals and activities, but they serve less to guide than merely to catalog underway S&T activities.
>
> There is recognition of the significance (to us and our enemies) of the commercial and global technology marketplace, but no effective processes and incentives to identify and evaluate commercial technology to meet DOD needs or inform new opportunities.
>
> There are emerging activities to understand better how our adversaries might exploit technology, but not the comprehensive effort needed to stay ahead of adaptive adversaries.

> The DOD S&T enterprise has not yet adapted to the post–Cold War and post–9/11 challenges posed by multiple and diverse adversaries exploiting and adapting to rapidly changing technological and operational opportunities.
>
> The technology community is responsive to defined capability needs, but future joint concepts and capability needs are not developed with an informed understanding of the technological possibilities.
>
> The current DDR&E organization works hard to deal with process reviews, oversight, and day-to-day emergencies, but has little time left for strategic thinking and planning.
>
> DARPA remains a source of technological innovation and risk taking, but a "fear of failure" culture in much of the rest of DOD's S&T community is not conducive to the informed risk taking necessary to meet the new security challenges.
>
> DOD is responding to the urgent need of applying technology to the challenges faced by war fighters in today's operations, but not enough planning is conducted to apply lessons learned through these experiences and institutionalize a robust capability to more rapidly insert technology into ongoing operations that could be sustained for the long haul (decades).

What is Needed?

DOD's mission solutions—new operational concepts and the vision of longer-term desired capabilities—should be inspired by a deeper understanding of (1) what technology can do for U.S. military capabilities and (2) how adversaries can exploit global technologies for their own advantage. Otherwise, opportunities are missed and "unpleasant" surprises are more likely.

Concurrently, DOD's S&T activities and investments should be more directly informed by DOD's strategic goals and top-level missions. To be so informed will require DOD's technology community to think about solutions at the major mission level and not just respond to specified requirements or identified capability needs.

The missions referred to here are the capital "M" missions—a long war against terrorists, dealing with rogue states with weapons of mass destruction, or defending the homeland, for example.

This study offers two sets of recommendations to accomplish these objectives—one set recommending the creation of portfolio strategists and a second set addressing how to enrich DOD's capacity to identify, understand, and exploit technology opportunities, especially those that exist outside of DOD's domain. The first set is described in this chapter, the second in chapter 8.

These recommendations neither fine tune the details of existing processes nor invent totally new ones. Instead they introduce new "forcing functions" into existing processes to strengthen mission pull *and* technology push—both of which are needed.

At the heart of these recommendations is a central theme—the Department of Defense can meet the strategic challenges of the 21st century only with a closer coupling of technologists and users (including requirements and capabilities developers).

Such collaboration can engender strategic, horizontally-integrating technology visions that are informed by concept and capability development and that inform strategy as well. Without an overarching strategic technology context, DOD will be unable to choose wisely among competing technological vectors and identify needed capabilities and enablers.

Accomplishing this vision entails returning to an earlier successful model of inserting DOD's technology community as front-end peer collaborators in the concept development and requirements processes. This collaboration can be enabled by creating a top-level mission-oriented mindset within the office of the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD [AT&L]).

Mission-Focused Portfolios

The emerging partnership between the USD (AT&L) and the Vice Chairman, Joint Chiefs of Staff (VCJCS), to link future requirements to capabilities across the DOD enterprise, would be significantly enhanced with the addition of a dedicated capacity to:

- anticipate the technological possibilities across a range of domains, time-horizons, and challenges, for the United States, its allies and partners, and its potential adversaries
- identify those technological possibilities that could create new capabilities key to meeting the broad challenges
- identify any disconnects between desired capabilities and technology availability
- propose investment strategies, cutting across the DOD enterprise, balancing risk and reward, to secure the technologies needed over time
- shape decisions for investment and disinvestment driven by available resources, shifting strategies, or outdated or flawed concepts

These functions could be provided by a few sets of top-level, mission-oriented, portfolio strategists. This mission-focused approach was used with considerable success in the 1960s and 1970s within the offices of the DDR&E (when that job had roughly the scope of the current USD [AT&L]). Its strategic and tactical offices played leading roles in devising and overseeing portfolios based on a wide, end-to-end perspective of a major mission—deterring nuclear strikes by the Soviet Union and assuring the U.S. commitment to Europe.

Consider deterring nuclear strikes by the Soviet Union as an example. This mission relied largely on the development and deployment of strategic nuclear retaliatory forces, to include specialized intelligence collection, global communication means, and command arrangements. This high dependence upon relatively novel technical means led to a central role in requirements decision-making by technical leaders in the Department of Defense and those national laboratories engaged in nuclear weapons development. Those leaders routinely discussed problems, progress, and choices with those in the requirements generation chain of command, including the Secretary of Defense, and with the President of the United States as well. The home office of the head of the U.S. arms control negotiating team was located within the offices of the DDR&E.

Aircraft equipped to deliver nuclear weapons were acquired through existing organizations. However, the nuclear-capable missile programs in all three military services were executed through newly-established, special-purpose acquisition organizations. Similarly, ballistic missile defense programs were conducted by dedicated organizations, largely in the Army. All of these special acquisition teams were, to varying degrees, monitored and controlled directly by the portfolio strategists of the DDR&E Strategic Office.

In addition to these hardware acquisition teams, there were many dedicated teams of technical personnel that devoted intense study to identifying unsuspected difficulties in executing retaliatory strikes and to devising solutions to suspected problems. DARPA was established in 1958 in response to the "technical surprise" of the Soviet Sputnik satellite program. In its early days DARPA focused on ballistic missile defense and directed energy—both of which are just now becoming fielded weapons.

Moreover, several specialized S&T execution agents were established or modified to bolster specific technical aspects of the strategic mission capability. Two examples within DOD were the Defense Nuclear Agency that performed S&T on nuclear weapons effects and the Ballistic Missile Submarine (SSBN) Security Program that performed S&T on those aspects of anti-submarine warfare related to the SSBN force, to assure its survivability. In both cases, the Strategic Office of DD&RE exercised direct technical direction as well as funding and policy oversight. Moreover, the DDR&E Strategic Office received the knowledge generated by this specialized S&T and used it to inform decisions on major weapons programs.

However, since the mid 1980s, the organization of the USD (AT&L) changed from a mission-oriented to a function-oriented basis. Re-establishing such a mission-orientation would be of great benefit to DOD, but the study recognizes that it will require staffing and cultural change.

Recommendation: Mission-Focused Portfolios

The Under Secretary of Defense for Acquisition, Technology and Logistics and the Vice Chairman, Joint Chiefs of Staff, should create a small set (no more than five) of mission-focused portfolio activities.

Purpose and Products

The small set of mission-focused portfolio activities should cover all major missions. Each portfolio would focus on a top-level DOD mission/challenge. The portfolio strategists would advise the USD (AT&L) and the VCJCS by providing a long-term, integrated enterprise-wide view of technology and capability opportunities in their specific mission area.

These portfolio strategists would lay out a hedging strategy, anticipating measures and countermeasures from the near- to far-term. They would identify synergies, opportunities, and threats, some of which may be missed within the more formal top-down processes. They would sponsor analyses, red teaming, and technical net assessment and would have support from federally funded research and development centers. They would recommend experiments to understand risks and reduce uncertainty. They would develop metrics to measure progress. They would make investment and divestment recommendations and need to be empowered to have influence on funding.

Their products would be used to develop and update a mission-oriented strategic technology plan, inform concept development, and help drive doctrine, organization, training, materiel, leadership, and education, personnel, and facilities (DOTMLPF).

Staffing and Organization

The strategy for each mission would be created and sustained by a small staff, reporting to the USD (AT&L). They would have no direct authority, nor any direct fiscal control, over the S&T budget, except as provided thru the USD (AT&L) under current rules and regulations. The cadre would be staffed with permanent spaces under the USD (AT&L) of AT&L civilians and uniformed personnel identified by the VCJCS.

The cadre would establish a day-to-day working relationship with the combatant commanders, military services, Joint Staff, and others who are engaged in the business of developing mission operational strategies and mission functional capabilities. Strategic technology portfolio members would need to develop domain experience and a working knowledge of the mission operational strategy. At the same time, they will be required to have the technology expertise necessary to relate to the AT&L side of the organization.

Using the Portfolios to Derive a DOD Strategic Technology Plan

One of the products of the portfolio teams would be an overall strategic technology plan, which should:

- establish the state of DOD's current technology base as it relates to the major mission areas
- derive the projected technology needs identified over time across the missions
- enumerate the resulting technology gaps and the resources (time, money, people) and partnerships with others, necessary to close these gaps and create opportunities
- identify the metrics necessary to track closure of the gaps

Implied in this process is the need to anticipate technology advances and to anticipate how potential adversaries will adapt to these advances. This task is dynamic, as is the task of tracking metrics and continually updating the plan.

In order to translate the mission portfolio work into a strategic technology plan, cross-mission analyses will have to be undertaken, looking for cross-mission gaps and overlaps in technology, over a 20 year time span. In addition, input from the "prospecting" and "speculating" functions of the technology development enterprise (described in the following chapter) should identify new technology thrusts capable of enabling entirely new capabilities, not identified via the mission perspective. As a product of the USD (AT&L) and VCJCS mission portfolio analysis, this plan will have a well-grounded mission context and be informed by operational requirements and technological possibilities—much more than just an amalgamation of the services' strategic technology plans.

An important element of the plan should be to describe the role of DOD's S&T community in meeting the following imperative stated in the 2006 Quadrennial Defense Review: "to work with other government agencies, allies, and partners and, where appropriate, to help them increase their capacities and capabilities and the ability to work together."

Benefits

Adopting a mission-portfolio approach and establishing a cadre of mission-portfolio strategists will create an environment where the user and technology communities can integrate viewpoints. It would strengthen the emerging USD (AT&L) and VCJCS partnership that is working to better connect future requirements to capabilities to technologies across the DOD enterprise.

As the mission-portfolio strategists accomplish their tasks, it will foster interaction with the combatant commanders, the force providers, the technology developers, the Joint Staff, and other elements of the Office of the Secretary of Defense. It would inform and motivate national strategy by suggesting strategic and tactical opportunities derived from their newly identified technology thrusts. It will inform the requirements community when a particular operational construct is better replaced by an emerging alternative. Additionally, it would help inform choices to be made by the Secretary of Defense on resource constrained strategic priorities by providing a coherent and strategically relevant technology framework.

Challenges

The major challenge will be assembling the right leaders and staff. They should be handpicked by the USD (AT&L) and VCJCS and drawn broadly from the DOD community, including technologists, futurists, strategic planners, operators, and analysts. In any job of this scope, stabilized tours of several years in order to master the complexities are needed for success. These strategy groups will have little impact unless the USD (AT&L) values their products and empowers them.

The major mission focus advocated in this report is not the only way to organize portfolios. However, the task force argues that it is the best way to accomplish the twin goals of (1) having concept and capability development more informed by technology opportunity and (2) having technology activities more directly influenced by the department's major challenges. These mission-oriented portfolios could coexist profitably with functionally-focused portfolios within a matrix environment.

Chapter 8.
Technology Opportunities

—expanding the number of technology opportunities—

The previous chapter described the importance of bringing technologists and users closer together through the establishment of portfolio strategists, whose activities ultimately lead to a department-wide strategic technology plan. A necessary complement to these activities is to increase DOD's capacity to identify, understand, and exploit the operational potential of technology. This cannot be obtained by focusing on DOD's S&T program alone. Where once the department had numerous technology development institutions that covered most of the relevant technology domains, today gaps have emerged for several reasons, including the growth of the commercial technology market place.

Thus, a second theme of this study is this: DOD's technology community must increase its capacity to understand and exploit technology opportunities, especially those that exist outside of DOD's domain.

This study characterizes six types of contributors to such a capacity:

- ***Developer.*** Responds to requirements. There are many of these, mostly within the military services and also in the defense agencies.
- ***Innovator.*** Pursues the demonstration of new, technically challenging high payoff capabilities, in response to current or anticipated needs. DARPA is the prime example.
- ***Speculator.*** Funds "bottoms-up" discovery to create disruptive breakthroughs in DOD areas; not directly requirements driven; often high risk; and typically requiring sustained investments over substantial time horizons. DARPA does some of this; more is needed DOD-wide.
- ***Prospector.*** Finds U.S. and foreign commercial solutions to address current needs; informs funding agents of what's

available now. Although this capability currently exists on an occasional and hoc basis throughout DOD and the intelligence community, it does not exist on a permanent basis and with an enterprise-wide perspective.[10]

- ***Worrier/Anticipator.*** Explores how foes could use technology to field capabilities disruptive to U.S. goals. This function involves S&T intelligence to help understand what adversaries are doing, red teaming to identify what adversaries could do, and net assessments to understand the consequences. This activity needs to be connected to decision makers so its products can inform major program and operational decisions, as well as shape intelligence collection. Current efforts in this area are far short of what is needed.
- ***Expeditor***. Enables very rapid (less than two years but could be as short as weeks and months) fielding of capabilities to meet needs of ongoing operations. A numbers of such activities have been created recently to meet demands of current operations, but these largely ad hoc enterprises do not appear to be robust enough to sustain a rapid fielding capability over the long term.

The DOD is well positioned with two of these functions—developer and innovator. The other four need to be either enhanced or created. This chapter describes ways to enhance the speculator, prospector, and anticipator functions at DOD. The expeditor function is discussed in chapter 9.[11]

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10. As an example of this function, the Navy has a group of globally-based individuals tasked to monitor relevant foreign technologies.
11. Further discussion of these functions can be found in Volumes III and IV of this study.

Speculator: Developing Potentially Disruptive Technologies

Technology can enable disruptive capabilities, developed either by the United States to gain asymmetrical advantage or by its foes to thwart U.S. objectives. The DOD needs to get much better at fostering the former and anticipating the latter. Often the very technology that can provide the United States with a disruptive advantage is itself disruptive to DOD's culture and antibodies form to reject it.

History shows that creative risk-taking is important in achieving disruptive breakthroughs, which in turn are necessary for providing the unexpected technology opportunities that enable new, unforeseen war fighting capability. Where innovators, such as DARPA, select their technology investments based on directly supporting military capability, the "speculator" mechanism is meant to fund "bottoms-up" discovery in those areas important to DOD but without clear commercial application. There is some of this activity going on in the department today, but not nearly enough.

The dictionary defines "disruptive" as the adjective form of the verb disrupts, which means to interrupt, separate forcefully, or shatter. In application to defense systems, "stealth" could be described as an enabling platform and force to "shatter" the cohesiveness of integrated air defense and early warning systems. Further, it has the ability to "separate forcefully" essential linked capabilities that enable surface-to-air missile systems to engage stealth platforms. To continue the examples, large-scale integrated circuits could be regarded as disruptive when they are employed to "shatter" the cost barriers that limit advances in pervasive and large-scale networks and processing.

A more general discussion of "disruptive" technologies and/or capabilities is found in the work of Harvard Business School Professor Clayton Christenson.[12] Such technologies are either "disruptive" to

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12. Clayton M. Christenson, *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*, Boston, Mass.: Harvard Business School Press, 1997.

current organizations and cultures and/or are "game changers" in their application—an example of which is the case of personal computers and multiple, redundant servers replacing mainframes.

Examples in the world of defense systems include the Global Positioning System, cruise missiles, sea-launched ballistic missiles, remotely piloted vehicles, ballistic missile defense, and nuclear weapons. Each of these systems made a major change in war fighting capability, but was also highly "disruptive" to existing organizations and cultures. Unmanned systems versus piloted aircraft and cruise missiles versus penetrating bombers are two such examples.

As would be expected for such counter-cultural cases, the obstacles to funding and developing such systems are much greater than those encountered in fielding the next generation of a traditional system. These obstacles include a lack of understanding, on the part of senior leaders, of the game-changing potential of such technologies, along with the effects of cultural resistance. Often it takes a fielded prototype in the right setting—sometimes in war—to break through the cultural barrier and get a well-understood message "up the chain of command."

Because of their crucial importance, disruptive technologies and/or capabilities require senior leadership attention. In almost all cases, to get a "disruptive" capability deployed requires very strong, high-level support, as well as an ability to overcome the institutional "systems"—which, as expected, will fight to resist the cultural change.

Thus, DOD needs to create an environment to expand, strengthen, and protect "speculators" operating on the frontiers, looking for the truly disruptive solutions. Critical to success is overcoming the fear-of-failure that tends to dominate the development and acquisition culture.

Recommendation: Speculator

The Secretary of Defense and other senior DOD leadership should receive frequent updates on the disruptive potential of threats as well as the potential for, and status of, fielding U.S. disruptive innovations.

The DDR&E should make disruptive potential a priority area of activity and be the department-wide focal point.

Working with the military services, defense agencies, and other U.S. government S&T communities, the DDR&E should commit an additional $200 million per year to this crucial area. The DDR&E should also collaborate with the Defense Threat Reduction Agency and National Nuclear Security Administration experts in the areas of nuclear and weapons of mass destruction matters.

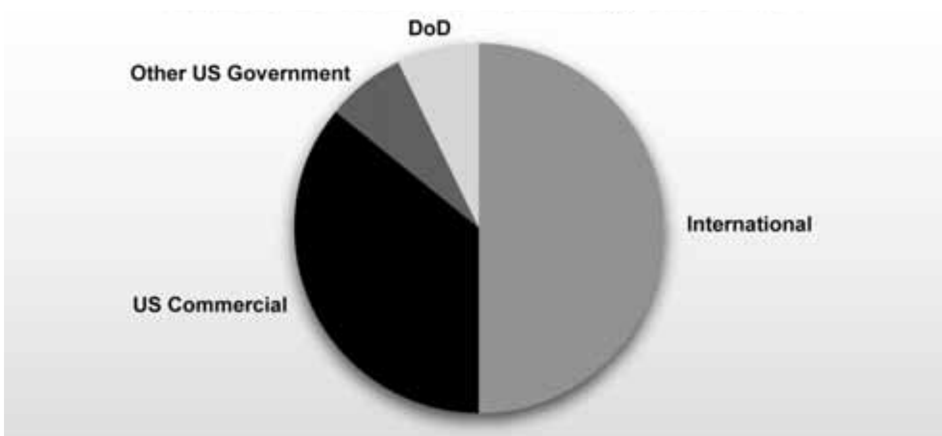
Prospector: Technology Reach

In the new global technology environment, identifying the "low-hanging fruit" that can be acquired or adapted for DOD needs is a critically needed capability. The DOD enterprise needs a "prospector" capacity designed to find solutions to current needs that are available in the non-DOD world.

Technology is becoming a greater necessity for business competition worldwide and international investment in technology is growing. Although about half of the world's investment in research and development is still performed in the United States, this percentage is getting smaller. Twenty seven percent of U.S. research and development is funded by the federal government and less than half of that is funded by DOD. About five percent of the scientists and engineers in the United States are directly employed by the government. Federal R&D funding has been relatively flat for the past 30 years as a percentage of the gross domestic product and has decreased from a peak in 1997.

In recent years, there has been a shift in U.S. DOD R&D investments from research into development. The long-term security of the nation still depends on DOD being at the leading edge of applying the newest in science and technology. In the past, such leading-edge technologies came largely from the U.S. government. That has not been the case for quite some time and, as indicated in figure 5, much of it is now international.

In contrast to DOD, commercial industry research, until recently, has been steadily increasing in both the manufacturing and non-manufacturing industries. The only industry group that receives the majority of its S&T funds from the government is the aerospace sector, which is relatively less militarily important today than it was during the Cold War. In the biological and social sciences, which are of growing military importance, the DOD investment is extremely small.



Source: "International Science and Technology Trends," Pocket Databook 2000, *National Science Foundation*

Figure 5. Science and Technology Investment

The DOD has reduced its oversight of defense industry independent research and development (IR&D), requiring no descriptive brochures or on-site reviews, making it more difficult to have awareness of what is going on, even in DOD-related industry. DOD has less visibility into technology developments in commercial industry; one reason being that acquisition regulations, intended to prevent corruption, make doing business with the DOD very difficult. The use of "other transaction authority" can enable commercial firms to more easily undertake business with the DOD.[13] However, to acquire foreign technology the DOD must also overcome other difficulties.

Export controls are intended to prevent proliferation of dual-use technology but they impede the integration of foreign technology and cooperation, and hinder U.S. firms from obtaining economies of scale. The "Buy America Act" intended to protect U.S. business, forestall off-shoring, and assure trusted sources restricts the use of foreign technology and hinders the development of techniques to overcome risks of buying offshore. The 1999 DSB report on globalization and security contains recommendations that remain valid today and are covered in Volume IV of this study.

In order to again become the leader in using technology, DOD must become much more adept at finding and using globally available resources, whether funded by U.S. and international industry, academia, DOD, or other government agencies. Thus, the department needs to create an organized function that can "prospect" commercial, non-DOD, and foreign technologies for good ideas and products.

Recommendations: Prospector

Establish and fund a DDR&E Center for the Application of Commercial and Foreign Technology, with a substantial travel budget, manned with experienced DOD scientists and engineers with foreign language skills and motivated to improve scientific collaboration.

Re-establish the 1498 database so that DOD S&T activities and their associated key personnel can be identified. Locate it at the Defense Technical Information Center (DTIC) and make it available online to all DOD scientists and engineers.[14]

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13. The "other transaction authority" allows DOD to enter into contractual arrangements called "other transactions" with private sector research and development partners. Other transaction agreements are characterized by enhanced flexibility and reduced administrative burden when compared with the typical government procurement contract. While initially authorized for use by DARPA, this authority has been extended to other DOD organizations.
14. No longer in use, the DD Form 1498 was generated by DOD principle investigators when making internal or contracted research and development investments. The collected

Expand the use of "other transaction authority" and other means to enable commercial firms to undertake business with the DOD. Annually, the USD (AT&L) should provide an award to the contracting agency that has done the best job of reaching out to commercial and international business, similar to the Packard Award.

Anticipator: Understanding Adversary Capabilities

In addition to developing stronger speculating and prospecting functions, the department needs to better understand how foes of the United States can exploit the global technology market. The innovative integration of widely available technologies is just as worrisome for the United States, and potentially just as powerful, as the use of new technologies.

Due to the availability of technology on the global market, U.S. adversaries have opportunities to exploit the same technologies as DOD. Further, countermeasures to U.S. systems are likely to be leveraged off the same global technology base. As more and more commercial products are integrated into military systems, these conditions are likely to worsen.

Current adversaries have shown the ability to respond to U.S. capabilities and act on their strategic advantage to deploy globally-available military systems and technologies in fast, low-cost, and innovative ways. Integrative innovation has become commonplace as a means to quickly achieve new capabilities without using exotic technologies. In addition, the global access to knowledge and quality education has made adversaries smarter in areas that directly enhance their ability to engineer new solutions.

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data, maintained by DTIC, described the objective, approach, and progress of each project as well as contact information for those participating in the activity. The database provided visibility into R&D efforts throughout DOD.

The issue of how adversaries can much more rapidly adapt technology into capabilities, as compared to the traditional acquisition cycle in the Department of Defense, is one aspect of this environment that must be addressed, and is discussed in the next chapter. But even more important is the need for DOD to have far better visibility into how adversaries are exploiting the rapidly changing technology domain in order to better counter these advances and reduce the potential for surprise.

Success in this area will require deliberate focus on "anticipating" how adversaries might exploit technology. Such information gathering cannot be conducted in a vacuum within DOD, and certainly cannot be done in the common organizational environment that is hostile to any disruption of the status quo. Success will require collaboration with the intelligence community, as well as with experts outside of the DOD community, who can bring insights to red teaming activities and net assessments of capabilities and countermeasures.

The major concern of this study is not the absence of people with the foresight and creativeness to anticipate possible threats. The problem is the lack of a DOD-wide coherent and comprehensive process that (1) identifies and organizes these potential threats in a manner that illuminates their relative danger and likelihood and (2) presents these results in a way that facilitates senior decision-making regarding programs, plans, and intelligence collection.

There are current activities that can be built upon and learned from. The Army has established the University of Foreign Military and Cultural Studies at Fort Leavenworth to foster red teaming competence. The Navy has a Deep Red project that conducts net assessments for its leadership. DDR&E and the Under Secretary of Defense for Intelligence (USD [I]) cosponsor a scientific and technical net assessment program to help identify future technology enabled threats to U.S. capabilities. These activities should be protected, encouraged, and fully engaged.

Recommendations: Anticipator

Establish a much more comprehensive approach to "anticipating" how adversaries might exploit technology. This requires increasing S&T intelligence to understand what adversaries are doing; conducting more and higher quality red teaming to identify what adversaries could do; performing net assessments to understand the consequences and providing senior-level decision makers access to the results. A first step is to assign higher priority and expand the current DDR&E and USD (I) Scientific and Technical Net Assessment Program.

Chapter 9. Technology Transition to Ongoing Operations

—speeding the transition of technology into fielded capability—

Failure to speed the transition of technology into fielded capabilities has consequences. U.S. military forces are not provided what they need to anticipate and respond to adaptive adversaries in ongoing operations. Major systems enter the field with obsolete technology, reduced quantities, and unnecessarily high cost. The high cost destabilizes other programs. Delay encourages "requirements creep," which leads to more delay. The department misses opportunities to exploit disruptive technologies.

The security threats the nation now faces present discontinuities to its established science and technology processes, policies, and procedures.[15] These processes need to transform from sequential, task-based, and budget-cycle-based to ones that are capable of parallel, opportunistic and adaptive operations. The "clock speed" of technology transition must more closely match that of technology innovation and the cycle time of new and emerging multilateral threats on the global battlefield.[16]

This study addressed the issues of transitioning technology into capabilities in two time dimensions: (1) very rapid insertion of new capabilities into ongoing operations, which is discussed in this chapter and (2) major system acquisition (chapter 10).

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15. In *The Age of Discontinuity*, Peter Drucker forecast the accelerating pace of change faced by firms in the 21st century. Those that assume continuity are likely to find keeping up with markets difficult or impossible as they are constrained by rules and mental models that no longer work. Charles Handy, in the "Age of Unreason," also makes some interesting related comments. The Department of Defense is finding it difficult to meet the "market" needs of the war fighter vis-à-vis the threats they face in the global war on terrorism.
16. In *Clock Speed: Winning Industry Control in the Age of Temporary Advantage,* Charles Fine discusses the varying process speeds of industries. Industries that do not recognize the "clock speeds" of the industry/market segments they are in will fail. His concepts are useful in thinking about current technology transition processes and the "market" they serve.

The challenges are different for each. For rapid insertion into ongoing operations the challenge is to turn the current improvised and temporary approaches into processes and practices robust for the long term. For major system acquisition it is to transform long-established practices into a process that will cut in half the time it nominally takes to field a system.

Expeditor: Inserting Technology-Enabled Capabilities into Ongoing Operations

The need for rapid technology insertion was not a major concern during much of the Cold War, with the exception of the Viet Nam war era. But processes and practices created during that war, to facilitate speedy introduction of new capabilities, were discarded when the war ended and there was a return to business as usual.

U.S. military forces face new circumstances and adapting adversaries every day. Clearly, the need for rapid fielding into ongoing operations has become critical. This study assumes it will be a continuing need as the nation fights a long war on terrorism and meets other challenges. Thus, DOD needs to be able to rapidly insert capabilities over the long haul (decades) by establishing processes and practices tailored to this challenge. Success will require extraordinary collaboration among war fighters, trainers, technologists, operational analysts, systems engineers, and testers.

To provide a rapid insertion capability today, DOD has created many ad hoc “rapid acquisition” programs and initiatives. “Rapid,” in this context, means as short as weeks or months, but in any case less than two years. These programs, which total over $3 billion per year, include service science and technology programs, the Joint Rapid Acquisition Cell, the Quick Reaction Special Projects, and the Joint Improvised Explosive Device Defeat Organization, to name a few.[17] The products from these programs focus on purchasing or integrating existing technologies, with minimal, if any, technology development. The main

17. Volume IV contains a description of these and other rapid acquisition programs.

challenge is technology integration (components, software, subsystems) with doctrine and training to produce new and improved capabilities.

Not surprisingly, given the challenges, these processes have yielded mixed results to date. The successes have engendered a mindset oriented toward developing innovative solutions and processes less compliant to the structured, “formulaic” approach that underlies the traditional acquisition process.

However, these fragmented processes do not appear robust for the long war. A lull in operations will precipitate a back-to-business-as-usual (and much more leisurely) approach. Attempts by the traditional acquisition community to provide oversight is slowing “rapid acquisition” to “faster traditional acquisition” by burdening it with formal requirements and approval processes. Prudent oversight is subsumed by overly rigid control.

With the exception of large-scale initiatives such as robotics, most rapid reaction solutions are either left in theater or not reused by units in other missions. Lessons learned are not widely enough shared. The effect is large numbers of solutions to common problems, resulting in duplicative efforts and the need for significant “after the fact” integration.

Other obstacles for current rapid acquisition efforts are fiscal resources and overall governance. No joint lead is designated or empowered to budget for, oversee, or execute joint rapid acquisition programs. Almost by definition, these programs exist outside the planning, programming, budgeting, and execution cycle, and can never meet its long-lead-time forecasting cycles. As a result, most survive on funding supplements to the defense budget.

Even with adequate funding, most current rapid acquisition programs do little beyond purchasing and delivering equipment. Training support for rapidly generated solutions is normally confined to initial user familiarity with little follow-on or sustainment training.

Recommendation: Expeditor

Create a Rapid Fielding Organization (RFO) to satisfy the growing list of war fighter-required needs, over what is anticipated to be an extended period of "long war." Combine most of the current "rapid" and "agile" programs into the RFO, leaving some programs remaining within the services, but coordinated with the RFO.

The RFO will be established with a high-level mandate and full program and budget authority. Using direct authority from the Secretary of Defense, through the USD (AT&L), the RFO will rapidly provide combatant commanders with capabilities necessary to conduct joint operations. It will field systems and solutions with associated equipping, manning and training. Perhaps most importantly, the RFO will provide joint institutional focus on achieving rapid response, with memory and knowledge-transfer.

The RFO will be non-conformist in its mode of operation. It will be extricated from the complex bureaucracy that encumbers today's traditional acquisition process, including the voluminous requirements and extended lead times for study, review, and approval. Keeping such an organization as ad hoc as possible will help to achieve this goal.[18]

The people required for such an elite organization should be hand-picked from among the best in government, the services, the private sector, and academia. Experimental Personnel Authority will allow the RFO to hire expert program managers from industry at competitive salaries and faster-than-normal civil service rules.

RFO processes will be driven by clear, concise, requirement statements provided to the RFO director by the combatant commanders. The short review and approval processes will enable quick action.

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18. According to a recent study by the Army-DARPA Senior Advisory Group, success of such an organization will require the following: (1) adequate and flexible funding, (2) monolithic leadership—a single point of decision, (3) strong top cover at the highest level, (4) buy-in by the user chain of command, and (5) involvement of the test community at the outset. Source: Personal correspondence with L. Lynn based on Transition of Technology Workshop of the Army-DARPA Senior Advisory Group.

The RFO's annual appropriated budget should cover development, deployment, and training. It also should cover sustainment for only a few years, either until the relevant service provides resources for long-term support in the budget, the capability transitions to a program of record, or it is divested. However, the RFO will be responsible for producing the plans for longer-term sustainment. Such sustainment will not always be needed, as "throw away" capabilities will be a feature of support of ongoing operations.[19]

The RFO will have an especially close and continuous relationship with its customers, the combatant commanders. In-theater development and testing will be required at times. The goal however, will be to insert new capabilities into units as they prepare and train for assignment. This is the ideal time, as new systems can be coupled with evolving doctrine that is constantly driven by operational experience. Such an approach will foster continuous learning and entail more use of prototypes and surrogates in testing. The essence of this concept is illustrated in figure 6.

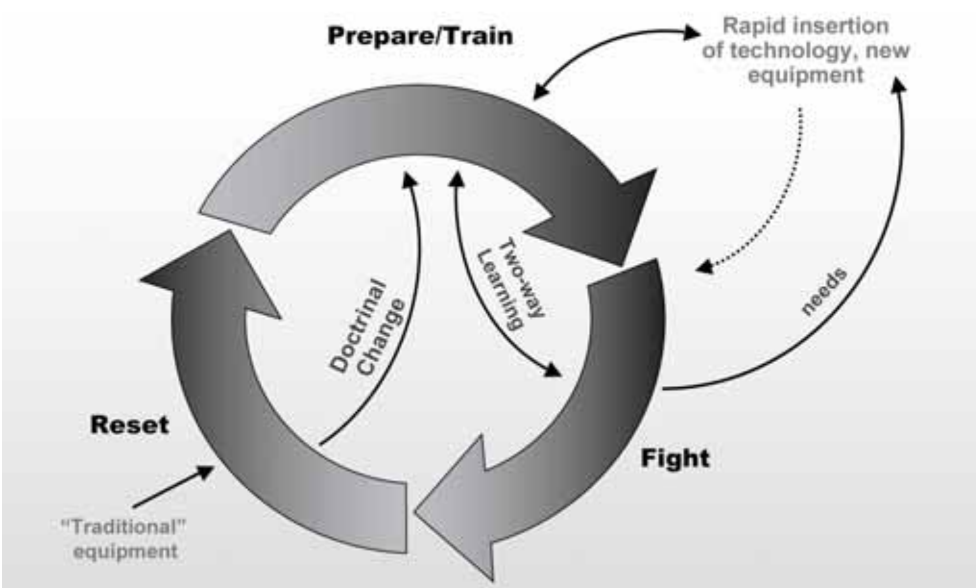

Figure 6. Inserting New Capabilities Rapidly

19. Some solutions to immediate war fighter needs will be designed for temporary use and will be left in the field. As such, these systems will not need a plan for long-term sustainment.

Chapter 10. Major System Acquisition

Simply put, traditional DOD acquisition programs take too long. Cycle times for new programs have, over the 1996 to 1999 period, averaged well over 10 years (the time between Milestone B and initial operational capability).

The causes are well documented: overly ambitious initial requirements often exacerbated by requirements growth during development; over optimistic cost and schedule estimates; immature technology; lack of flexibility to adjust requirements when problems arise; funding instability; and lack of consideration of affordability, producibility, or sustainability during early development.

Rapid cycle times are impeded when bureaucracy and process substitute for executive leadership. Conflicting lines of authority, accountability, and responsibility for committed outcomes contribute to a lack of speed and agility in fielding capabilities with new technologies. Cultures also tend to resist disruptive technologies in favor of near-term and familiar approaches.

Further challenges include the decline in technical and program management expertise in the DOD and, to some degree, in the defense industry. Government and industry's ability to execute complex system development programs will be challenged with marginal supply chains, quality of workforce issues, and S&T funding pressure in the absence of an annual supplemental to the defense budget.

DOD must become more disciplined and agile in its ability to provide timely insertion of technology into major systems. More discipline will enable the department to cut in half the time it takes to field militarily useful blocks (versions) of a system (to five or six years for block one and five years or fewer between blocks).[20] With more agility, new technology options can be exploited in subsequent versions to meet changing operational challenges. This approach requires the following:

- bringing issues of cost, technology, manufacturing, and integration readiness in early, before deciding what to buy
- assuring technology readiness by Milestone B
- controlling appetites for performance in each block
- relaxing requirements if appropriate during each block to protect cost and schedule
- conducting a vigorous S&T and experimentation effort in parallel to create options for new capabilities in future blocks

Managing "Requirements"

Issues involving cost, schedule, and risk are not considered early enough in the requirements setting process.[21] Too often, emphasis is placed on performance, with insufficient attention to schedule, affordability, supportability, and risk. DOD can adjust its practices and processes, as shown pictorially in figure 7, to perform the needed systems analysis and systems engineering. Cost, performance, risk, and schedule would be addressed within a defined trade space, using modeling, simulation, technology demonstrations, and prototyping, as appropriate.

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20. The most recent review of the traditional acquisition process was the *Defense Acquisition Performance Assessment*, January 2006. The findings and recommendations from this assessment provide a sound basis for improvements. They include: (1) planning the time from Milestone B to initial operational capability (IOC) to be no greater than 6 years; (2) greater user involvement in the acquisition process; (3) budget flexibility to accelerate programs and later spirals; (4) greater visibility by the department leadership into technology maturity; and (5) the use of "spiral development" as the norm.
21. At least two recent Defense Science Board Studies (*Report of the Defense Science Board/Air Force Scientific Advisory Board Joint Task Force on Acquisition of National Security Space Programs*, May 2003 and the *Defense Science Board Summer Study on Transformation: A Progress Assessment*, February 2006) have pointed out deficiencies in the "requirements process" as it affects efficient and effective development of military systems.

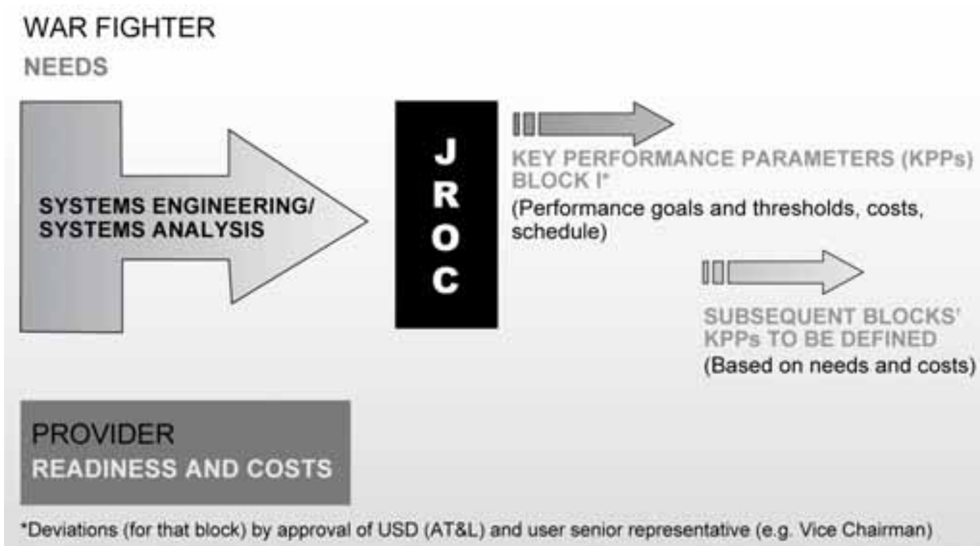

Figure 7. Incorporating Systems Engineering Early in System Development

The need to make informed tradeoffs extends beyond the initial requirements setting stage. In the development of military systems, unforeseen problems can arise that lead to cost and schedule overruns. What is lacking is a process that provides timely decisions to relax requirements, including key performance parameters, if necessary to meet cost and schedule commitments while still providing a cost-effective and militarily-useful system. Hence, there is a tendency to strive to meet key performance parameters at the expense of cost and schedule, leading to overruns and delays in fielding.

Recommendation: Managing Requirements

Milestone Decision Authority must assure that a rigorous systems engineering/analysis process underpins input to the requirements process. This process includes development planning that relates candidate technologies and systems development processes to war fighter needs as well as to costs and technology readiness. This approach would involve modifying or replacing aspects of the current Joint Capabilities Integration and Development System process.

Create and enforce a process allowing program managers to receive timely decisions on requirements relief during the program execution phase for each block, without having to go back to the Joint Requirements Oversight Council (JROC).

Technology Readiness

To date, Milestone A has been “optional” and infrequently held. Thus, DOD’s attention is not adequately focused on the technology development phase (from Milestone A to Milestone B). As a result, opportunities are lost to provide early risk reduction or to accelerate technology development and meet war fighter needs sooner. DOD is not following the principles described in the Defense Acquisition Guidebook: “…the S&T Program is uniquely positioned to reduce the risk of promising technologies before they are assumed in the acquisition process.”[22]

One consequence is that most DOD systems (platforms, weapons, networks, systems-of-systems) start Milestone B with immature technologies (below Technology Readiness Level [TRL] 6). These programs offer some form of risk mitigation intended to enhance performance to TRL 6 after Milestone B approval, but the result typically is large schedule slips and significant cost overruns.

Congress demonstrated its concerns about cost and schedule growth in DOD programs through the 2006 Defense Authorization Act, Section 801. This act requires the USD (AT&L) to certify that needed technologies are at TRL 6 or higher, prior to Milestone B. This requirement gives the department a new tool in reducing the risk of program delay or failure. This same legislation does allow waivers but requires that the Milestone Decision Authority notify Congress within 30 days of the waiver approval.

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[22] See the *Report of the Defense Science Board Task Force on The Manufacturing Technology Program: A Key to Affordably Equipping the Future Force*, February 2006.

Recommendation: Technology Readiness

Make Milestone A mandatory for major systems acquisition. A favorable Milestone A decision would not imply the initiation of a new acquisition program; a Milestone B decision would still be required.

Plan and execute multiple technology demonstrations to generate more options and minimize single points of failure. (These demonstrations will require added up-front resources). Address affordability, producibility, and supportability to surface potential "cost killers" and create concurrent manufacturing and supportability plans and cost estimates. Establish a strong partnership and accountability among the user (or user representative), the program executive officer, and the component S&T executive through a memorandum of agreement at Milestone A. Use independent red teams to judge technology readiness; manufacturing and integration readiness; and the likelihood of meeting performance, cost, and schedule goals.

Spiral Development

Department of Defense Instruction 5000.2 defines spiral development as a process where "a desired capability is identified, but the end-state requirements are not known at program initiation." Those requirements are refined through demonstration and risk management; there is continuous user feedback; and each increment provides the user an important new capability. The characteristics of future increments depend on feedback from users, changes in the security environment, the results of experiments, and technology maturation.

Figure 8 illustrates spiral development. The initial increment or block is designed to provide a militarily useful capability quickly and with low risk. Its key performance parameters are based on essentially-proven technology (TRL 6 or better). Research and development to support future blocks is ongoing, and, when ready, milestones for development (and subsequently production) of future blocks are conducted. It is a process agile enough to accommodate changing operational needs and adopt new technology opportunities into future versions. Adequate funding must be provided for research, development, and procurement of all blocks. Experimentation plays an important role throughout and early involvement of the operational test community is vital.

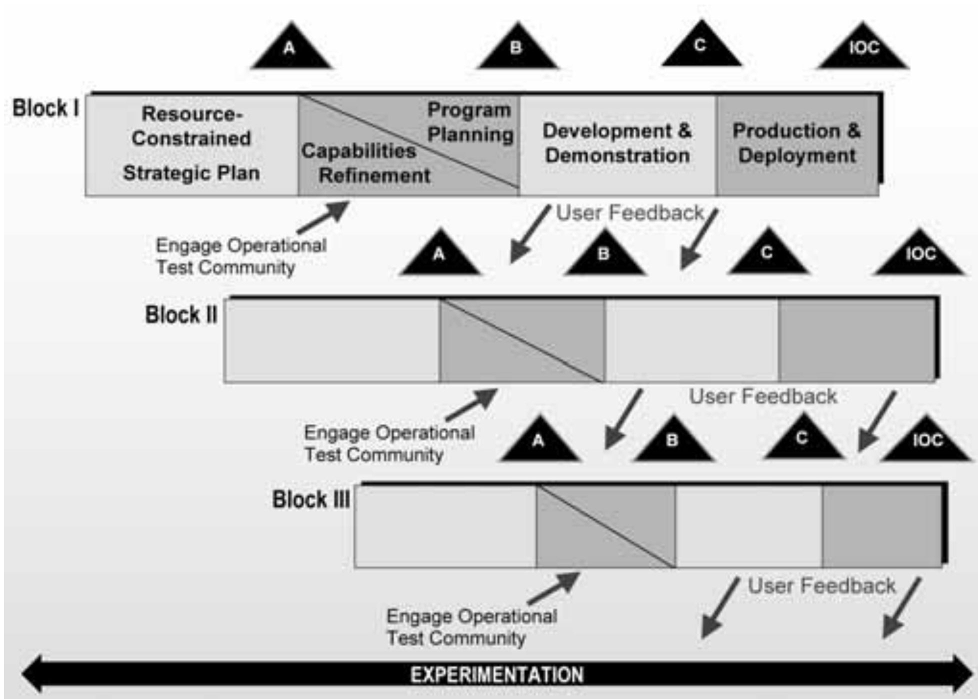

Figure 8. Spiral Development

The spiral-development approach is common in industry and not new to DOD. Development of surface launched ballistic missiles and inter-continental ballistic missiles, which began in the 1950s, had these characteristics as did later developments, particularly in aircraft. DOD needs to regain this art. Practice and process changes will be required, including in budgeting, requirements setting, experimentation, test and evaluation, logistics, training, and operational planning. Increased user involvement is essential.

Recommendation: Spiral Development

USD (AT&L) direct the following for "traditional" acquisition programs:

Mandate the use of spiral development, entering system design and development (SDD) of each block, with mature technology, manufacturing, and integration readiness levels—TRL 6, Manufacturing Readiness Level 6, and an equivalent level of integration readiness. Plan the program to provide the initial operational capability of each block within 5 years of the initiation of SDD of that block.

Design programs for minimum schedule. Do not start a program until funding consistent with that schedule is available.

Provide program stability in funding, an experienced workforce, and program management through a predefined phase of the program.

Provide adequate resources for up-front R&D on future blocks, running concurrently with the development of prior blocks.

Use a modular, open-system approach, so that capability can be readily added to the basic system. If future improvements are known in advance, program for pre-planned upgrades. More generally, be prepared to incorporate spiral upgrades as dictated by demonstrations of necessary technologies, changing operational needs, and availability of funding (will require a Congressionally-approved wedge for application to future spiral upgrades).

Use truly independent, expert review teams for sanity checks.

Chapter 11.
Cross-Cutting Enablers

This study identified a number of cross-cutting enablers, essential to all aspects of technology execution. Without attention to these enablers, it will be very difficult for the department to sustain the transformation needed in S&T planning and execution. These enablers fit into the following areas:

- **Human resources**. In-house technical expertise needs to be revitalized in order to ensure technological superiority over the long-term.
- **Systems engineering**. DOD needs to strengthen its systems engineering capabilities to oversee the development of complex systems-of-systems.
- **Budgets**. Budget flexibility is needed to enable an agile process that can respond rapidly to new challenges and opportunities.
- **Industrial base**. Steps are needed to revitalize internal research and development in industry and foster competition.
- **Incentives**. Competition, accountability, and *earned* award fees provide incentives to value innovation, speed, agility, and prudent risk taking.
- **Ubiquitous connectivity and security**. Data, information, and knowledge must be able to flow rapidly and securely from all sources to all users.

Human Resources

Concerns about the state of the K-12 education system in the United States have been raised in many studies.[23] In its 2001 report, the Hart-

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23. *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Future*. National Academy of Sciences, National Academy of Engineering, and Institute of Medicine of the National Academies. October, 2005. *National Defense Education and*

Rudman Commission raises the problem to the status of a national security crisis. The report states: “Second only to a weapon of mass destruction detonating in an American city, we see nothing more dangerous than failure to properly manage science, technology, and education … The inadequacies of our systems of research and education pose a greater threat to our national security … than any conventional war.”[24]

The problem is most severe in math and science. As observed in a recent National Academies report: “The scientific and technical building blocks of our economic leadership are eroding at a time when many other nations are gathering strength … This nation must prepare with great urgency to preserve its strategic and economic security.”[25]

DOD is among the institutions most vulnerable to the impending shortage of highly trained engineers and scientists. The DOD civilian corps is particularly vulnerable due to an aging workforce, outsourcing of research, and non-competitive pay. There is little career development or education (as opposed to training) available for civil servants. On the military side, the situation for the acquisition workforce is similar. (In the late 1960s, the Air Force ran a Blue Room, focused on the officer corps, to ensure the best talent was available for that service’s programs.)

Skill sets in which there is inadequate supply in DOD include systems engineering, including the broader disciplines of systems analysis and system-of-systems engineering; biological science; and the broad subset of social sciences that deals with organized human behaviors.

Innovation Initiative: Meeting America’s Economic and Security Challenges in the 21st Century, American Association of Universities, January 2006. *Losing the Competitive Advantage? The Challenge for Science and Technology in the United States*, AEA, August 2006.

24. *Road Map for National Security: Imperative for Change*, Phase III Report of the U.S. Commission on National Security/21st Century. February 15, 2001.

25. *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Future*.

Recommendation: Human Resources

Institute a dedicated career development organization for DOD's technical workforce—military and, especially, civilian—to develop and sustain the existing workforce as well as develop and execute recruitment strategies to add highly-qualified scientists and engineers.[26]

The Science, Math, and Research for Transformation (SMART) National Defense Education Program (NDEP), mandated by Congress in 2005, should be protected, expanded, and targeted to the most critical DOD needs.

Expand internship opportunities to foster early institutional ties through personal mentoring. Sponsor programs beginning at the high-school level, with the goal of reaching 50,000 to 100,000 students per year—an investment of $150 million per year.

Systems Engineering

Systems engineering is the process responsible for managing the trade-offs necessary to develop and field a system that is affordable, sustainable, delivered on schedule, satisfies users' needs, and minimizes risk The field of system engineering, as used in this broad sense, incorporates the following as sub-fields: system analysis, system architecture, system test, verification and validation, risk mitigation and management, virtual (system modeling and simulation driven) engineering, and product development.

DOD system engineering capability has declined over the past 10 years.[27] Factors contributing to this decline include manpower ceilings that were placed on the acquisition workforce following the collapse of the Soviet Union, an increase in government outsourcing, and various

26.The Air Force Blue Room activity, used in the late 1960s, is a model, and is described in Volume IV.

27. Supporting references include the *Defense Acquisition Personnel Assessment Report*, March 21, 2006 and *Defense Science Board/Air Force Scientific Advisory Board Joint Task Force on the Acquisition of National Security Space Programs*, May 2003.

acquisition reforms. Market forces played a role as well. As senior, experienced DOD system engineers retired, or left the field through transfers, the vacuum was not filled.

Recommendations: Systems Engineering

Re-establish the program-level position of chief system engineer, properly resourced, and reporting at a senior program level. This individual would be responsible and accountable for life cycle trade-space management and all system engineering decisions and actions.

Re-build the system engineering workforce in government and industry. Within DOD, this involves managing system engineering careers including: higher pay grades and opportunities for advancement; participation in quality professional societies and activities; and research and training in state-of-the-art system engineering tools.

Fund competitive research in industry and academia to develop improved system engineering tools and practices; use truly independent red teams to assure the quality of systems engineering applied to major programs and activities.

Budgets

Lack of funding flexibility and inadequate fiscal planning impede the acceleration of technology into fielded capability. Currently, two-year budget cycles and the inadequate level of R&D reprogramming authority inhibit the pursuit of technology options that could support agile acquisition. Senior managers need more flexibility to terminate less promising technology efforts and reprogram funds to support technology options with higher potential payoff.

Options for subsequent blocks in a spiral development process depend on the knowledge gained from research and development and experimentation. Adequate S&T investment is a key to providing technology options for future military systems. Of particular importance here is the support for basic and applied research. Over the past 30 years, basic and applied research has declined as a percentage of the overall science and technology budget from about 78 to 49 percent.

Recommendations: Budgets

For acquisition programs, restore the practice of establishing management reserves within that budget to handle unforeseen problems while maintaining schedule and cost baselines.

Budget funding for research, development, test, and engineering for future spirals through the future years' defense plan.

Sustain S&T funding at the real level of the fiscal year 2007 budget in order to maintain technological superiority.

The Industrial Base

This study raises two concerns: (1) reduction of IR&D within the defense industry and (2) reduced opportunities for competition due to defense industry consolidation.

The short-term focus of the defense industry has resulted in emphasis on bid and proposal to the detriment of IR&D. Causes include DOD's permitting contractors to merge IR&D and bid and proposal in their allowable overhead. As a result, industry has shifted its investments toward product sustainment rather than new technology development for future products.

The defense industry consolidation of prime and integrating contractors has been accompanied by vertical integration in the residual primes and integrators. They now have internal incentives to select products and subsystems from divisions of their company. This tendency shuts out 2nd and 3rd tier suppliers, and withers the industrial base.

The DOD can take steps to foster more competition and innovation in industry and thus help ensure technological superiority for the war fighter.

Recommendations: The Industrial Base ________________________________

DOD should:

Reinvigorate IR&D by requiring separate reporting for IR&D and bid and proposal. This can be implemented with a DOD regulatory change. Further, DOD should ask industry to set a corporate average as 3 percent of sales for the DOD-related IR&D budget.

Enforce full and open competition for 2nd and 3rd tier contractors by the prime and integrators in order to foster a vigorous industrial base. Prime contractors will need to establish formal and open make-or-buy decision processes, with DOD reviewing the plans and monitoring the execution.

Fund competitive, alternative sources of R&D to foster continued innovation (in performance, cost, etc.), and provide an alternative if the incumbent does not perform, as well as a competitor for the next spiral.

Incentives

Incentives play an important role in transforming the culture of an enterprise to value innovation, speed, agility, and prudent risk taking. The sound of the guns is a most powerful incentive and large parts of the DOD enterprise are making that transformation. One challenge is to migrate that culture into DOD's technology transition and acquisition processes. Proper incentives needs to be created and disincentives eliminated. The economic relationship between the government and the defense industrial base is an important component. Profit and other economic incentives can drive speedy technology transition for new capabilities and improvement to in-service systems.

Accountability and competition are potent incentive tools. The operational user has the greatest incentive to get capabilities to the field much more rapidly, but has had little influence on the process. Holding professionals in the government acquisition business accountable for system outcomes and using the outcomes as the basis for rewards and penalties would help to create an environment where speed and agility are valued.

Recommendations: Incentives

For industry, more closely align consequences (award fees, follow on contracts) to performance than is done today.

Hold professionals in the government acquisition business accountable for system outcomes and use the outcomes as the basis for rewards and penalties**.** With the shorter acquisition cycle it will be easier for individuals to directly be associated with program success or failure.

Give the combatant commands (the ultimate users) more influence in the requirements process and shaping the future force. *The Defense Science Board 2005 Summer Study on Transformation: A Progress Assessment* describes a way to accomplish this.

Ubiquitous Connectivity and Security

Data, information, and knowledge must be able to flow rapidly and securely from all sources to all users. Specific recommendations are provided in the report of the companion *Defense Science Board 2006 Summer Study on Information Management for Net-Centric Operations.*

Part III

Summary of Recommendations

Chapter 12.
Summary of Recommendations

This study had two major tasks:

- identify a set of 21st century operational capabilities and their enabling technologies
- recommend how DOD should conduct strategic technology planning and speed the transition of technology into fielded capability

This chapter concludes the report with a summary of key findings and recommendations.

Critical Capabilities and Enabling Technologies

Based on missions identified in the Quadrennial Defense Review, the study identified four critical capabilities that support the full range of future military missions

- mapping the human terrain
- ubiquitous observation and data recording in difficult terrain
- contextual exploitation: rapidly extracting actionable information hidden in massive clutter
- rapidly producing effects tailored to the circumstances

The set of capability vectors and enabling technologies identified in this study are expected to spur debate, further analysis, and prioritization. They provide a focus to inform DOD science and technology planning, to redistribute S&T investments, and to forge new partnerships and relationships. They will not be the ultimate word on the subject. Although this set of capabilities was crafted to a great extent to deal with uncertainty, the evolving U.S. strategy and uncertainty about the future security environment will continue to foster new thinking about critical needs. A major challenge will be to avoid the tendency to generate large lists without prioritization.

The overarching recommendation is that DOD refocus its S&T priorities and investments to emphasize technology development in these four areas. Some specific recommendations are summarized below. More detail is provided in Volume II of the report.

Recommendations: Human Terrain Preparation

Increase the priority and accelerate the creation of a continuous learning environment for training and professional military education to include:

- more exploitation of commercially developed distance learning tools and more experiments on alternative approaches
- creating a DOD program linking service efforts to design training tools and processes to develop cognitive decision making skills in junior leaders
- rewarding service members for pursuing less structured but equally compelling professional military programs of study that develop their skills in human terrain preparation
- assigning higher priority and more resources to the development of immersive games, simulators, training, and mission-rehearsal tools to develop multi-cultural interpersonal skills supporting small unit operations

Sustain a long-term commitment and robust effort to develop and adapt automated language processing technologies.

Develop an S&T roadmap for human, social, cultural, and behavior (HSCB) modeling and create an S&T portfolio for such modeling that would

- attract the best and brightest from the HSCB community to work DOD problems (this could involve expanding the Defense Science Study Group program to include social scientists)
- establish HSCB modeling benchmarks, metrics, experimentation, and validation techniques

- be closely connected to the combatant commands and other potential users

Recommendation: Ubiquitous Observation and Recording

- The Army, Marines, and DARPA should partner in an effort to accelerate the maturation of the “soldier-as-sensor” concept. The program should also include the development of relevant miniature sensor technologies and automated debriefing tools.
- A sustained series of ATDs and ACTDS should be supported through DARPA and DDR&E to develop and demonstrate the ability to task and integrate local collection with wide area assets. U.S Strategic Command and U.S. Southern Command should be major participants in these activities because of their global ISR responsibilities.
- DARPA and related R&D agencies should sustain a focused program to develop energy-efficient microsensors and the platforms to deliver them, along with development of the systems network concepts to enable close-in sensing.

Recommendations: Contextual Exploitation

- Conduct a major review of ongoing efforts to prioritize, integrate, as necessary, and identify areas where additional funding can accelerate maturation of key technologies.
- Establish goals and metrics to monitor progress; such as exabyte storage, terabyte-per-second data transfer, seconds-to-minutes analysis and decision cycle time.
- Relax restrictive rules for obtaining access to new sources of technology coming from outside DOD and often outside of the United States.
- Recruit non–DOD partners—the Departments of Health and Human Services, Homeland Security, Transportation, Justice, State, and Commerce, as well as private entities—as sources, developers, and users.

Recommendations: Rapidly Tailored Effects

For influence operations:

- DOD should undertake a major research and tool development effort to understand and enhance the training and execution (including assessing results) of influence and related non-kinetic operations. This effort should include developing credible "cause-effect" models.
- DARPA and the service laboratories, working with U.S. Strategic Command and other combatant commanders, should expand emphasis for dealing with uncertainty and ambiguity in decision support tool development and for providing credible "cause-effect" models. Good use should be made of advances in the commercial sector.

For time-critical conventional strike:

- DOD should develop a comprehensive plan to evolve this capability. The plan should encompass both nearer term options and radically new potential capabilities that could result from R&D in directed energy or other technologies. The plan should be supported by a careful systems analysis of the various options, using quantitative measures of effectiveness, and spanning all of the critical issues including the requisite real-time decision-making.

For WMD protection and mitigation:

- Increase medical surge capabilities by developing rapid diagnostics and broad spectrum treatments and broadening the cadre of trained personnel.
- Increase preparedness for crisis communications by preplanning content and improving regional communication systems.
- Institute multi-level planning to prepare regional response assets and enable rapid integration of federal support.
- Reassess restoration processes and cleanup standards for a range of WMD attack scenarios.

- DOD leadership should re-instate nuclear survivability as a security requirement in critical war fighting and support functions.

Strategic Technology Planning and Technology Transition

Three themes shaped the study's recommendations in these areas:

1. The Department of Defense can meet the strategic challenges of the 21st century only with a tighter coupling of the user and technology communities.

Recommendations: Strategic Technology Planning

- The Under Secretary of Defense for Acquisition, Technology and Logistics and the Vice Chairman, Joint Chiefs of Staff should create a small set (no more than five) of mission-focused portfolio activities.
- Integrate the output of these activities into a department-wide strategic technology plan.
- The plan should include working with other government agencies, allies, and partners and helping them increase their capacities and capabilities and the ability to work together.

2. DOD's technology community must increase its capacity to understand and exploit technology opportunities, especially those that exist outside of DOD's domain.

Recommendations: Technology Opportunities

- Promote more "bottom-up" discovery to create disruptive capabilities. The DDR&E should make disruptive potential a priority area of S&T activity and be the department-wide focal point. Working with the services, defense agencies, and other U.S. government S&T communities, the DDR&E should commit an additional $200 million per year to fund initiatives with disruptive potential.

- Foster greater understanding and exploitation of commercially available technology by establishing a DDR&E Center for the Application of Commercial and Foreign Technology, and expanding the use of "other transaction authority" and other means to enable commercial firms to undertake business with the DOD.
- Establish a much more comprehensive approach to anticipate how adversaries might exploit technology by increasing S&T intelligence to understand what adversaries are doing, enhancing red teaming to identify what adversaries could do, and conducting net assessments to understand the consequences. Expand and assign higher priority to the current DDR&E and USD (I) Scientific and Technical Net Assessment Program.

3. Transitioning technology rapidly into fielded products is a key to meeting the national security challenges of the 21st century.

The study addressed two dimensions of technology transition: inserting technology solutions into ongoing operations and the need for more agile, rapid major systems acquisition.

Recommendation: Expeditor

- Create a Rapid Fielding Organization to satisfy the growing list of war-fighter-related needs, over what is anticipated to be an extended period of "long war." Combine most of the current "rapid" and "agile" programs into the RFO, leaving some programs remaining within the services, but coordinated with the RFO.

Recommendations: Major Systems Acquisition

- Assure that rigorous systems engineering/analysis; accounting for cost; and technology, manufacturing, and integration readiness underpins input to the requirements process.
- Provide timely decisions on requirements relief during the program execution phase.
- Make Milestone A mandatory for major systems acquisition.

- Plan multiple technology demonstrations to generate more options and minimize single points of failure.
- Mandate the use of spiral development to provide the initial operational capability of each block within five years of the initiation of SDD of that block. Conduct, in parallel, robust R&D and experimentation to provide options for future blocks.

Improved capabilities in several cross-cutting areas will be essential to achieve such a broad transformation in S&T planning and execution.

Recommendations: Cross-cutting Enablers

- **Technical expertise.** Institute a dedicated career development organization for DOD's technical workforce. Protect and expand the Science, Math, and Research for Transformation NDEP program. Expand internship opportunities.
- **Systems engineering**. Rebuild the system engineering workforce and re-establish the program-level position of chief systems engineer.
- **Budget flexibility**. Restore practice of establishing management reserves within acquisition programs. Sustain S&T funding at the real level of the fiscal year 2007 budget.
- **Industrial base.** Reinvigorate IR&D by requiring separate reporting for IR&D and bid and proposal; enforce full and open competition for 2nd and 3rd tier contractors by the prime and integrators; and fund competitive, alternative sources of R&D.
- **Incentives**. For industry, more closely align consequences (award fees, follow on contracts) to performance than is done today. Hold professionals in the government acquisition business accountable for program successes and failures. Give the combatant commands (the ultimate users) more influence in the requirements process and shaping the future force.

- **Ubiquitous connectivity and security**. Data, information, and knowledge must be able to flow rapidly and securely from all sources to all users. Specific recommendations are provided in the report of the companion *Defense Science Board 2006 Summer Study on Information Management for Net-Centric Operations.*

The processes and practices in DOD today—that largely evolved during the Cold War—must be shaped to deal with new security challenges. The recommendations presented in this report will enable such a transformation—infusing the knowledge, agility, flexibility, and speed that are essential to future success.

Appendix A.
Terms of Reference

THE UNDER SECRETARY OF DEFENSE
3010 DEFENSE PENTAGON
WASHINGTON, DC 20301-3010

ACQUISITION,
TECHNOLOGY
AND LOGISTICS

JAN 13 2006

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Terms of Reference – 2006 Summer Study on 21st Century Strategic Technology Vectors

Many technology thrusts were initiated during the Cold War to support operational needs, but a few strategic capabilities proved enormously successful to enhancing U.S. combat capabilities. Stealth, speed, precision, and tactical ISR were developed to penetrate enemy battlespace with minimal losses and increase combat effectiveness. These capabilities provided the highest operational leverage, especially against State actors who chose massed force on force modes of conflict. Although hindsight easily verifies the importance of these capabilities, their implementation was uneven and problematic.

Today, adversaries (both State and non State) have moved away from massed forces to negate or mitigate U.S. combat capabilities. Denial and deception proved very effective in reducing air power effectiveness in the Kosovo air campaign. Dual use technology bestows strategic capability to small groups for relatively low investments and also allows both State and non State adversaries to economically develop effective countermeasures which lessen U.S. capabilities. The very nature of dual use technology creates significant uncertainty about any group's capabilities. Non state actors exploit seams in the international system by operating within the boundaries of sovereign states and take advantage of legal systems to plan, equip and train their forces. In effect, adversaries created operational safe havens against U.S. military capabilities.

In addition, the Department of Defense (DoD) is increasingly involved in two major mission areas of non combat operations. These include stability operations and domestic civil support missions during catastrophic natural incidents or WMD events. These mission areas stress DoD differently than combat operations and require the identification and development of new DoD capabilities.

The next generation of DoD capabilities must counter or negate safe havens and provide more effective capability in the new mission areas. Potential operational mission characteristics include:

1) US and allied freedom to operate in both State and non State's safe havens in order to deny the adversary sanctuary;
2) Ability to identify and track at suitable standoff distances, material, transactions, and items of interest across all environments;
3) Creation of sufficient situational awareness at all user levels to know when action is required and then act upon it with a high degree of effectiveness.
4) Ability to avoid substantial collateral damage and non-combatant casualties in all environments.

The Summer Study should:

1) Review previous attempts (both successful and not) by DoD to identify critical technologies in order to derive lessons that would help illuminate the current challenge;
2) Identify the National Security objectives for the 21st century and the operational missions that U.S. military will be called upon to support these objectives;
3) Identify new operational capabilities needed for the proposed missions;
4) Identify the critical science technology, and other related enablers of the desired capabilities. In addition, the Study should identify the initiatives and developments needed to achieve these enablers including human capital and industrial base issues;
5) Assess current S&T investment plans' relevance to the needed operational capabilities and enablers and recommend needed changes to the plans;
6) Identify mechanisms to accelerate and assure the transition of technology into U.S. military capabilities.
7) Review, and recommend changes as needed, the current processes by which national security objectives and needed operational capabilities are used to develop and prioritize science, technology, and other related enablers, and how those enablers are then developed.

The Study will report its results on an interim basis to me. Its final product should provide an evaluation process by which decisions can be made and a technology roadmap to achieve the desired operational capabilities.

The study will be sponsored by me as the Under Secretary of Defense (Acquisition, Technology and Logistics), and Director, Defense Research and Engineering. Dr. Ted Gold and Dr Bill Graham will serve as the Summer Study Chairmen. Ms. Beth Foster will serve as the Executive Secretary. CDR Cliff Phillips will serve as the Defense Science Board Secretariat representative.

The Task Force will operate in accordance with the provisions of P.L. 92-463, the "Federal Advisory Committee Act," and DOD Directive 5105.4, the "DoD Federal

Advisory Committee Management Program." It is not anticipated that this Task Force will need to go into any "particular matters" within the meaning of Section 208 of Title 18, U.S. Code, nor will it cause any member to be placed in the position of acting as a procurement official.

Kenneth J. Krieg

Appendix B. Study Membership

CHAIRMEN

Name	Affiliation
Theodore Gold	Private Consultant
William Graham	Private Consultant

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Mary Margaret Evans	Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics
Christina Filarowski-Sheaks	Office of the Under Secretary of Defense for Policy
Dan Flynn	Central Intelligence Agency
Robert Foster	BioSystems, OSD
Brendan Godfrey	Air Force Office of Scientific Research
Joanna Ingraham	Defense Threat Reduction Agency
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Lt Col Dave Pere, USMC	U.S. Marine Corps
Jonathan Porter	Office of the Deputy Assistant Secretary of the Air Force for Science, Technology, and Engineering
Terry Pudas	Force Transformation Office, Office of the Secretary of Defense
Dennis Schmidt	Office of the Assistant Secretary of the Army, for Acquisition, Logistics and Technology
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Grace Johnson	Strategic Analysis, Inc.
Brad Smith	Strategic Analysis, Inc.
Stacy Zelenski	Strategic Analysis, Inc.

Appendix C.
Presentations to the Task Force

Name	Topic
FEBRUARY 15–16, 2006	
Honorable John J. Young, Jr. Director, Defense Research and Engineering	Research and Engineering Perspective
Major General David Fastabend, USA Deputy Director/Chief of Staff, Futures Center, U.S. Army Training and Doctrine Command	Future Warfare...The Next Big Thing
Brigadier General Thomas Waldhauser, USMC, Deputy Commanding General, Marine Corps Combat Development Command	How the Marine Corps Sees the Future of Warfighting
Dr. Timothy Stearns, Associate Professor, Departments of Biological Sciences and Genetics, Stanford University	The Threat of Biotechnology
Major General Michael Vane, USA Vice Director for Force Structure, Resources and Assessment, J-8	Delivering Joint Capabilities to the Warfighter
Dr. Craig Fields	What is Technology Strategy?
Colonel Patrick Kelly	Quadrennial Defense Review Strategy
Mr. Jeff Green DOD Office of the General Counsel	Standards of Conduct
MARCH 13, 2006	
Mr. Kevin Woods Institute for Defense Analyses	The Iraqi Perspectives Project
Mr. Michael Vickers, RAND	Technology Implications of the 2005 Quadrennial Defense Review
Major General Mike Worden, USAF Dr. Thomas Cruse	Defense Technology Challenges—An Air Force Perspective

APRIL 20, 2006

Philip Anton, RAND	Technology Revolution 2020: Bio/Nano/Materials/Information Trends, Drivers, Barriers, and Social Implications Report

MAY 15–16, 2006

Mr. Dan Flynn Director, Long-range Military-security Program, Office of the Director of National Intelligence	Foreign Perspectives on Future War: Emerging Disruptive Challenges
Honorable John J. Young, Jr. Director, Defense Research and Engineering	Discussion
ADM Michael Mullen USN Chief of Naval Operations	Discussion

JUNE 7, 2006

ADM Edmund Giambastiani, USN Vice Chairman, Joint Chiefs of Staff	Discussion
Mr. Alan Shaffer Office of the Director, Defense Research and Engineering	DOD Science and Technology Program
Ms. Monica Shephard and Col Bob Morris Joint Forces Command	Discussion

Appendix D.
Technology Maturity

The Future Capabilities and Enabling Technologies panel judged each constituent technology with respect to its development maturity and uniqueness to the Department of Defense. This analysis led to a simple categorization scheme, shown in the following set of tables, one for each of the four critical capabilities.

Table D-1. Human Terrain Preparation

Technology Areas	Promising but Immature	Under Development Showing Progress	Leverage Commercial Developments	Mature in DOD
Rapid training and continuous learning	Human/team performance measurement	Language/culture/ leadership tutoring tools	High-fidelity immersive games, training and mission rehearsal (GTMR) tools	
Automated language processing		Foreign-to-English translation Speech-to-text transcription	Information management and text processing	
Human, social, cultural, and behavior (HSCB) modeling	Macro HSCB models Micro HSCB models Integrated micro-macro models			

Table D- 2. Ubiquitous Observation and Recording

Technology Areas	Promising but Immature	Under Development Showing Progress	Leverage Commercial Developments	Mature in DOD
Day/night all-weather wide area surveillance	High altitude, long endurance platforms Giga-pixel optical imaging	Space based GMTI/SAR		Active/ passive hyperspectral sensors Foliage penetration sensors
Close-in sensor and tagging systems	Stealthy, precision delivery platforms Microsensor technologies	High performance, high efficiency signal processing Ultra high density packaging for millimeter-scale sensors and tags Native signature recognition at long ranges (human and object)	Efficient energy storage technology	Miniature sensor and tag technology High-density packaging for centimeter-scale devices
Soldier as a collector	Miniature sensor technology Interactive automated debriefing	All-domain precision geolocation Soldier centric communications and networking technology Body borne flexible displays	Efficient energy storage technology	

Table D-3. Contextual Exploitation

Technology Areas	Promising but Immature	Under Development Showing Progress	Leverage Commercial Developments	Mature in DOD
Mega-scale data management		Multi-level security and accreditation	Data management and fusion from very diverse sensors	
Situation dependent information extraction		Contextual analysis and intent recognition Entity, relationship and pattern analysis Data-to-information -to- target recognition	Information retrieval and knowledge discovery	
Human/ system collaboration	Human-guided algorithms		Natural man-machine interface Knowledge representation	

Table IV-4. Rapidly Tailored Effects

Technology Areas	Promising but Immature	Under Development Showing Progress	Leverage Commercial Developments	Mature in DOD
Influence operations	Kinetic and non-kinetic cause/ effect models	Decision support tools incorporating complexity and ambiguity	Storytelling, gisting, and advanced visualization Gaming technology for campaign planning, targeting, shaping	
Time-critical conventional strike	Directed energy weapons Hypersonic delivery vehicles			Ballistic missile technology
WMD protection and mitigation	Rapid diagnostics and environmental monitoring, including standoff biological and radiation detection Broad spectrum medical counter-measures	Decontamination technologies Nuclear weapons effects prediction, mitigation		

Appendix E.
Glossary

ATD	advanced technology demonstration
ACTD	advanced concept technology demonstration
DARPA	Defense Advanced Research Projects Agency
DDR&E	Director, Defense Research and Engineering
DOD	Department of Defense
DOTMLPF	doctrine, organization, training, materiel, leadership, and education, personnel and facilities
DSB	Defense Science Board
DTIC	Defense Technical Information Center
EMP	electromagnetic pulse
GALE	Global Autonomous Language Exploitation
GPS	Global Positioning System
HSCB	human, social, cultural, and behavior
IR&D	independent research and development
ISR	intelligence, surveillance, and reconnaissance
JROC	Joint Requirements Oversight Council
NDEP	National Defense Education Program
OODA	observe, orient, decide, act
QDR	Quadrennial Defense Review
R&D	research and development
RFO	Rapid Fielding Organization
S&T	science and technology
SDD	system design and development
SMART	Science, Math, and Research for Transformation
SSBN	ballistic missile submarine (nuclear)
TRL	technology readiness level
UAV	unmanned aerial vehicle
USD (AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics
USD (I)	Under Secretary of Defense for Intelligence
VCJCS	Vice Chairman, Joint Chiefs of Staff
WMD	weapons of mass destruction