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on

21st Century Strategic Technology Vectors

Volume II
Critical Capabilities and Enabling Technologies

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Volume I of the Defense Science Board 2006 Summer Study on 21st Century Strategic Technology Vectors represents the consensus view of the study's membership. This volume (II) is the report of the Critical Capabilities and Enabling Technologies panel of the summer study. Its findings and recommendations were used to create volume I and it provides additional detail. Findings and recommendations provided in this and the other panel reports (volumes III and IV) do not necessarily represent the consensus view of the full summer study membership.

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Chapter 1. Introduction

The Capabilities Panel was charged by the terms of reference to do several things:[1]

1. Examine the operational missions that the U.S. military might be called upon to perform in support of emerging national security objectives.
2. Identify new operational capabilities that would be needed to successfully accomplish those missions.
3. Identify the critical science, technology, and other related enablers of the desired capabilities.

To accomplish these tasks, it was first necessary for the panel to define exactly what was meant by "mission," "capability," and "technology," and define the criteria that would be used to measure criticality. The panel adopted the following definitions:

Mission. The task, together with the purpose, that clearly indicates the action to be taken and the reason therefore (Department of Defense [DOD] definition).

Capability. The ability to execute a specified course of action (DOD definition). The panel found it useful to think of capability as the tasks associated with performing a particular mission to a set standard.

Technology. A science- or engineering-based way of doing things that supports one or more capabilities.

Whether or not a capability could be thought of as critical, would be based on three reasons:

1. Appendix A contains the terms of reference for the Defense Science Board 2006 Summer Study.

1. A lack of the capability will expose the United States to great risk.
2. The need for the capability will be essential for the successful execution of a mission.
3. Possession of the capability will give the United States an asymmetric advantage.

Likewise, the panel decided that technologies would be critical if they:

- are essential to achieve a critical capability
- are essential for achieving a number of important capabilities
- contribute significantly to a number of critical capabilities
- can be employed by adversaries in ways that can defeat U.S. capabilities

The panel looked to the Quadrennial Defense Review (QDR) for help in identifying operational missions. The panel made the assumption that those missions specifically highlighted in the document were those of greatest interest to the department. They were:

- defeat terrorist networks
- prevent acquisition and use of weapons of mass destruction (WMD)
- defend the homeland
- shape nations at strategic crossroads

To these missions the panel added stability, security, transition, and reconstruction (SSTR) operations. This addition was made based on the belief that SSTR operations will be an important mission in the future just as it is today in Iraq and Afghanistan.[2] The decision to concentrate on the missions highlighted in the QDR, with the addition of SSTR, had the effect of forcing this study away from an examination of conventional warfare and toward more non-traditional missions and capabilities.

2. The term SSTR, referenced in the 2006 ODR, was adopted as of November 28, 2005, in DOD Directive 3000.05.

In the chapters that follow, this report explains the methodology used by the panel to examine the five selected missions and the process by which the most important capabilities, their enabling technology areas, and the constituent technologies that underpin them were identified. Chapters 4–7 examine each of the capabilities in greater detail, making judgments and recommendations on how the department can best achieve the desired capabilities. Chapter 8 discusses technology push as it relates to capability achievement. The report concludes with a summary of its key findings and recommendations.

Chapter 2. Analysis Methodology

Due to the breadth of the task with which the panel was charged, it was decided early on that an analysis framework was required to assist in organizing the panel's deliberations and assuring consistency and discipline in identifying the most important technologies for the department. This approach also ensured that there was a traceable audit trail to illustrate how and why the study conclusions were reached. While the panel did some "technology push" brainstorming, the analysis framework was driven by critical missions and capabilities that the panel concluded were required by the department.

Figure 1 provides an overview of this analysis framework, which will be described in the remainder of this chapter. One of the key elements of the approach is that it was conducted by a small group of broadly experienced senior people in an environment that fostered discussion and debate. The panel was composed of roughly equal numbers of retired general officers with operational experience, and industry and laboratory executives with deep technical backgrounds.[3] This balance was essential to achieving the end results. Neither technologists nor operators alone would have been able to evaluate the potential of developing technologies, determine their impact on required capabilities, and effectively rate the contribution of the capabilities on the mission objectives.

The framework also forced the group to make choices. The tendency to treat all technologies and capabilities as being equally important was resisted. By rating the impact of candidate capabilities on required missions and the impact of the technologies on the desired capabilities, the panel created prioritized lists of both capabilities and technologies. These results were then examined and discussed by the panel to develop insights that provided feedback to earlier steps in the process. The panel discussions also aggregated related capabilities to define four high-level critical capabilities that were the central result of the study. This feature of using an analytic framework informed by seasoned judgment is an important difference from many of the

3. Appendix B lists the panel membership.

existing methodologies currently in use in the department, such as the Joint Capabilities Integration and Development System (JCIDS) where the process dominates and is so cumbersome that it is difficult to develop focused conclusions or to see end-to-end solutions whole.

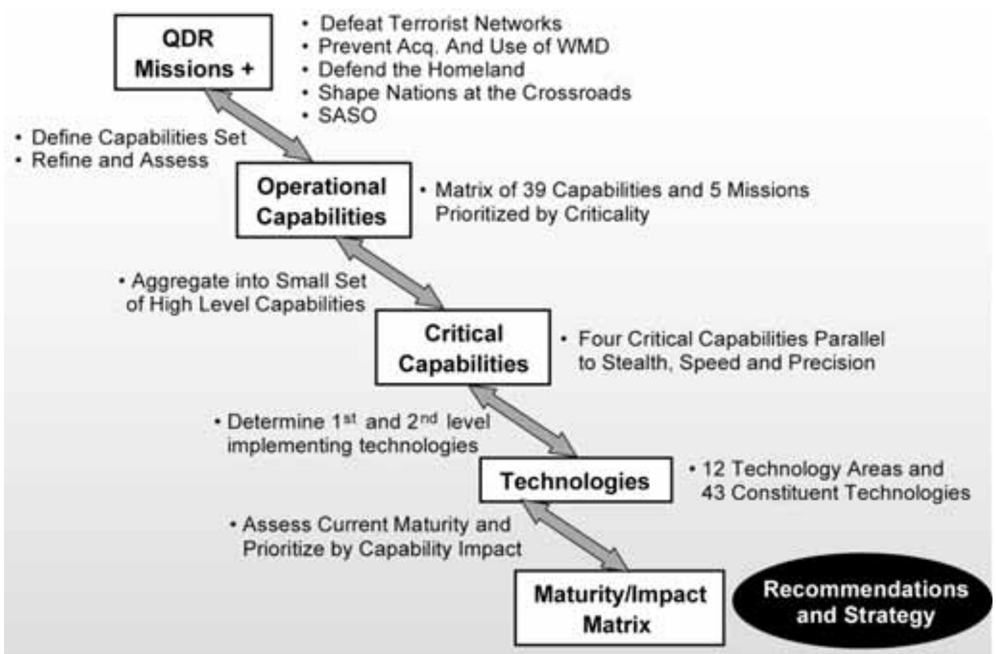

Figure 1. Summary of Analysis Framework

Embedded in the analysis are important assumptions that had significant impact on the study conclusions. For example, the fact that all missions were weighted equally placed a premium on breadth—capabilities and technologies that impacted many missions were rated higher than those narrowly focused on only a single mission. Others could make different assumptions and consequently draw different conclusions. The panel did not try to justify its assumptions. Rather, it identifies them explicitly in the following sections so that the analysis can be repeated if different assumptions are desired.

Missions

As stated in the introduction, the panel started with the Quadrennial Defense Review (dated February 6, 2006) in which the department's civilian and military leaders identified priority areas for the foreseeable future:

- defeating terrorist networks
- defending the homeland in depth
- shaping the choices of nations at strategic crossroads
- preventing hostile state and non-state actors from acquiring or using WMD

The panel decided to add stability, security, transition, and reconstruction (SSTR) as a fifth mission because it is—and will remain—a priority mission along with the QDR list, as exemplified in the current operations in Iraq and Afghanistan. There was also some uncertainty about the meaning of the QDR mission "shaping the choices of nations at strategic crossroads." The panel chose to interpret this mission broadly so that it includes both addressing emerging nation-state peer competitors and influencing lesser states that are truly at strategic crossroads.

In its analysis, the panel treated all five of the missions with equal weight. The implication of this decision is that capabilities and technologies that have broad applicability were given more import than those that narrowly addressed only a single mission.

Operational Capabilities

After framing the mission drivers, the panel developed the set of operational capabilities that would be used to assess the impact of candidate technologies. The process for this effort relied extensively on the experiences of the entire study team, especially the military officers. Each study participant, including the government advisors, was asked to identify the three most important capabilities that, in their judgment, were required to execute the five missions. This survey produced over 100 operational capability recommendations.

A small group within the panel reviewed the inputs to eliminate duplication and combined closely-related capabilities to define the 39 operational capabilities that formed the basis for the subsequent work within the study. In making these recommendations, the guidance was to give priority to those capabilities which the department needed most to improve. As a result, many important areas, such as improved precision or stealth, were considered "good enough" in a comparative sense and did not appear on the consolidated list.

After review by the entire panel, the capabilities were prioritized by weighting their impact on each of the five missions according to the following criteria:

- crucial, to indicate that the mission could not be completed without the capability
- important, to indicate that the capability made significant contributions to mission success
- contributes, to indicate that the capability was somewhat useful to the mission
- not applicable

The detailed results of this process are presented in Appendix C and summarized in tables 1 through 3. In these table, the capabilities are sorted into three groups of decreasing priority: (1) the highest containing those capabilities that are deemed crucial to two or more missions, (2) the next containing those that are crucial to one mission, and (3) the last containing those capabilities that may be important but have not been assessed as absolutely crucial to any mission. Within each group relative priorities were established by the number of capabilities deemed "crucial," "important," and "contribute."

These capabilities were then compared with the Level 1 and Level 2 Joint Capability Areas (JCAs) to ensure that there were no important omissions from the study.[4] The only significant difference between the

4. JCA Tier 1 & Tier 2 Taxonomy, as listed in "Joint Capability Areas," briefing provided by the Office of the Chairman, Joint Chiefs of Staff, August 24, 2005.

study's 39 operational capabilities and the 102 Level 2 JCAs is the fact that many of the JCAs were mapped into two of the study's operational capabilities—air / land / sea supremacy and force / strategic asset protection. The reason for this is that the JCA placed more emphasis on war fighting than did the QDR augmented with the SSTR mission.

Table 1. Capabilities Crucial to Two or More Missions

	Missions				
	Terro	Home	WMD	Xroad	STTR
Human Intelligence	Crucial	Crucial	Crucial	Crucial	Crucial
Knowledge discovery/data fusion/decision support	Crucial	Crucial	Crucial	Crucial	Crucial
Identify, covertly tag and track people and objects globally	Crucial	Crucial	Crucial	Not Applicable	Crucial
Culture/language understanding	Crucial	Important	Crucial	Important	Crucial
Strategic surprise anticipation	Crucial	Crucial	Crucial	Important	Important
Covert penetration ops	Crucial	Important	Crucial	Important	Crucial
Modeling societal dynamics, stability and influencers	Crucial	Important	Contributes	Crucial	Crucial
Info security/IW/cyber supremacy	Crucial	Crucial	Contributes	Crucial	Contributes
Strategic communication	Important	Important	Important	Crucial	Crucial
Air/land/sea supremacy	Important	Crucial	Important	Important	Crucial
Strategic shaping	Contributes	Important	Crucial	Crucial	Important
Joint precision strike from sanctuary	Important	Important	Crucial	Crucial	Contributes
Support/enforce int'l treaties and alliances	Important	Important	Crucial	Crucial	Contributes
Rapid strategic decision making and translation to war plans and ops	Important	Crucial	Crucial	Important	Contributes

LEGEND: Crucial; Contributes; Important; Not Applicable

Note: Tables 1–3 use the following abbreviations for the 4 QDR mission areas: Terro (defeating terrorist networks); Home (defending the homeland in depth); WMD (preventing hostile state and non-state actors from acquiring or using WMD); Xroad (shaping the choices of nations at strategic crossroads).

Table 2. Capabilities Crucial to One Mission

	Missions				
	Terro	Home	WMD	Xroad	STTR
Persistent ISR of fixed and mobile targets	Important	Important	Important	Important	Crucial
Civil affairs and reconstruction	Contributes	Important	Not Applicable	Important	Crucial
Maritime domain awareness	Contributes	Crucial	Important	Contributes	Not Applicable
Remote WMD detection	Not Applicable	Crucial	Important	Contributes	Contributes
Small unit leadership training	Important	Contributes	Not Applicable	Not Applicable	Important
Secure/render safe WMD	Not Applicable	Important	Crucial	Not Applicable	Contributes
Soldier focused capability (“strategic corporal”)	Important	Not Applicable	Not Applicable	Not Applicable	Crucial
Medical surge for mass destruction events	Contributes	Crucial	Not Applicable	Contributes	Contributes
Broad spectrum medical treatments and preventatives	Contributes	Crucial	Not Applicable	Contributes	Contributes
Portal CBRN detection and ID	Not Applicable	Crucial	Contributes	Not Applicable	Contributes
Consequence management	Contributes	Crucial	Contributes	Not Applicable	Not Applicable
Small unit/soldier protection	Contributes	Not Applicable	Not Applicable	Not Applicable	Crucial

LEGEND: Crucial Contributes Important Not Applicable

Table 3. Other Important Capabilities

	Missions				
	Terro	Home	WMD	Xroad	STTR
Rapid training for quick reaction missions	Important	Contributes	Important	Contributes	Important
Survivable global joint tactical communications	Contributes	Important	Contributes	Contributes	Important
Joint networked C2	Contributes	Important	Contributes	Contributes	Important
Immersive live/virtual/constructive training	Contributes	Important	Contributes	Not Applicable	Important
Force/strategic asset protection	Contributes	Important	Not Applicable	Contributes	Important
Rapid task organization and force reconstitution	Contributes	Contributes	Not Applicable	Important	Contributes
Rapid decontamination	Contributes	Important	Contributes	Not Applicable	Not Applicable
Offensive and defensive space dominance	Not Applicable	Contributes	Not Applicable	Important	Not Applicable
Efficient power generation and storage	Contributes	Not Applicable	Not Applicable	Not Applicable	Important
Reduced footprint	Not Applicable	Not Applicable	Not Applicable	Contributes	Important
Rapid logistics	Not Applicable	Not Applicable	Not Applicable	Important	Contributes
Undersea warfare	Not Applicable	Not Applicable	Not Applicable	Important	Not Applicable
Rapid resource delivery to the battlefield	Contributes	Not Applicable	Not Applicable	Contributes	Contributes

LEGEND: Crucial Contributes Important Not Applicable

Critical Capabilities

The panel examined the ranking of operational capabilities with the goal of collecting similar or mutually supporting capabilities into a small set of “critical capabilities” as defined in the introduction. These became the study’s recommendations to the department as the modern analogs to “speed, stealth, and precision” as requested in the study’s terms of reference. In accomplishing this task, attention was limited to approximately the top half of the operational capabilities. The dividing line was established at “soldier focused capability,” at and above which all capabilities are crucial to at least one mission and important or crucial to at least one other mission. The result of this effort was the definition of four critical capabilities that represented consolidation of the crucial/important operational capabilities:

1. human terrain preparation
2. ubiquitous observation and recording
3. contextual exploitation
4. rapidly tailored effects

These four critical capabilities are all interdependent, as illustrated in figure 2. Each requires the other, in and of itself, and the set of four is needed to provide a fully effective posture to address the QDR plus SSTR missions. In fact, in the view of the panel, the four capabilities with their interconnectedness define a 21st century transformation of the observed-orient-decide-act (OODA) loop. Each of these critical capabilities and the operational capabilities that compose them are discussed briefly in the remainder of this chapter. They are discussed in further detail, along with the key technology areas and their constituent technologies, in Chapters 4–7.

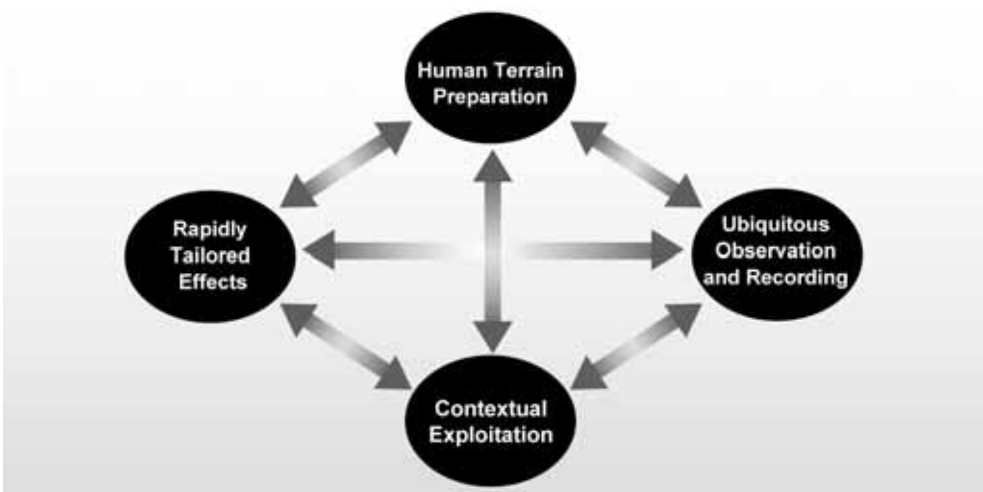

Figure 2. Four Broad Capability Categories—an OODA-like Loop for the 21st Century

Human Terrain Preparation

In the Cold War, significant intellectual effort was directed at understanding and developing strategies to counter the Soviet Union. The nation now faces a much more complex set of adversaries, both state and non-state actors, about whom a comparable understanding has not been developed. The terrorist threat, in particular, with its amorphous, loosely networked characteristics makes this an especially challenging problem. Since much of the action against both terrorists and insurgents will be conducted by small units, either special or conventional forces in situations other than major combat operations, decisions made at lower levels of command will have the potential for broad-reaching, even strategic consequences. Consequently, preparing the human terrain—both ours and theirs—is rapidly becoming a critical capability.

The operational capabilities relevant to this critical capability affecting most of the five missions include: cultural and language understanding; modeling societal dynamics, stability, and influencers; strategic communication; and strategic shaping. While traditional technologies will contribute to many of these capabilities, there is also a significant opportunity to better leverage the social and neurosciences, particularly those analytic elements that create models to assist in understanding individual and collective group behavior.

Small unit leadership training and enhanced soldier-focused capabilities are crucial or important to most of the missions.[5] These capabilities can be enhanced by immersive games and other social science-derived intensive training concepts. They can also be supported by a number of information technology concepts that will provide individual soldiers relevant "Google"-like search capabilities to increase their understanding of the new cultures and surroundings in which they are likely to be deployed.

Ubiquitous Observation and Recording

Adversaries operate in ways to use stealth as a strategic advantage—nation-states are using unconventional and insurgency operations to their benefit, and non-state actors are inherently hidden in a large neutral or possibly sympathetic population. Consequently, the United States needs to observe and record those events for later correlation in order to find small warning signals in vast amounts of clutter. These observations need to be as close to continuous as can be achieved. Further, they must span as complete a range of sensor modalities and observation distances as practical. While traditional wide-area, all weather intelligence, surveillance, and reconnaissance (ISR) is required, many of the targets, especially those indicative of WMD activity and terrorist network planning, require very close range sensing to be effective. Moreover, traditional ISR itself must be adapted and advanced to more effectively deal with urban environments.

The operational capabilities, crucial to most of the missions, that the panel aggregated into this ubiquitous observation and recording category include: human intelligence; identification; covert tagging and tracking of people and objects globally; persistent ISR of fixed and mobile targets; and remote WMD detection. One of the key insights of the study is that in many of the new missions, particularly SSTR and

5. *Defense Science Board Task Force on Force Protection in Urban and Unconventional Environments*, Washington, D.C.: Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, March 2006.

defeating terrorist networks, the individual soldier on patrol can be an important observer. DOD should develop technologies to exploit this capability more effectively through better debriefing and knowledge representation technologies.

Contextual Exploitation

The development and deployment of ubiquitous observation capabilities will generate massive amounts of data, only a small fraction of which will contain actionable information. The challenge of "connecting the dots" for new targets, has proven to be a very difficult one. In many cases to date, such as the September 11, 2001 attacks, the relevant indicators were only identified after the attack with the benefit of knowing that an event had occurred. Increased observation provides hope of better detection, but only if the capability to process the data and turn them into relevant information is also developed.

The broadly important operational capabilities that the panel consolidated into the contextual exploitation group include: knowledge discovery/data fusion/decision support, strategic surprise anticipation, rapid strategic decision-making, and translation to war plans. To create these capabilities, the DOD must get better at handling massive amounts of data and at exploiting the synergies of both the computer and the human in data analysis, fusion, and integration.

Rapidly Tailored Effects

The last of the four critical capabilities central to dealing with the priority missions is the ability to take action quickly and effectively to influence, dissuade, or defeat the enemy in ways that matter to him while minimizing the unintended consequences of the action, namely, rapidly tailored effects. The span of potential actions is much broader than those characteristic of combat and range from influence operations to prompt global strike. Actions include both offensive and defensive options, since, for example, the ability to defend/mitigate WMD is likely to have an important deterrent effect.

One of the major challenges associated with this crucial capability is in knowing what action to take. For amorphous, non-state actors who do not have significant territory and infrastructure, it has been difficult to understand their values and what they hold dear, so that the United States can put them at risk in a meaningful way. This uncertainty highlights one of the synergies illustrated in figure 2—that the capability developed in understanding the human terrain will be essential in planning and selecting the most effective action the United States can take in a particular situation.

The operational capabilities that the panel found to be crucial or important to most of the priority missions include: covert penetration operations; information security, information operations, and cyber supremacy; air/land/sea supremacy; joint precision strike from sanctuary; secure and render safe WMD; medical surge; and broad spectrum medical treatments and preventatives.

Technologies

Having outlined the set of capabilities needed to execute the four QDR plus SSTR missions, the panel next turned its attention to determining what technologies were required to achieve those capabilities. The panel's mix of senior military, industry, and laboratory personnel was instrumental in creating a balance between operational capabilities "pull" and technology "push." Initially, the panel determined what it collectively viewed as the three most important technology areas required to service each of the four critical capabilities. This determination was accomplished subjectively by dividing the panel into four groups, each one representing one of the critical capabilities. Each group, which contained subject matter experts from both a technology as well as a user perspective, was asked to settle upon the three most critical technology areas appropriate to the capability they represented. The results are presented in table 4.

Table 4. Technology Areas Associated with Critical Capabilities

Critical Capability	Technology Area
Human terrain preparation	▪ Human, social, cultural, behavioral modeling ▪ Automated language processing ▪ Rapid training and learning methods and aids
Ubiquitous observation and recording	▪ Day/night all-weather wide area persistent surveillance ▪ Close-in sensing and tagging ▪ Soldier-as-collector
Contextual exploitation	▪ Mega-scale data management ▪ Situation-dependent data exploitation ▪ Human/system collaboration
Rapidly tailored effects	▪ Time-critical focused conventional strike ▪ Influence operations ▪ WMD protection and mitigation

Having identified and agreed upon the 12 key technology areas associated with the critical capabilities required for the mission challenges of the 21st century, the panel members dug deeper into each of the 12. Drawing upon both inside and outside domain experts, the following information was generated for each technology area:

- A description including, where relevant, performance metrics that established the level of performance required.
- The overall state of readiness, as measured on the technology readiness level (TRL) scale.[6]
- The underlying technologies (referred to as "constituent technologies") required for implementation, including, where possible, performance goal metrics. Each constituent technology was further examined to assess:
  - Its TRL, as well as a characterization into one of the following four categories:

6. See the Technology Readiness Level Assessment Deskbook, pg. 240 for full details (https://acc.dau.mil/CommunityBrowser.aspx?id=18545).

        - promising but immature, needs focused R&D investment
        - showing progress, investments being made, stay the course
        - action is largely in commercial sector; adapt and transition to DOD when appropriate
        - technology is ready today, adopt within DOD
    - What needs to be accomplished or developed to get it ready for operational use—included here were technical issues as well as service acceptance and training.
    - A rough order of magnitude cost estimate, where possible, for the development effort required.
- Other corollary issues germane to the particular technology area. These included such items as model validation, interoperability and standards, alternative technologies that were on the horizon, special support requirements, unusual cost or risk issues, and others.

Through this process, 43 constituent technologies were identified, along with the information described above. These are further detailed in Chapters 4–7, where they are described in the context of the capability and critical technology area into which they primarily fit.

The 43 constituent technologies were assessed as to their relative importance in fulfilling the five missions with which this process was initiated. This was accomplished by subjectively determining the impact each constituent technology would have on the 39 capabilities derived from the five missions. Technology impact on capability was defined in the same manner as described above for capability impact on mission, namely, for each capability, whether the given technology was:

- required
- very important
- a contributor of less importance
- not applicable

Thus, a matrix of 43 constituent technologies by 39 capabilities was established with the intersections containing a "score" of relative importance. The score for "required" was twice the score for "important," which in turn was twice the score for "contributor." Each of these technology scores was then summed over the 39 capabilities, with each technology score further weighted by the relative importance of each capability in accordance with tables 1, 2, and 3. The capabilities in table 1 (crucial to two or more missions) were given twice the weight of the capabilities in table 2 (crucial to one mission), which in turn were given twice the weight of the capabilities in table 3 (important but not crucial).

The results of this double weighting and summing thus provided a convenient and relatively simple way of accounting for each constituent technology's relevancy to mission capability by linking it back through the capabilities that it serviced, and then through the missions that those capabilities in turn serviced. Once sorted according to the overall result, an indication of relative ranking and priority is established. The results are presented in table 5. All of the results summarized here are documented in Appendix C, which contains the details of the spread sheet the panel used to keep track of these analyses.

Although table 5 lists the relative importance of the various technologies that were identified, based on their mission contribution, it is not very helpful in establishing a technology roadmap or strategy. The problem lies in the fact that the technologies listed in table 5 vary considerably in terms of their maturity, if and where they are being pursued, the significance of DOD investment, and other factors. A more useful view is obtained by parsing the technologies into the four categories of development characterization discussed above: (1) promising but immature, needs focused R&D investment; (2) showing progress, investments being made, stay the course; (3) action is largely in commercial sector, adapt and transition to DOD when appropriate; or (4) technology is ready today, adopt within DOD. This parsing is presented below in tables 6, 7, 8, and 9. The shading in the four tables represents those technologies that are in the top 20 of the overall rankings.

Table 5. Constituent Technology Ranking

1. Contextual analysis and intent recognition tools
2. Entity relationship, pattern analysis
3. Miniature sensor technology
4. Knowledge discovery (data to information to target recognition)
5. Efficient energy storage technology
6. Data management from very diverse sources
7. Macro human social cultural behavioral models (structure/trends)
8. Decision support tools (complexity & ambiguity)
9. All-domain precision geo-location
10. Cause-effect models (environment, infrastructure, socio-cultural, DIME, PMESII)
11. Storytelling, gisting and advanced visualization)
12. Socio-culturally relevant immersive games, training & mission rehearsal tools
13. Micro human social cultural behavioral models (networks/events)
14. Campaign planning/targeting/shaping tools (gaming, weapon/target pairing, effects estimation)
15. Integrated coherent micro-macro quant models (taxonomies, application programming interfaces, semantics)
16. Interactive automated debriefing
17. High performance and high efficiency signal processing
18. Advanced context/concept search, information retrieval and knowledge discovery
19. Foreign-to-English translation (voice, chat, email, broadcast, conversation, gisting)
20. Soldier-centric communications/networking technology (waveforms, transmit/receive)
21. Multi-level security and accreditation
22. High density packaging
23. Language/culture/leadership tutoring and coaching tools
24. Rapid diagnostics & environmental monitoring
25. Space-based ground moving target indication/synthetic aperture radar
26. Active and passive hyper spectral sensing
27. High altitude long-endurance platforms
28. Human/team performance measurement models-tools
29. Broad spectrum medical countermeasures
30. Human guided algorithms
31. Speech-to-text transcription (e.g., Phraselator; voice response; speech-to-speech)
32. Body-borne flexible displays
33. Natural man machine interface
34. Directed energy
35. Stealthy/precision delivery platforms
36. Standoff active radiation detection
37. Gigapixel optical imaging
38. Knowledge representation
39. Nuclear weapons effects & impact models
40. Decontamination technologies
41. Hypersonics
42. Foliage penetration sensors
43. Ballistic missile technology

One caveat for the structured process used by the panel cannot be emphasized too strongly. *The methodology that was followed is presented solely as a way of thinking about the problem of capabilities and technology prioritization and as a mechanism for linking technology investment to missions that the department considers important.* The results were influenced by the assumption that all five missions were of equal importance. That may or may not be the case as viewed by senior members of the department and the administration, and changes in that assumption will affect the prioritization of the individual technologies. Thus, DOD should examine the process and adapt it to its purposes while retaining the major characteristics of simplicity, understandability, traceability, and balancing senior level operational and technical perspectives. The department should apply sufficient resources to do it well and produce its own results and prioritization.

Having noted that, however, the panel believes that it is unlikely that the increased importance of, and inter-relationship between, the four critical capabilities will diminish, nor will the growing prominence of the social sciences change. These results are a function of the types of operations that now dominate many of the activities of America's troops, immerse them in cultures and societies that are unfamiliar to them, and place them in situations in which tactical actions can have strategic consequences. The department must do better at equipping and training at all levels of command and responsibilities in order to more effectively operate within this new 21st century security environment.

Table 6. Promising but Immature Technologies, Need Focused Research and Development Investment

Miniature sensor technology/TRL 3-5
Macro human, social, cultural, and behavior (HSCB) models (structure/trends)/TRL 4-6
Kinetic and non-kinetic cause-effect models (environment; infrastructure; socio-cultural; diplomatic, information, military, economic [DIME]; political, military, economic, social, infrastructure, information [PMESII])/TRL 2-6
Micro HSCB (networks/events)/TRL 2-4
Integrated coherent micro-macro quant/comp models (taxonomies, application programming interfaces, semantics)/TRL 1-2
Interactive automated debriefing/TRL 3
Rapid diagnostics and environmental monitoring/TRL 3-5
High altitude long-endurance platforms/TRL 3
Human/team performance measurement models-tools/TRL 3-6
Human guided algorithms/TRL 2
Directed energy/TRL 3-7
Stealthy/precision delivery platforms/TRL 6
Standoff active radiation detection/TRL 1-3
Gigapixel optical imaging/TRL 3
Nuclear weapons effects and impact models/TRL 2-5
Hypersonics/TRL 4-5

Table 7. Technologies Showing Progress, Investments are Being Made and Should Continue

Contextual analysis and intent recognition tools/TRL 3
Entity, relationship and pattern analysis/TRL 3
Knowledge discovery (data to information to target recognition)/TRL 2
Decision support tools (complexity & ambiguity)/TRL 3
All-domain precision geo-location/TRL 4-5
High performance and high efficiency signal processing/TRL 5
Foreign-to-English translation (e.g., voice, chat, IM, emails; broadcast, conversational; gisting; summarization; (un)constrained)/TRL 3-7
Soldier-centric communications/networking technology (waveforms, transmit/receive)/ TRL 5
Multi-level security and accreditation/TRL 3
High density packaging/TRL 5
Language/culture/leadership tutoring and coaching tools/TRL 4
Space-based ground moving target indication/ synthetic aperture radar /TRL 5
Speech-to-text transcription (e.g., Phraselator; voice response translator; 2-way speech-to-speech)/TRL 2-6
Body-borne flexible displays/TRL 4
Decontamination technologies/TRL 2-6

Table 8. Technologies Being Developed in the Commercial Sector, Adapt and Transition to DOD When Appropriate

Efficient energy storage technology/TRL 5
Data management from very diverse sources/TRL 5
Storytelling, gisting and advanced visualization)/TRL 2-5
High fidelity, socio-culturally relevant immersive games, training and mission rehearsal tools/TRL 3-6
Campaign planning/targeting/shaping tools (e.g., gaming; stochastic estimation; weapon-target pairing; (non)lethal weapon effects)/TRL 3-6
Advanced context/concept search, information retrieval and knowledge discovery (data mining)/TRL 2-6
Broad spectrum medical countermeasures/TRL 1-3
Natural man machine interface/TRL 2-3
Knowledge representation/TRL 3-5

Table 9. Technology is Ready, Adopt within DOD

Active and passive hyper spectral sensing/TRL 5
Foliage penetration sensors/TRL 5
Ballistic missile technology/TRL 7-9

The shaded lines in each of the tables above identify technologies that are in the top 20 of the 43 technologies ranked in this report.

Chapter 3. A Different Assessment of Capabilities

The highly structured methodology described in the previous chapter has advantages of traceability and imbedded linkage of operations and technology perspectives. However, the panel recognized that this approach did not allow for a more intuitive derivation of capabilities based on an understanding of what is known about current and emerging adversaries. Therefore, a sub-panel was formed to identify capabilities based on this more intuitive approach as an independent check on the results produced by the more structured approach.

A Succinct View of the 21st Century Adversary

In less than two decades, fundamental changes have occurred in the security environment facing the United States. The environment has changed from one dominated by a single adversary that had been studied for decades, to an environment with adversaries about whom little is known and whose actions are therefore less predictable. The former Soviet Union was a well-developed, geographically based nation-state with a large physical, economic, and industrial infrastructure that could be watched and assessed over time. These characteristics enabled development of an understanding of what motivated it, as well as its inherent value structure.

This Cold War adversary contrasts with many of the transnational, terrorist, and/or loosely knit extremist organizations, motivated by ideas and concepts alien to the American way of thinking, and embracing value structures that are difficult to understand. This lack of understanding hampers the nation’s ability to take actions that influence or deter; of those actions we do take, to understand and predict the consequences, both intended and unintended; and to act in ways consistently supportive of U.S. strategic objectives. Most importantly, the department is in the early years of trying to gain that understanding, much like the situation with respect to the former Soviet Union in the 1950s.

Another important difference has also become evident and adds different dimensions to the problem of gaining that fundamental understanding. Because of the bureaucratic nature of the former Soviet Union's government, their decision process was ponderous, their military control highly centralized, and their actions evolved over months to years. Today's adversaries, in contrast, have demonstrated agility that allows them to adapt in days or even hours. Their agility offers little time to observe what they do before they do it. Moreover, their tendency to hide their people, assets, and actions within the civilian population of the countries in which they operate makes them even harder to counter.

As a result, although the United States may collect lots of "data" of various kinds, the actionable information that can be extracted about the enemy lies buried in all of the other extraneous data that is collected. Thus, a new paradigm of contradictory demands emerges—the necessity to take quick and effective action against an agile, poorly defined enemy based on observables that are buried in all kinds of irrelevant and unrelated clutter and noise. Yet despite the differences between the current era and the Cold War, today's enemies retain the same motivating characteristic—the ability to bring great harm against the nation.

Dealing with 21st Century Adversaries

Given these challenging characteristics associated with current and expected future adversaries, an ability to reduce their potential for harm leads logically to a set of four "musts" that correspond well with the four critical capabilities derived in the panel's more deliberate process.

1. **Understand "what makes him tick."** Deterrence through the threat of holding hostage things an adversary values is always the first line of defense. But today's adversary is neither fixed nor monolithic. His goals, objectives, and value structure are all fuzzy. Without understanding these things better than is done currently, the nation will have little ability either to offer meaningful "carrots" or to carry meaningful "sticks." Enhanced understanding is also central to taking productive offensive and defensive, and combat and humanitarian actions while avoiding counterproductive results because of unintended consequences. Thus, understanding what motivates the adversary is central to everything else.

In parallel, significant improvement needs to be made in training provided to the troops, and in particular to junior officers and enlisted personnel who, with little time for preparation, are now thrust quickly into unusual environments with unfamiliar language, social, and cultural behavior. The panel's process came to the same needed set of capabilities under the name of "human terrain preparation."

2. **Observe, archive, observe, archive.** Today's adversaries are highly agile and "stealthy." An ability to pull meaningful indicators or signals regarding their actions and intentions out of the noise and to understand what they are about to do before they do it will depend on continual observation of their key people, physical resources, actions, and patterns of behavior. Further, since much of what is observed may only be meaningful after some event occurs, it will be necessary to also archive everything collected so that it can be analyzed and reviewed at any time in the future. Thus, observing and archiving everything about adversaries is of critical importance. This corresponds to the "ubiquitous observation and recording" capability derived from the panel's structured process.

3. **"Connect the dots" quickly.** The observables inherent to today's adversaries do not in themselves provide actionable information for all of the reasons discussed above. The key to transforming the vast amount of data that is collected into useful observables and ultimately to information upon which timely action can be taken is to discern important patterns of adversary actions and behavior through geographical, temporal, and societal analysis and association. The task is made more difficult because adversary agility often drives quick execution of this difficult task. Thus, an ability to quickly "connect the dots" in the context of unfolding events coupled to the specific nature and culture/behavioral norms of the adversary plays a critical role in understanding what is happening, what is about to happen, and what actions can be taken to counter. The panel's process yielded "contextual exploitation" as the corresponding critical capability.

4. **Act quickly and decisively in a way that matters to an adversary.** Although obvious, this task is difficult to do against today's adversary. "Act" must span the range of offense to defense, destruction to rebuilding, punitive measures to humanitarian aid to political reward.

With a limited understanding of the adversary and his ability to adapt quickly, a quick decision to select the "right" action—that is one that accomplishes the intended objective without counterproductive consequences—and executing it with the right toolset is difficult to achieve and, at a minimum, demands more options in the toolkit. This ability to act quickly in a wide variety of ways that matter to the adversary is the critical "take action" component of the four high level capabilities. This capability has been referred to as "rapidly tailored effects."

Chapter 4. Human Terrain Preparation

As discussed previously in this report, today's adversaries are neither fixed nor monolithic. Their goals, objectives, and value structure are yet to be well understood. Without better understanding, the nation has little ability to either offer meaningful "carrots" or carry meaningful "sticks." Enhanced understanding is also central to taking productive offensive or defensive combat, security, and humanitarian actions while avoiding counterproductive results because of unintended consequences. Understanding "what makes the adversary tick" is central to everything else.

Significant improvement in training troops is also needed—in particular junior officers and enlisted leaders, who, with little time for preparation, are now being thrust quickly into unusual environments with unfamiliar language, social behaviors, and cultural norms. This collection of human understanding and enhancement is referred to as "human terrain preparation" (HTP).

Capability Description and Technology Areas

With the emergence of the new 21st century strategic threat—which is significantly different from the peer competitor nation-state of the Cold War era—it is increasingly important that the United States mount a serious effort to understand adversary objectives and motives. During the Cold War, substantial intellectual effort was directed at understanding and developing strategies to counter the Soviet Union. The nation and the department have not yet had time nor committed the level of effort needed to develop a comparable understanding of 21st century strategic threats—terrorists, warlords, insurgents, rogue WMD proliferators, drug smugglers and syndicates, weapons traffickers, and failed states. The amorphous, often opaque characteristics of the threat spectrum make this a more challenging problem than that of the Cold War. Furthermore, much of the engagement against 21st century strategic threats should be conducted in pre-conflict (phase 0) conditions, so that the United States can prevent hostilities and disagreements from developing into a full-scale armed confrontation. Gaining the necessary understanding of the cultures and motivations of threats and noncombatants, and the environment within which they reside, as well as understanding how to prevent hostilities from escalating, requires the United States to apply political, military, diplomatic, economic, and other social options.

Recent experience in Iraq and Afghanistan has shown that managing successful stability and reconstruction operations requires as much social awareness as military combat savvy. A major challenge to overcome has been a severely limited joint, service, or interagency integrated capability (organization, methods, tools, training) to effectively collect/consolidate, visualize, and understand socio-cultural ("green data") in order to assist commanders in understanding the "human terrain" in which they operate. In many instances, the decisive terrain has been the vast majority of noncombatants who are not directly involved in the fighting, but whose support, willing or coerced, has been critical to influence. Winning the hearts and minds of the local population by providing aid to improve their lives has been equally as important—and can no longer be subordinated—to projecting military force or capturing and killing the enemy. Consequently, *preparing the human terrain*—both ours and theirs—will be a critical capability.

Another key challenge is developing a common socio-cultural methodology and toolkit for analysis, planning, and training. HTP should provide a joint common relevant picture of the socio-cultural human terrain for use by tactical elements, operational commanders, theater planners, strategic decision- and policy-makers, interagency organizations, and coalition partners. While traditional technologies will contribute to the HTP capability, the panel found that there is a significant need to better leverage the social sciences, particularly those analytic elements that create models to assist in understanding and representing human systems, both ours and theirs.

From the many areas important for maturing HTP, the panel found that three critical technology enablers of the HTP capability should be given priority: (1) rapid training and continuous learning; (2) automated language processing; and (3) human, social, cultural, and behavior (HSCB) modeling. These technology areas will provide analysts and war fighters with the necessary tools to:

- Search, query, exploit, understand, and train/learn from vastly more foreign multi-lingual, socio-cultural speech and text than would otherwise be possible by human transcribers and translators alone.
- Automatically extract entities and entity-relationships from massive amounts of data (unstructured, semi-structured, structured) and discover instances of relationships and patterns of activities among those entities.
- Apply quantitative and computational models based on a wide range of nonlinear mathematical and nondeterministic stochastic computational approaches for capturing social phenomena and pathological behavior.
- Collaborate, reason, and share data, information, knowledge, and analyses so that analysts and war fighters can hypothesize, test, and propose theories and mitigating strategies about plausible futures so that decision- and policy-makers can effectively evaluate the impact of current or future policies and prospective courses of action.

Rapid Training and Continuous Learning

Training is a core enabler for every joint war fighting capability and is most successful when tools and methods embrace the cognitive complexities of how people learn. Focusing on QDR missions and the high probability of SSTR missions makes clear that future warriors, particularly junior leaders on the future battlefield, must be mature, adaptive, and fully aware of the human dimension of the battle space in which they operate. In its pamphlet defining future force capabilities, U.S. Army Training and Doctrine Command concludes that future force leaders must excel at critical reasoning and creative thinking. The escalating tempo of operations will demand higher order cognitive skills, including the rapid synthesis of operations, intuitive assessments of situation, rapid conceptualization of friendly courses of action, and the ability to adjust and adapt thinking and tactical decisions to rapidly changing condition and situations. It further states that skill sets such as negotiation, cultural sensitivity, dealing with ambiguity, and conflict resolution are normal requirements in the future environment.

Recognizing that tactical actions have strategic significance, DOD must orient the breadth and depth of its junior noncommissioned officer and officer education programs toward rapidly preparing leaders, particularly at the small unit level, for that complex battle space. The panel determined that learning tools and methods should focus on rapidly developing cognitive decision-making skills, knowledge, competencies, and experiences in several areas, including: critical thinking and decision-making when encountering complex situations under duress; avoiding common “counter-intuitive” judgment errors, such as mirror imaging and confusing the unfamiliar with the improbable; key SSTR tasks in crowd control, policing, evidence collection, negotiation and reconstruction; and assimilating relevant socio-cultural terrain factors into each operation, mission, and battle staff function.

Constituent Technologies

The panel identified three compelling constituent technologies that require focused DOD efforts to best realize the potential for improvement over current training, learning methods, and aids. These are: high-fidelity immersive games and training, and mission rehearsal tools; language, cultural, and leadership tutoring tools; and human and team performance measurement. Improvements in these technologies should seek to develop multi-cultural interpersonal skills in support of small unit operations, with the ultimate goal of accelerating the pace of learning, competency, and decision-making effectiveness. Future success at the junior leader level may hinge upon an individual’s opportunity to acquire years of knowledge and experience in cultural awareness, intuitive decision-making, and skill at arms in a matter of weeks.

High-Fidelity Immersive Games and Training, and Mission Rehearsal Tools

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 movie and gaming industries, while incorporating natural language dialogue, cognitive models, and learner models to maximize the learning opportunity and accurately determine a learner's progress. Authoring tools that allow users to rapidly manipulate relevant scenarios are an important and necessary characteristic of future tools. These tools should offer the opportunity to introduce lessons learned from the contemporary operational environment, and then tailor the tools to address specific training needs at the individual level. Finally, DOD must undertake efforts to standardize the tools that are developed so that can be linked in order to facilitate team-level immersive events for the service member on the ground and in the joint environment. The proliferation of massive, multi-player games suggests promise in this technical area.

Language, Culture, and Leadership Tutoring Tools

Language, culture, and leadership tutoring tools will need to be an integral part of training-related technologies in order to more rapidly prepare junior leaders and small units for the unique cultural dimensions of the future battle space. Ultimate mission success will likely depend less upon victory in conventional kinetic operations and more upon forces on the ground or in port being adept and influential in the complex social networks found in stability and support operations. 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. Advances in automated language processing, discussed earlier in this chapter, are critical as the foundations for these tutoring tools.

Human and Team Performance Measurement

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 better define future individual training needs. Measurement of performance, particularly in high stress environments experienced on the battlefield, with the added complexities of the urban environment, and stability and support operations, requires additional study. Such measurement, combined with user-friendly authoring tools, informs trainees and the chain of command, and influences developmental efforts for future training sessions. Several current programs and research efforts offer promise in achieving the technical goals described by this panel. A brief description follows.

Combat Leader's Environment (CLE). The U.S. Army's School of Command Preparation at the Command and General Staff College recently completed a proof of concept for the CLE. This virtual simulation tool places battalion- and brigade-level leaders in an immersive environment designed from lived experiences. It provides each learner with an opportunity to "think about how they think" in a cognitively authentic context. The fundamental premise is that one could improve decision-making by environmental realism, repetition, variability, and ambiguity.

Learning with Adaptive Simulation and Training (LAST). This Army technology objective, managed by the U.S. Army Simulation and Training Technology Center of Research, Development and Engineering Command, seeks to deliver effective and engaging training simulations that incorporate realistic political and cultural effects of the environment and behaviors of an adaptive, asymmetrical enemy force. The research focuses on two major areas. First, it seeks to develop the pedagogical design and enhanced tools and methods for rapidly creating and modifying scenarios relevant to the common operating environment in virtual simulations. Second, it develops enhanced virtual entities, behavioral models, and political and cultural effects in integrated virtual simulations. These efforts are expected to produce improvements in instruction and training, decision-making, and learning retention through the use of a critical incident scenario library, the presentation of increasingly difficult scenarios in a training environment (gated training), and through enhanced methods of performance assessment and feedback to the trainee. A key feature includes advanced tools and methods that will enable trainers to rapidly create relevant virtual simulations.

Enhanced Learning Environment with Creative Technologies. This Army technology objective, managed by the U.S. Army Simulation and Training Technology Center of Research, Development and Engineering Command, seeks to capitalize on the unique ability of the University of California's Institute for Creative Technologies to incorporate the most advanced techniques of the movie and gaming industries in a number of technical areas. These techniques include advanced virtual humans (such as, task reasoning, emotions, natural language, gestures, spatial cognition), story management, artificial intelligence, coaching, advanced graphics, sound, and integrating architecture to create the required tools, methods, and training modules. Research seeks to develop pedagogical design, methods, tools, and metrics required for the use of interactive simulation technology as a means to deliver effective training. The program 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 retraining.

Automated Language Processing

Foreign language speech and text are indispensable sources of intelligence, but the vast majority available is unexamined. Foreign language data and their corresponding providers are massive and growing in numbers daily. Moreover, because the time to transcribe and translate foreign documents is so labor intensive, compounded by the lack of linguists with suitable language skills to review it all, much foreign language speech and text are never exploited for intelligence and counter-terrorism purposes. And it would be impossible to find, train, or pay enough people. 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.

Automated Language Processing Constituent Technologies

The panel identified three priority constituent technologies on which DOD should focus—technologies that will realize significant improvement over current automated language processing efforts. These are: (1) foreign-to-English translation technologies, (2) speech-to-text transcription technologies, and (3) information management and text processing technologies (also applicable for the contextual exploitation capability). Improvements in these technologies should allow automated processes and English-speaking users to examine and analyze all multi-lingual speech and text that is available in the information space; allow any user—be it a tactical, operational, or strategic planner; analyst; or decision-maker—to acquire basic language proficiency in days and expert language proficiency in months, for any language; and to continue improvements in word error rate, precision and recall, and usability measures, such as effectiveness, efficiency, and user satisfaction.

One example of an R&D program in this area that integrates all three constituent technologies is the Defense Advanced Research Project Agency's (DARPA) GALE (Global Autonomous Language Exploitation) program, illustrated in figure 3. 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 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.

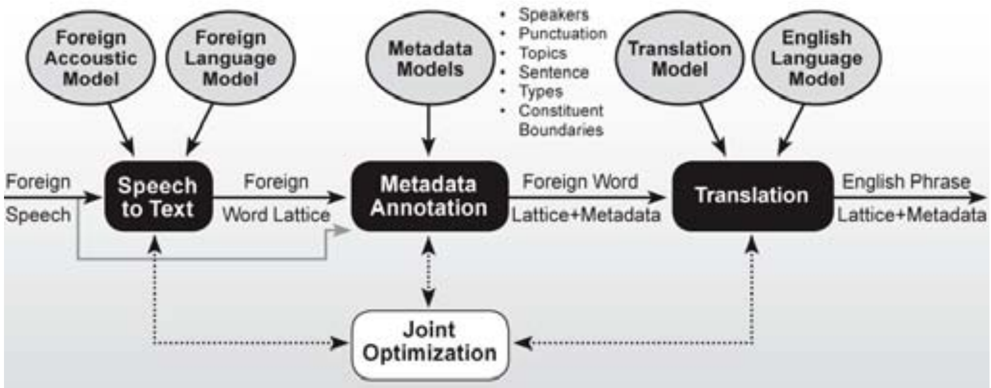

Figure 3. GALE System for Transcription of Foreign Speech into English Text

Foreign-to-English Translation

Goals for foreign-to-English translation include: (1) providing high accuracy machine translation and structural metadata annotation from multilingual text document and speech transcription input at all stages of processing and across multiple genres, topics, and mediums (such as, Arabic, Chinese, the Web, news, blogs, signals intelligence, and databases); (2) understanding—or at least deriving semantic intent from—input strings regardless of source; (3) reconciling and resolving semantic differences, duplications, inconsistencies, and ambiguities across words, passages, and documents; (4) more efficient discovery of important documents, more relevant and accurate facts while decreasing the amount of time required to do it, and passages for distillation; (5) providing enriched translation output that is formatted, cleaned-up, clear, unambiguous, and meaningful to decision-makers; (6) eliminating the need for human intervention and minimized delay of information delivery; and (7) fast development of new language capability, swift response to breaking events, and increased portability across languages, sources, and information needs.

Some examples of critical contributing technologies include: improved dynamic language modeling with adaptive learning; advanced machine translation technology that utilizes heterogeneous knowledge sources; better inference models; better tagging and annotation algorithms; language-independent approaches to create rapid, robust technology that can be ported cheaply and easily to any language and domain; syntactic and semantic representation techniques to deal with ambiguous meaning and information overload; and cross- and mono-lingual, language-independent information retrieval to detect and discover the exact data in any language quickly and accurately, and to flag new data that may be of interest.

Speech-to-Text Transcription

Automatic speech-to-text transcription seeks to produce rich, readable transcripts of foreign news broadcasts and conversations (over noisy channels and/or in noisy environments) despite widely-varying pronunciations, speaking styles, and subject matter. In general, the two basic components of rich transcription are speech-to-text conversion (finding and transcribing relevant words) and metadata extraction (pulling out features to annotate the transcripts to provide more useful information to the user). There are also two basic approaches to speech-to-text transcription—those that use constrained vocabularies (such as, Phraselator), and those that do not. Recent achievements (2004) include word error rates of 26.3 percent and 19.1 percent at processing speeds of 7 and 8 times slower than real-time on Arabic and Chinese news broadcasts.

Goals for speech-to-text transcription include: (1) providing high accuracy multilingual word-level transcription from speech at all stages of processing and across multiple genres, topics, speakers, and channels (such as Arabic, Chinese, and other relevant speech dialects from news broadcasts, talk shows, the Web, signals intelligence, and databases); (2) representing and extracting "meaning" out of spoken language by reconciling and resolving jargon, slang, code-speak, and language ambiguities; (3) dynamically adapting to (noisy) acoustics, speakers, topics, new names, speaking-styles, and dialects; (4) improving relevance to deliver the information decision-makers need; (5) assimilating and integrating speech across multiple sources to support exploration and analysis to enable natural queries and drill-down; and (6) increased portability across languages, sources, and information needs.

Some examples of critical contributing technologies include: improved acoustic modeling; robust feature extraction; better discriminative estimation models; improved language and pronunciation modeling; and language independent approaches that are able to learn from examples by using algorithms that exploit advances in computational power plus the large quantities of electronic speech and text that are now available. The ultimate goal is to create rapid, robust technology that can be ported cheaply and easily to other languages and domains.

Information Management and Text Processing

There are many technologies that fall within this category—too many to address in detail here. The contextual exploitation capability area describes some of the more important technologies. This section supplements that discussion with a description of a few other key technologies of particular value to HTP.

Information retrieval has been responsible for the development of many useful algorithms and techniques for document analysis. This is in part due to the statistical nature of information retrieval, which itself derives from the vast amount of data such programs typically face. The essential problems in information retrieval are concerned with both similarity and ranking. Binding similar documents together makes information retrieval conceptually coherent; ranking them in order of relevancy to a query makes it efficient.

"Advanced search" uses a combination of an advanced keyword approach (to compensate for common typing/spelling confusions and idiosyncrasies) and probabilistic latent semantic analysis to ascertain if a particular topic is being discussed without using specific keywords. Latent semantic analysis is one of a large class of unsupervised machine learning techniques that transform the original representation of texts to a new representation reflecting patterns of word occurrences in a large corpus of texts. In some situations, using this new representation can provide a small improvement in the effectiveness of processes such as search or classification applied to the text versus using a representation based on the original words and phrases of the document. Latent semantic analysis is mostly likely to provide an advantage when the data has an underlying structure (modeled as dimensions in a real-valued space) that matches up nicely with the categories to which a system is trying to assign texts.

Entity extraction methods extract key facts from documents by accurately mining information from free text based on user requirements. These approaches were developed to be most effective when formal reports and articles are the materials for analysis. Entity extraction techniques are likely to be less effective in the chat medium, where content is less structured and language use is less formal. Abbreviations, misspellings, slang, and more speech-like constructions are the norm rather than the exception in chat. Although name translation remains problematic, automatic name extraction (or tagging) works reasonably well in English, Chinese, and Arabic. Researchers increasingly focus on sophisticated techniques for extracting information about entities, relationships, and events.

Relationship extraction is much harder than entity extraction, and is important when seeking to extract entities and their relationships from textual narratives about activities, people, materials, and organizations, for example. Advanced techniques are able to efficiently and accurately discover, extract, and link sparse evidence contained in large amounts of unclassified and classified data sources such as public news broadcasts or classified intelligence reports.

Detection uses advanced techniques to detect and discover the exact information a user seeks quickly and effectively and to flag new information that may be of interest. Cross-language information retrieval is the current focus of the research community with recent results showing the technique can work roughly as well as monolingual retrieval.

Summarization reduces (substantially) the amount of text that people have to read. Researchers are now working on techniques for automatic headline generation (for single documents) and for multi-document summaries (of clusters of related documents).

Graphical representations are critical to enable “connecting the dots” when representing data and patterns as graphs. Patterns specified as graphs with nodes representing entities such as people, places, things, and events; edges representing meaningful relationships between entities; and attribute labels amplifying the entities and their connecting links, are matched to data represented in the same graphical form. These highly-connected evidence and pattern graphs also play a crucial role in constraining the combinatorics of the iterative graph processing algorithms such as directed search, matching, and hypothesis evaluation.

Link discovery starts from known entities and uses statistical, knowledge-based, and graph-theoretic techniques to identify explicit links, infer implicit links, and evaluate their significance. Search is constrained by expanding and evaluating partial matches from known starting points, rather than the alternative of considering all possible combinations. The high probability that linked entities will have similar class labels (often called autocorrelation or homophily) can be used to increase classification accuracy.

Pattern learning techniques can induce a pattern description from a set of exemplars. Such pattern descriptions can assist an analyst in discovering unknown terrorist activities in data. These patterns can then be evaluated and refined before being considered for use in detecting potential terrorist activity. Pattern learning techniques are also useful in enabling adaptation to changes in terrorist behavior over time.

Figure 4 depicts an experiment where a multi-lingual information retrieval front-end system comprised of various information management and text processing technologies was used to “automatically” ingest massive amounts of open-source text data, transform and translate it, and extract and auto-populate model-relevant data to a back-end analytical HSCB model. The analytical problem was to understand and forecast the preconditions and root causes that give rise to instability and conflict within nation-states (Indonesia and Thailand in this case).

The data were drawn from a variety of open sources, and included over 1 million English documents and 2,300 foreign documents. The HSCB model—termed RAM—was a Bayesian network and hidden Markov model that measured the amount of rebel activity by a number of nefarious groups in the region—that is communist, socialist, separatist, and Islamic extremist groups such as GAM, GMIP, PULO, BRN, and JI.[7]

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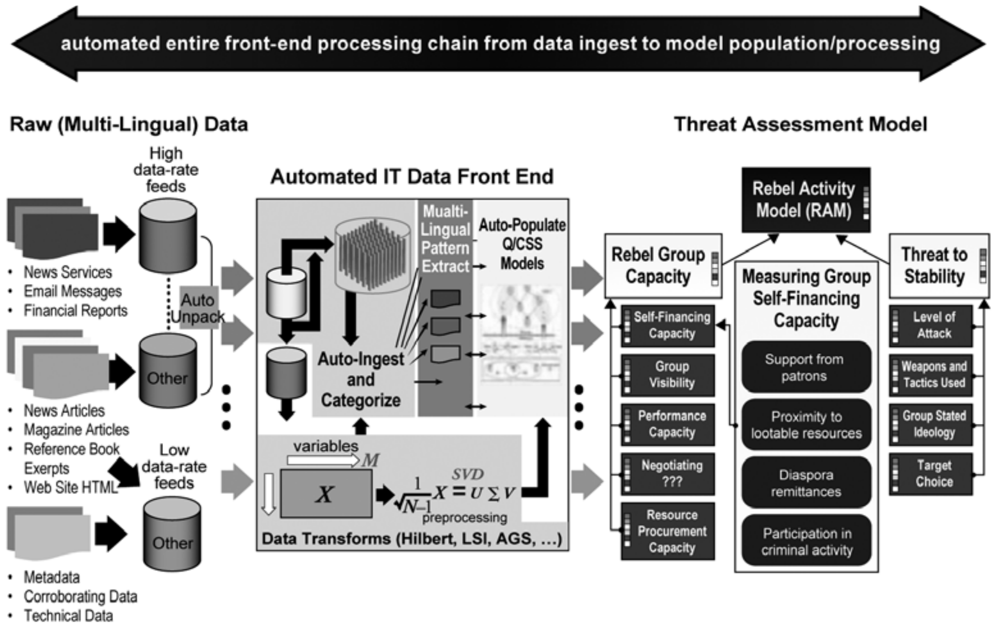
7. The extremist groups identified here are: Free Aceh Movement (GAM); Gerakan Mujahideen Islam Pattani (GMIP), Pattani United Liberation Organization (PULO), Barisan Revolusi Nasional Melayu Pattani (BRN), and Jemaah Islamiyah (JI).



Massive savings in human labor	Total Documents	Manual Person Years*	Person Years*	Non-Recurring Costs Person Years*
Totals	1,236,300	117	0.05	0.76
Total Staff Needed (to process in Sapling time-frame)		280.8		1.82
Total Manpower Savings (in man years) * Time required is 12 minutes per document				115
Total Cost in Labor** ** One man-year = $100K (NDU est.)		$11,700,000	$4,859	$75,833
Total Cost Savings		$0	$11,695,141	$11,624,167
Cost Savings Per 1,000 Documents		0	9,460	9,402

Figure 4. A Multilingual Information Retrieval Front-End System

The multi-lingual front-end system included a language-independent transformation and categorization tool based on a Hilbert engine that encodes ASCII (American Standard Code for Information Interchange) text into numerical vectors, and a linguistic pattern analyzer that automatically populates the RAM with model-relevant data. The results of the experiment show that given a corpus of 1,236,300 documents (2,300 being foreign Bahasa documents), it would take 117 man years for a human to read it all (assuming 12 minutes to read each document), or 280 humans to read the documents in six months, whereas the automated system based on linguistic pattern analyzer, the Hilbert engine, and RAM would take 0.05 man-years with a one time cost of 0.76 man-years to configure the linguistic pattern analyzer with the necessary English and foreign scripts. Assuming it would cost $100,000 per man-year, the automated front-end would provide a savings of $11,695,141 over the human method.

Human, Social, Cultural, and Behavior Modeling

A motivation and justification for human, social, cultural, and behavior modeling in the context of military operations can be found in the following definition of war provided by Franklin C. Spinney:

> At its most fundamental level, the conduct of war is a clash of independent wills operating in the moral, mental, and physical domains. War is not a mechanical phenomenon of physics or technology. War is a living phenomenon, evolving continuously through the interaction of competing human minds with chance and necessity. Moreover, the conduct of war is a group activity embodying multiple interactions among complex formal hierarchies of individuals, each operating according to its own tempo and rhythm under conditions of stress and uncertainty. Organizational culture is, therefore, of paramount importance to the performance of military institutions. A common culture is the harmonizing glue, the shared set of beliefs, values, traditions, and experiences. It makes it possible for the complex hierarchies to take the initiative rapidly or react with a variety of responses to sudden external changes. They will not fly apart in a struggle to gain sustenance, avoid danger, and overcome obstacles and enemies. When addressing cultural change, it is also important to recognize that a military culture does not exist in isolation but interacts continuously with its supporting domestic environment.[8]

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8. Franklin Spinney, John Sayen, and Donald E. Vandergriff, "Why It's Time to Adapt to Changing Conditions," in *Spirit Blood and Treasure,* Donald Vandergriff (editor), Presidio Press, 2001.

Considering this definition, it is not surprising that most senior military leaders have repeatedly proclaimed that that human resources—soldiers, sailors, airmen, and Marines—are the military's greatest competitive edge in battle and in peace. Courage, integrity, loyalty, and commitment—all human, social, cultural, and behavior dimensions—have mattered throughout history.

For purposes of this report, HSCB modeling refers to the disciplines and branches of science that investigate human social phenomena (cognition, conflict, decision-making, cooperation) at all levels of data aggregation (individual, group, societal, global). The social sciences play a key role in HSCB modeling—providing an understanding of a multitude of complex, often nuanced issues and how to make better tradeoffs. For example, a war may have begun because of poor economic conditions or ethnic hatred; targeting infrastructure may cause the country to come to the negotiation table but it may also aggravate the conditions that created the conflict in the first place.

Figure 5 illustrates the main social science disciplines that are critical to exploit: cognitive science, psychology, sociology, political science, economics, and cultural anthropology. Other social science specialties that may be of situational importance to utilize include business administration, media and communication, criminology, education, environmental studies, ethics, geography, law, history, international relations, linguistics, literature, management and organization, philosophy, environmental studies, public policy, religious studies, social work, urban and regional studies, and women's studies.

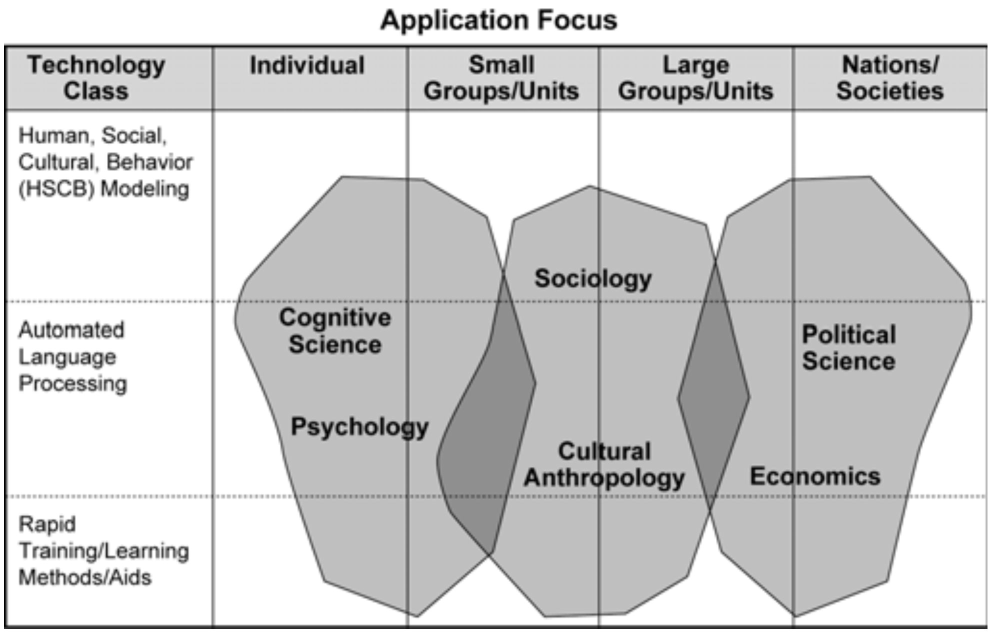

Figure 5. Critical Social Science Disciplines

Another important aspect of HSCB modeling is the direct and intensive application of quantitative and computational modeling and simulation techniques from mathematics, physics, statistics, operations research, and computer science, coupled with one or more of the various social sciences just described. 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. These include advanced quantitative statistical and econometric methods, event history analysis, artificial neural networks, wavelet analysis, content analysis, systems dynamics, geographic information systems, social network analysis, and multi-agent systems or agent-based modeling. Examples where there have been some "limited but promising" successes in coupling social science methods with quantitative/computational techniques is in marketing research to project sales of consumer goods, and in politics to forecast election results based on polling and other data.

A goal for the DOD should be to extrapolate proven successes in HSCB modeling to a broader set of national security problems. Some illustrative examples include:

- a national system of government as a complex adaptive societal system for dealing with emerging issues through policy and other measures
- an extremist belief system as a cognitive structure that uses radical notions arrayed as concepts and associations to interpret information and assign meaning
- an election, on any scale, as a computation of political preferences among a group of voters
- a counterterrorism system as a set of computational information processes, capabilities, and activities organized for the purpose of preventing terrorism or dampening its effects when not preventable

These applications of HSCB modeling help users investigate patterns of human phenomena that range from cognitive systems to groups, organizations, societies, nations, civilizations, and world systems, and do so at time scales ranging from milliseconds (brain activity) to many hundreds of thousands of years (human origins).

Constituent Technologies

The panel identified three constituent technologies critical to enable the HSCB modeling capability: (1) macro HSCB models, (2) micro HSCB models, and (3) integrated micro-macro (unified) models. Although promising, there are significant challenges and issues associated with these three constituent HSCB modeling technologies. They include: (1) advancing the accuracy and reliability of HSCB models for assessment, prediction, and forecasting purposes (yet recognizing the limits to HSCB modeling for prediction and forecasting); (2) getting reliable data at the “right” level and unit of analysis (such as 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 to the methods used in the physical sciences, and getting the DOD science and technology (S&T) community to recognize the reality that absent rigor there is still value in provoking thought.

Macro HSCB Models

Macro HSCB models refers to the class of models that allow structure, interconnections, dependencies, and trends associated with macro organizational entities, such as nation-states, socio-cultural regions, and economies and political systems to be understood. Examples include: system dynamics models, organizational and network flow models, politico-econometric structural (regression) equation models, Bayesian belief/influence network models, and hidden Markov models.

As an example, consider what a system dynamics macro HSCB model of nation-state instability might look like. Figure 6 illustrates a system dynamics model whose goal is to measure the level of instability within a nation-state. The model is based on the theory of loads versus capacities—state stability is a function of the relationship between the loads (or pressures) on the state, and the capacity (or power) of the state to manage and abate them. Dissidents and insurgents create loads on the state, for example, by drawing down disproportionate amounts of resources from the state that could be used for other purposes as they undertake anti-regime activities such as protests, riot, or acts of violence.

The escalation of dissidents and insurgency is a precursor to propensities for large-scale instability and conflict. Dissidents and insurgents undermine the overall political support by the citizenry for the state or regime, shifting the balance of power. Counterbalancing this is the resilience of the state or regime, and its ability to withstand loads that lead to instability. In the figure, the top curve represents the nominal insurgent growth with no intervention by the regime. If the regime attempts aggressive removal of insurgents, the second curve projects that the insurgent population is reduced for a short period of time, but then increases again. However, by preventing recruitment through mediating anti-regime messages all together, a “tipping point” occurs where the regime can reduce the number of dissidents recruited and, ultimately, the number of insurgents as reflected in the bottom curve.

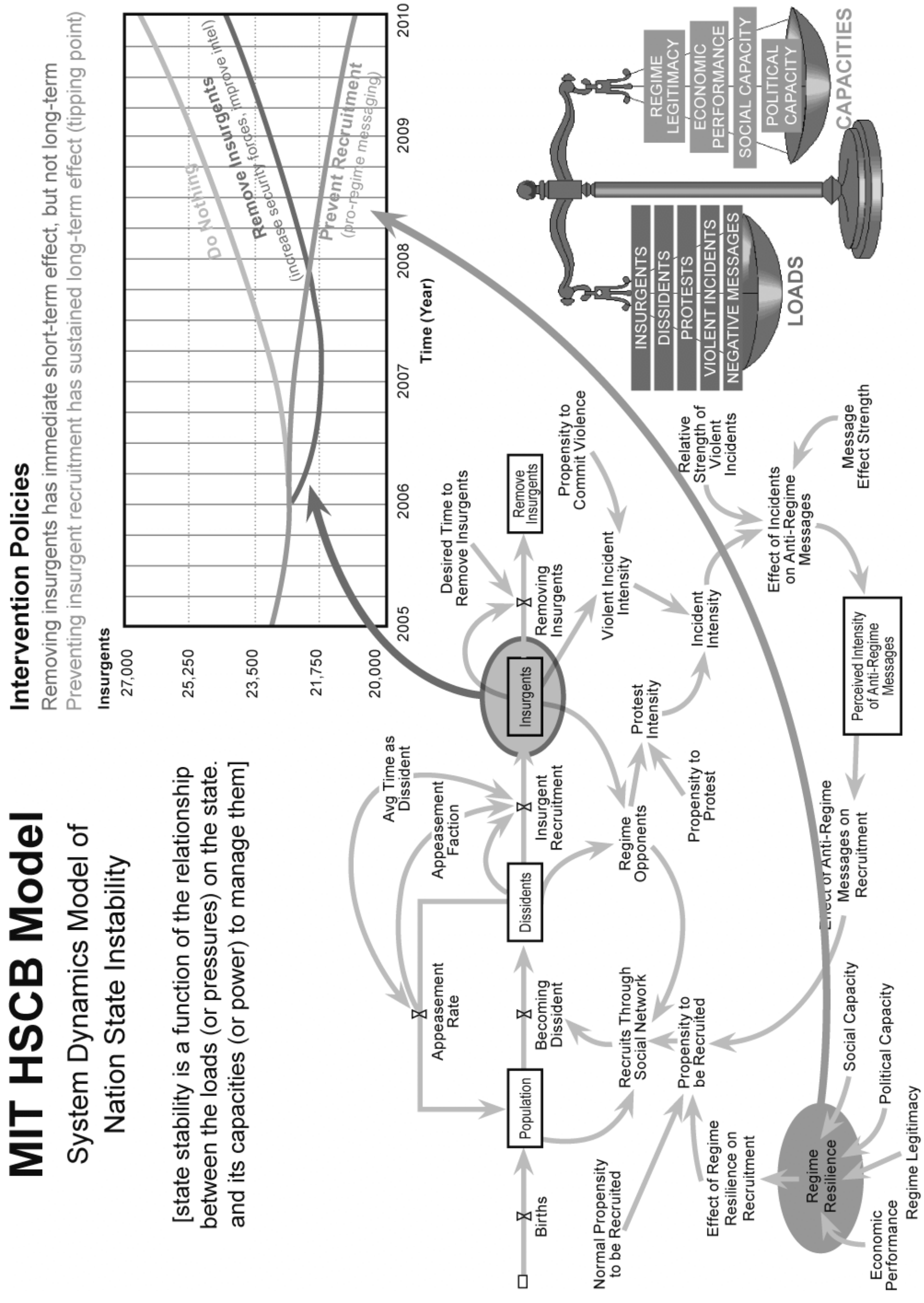

Figure 6. MIT System Dynamics Model for Nation-state Instability

A different approach to macro HSCB modeling developed by Claremont Graduate University for the same problem as described above is a politico-econometric nation-state fragility model termed the Politics of Fertility, Economics and Development (POFED) model. This model takes the form of a system of nonlinear dynamical regression equations comprised of five equations and dependent variables: fertility (or birth rate), income, human capital (measured as literacy in terms of high school graduates), instability (political deaths in this case), and relative political capacity. The POFED model was developed to understand dynamic interactions between per capita income, investment, instability, political capacity, human capital, and birth rates for the same two countries that the MIT system dynamics model focused on.

The POFED model is based on the theory that a nation is fragile when the per capita income of its population declines over time, thereby generating a "poverty trap." An important predictor of fragility is the extent to which a government extracts resources from its population. Weak governments fall below average extraction levels obtained by similarly endowed societies, while robust societies extract more than one would anticipate from their economic endowment and allocate such resources to advance the government's priorities. Instability results from the interaction between economic and political performance. Weakening states decline in their ability to extract resources, but still perform above expectations, while fragile states under-perform relative to others at comparable levels of development, continuing to lose ground in relative terms. Finally, strengthening states are still relatively weak but begin to gain in relation to their relative cohort. In general, assistance provided to strong or strengthening states will have positive effects on stability, while similar contributions to weak or to a lesser degree, weakening states, will be squandered.

The relative political capacity metric measures the ability of the government to extract resources (usually measured in dollars, for example) from the country through various means, such as taxes, labor, or military service. The instability—measured in deaths—reflects the level of political violence and anti-regime sentiment in the country. A relative political capacity of zero is the norm—that is, it indicates that the government is acting in a nominal capacity compared to other countries that have been assessed using these techniques. A negative measure indicates that a government is underperforming and weak, while a positive level indicates that a government is efficiently extracting resources. Computing the relative political capacity for a country allows for a determination of the tendency of a particular country toward behavior that could lead to state failure. The accompanying instability metric, based on violent incidents, provides a metric for assessing the resilience of the country to insurgency and to natural disasters that undermine the state's ability to govern.

Micro HSCB Models

Micro HSCB models refers to the class of models that allow relationships, interactions, intent, activities, and events associated with micro-organizational entities to be understood—entities such as religious and ethnic tribes, militias, or insurgent and terrorist networks. Examples include link and social network analysis models, socio-cultural ethnographic models, cultural identify affinity maps, cognitive and behavioral models, multi-agent systems, and cellular automata diffusion models.

As an example, consider what a cognitive/behavioral micro HSCB model to capture human performance of an individual would look like. The components of even the most simplistic model would need to include the following:

- perception—capturing information from the environment for memory storage, and sensing it directly or through communications from others
- motor behavior/response execution—carrying out physical operations on the environment
- planning—dynamically determining the tasks to be executed based upon the mission/goal at hand
- memory—storing information for later use, retrieving relevant data when needed, and forgetting facts and skills with time
- workload/attention—capturing the effort required to perform a mission and its effects thereon
- situation awareness—measuring how well individuals understand information relevant to their goals

- learning—displaying improvements in performance with practice and new data
- stress—mapping the influence of negative global factors on performance
- individual differences—the impact of differences in attributes such as expertise, culture, and personality on individual behavior

To work, this human performance model would need to generate sequences of realistic user actions that: (1) receive input about the environment, (2) actively maintain a representation of this input for use in current cognitive processing, (3) evaluate the contents of this actively maintained representation and determine how to respond to them, (4) generate actions in accordance with a response plan, and (5) learn knowledge from experience and store/retrieve it when required.

The question of how best to develop a detailed human performance model is one that has been considered for many years in the cognitive sciences and psychology communities. Such considerations include whether to build upon a single existing modeling framework (for example, Adaptive Control of Thought—Rational); to adopt separate approaches for each model component (such as selecting one model for visual perception, a second for working memory); or to allow flexibility in selecting a unified model or model component, based upon the application need. Many of the major computational modeling systems can be downloaded from various academic and government laboratories and examined in detail to help make such decisions. Indeed, some of these human performance models have been validated across a wide range of ages (including children, young adults, and the elderly), and in a variety of domains.

Integrated Micro-Macro Models

Integrated micro-macro (unified) models refer to the class of models that essentially tie the modeling elements of the previous two together. One of the more difficult problems 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 multi-disciplines of the social sciences. Similarly, understanding social systems and social change—both sources and consequences—via integrated micro/macro models requires coupling multitudes of model ensembles, relating their input and output to each other. Just as with the physical sciences, a single model cannot capture all the phenomena in a complex social process.

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 macro HSCB models are called Analyzing Complex Threats for Operations and Readiness—a country-level macro-structural model that identifies key factors (such as gross domestic product per capita, life expectancy, ethnic diversity, global trade patterns) that can contribute to different kinds and levels of conflict and country instabilities; and Fuzzy Analysis of Statistical Evidence—a pattern classification algorithm that analyzes the relationships between country macro-structural factors and historical instances of country instability.

The micro HSCB model is called FORecasts of Crisis and Instability using Text-based Events—a set of models that in near-real-time monitors, assesses, and forecasts indicators of near-term instability by automatically parsing and converting electronic news stories into indices that reflect the character and intensity of behavioral interactions between people, the organizations they form, and the institutions where they work. The results of the integrated micro-macro HSCB model have been promising by demonstrating the potential to accurately forecast not just the occurrence, but also the level of intensity of country-specific instabilities five years in advance with about 80 percent overall accuracy.

On the other hand, most attempts at producing unified micro-macro HSCB models of cognition (Adaptive Control of Thought—Rational; Goals, Operators, Methods, Selection; Executive-Process/Interactive Control; Soar) have not confronted the many complications involved in capturing the behaviors of higher level entities such as organized teams. When they have attempted to model teams, it was generally done for simple missions, with the primary extension of their models involving the addition of communication tasks that allow one individual to communicate with one or more other members of the team and remember the results. In addition to developing approaches for extending existing individual human models, the embodiment of team behavior would ideally allow the operator of the system to observe and interact with its components at various levels of aggregation. This suggests that whatever specific enhancements are made should naturally combine to allow viewing simulations at a variety of different levels, from large teams to small teams to individual team members.

Technology Strategies and Recommendations

As described near the end of chapter 2, the panel assessed each constituent technology with respect to its development maturity and uniqueness to DOD. This assessment led to a simple categorization scheme shown in table 10, into which the particular technologies for HTP have been assigned.

Table 10. Human Terrain Preparation Technologies Categorized According to Development Maturity

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

In this context, noting that DOD has nothing “at the ready,” the panel recommends that DOD:

- **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:

    - 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, and 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 effort will involve tapping into and leveraging commercial research and development 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 benchmarks, metrics, experimentation, and validation techniques for HSCB modeling
- be closely connected to the combatant commands and other potential users

Chapter 5. Ubiquitous Observation and Recording

The QDR identified an emerging threat environment that fundamentally challenges the ability of traditional U.S. surveillance systems to detect, track, and identify adversaries. The tanks, submarines, and aircraft characteristic of enemy forces of previous eras are being augmented or replaced with small and dispersed teams and individuals. The United States now faces opponents who can employ what might be considered the ultimate form of stealth: individuals hiding in plain sight. Today's adversaries exploit the urban environment by hiding among its populace or seeking the natural cover of foliage to block observation by traditional sensor systems.

To counter this new threat, the panel believes that new technology exists or could be developed to provide new levels of spatial, temporal, and spectral resolution and diversity. Furthermore, the ability to record terabytes of data will provide an omnipresent knowledge of the present and the past that can be used to rewind battle space observations in TiVo-like fashion to identify and locate even low-level enemy forces. The panel's concept extends the vision of persistent ISR to a more comprehensive capability in time and space called "ubiquitous observation and recording."

Capability Description and Technology Areas

Today's surveillance systems often provide either episodic observation with exquisite detail or coarse resolution with higher temporal sampling rates. These systems are usually operated independently with tasking often uncoordinated with the commanders in the field. Hence, their continuity of coverage is typically only marginally useful to the commander.

The panel's concept for ubiquitous observation and recording is a system of sensors that will be able to provide both surveillance of large areas and close access surveillance of individuals and small groups. The sensor system would be coupled to a data collection system able to record and store everything captured by the sensors for long periods of time. The sensors in this network will need to be very diverse. They should include systems such as very-high-frequency imaging radars to penetrate foliage; high-frequency radars that can provide high-resolution day/night images and moving-target tracking in all weather; and optical systems that can detect, locate, and track systems with the high resolution in low night light conditions. Additionally, these sensors will need to be augmented with close-in sensors and tags, as well as humans on the ground in intimate contact with both the enemy and the noncombatant population. These close-in sensors will span the full spectrum of phenomenology from seismic and acoustic sensors to chemical, biological, and radiological sensors.

To be most effective, this system of sensors will need to act as a hierarchically integrated network, where each layer in the network provides a region of focused attention with the next layer providing greater resolution in space and time but over a narrower area. Although full integration between every sensor is not required, it is critically important that certain subsets of sensors be vertically integrated to provide for rapid focus of attention spanning the space from broad-area to close-access.[9]

The system construct for ubiquitous observation and recording is shown in figure 7, and consists of three principal technology areas:

1. **Day/Night All-Weather Wide Area Persistent Surveillance.** A two-layer approach is envisioned: (1) large regions measuring approximately100 kilometers square under constant surveillance with day/night all-weather radars that can detect and track moving targets and image stationary targets at resolution measured in feet to meters, and with temporal sampling measured in tens of seconds; and (2) focus areas (cities) measuring approximately 20 kilometers square, observed continuously at a resolution of one meter and a sampling time of one second with the sensitivity to see like "an owl in the night."

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9. This concept is a further refinement of the layered ISR architecture developed by the DSB Task Force on Future Strategic Strike, and documented in its February 2004 report.

2. **Close-in Sensing and Tagging.** This area entails the prolific use of hand-emplaced or autonomously delivered unattended networked sensors and tags to enable detailed quantitative tracking and measurement of individuals, vehicles, small groups, and other dispersed assets of value to the enemy.
3. **Soldiers as Collectors.** An untapped real-time resource are the "boots on the ground" that could provide "cop on the beat" insights and intelligence.

Regions of interest for focusing assets are determined by conventional intelligence means, assisted by the entire array of sensor systems themselves, providing near-real-time updates.

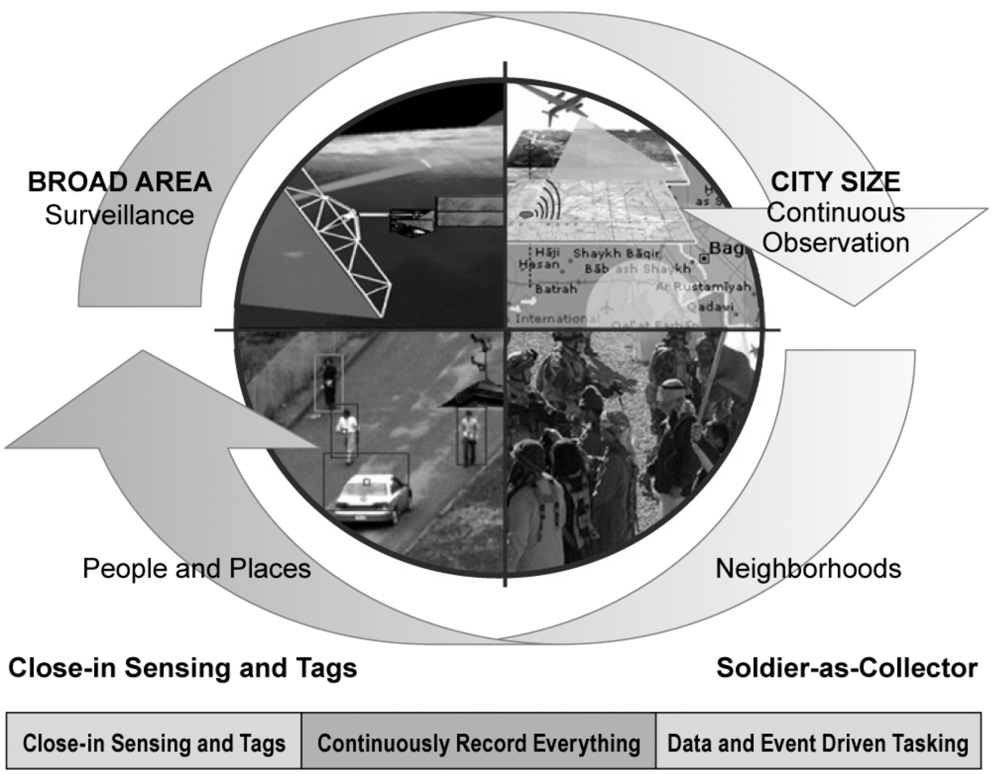

Figure 7. Ubiquitous Observation and Recording Concept

Day / Night All-Weather Wide Area Persistent Surveillance

The limited information in both space and time provided by broad area surveillance dictates the need for a two-layer architecture consisting of long-range collection systems coupled to a focused, limited, local area unmanned aerial vehicle (UAV) suite with short-range sensors. The key architectural strategy is to use sufficient persistent sampling at limited resolution, combined with sufficient resolution and limited persistence.

The integration of these two collection systems can provide a virtual capability in a region between both systems as shown in figure 8. The broad area surveillance network is likely to include both satellites and a number of high-altitude air vehicles with endurance measured in weeks. Continuous coverage is vital for tracking moving objects in an environment that is dense with both targets and confusers. Resolution on the order of one meter or less with update rates of one-per-second or less are needed for tracking moving objects operating in the midst of other moving objects. Both optical and radar sensor systems candidates will be used for these tasks.

Radar Technologies

Radar sensors are often preferred for broad area surveillance since they can provide all-weather day/night coverage. Substantial improvements in radar sensor technology will be needed to provide the level of capability envisioned for ubiquitous observation. Current radar technology can provide significant high resolution area coverage of fixed objects using synthetic aperture radar (SAR) technology, but at very low update rates over large areas. It is possible today to provide moving object radar detection but with poor angular resolution. A significant advance in radar technology will be needed to provide high update rates with high resolution over a wide area of coverage.

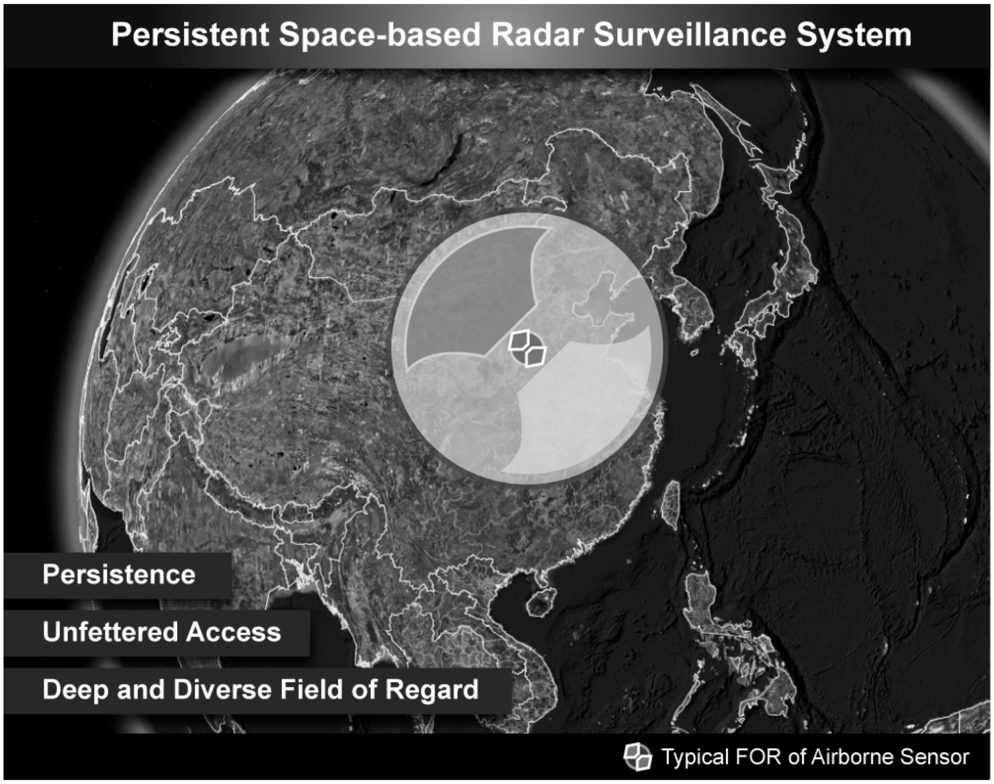

Figure 8. A Well-Balanced Intelligence, Surveillance, and Reconnaissance Architecture

The ultimate vision for broad area radar surveillance is to provide efficient coverage by ultra-long endurance, high-altitude UAVs cued by a space-based radar system, illustrated in figure 9. The key attributes of a mixed space-based and airborne surveillance system are as follows:

- deep, theater-wide, assured access, requiring an element that is space-based
- persistent awareness and tracking of significant movements and near-continuous access to regions of interest
- day/night, all-weather surveillance with radar surveillance systems using ground moving target indication (GMTI) for the broad area coverage and focused SAR imaging on selected targets
- timely information in response to user needs through dynamic theater/combatant commander tasking

- terrain knowledge sufficient for visualization and for targeting precision-guided munitions, requiring radar-based high resolution terrain imaging (high resolution terrain imaging or precision digital terrain elevation data)
- sufficient capacity to enable a new paradigm: “information needs driven tasking,” which calls for an integrated, electro-optical/infrared/SAR/GMTI dynamic tasking capability
- ubiquitous observation through the use of an intelligent closed loop dynamic database

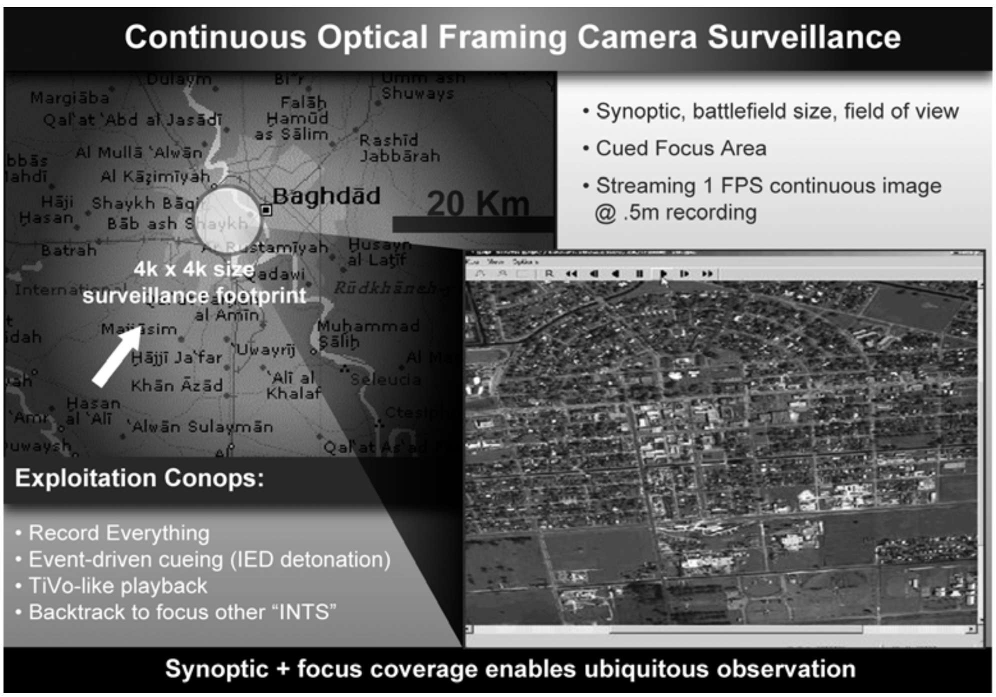

Figure 9. Field of View Provided by Space and Airborne Radar Sensors

The space radar segment will provide both SAR and GMTI of ground forces in close contact and in real time with accuracy sufficient to target enemy forces. This evolution of space surveillance systems will provide not only strategic intelligence information, but real time tactical targeting information. The persistence and revisit rate of the space-based surveillance system will be a function of both the individual satellite design and the constellation size. Additionally it will be necessary to exploit all the radar scattering information that can be obtained by using full-polarization GMTI and high-range-resolution GMTI to dissect the target and enable target characterization along a broad dimensional basis. In this way sufficient information can be obtained in order to focus and task higher resolution optical sensors. There are a multitude of trade offs that can be made among these factors, as well as among the capabilities of the airborne sensors that augment this constellation to provide increased persistence and resolution.

The improved capability of these surveillance systems will increase the incentive for an adversary to target these systems for defeat or countermeasures. The threats that these systems will face create the requirement for these systems to be designed for survival in such an environment. It is envisioned that a space-based surveillance system will be designed to withstand an attack by either a high-altitude nuclear detonation or electronic counter-sensor jamming systems intended to "blind" the radar sensors. These increased threats may stress the current state of radiation-tolerant electronic designs of radio-frequency transmit and receive modules, as well as computing power efficiency of today's digital signal processing systems.

It is important to remember that broad area sensors will operate as part of an integrated network. These systems are most useful when their tasking is coordinated with other sensors in the network. Similarly the collection and exploitation of all data in a timely and intelligent fashion is key to the overall system performance and utility.

Optical Technologies

Going beyond persistent surveillance to a continuous or video level of observation (<1 meter and >1 hertz imagery), offering a continuous "God's eye view" of large areas, will enable a dramatic improvement in situational understanding. This improvement will be achieved when high-resolution, high-update-rate data can fill in gaps and help tie together all sources of intelligence collection. 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, to then use that knowledge to focus communication and signals intelligence sensors or search through achieved data. This view can provide the foundation upon which to map all other intelligence, much the same as imagery intelligence is tied to terrain databases today.

Current video optical sensor technology offers area coverage through the use the use of a multitude of separate optical sensors (figure 10). This system does not scale well to very broad areas (such as a large city or country) due to the large number of sensors required. Multiple high-altitude, long-endurance air-vehicle-based optical sensors offer an attractive alternative when the goal is to cover such large areas.

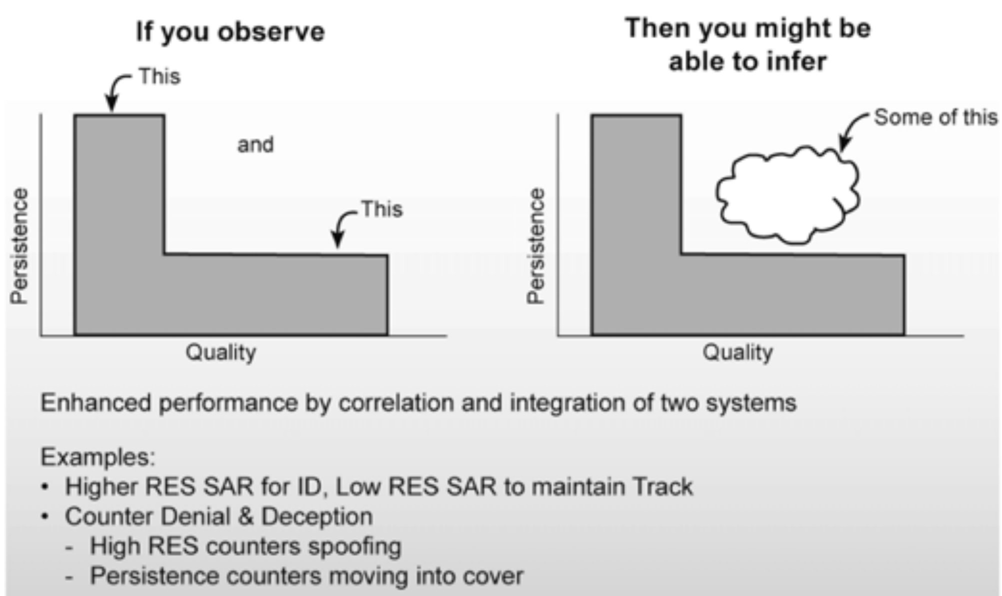

Figure 10. Hypothetical Synergy in Mixed Architectures

The elements that will enable such broad area video surveillance capability will include: arrays of small, low-cost 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 low-earth-orbit or mid-earth-orbit radar surveillance systems to provide a broad synoptic integrating view. Enabling technologies to achieve ubiquitous observation and recording as envisioned by the panel will likely include hydrogen powered UAVs for long endurance (H2 IC engines and longer-term hydrogen fuel cells); ultra-light weight sensor systems (radar, infrared, and optical); light-weight optics; large area (1 billion pixel) focal plane sensors; radiation-hard digital electronics for space transmit and receive modules; and 50 percent efficient space solar power.

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

Close-in Sensors and Tagging Systems

The diffuse nature and low signature of current and future threats will make close-in ISR increasingly important. Such close-in sensing must include both traditional human intelligence, as well as a new set of sensors that must be placed very close to their targets because of the inherently low signature of these targets (which may be a single individual or small weapon). Outlined below is how technology can support both human intelligence and physically emplaced sensors and networks. Covertness will come from both the small size of the sensors as well as innovative camouflage and deception for the sensors and their means of communication.

Constituent Technologies

The vision for close-in sensors is to develop a broad spectrum of sensors (chemical, biological, radiation, acoustic, seismic, optical, or infrared, for example) with integrated command and control (tasking) and data exfiltration links. The size of these sensors might range from that of a shirt button to that of a soda can (with < 1 cm^3 as a nominal goal). Also required is the means to precisely deliver these sensors across a broad area (1 meter circular error probability into a city or a nation) and the energy sources that will permit the sensors to operate from weeks to months.[10]

Current R&D programs for tagging, tracking, and locating should be enhanced to provide capability to deploy and use tags, taggants, and sensors for close observation in areas of denied access. 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 provide ability to track and identify people and materiel that move from locations of interest to other locations, and a combination of nanotechnology, biology, and chemistry promise to provide significant increases in capability to conduct pervasive surveillance on a global basis with minimized exposure of personnel and minimized probability of compromise of the deployed assets. Additional emphasis needs to be directed toward exfiltration of data from remote locations and autonomous control of sensors, including movement based on sensed information. Increases in science and technology investment 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. R&D in these areas and potential threats to U.S. forces and critical national infrastructure.

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10. An in-depth review of DOD's energy usage practices and energy requirements was conducted in a parallel study by the Defense Science Board Task Force on DOD Energy Strategy, report forthcoming.

Microsensor Technologies

There are a variety of technologies that can support this vision for close-in sensing. Advances in high-density electronic packaging, largely driven by the handheld consumer electronics industry, have been dramatic in recent years. Similarly, there have been considerable advances in some relevant sensor technologies (such as microphones and video cameras). However, there are a variety of military-specific sensors that the department cannot rely on industry to produce. Chemical, biological, and radiation sensors are at the top of this list. There has been significant activity in existing DOD sensor programs, but progress has been slow. Other agencies, such as the Department of Homeland Security, have started related programs in which DOD should be informed to avoid unnecessary duplication of effort. The panel encourages continued effort, but ones that are well synchronized across the interagency.

In addition to the sensing technologies themselves, high performance, efficient signal processors are required to process sensor data and reduce bandwidth prior to data exfiltration. Such bandwidth compression is often required both to minimize sensor detection and to conserve power for communications. Although there has been notable progress in commercial low-power signal processors, the DOD needs are so extreme (1-10 mW) that continued development of DOD–specific custom processors for this application is warranted.

Energy and Communications Technologies

Whether close-access sensors can be easily observed is often dominated by the energy source and the communications system antenna. Although there have been extraordinary advances in battery technology in the past several years, the performance and lifetime of modern close-access sensing systems is still largely determined by battery life. A 100-fold increase in battery energy density should be a goal for these systems. The panel encourages continued research into advanced technologies such as energy scavenging, but recognizes that practical energy scavenging systems (except for solar cells) are not likely to appear within the next decade. Creative antenna designs continue to emerge and R&D in this area is also encouraged due to the critical need for small antennas. Specialty materials (such as, materials that morph, change color, or have unusual visual or electronic properties) will continue to be key for antennas, energy sources, and structures for these sensors.

Deployment Enablers

The final technology challenge noted by the panel is the ability to deploy close-access sensors undetected. Work on low-observable, autonomous, air, land, and sea vehicles specifically designed for precision (<1 meter circular error probability) sensor emplacement across a broad region will continue to be a needed R&D investment area.

Soldier as a Collector

The need for close-access sensing and the likelihood of U.S. troop presence on the ground in conflict areas of stabilization zones offers the opportunity to create networks of sensors using the individuals as the platform to carry and/or distribute sensors, as well as to utilize their innate human sensing capabilities in a networked fashion. Fielding such networks would enable ground forces to fill a tactical intelligence gap that has become evident in current operations against adversaries able to adapt in near real time. Tactical intelligence gathered by these networks will complement national collection means in modern operations—especially in preventive and post-combat operations. A major lesson of recent operations is that human-to-human interchange in the operational theater can significantly increase the likelihood of success.

The timely collection of facts obtained at the tactical (and even the interpersonal level) may help to create better operational decisions at all levels. 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.

Constituent Technologies

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. The organized collection, analysis, and reporting of such information provides for heretofore unobtainable improvements in the ability to

- maintain blue force situational awareness while performing dedicated collection or other missions
- monitor, record, and assess information in the relevant context for supported echelons
- obtain imagery, audio, and other soldier-observed/collected data sharing with which to support command and control decisions
- archive and retrieve close-in, detailed data to support future intelligence, operations, rehearsal, and training

Micro/Miniature Sensors

Several technologies must be developed and/or integrated to seamlessly integrate a network of sensors capable of collecting and archiving the data from within each soldier's sphere of influence. Many front-end sensors (especially small digital/video cameras, audio recorders, and Global Positioning System [GPS] receivers) are commercially available and 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 as soldier-borne equipment. Examples of these technologies include chemical and biological detectors, small multi-spectral sensors, mobile ad-hoc communication networks, and geolocation systems that will work in GPS-denied areas (such as in buildings). Also under development are some interesting technologies that can aid soldiers in their interaction with local civilians. These include automatic language translators (discussed in the automated language processing section in Chapter 4) and technologies to automatically detect intentional deception of people being interviewed by soldiers.

Automated Debriefing Tools

To aid the soldier himself as the collector, the panel believes that automated and interactive debriefing tools will be needed. These tools will allow the soldier to quickly and efficiently collect personal observations and deliver them to the network with minimal effort. As soldiers in the field are already burdened with numerous stresses, this system should be seen as something to make their tasks easier rather than more burdensome.

Recording

The archiving, retrieval, fusion, and contextual understanding of the data collected will be a key element in determining the utility of a soldier-based sensor network. These technologies were discussed previously in this report.

Energy

Energy sources will 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- to 100-fold improvement in current energy storage per unit weight is both useful and necessary. Although industry is pushing these technologies hard, the extreme needs of DOD users warrant continued R&D investment in ultra-high-density energy storage technologies.

Technology Strategies and Recommendations

The maturity matrix for the priority constituent technologies for ubiquitous observation is shown in table 11. Outside of energy storage technologies, which are today being driven largely by commercial electronics, the priority technologies for ubiquitous observation are more specialized for DOD and intelligence community purposes, and will therefore require sustained investment to advance. Such has been the case for hyperspectral and foliage penetration sensors. The panel believes that these particular technologies are ready for operational fielding. In more speculative domains, such as microsensors, bioinspired and bio-electronic tags and sensors, devices in the micro to nano domains, molecular scaled taggants, and micro delivery platforms, investment is deserved.

Table 11. Ubiquitous Observations Technologies Categorized According to Development Maturity

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 hyper-spectral 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 & tags ▪ Native signature recognition at long ranges (human and object)	▪ Efficient energy storage technology	▪ Miniature sensor and tag technology ▪ High density packaging for centi-meter scale devices
Soldiers-as-collectors	▪ Microsensor technology ▪ Interactive automated debriefing	▪ All-domain precision geolocation ▪ Soldier-centric communications and networking technology ▪ Body-borne flexible displays	▪ Efficient energy storage technology	

To achieve significant progress toward the panel's vision for ubiquitous observation, DOD must consider the management recommendations found in the main report. This capability is but the latest vision for ISR and, as with all previous visions, it must cut across all services and the intelligence community if it is to be realized. As such, cross-cutting programming, management, and oversight will be needed. In addition, three more technically focused recommendations should be pursued to support the ubiquitous observation vision:

1. **The Army, Marines, and DARPA should partner in an effort to accelerate the maturation of the soldier-as-collector concept.** The program should also include monitoring and developing relevant miniature sensor technologies and automated debriefing tools.

2. **A sustained series of advanced technology demonstrations and advanced concept technology demonstrations 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. Special Operations Command should be major participants in these activities because of their global intelligence, surveillance, and reconnaissance responsibilities.

3. **DARPA and related research and development 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 6. Contextual Exploitation

A new set of information-rich exploitation and collaboration tools are needed to bridge the functional capabilities of ubiquitous observation to rapidly tailored delivery of scaled effects. The need is driven in part by the panel's vision for ubiquitous observation and recording, but also by the environments in which the U.S. military must now operate. 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 of adversary activity with everyday commerce and civil life, communications, and much-increased expectation of mission effectiveness and avoidance of collateral damage. Within this milieu, target identification and location and decision-making still remain central elements of combat. The concept of "target" has expanded and now includes complex and often ambiguous entities, down to individuals in indigenous populations. In this increasingly demanding operating environment, the war fighter needs target discrimination tools that provide more rapid, accurate, and contextually relevant effects.

Capability Description and Technology Areas

The succinct description of contextual exploitation is the over-used phrase "connecting the dots." The massive amounts of data already being generated by open, military, and intelligence sources demand much better automated tools for both analytical and real-time applications. The challenge is even more significant as the advances described for ubiquitous observation become a reality. The panel's assessment identified three technology areas as priorities for the contextual exploitation capability:

1. mega-scale data management
2. situation-dependent information extraction
3. human/system collaboration

The combination of these technologies will open new opportunities to automate the discovery of relationships among apparently independent events, actions, things, or people, masked by military and civilian clutter, and will provide tools to raise the level of human computer interaction from interface to broad domain collaboration. These tools will be used to extract salient and related features, and to enable time-critical targeting and intent recognition of evolving threats. Their development is being driven largely by the commercial sector and fueled by rapid innovations in underlying technologies such as computation, data storage, and software architecture.

Mega-Scale Data Management

Future operations can be expected to require the contextual exploitation capability to handle exabytes of data at transfer rates of terabytes per second, coupled to decision timelines in seconds to minutes. As the threat base evolves, there will be a greater dependence on integrated, multiple-domain sensors with much greater dynamic range, spatial reach, sample rate, and temporal history. Mega-scale data management will apply an integrated, federated, and scaleable data framework to link disparate information sources and provide robust knowledge management to permit conclusions based on contextual relationships. It will also incorporate a robust security and access environment to enable information to be routed and shared appropriately in a timely manner. 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 will minimize catastrophic errors due to cognitive biases and other limitations.

In the private sector, the ability to model and improve marketing analysis, energy exploration, and financial forecasting have benefited from the application of these technologies. Within DOD, however, efforts to manage and exploit large data sets, conduct mission planning, and contingency management have had limited success. The panel (indeed the entire study team) believes that DOD must become a much more agile and responsive adapter of commercial advances in this and related fields in order to achieve the anticipated operational demands of data management.

Situation-Dependent Information Extraction

Situation-dependent information extraction uses advanced algorithms to support situation associative processing and improve human systems collaboration. 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. Application of these techniques for disparate sensors that are not temporally or specially matched would enable DOD to detect, discern, analyze, and understand the actions of stealthy adversaries embedded in complex domains.

Effective implementation and utilization of these tools in conjunction with better understanding of the operational environment and adversary activities will improve performance of U.S. forces across the decision-making spectrum from tactical to strategic, and across the pre- to post-conflict timeline. Improvements in link analysis and intent inference will result in faster and more complete understanding of options leading to better decisions. Many of the tools described as applicable to human terrain preparation, especially for automated language processing, apply to this technology area as well.

Human/System Collaboration

Human/system collaboration is the least mature of the three priority technology areas identified by the panel. 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 is to transform the interactions between humans and systems from an “interface” to a true “collaboration.” Through the development of the capability for computers to assist in tasks that today can be done only by humans, significant performance improvements should be expected, with goals of 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.

To illustrate the areas where technology can be developed to enhance human-systems collaboration, the panel investigated three constituent technologies:

1. natural man-machine interfaces
2. knowledge representation
3. human-guided algorithms

Natural Man-Machine Interfaces

The need for effective interfaces between the user/operator and the computer is obvious, 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." It is imperative to understand how humans interpret and understand data to create useful information in both time-pressured and life-threatening environments. The desire is that the interface 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 are likely to expand beyond just the visual and will include voice/speech, tactile, and other concepts (such as psychophysical context or physiological measurements of operator "state"). The mode of interaction could be keyed in part by the physiological state of the individual.

This area is one where there is significant activity outside the department in the commercial sector in such industries as gaming, virtual reality, and large-scale data analysis application, including weather forecasting, financial analysis, and energy exploration. The department should establish an effort to actively monitor commercial developments and exploit them as appropriate for military missions.

Knowledge Representation

For the human and the computer to truly collaborate, it is necessary to improve the ability to represent human knowledge in a manner in which a computer can both store and operate. 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 and 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, but, as with the man-machine interface area, there is significant activity outside the department. Consequently, the panel recommends that the department establish a program to monitor and exploit these developments for the military mission. For military applications, knowledge representation challenges include representing commander's intent and tactics and to represent 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 real-time plan generation for command and control applications (including tasking exploitation resources) often fall short due to: (1) the inability of the algorithm designers to build in the broad set of models required to capture the richness of these real-world problems, and (2) the heuristics required to trim the huge search spaces involved.

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

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. Said another way, in developing algorithmic approaches, it is nearly impossible for the algorithm designer to anticipate and build in models and heuristics for all possible contexts, although designers are often able to build many that are broadly applicable across contexts and to build in a finite set of context-specific ones. Human-guided algorithms have “hooks” built in and associated human-system interface (also known as graphical user interface) mechanisms that allow operators to participate in the decision-making. The software architectures for such solutions must be designed early in the design cycle to accommodate these interactions. Furthermore the solution must be “instrumented” with additional data structures that are used to tag the solution to indicate which models and heuristics were employed in developing the solution. This approach provides insight to the human operator as to why and how a specific solution was developed.

This area is judged by the panel to be 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 and help achieve the goal of at least two orders of magnitude improvement in the time for complex analyses characterized by uncertainty and ambiguity by creating the capability for computers to assist in tasks that today can be done only by humans.

Technology Strategies and Recommendations

The panel’s assessment of the maturity and uniqueness of the priority technologies for contextual exploitation is summarized in table 12. 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 data collection 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.

Table 12. Contextual Exploitation Technologies Categorized According to Development Maturity

Technology Areas	Promising, but Immature	Under Development Showing Progress	Leverage Commercial Developments	Mature Within 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	

Central to the challenge is how to move ahead. 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 neither structured governance nor coherent planning across the department. Risks must be addressed as well. For example, great potential exists for adverse public and political reaction given contemporary concern for 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 for progress include:

- **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.

Chapter 7. Rapidly Tailored Effects

The complexities of the 21st century and the challenges inherent in countering a wide range of adversaries operating within an equally wide range of societal and political environments demands a “tool kit” of capabilities applicable to “assuring, influencing, dissuading, deterring, and/or defeating” these adversaries under any and all conditions. In the long war environment with highly adaptive adversaries, affordability and rapid maturation of such capabilities are of increased importance.

Capability Description and Technology Areas

The desired, enriched set of capabilities for rapidly tailored effects should be capable of dealing with a wide range of challenges and be:

- instantaneously deliverable
- scalable in scope and effect
- applicable from tactical to strategic, and include WMD use prevention and mitigation
- useable by a broad range of friendly forces (both skilled and unskilled, including allies and coalition partners)
- feasible and affordable in the long war environment (from pre- through post-conflict)
- tightly linked to human terrain capabilities
- delivered with minimal vulnerabilities and counterproductive damage

This capability is extremely broad, and has historically been a major focus of DOD’s planning and acquisition, most especially to achieve “defeat” and “defend” (such as against missile threats). The panel therefore chose key gap areas as the priority technology areas for expanding the tool kit of rapidly tailored effects: WMD protection and mitigation, influence operations, and time-critical fires from afar.

Influence Operations

Influence operations, while related to information operations, primarily target a different audience. A recent document, approved by the Secretary of Defense, defines information operations 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."[11]

The definition above, and the definition found in the Joint Information Operations Publication 3–13, both focus operations on an adversary's information and information systems. The importance of information operations is in no way diminished by this panel or by the DSB; in fact, defensive computer network operations is being addressed in a parallel DSB 2006 Summer Study on Information Management for Network-Centric Operations.

However, the term adversary, while suitable for information operations, does not adequately address the primary target audience(s) of influence operations.[12] In the case of ongoing operations in Iraq, one former Army brigade combat team commander categorized Iraqi citizens into three broad categories: "those who would never accept the Coalition's presence in Iraq (religious fundamentalists, insurgents, terrorists); those who readily accepted the Coalition's presence in Iraq (typically secular, Western-educated pragmatists); and the vast majority of Iraqis, who were undecided."[13] These last two categories are the primary focus of influence operations.

While historical use of information operations has been focused on broad population centers at the strategic level, influence operations may take on a more tactical flavor and be tailored for population clusters

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11. Department of Defense Information Operations Roadmap, October 30, 2003.
12. *Defense Science Board Task Force on Force Protection in Urban and Unconventional Environments*, pg. 27, March 2006.
13. Colonel Ralph O. Baker, U.S. Army, "The Decisive Weapon: A Brigade Combat Team Commander's Perspective on Information Operations," *Military Review*, May–June 2006.

within a given commander's area of responsibility. Tactical influence operations will need to be much more agile than the larger, more bureaucratic information operations, particularly the psychological operations portion which tends to be often overtaken by events by the time it is implemented. Greater agility will allow theatre commanders to stay ahead of a rapidly evolving information operations campaign that is executed by potential adversaries. In order to maintain the initiative over U.S. opponents, it will be important to keep the media rapidly informed of the facts surrounding newsworthy events.

Training at the soldier/Marine level will be critically important to facilitate the rapid dissemination of information consistent with the desired messages and themes of a well-thought-out public and press engagement strategy. An ability to implement the notion of soldier as "transmitter" will have a profound effect on the ability to "win hearts and minds," and to earn the respect, trust, and confidence of a potentially hostile population. In spite of current objectives in Iraq that involve achieving that respect, trust, and confidence within 12 months, the panel believes that the effective development of influence operations will take some time. In a cross-over example with the HTP capability, developments in language processing and cognitive sciences may identify specific, culturally sensitive messages and actions that can achieve predetermined reactions in individuals and small groups, to obtain desired objectives in a timely manner.

In the current tactical environment, theatre commanders, of necessity, often take the initiative to develop their own approaches. A good example is presented in Col. Ralph Barker's paper, in which he describes his experience as part of a brigade combat team in Baghdad in 2004. The example is centered on an incident involving a vehicle-borne improvised explosive device (VBIED) at a Baghdad checkpoint known as Assassin's Gate. The attack resulted in the death of about 50 Iraqi civilians waiting at the checkpoint. In this example, Col. Baker discusses how the tight controls that he was under from higher headquarters, not to release a statement to the local press, resulted in valuable time lost in the information operations campaign against the insurgents. While headquarters was gathering facts and preparing for a press conference later in the day, the insurgents were busy passing information "…to the press… that Coalition Soldiers were responsible for the casualties at the checkpoint because of an overreaction to somebody shooting at them from the intersection; that is, the terrorists were spreading a rumor that the carnage on the street was not the result of a VBIED but rather, the result of an undisciplined and excessive use of force by [his] soldiers."

As this misinformation started to multiply in the Arab media, Col. Baker made the decision to have his field-grade officers talk to the local press at the scene to present the facts that were known at the time. The rapid presentation of the facts helped calm the situation, and resulted in a decision by the commander to engage the press, especially Arabic press, as quickly as possible with whatever releasable facts were known at the time. The brigade also kept the press updated with additional facts as they became known. Thus, the brigade was able to respond more rapidly, and to a greater effect, than the insurgent information operations effort. This active engagement approach to influence operations helped to mitigate adverse domestic reactions that nearly always followed in the wake of major incidents, and thus provides a real-world example of how influence operations can be carried out at the tactical level.

Technical Tools for Influence Operations

While the tools that are normally part of psychological operations (pamphlets, loud speakers, press releases, etc.) are likely to support future influence operations, the panel also identified the need to develop new tools to help theatre commanders make, and understand the possible impact of, choices involving military and civil/infrastructure operations. Particularly in the case of civil/infrastructure operations, the credibility of coalition forces will be directly tied to a demonstrated ability to improve the quality of life, physical security, and societal stability of the local population. New models are needed in the areas of non-kinetic cause-effect models; campaign planning/targeting/shaping tools; storytelling, gisting, and advanced visualization; and ultimately decision support tools that provide recommended courses of action.

Because the analysis of conflict and nation-state instability is inherently complex and uncertain, no one social science theory or quantitative/computational model is sufficient. An ensemble of methods and models must be integrated within a single decision-support framework to generate a range of plausible futures. Robust adaptive strategies that hedge across plausible futures will provide practical options for the decision-maker.[14] Within a validated theoretical framework, these models and decision support tools will provide strategic early warning capability and actionable options for influencing and preserving the stability of the majority of population within a given area of operations, and minimize the likelihood of deadly conflict. The reader is no doubt struck with the link back to many of the same tools and issues important to the HTP capability.

Time-Critical Conventional Strike

Almost every recent study of how the United States should better prepare itself to deal with the challenges of anti-terrorism, counter insurgency, shaping the choices of emerging powers, and countering the acquisition or use of WMD has included statements about the need for a capability to quickly deliver a conventional strike against time-critical targets. In many of these 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.

Despite the often repeated statement of need, no such capability exists today. Given a situation in which three of the four critical capabilities of the 21st century OODA-like loop do their job and indicate a rapidly emerging threat in an otherwise remote area where the United States does not have forward deployed assets, the rapidly tailored effects capability will have nothing to offer outside of a nuclear strike. Needed in the rapidly tailored effects tool kit is the ability to rapidly deliver a 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:

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14. Popper, Steven, W., Robert J. Lempert, and Steven C. Bankes, "Shaping the Future," *Scientific American*, pp. 66–71, April 2005.

- response time of less than a half hour (total time to impact, including decision time)
- standoff range of greater than 1,000 kilometers
- delivery accuracy of a few meters
- logistics that involves no local support requirements

Unlike most of the other eleven technology areas in the four critical capabilities, relatively mature technology is available to enable significant new capabilities for several options. In fact, with modest engineering, as opposed to ground-breaking S&T, these options could provide an initial capability within a decade. The acquisition of such a capability has not happened, however, because each of the available options has drawbacks, and it has proved difficult to reach a consensus on which solution is good enough and represents a reasonable compromise between all of the objective attributes. Options and issues include:

- ballistic missile launched from the continental United States or submarine-launched ballistic missiles
  - mistaken interpretation of a nuclear launch
  - achievable accuracy
- medium-range ballistic missile launched from submarine
  - availability of launch platform
  - sub-surface launch technologies
- medium-range ballistic missile launched from allied country
  - political issues related to launch approval
  - political issues related to “cost” to the United States of basing
  - policy issues related to the Intermediate-Range Nuclear Forces Treaty

- air- or surface-launched cruise missile
  - response time and availability of launch vehicle with improved reliability
  - flight time of cruise missile

S&T investments could yield even more capable systems, but there are technical and policy issues associated with these as well. For example:

- air breathers
  - hypersonic technology immaturity and expense
- space-based directed energy
  - directed energy technology
  - policy issues related to space basing
- terrestrial-based directed energy
  - directed energy technology
  - technology related to use of relay mirrors
- long-range (intercontinental) gun
  - various gun and material technologies

Two other issues stretch across all of the options and need to be addressed as well. First, timeliness of decision-making must match timeliness of the weapon in order for the mission to succeed. A weapon that can reach its target in tens of minutes or less is useless if the decision to use it takes hours or days. The use of technology to aid difficult decision-making in complex multi-dimensional situations must accompany any effort to develop the weapon component of a rapid conventional strike, as discussed previously. Equally important, however, will be pre-determined policies and practice to achieve timeliness.

The second cross-cutting issue associated with a rapid conventional precision strike is the persistence of the ISR target tracking and identification that must accompany such a capability. The greater the probability that custody of the target position and identification remains unbroken the less is the need for the timeliness of the strike. There is not a linear relationship between the two, but the relationship is strong and should be taken into account when addressing how to balance the requirements between the two.

WMD Protection and Mitigation

A recurring theme in DSB studies has been that the accelerating global proliferation of WMD and associated accountability, safeguards and security, reliability and maintenance, and utility and delivery technologies require a comprehensive approach to war fighter and system protection, consequence management, and continuity of operations. Proficiency in these areas has the added benefit of deterring adversaries and of being transferable for response to natural catastrophes in which DOD will have an important supporting role.

The panel's assessments of critical constituent technologies benefited from the comprehensive report of the *Defense Science Board 2005 Summer Study on Reducing Vulnerability to Weapons of Mass Destruction*. One of the 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). Attaining these capabilities will require the development of rapid diagnostics and environmental assessment tools, the discovery and application of broad-spectrum medical countermeasures (for pre- and post- exposure), and rapid decontamination agents and protocols. A more specialized area of concern to the panel is the significant drop-off in attention to nuclear survivability, both technically and operationally. S&T areas that would contribute most importantly to mitigating the effects of WMD are discussed below, together with desired performance and technical goals as well as challenges and issues.

Rapid Diagnostic and Environmental Monitoring Tools

Effective crisis management during a WMD attack demands the rapid integration of diverse information. Accurate situational awareness is critical to decision-making and to mounting a rapid and appropriate response; knowledge of the nature and extent of the attack are essential for both. Therefore methods and procedures for rapid, minimally invasive screening of biological, chemical, or radiation exposure must be developed. Results from tests of individuals should be available within minutes and of the environment within hours.

Furthermore, because a limited number of medical or environmental experts are likely to be available during a crisis, such screening should be simple enough to be performed by non-professionals. In addition, the ability to provide safe stand-off for operators will be important. Technologies for biological and radiation today do not support that requirement. For radiation detection, advanced active interrogation concepts have been proposed but are very immature and will require a sustained R&D investment for quite a few years. For bio-agent detection, concepts proposed to date have proved of limited utility. In both cases, system concepts for remotely delivered and operated in-situ sensors should be matured as the nearer term gap-filler.

For large, perhaps isolated areas or long-term operations, portable and/or transportable detection and diagnostic equipment may be required. These systems must be fortified for a variety of field environments to include air flight and drops, a range of temperature, humidity and hazardous environments, and include supportable power systems appropriate for operational needs (such as 12-to-24 hour uninterrupted operation, with replacement components comprising less than ten percent of total weight and volume; nominal system reliability of at least 95 percent over the operational envelope). Communications and information integration requirements for assessment and decision-making also indicate that rapid data acquisition (15 minutes or less) with real-time analysis and display/send features are required.

Broad Spectrum Medical Countermeasures

Medical countermeasures, as well as the means to deploy them in time frames from hours to one or two days, should be in place for use in a WMD attack or similar crisis. The anthrax attacks of 2001 illustrated that post-event treatment for a biological attack, even when available, currently requires active medical intervention for each victim for weeks to months. Long timeframes can also be envisioned for treatment of chemical or radiological exposures. Scientific and technological advances in the development of countermeasures could reduce dramatically the time for surge response in an event and substantially reduce human suffering.

Broad spectrum, active, and passive countermeasures (drugs and vaccines) for protection from exposure to chemical and biological agents must be discovered, developed, and deployed, but in many cases the fundamental knowledge required to accomplish these goals is still lacking. The department has recently made a commitment in the Transformational Medical Technologies Initiative (TMTI) to pursue this path, but it is not without significant risk. Technological and process advances and improvements are needed in the areas of drug testing, approval, simulation, and modeling to speed and better inform scientific investigations. Because the DOD has limited expertise in these areas, future progress will depend on active collaboration with researchers in academia and the biomedical industry.

While TMTI is initially focused on only two classes of biological threats, the department will be expected to address rapidly emerging threats as well. One example of relative neglect by DOD and the larger community (the Departments of Health and Human Services and Homeland Security) is the nuclear threat. However, as biomedical science and nuclear event survivability research advance, it should also be possible to develop countermeasures that reduce radiation exposure deaths substantially. Preliminary ongoing medical science investigations have shown some promise in this area, and such research should be working towards a goal of reducing exposure mortality by 90 percent.

Rapid Decontamination

Timely and safely restoring operations is crucial to minimizing the impact of a WMD event or similar crisis. Directed research, development, and technology transition should aim to improve decontamination processes to provide 99 percent assurance for reconstitution of operations within 15 minutes to 1 hour. Using a layered approach to 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 for chemical or biological exposures have some similarities in the decontaminating agents that can be used, but radiological or nuclear contamination requires different procedures. In all cases, there remains a pressing need for additional work to define standards and processes for cleanup for each modality using currently available technologies. An overriding issue, long identified but yet to be resolved, is "how clean is safe?" Answering this question requires both interagency efforts and a well thought-out plan for public communication. Moreover, it can have different answers in civilian or military environments, and DOD must take responsibility for establishing its own standards in the wide array of operational environments it faces. As noted in the 2005 Defense Science Board summer study, the anthrax events in 2001 illustrated the importance of this issue in the biological realm, with enormous cost and time delays for reconstitution of postal facilities in the United States. Current radiological cleanup standards employed by the Environmental Protection Agency are equally restrictive and would result in enormous economic impacts even for radiological events in which there is little or no loss of life.

Maintaining or Restoring Functionality after a Nuclear Attack

A nuclear attack has the capacity to inflict immediate damage orders of magnitude above other modalities. The issue of mitigation and recovery in such a case was studied for many years during the Cold War, but much of that knowledge is forgotten. Prudent sheltering and showering by individuals, for example, can go far to mitigate the impacts of radiation exposure. With respect to both civilian and military infrastructure—and equally critical war fighting capabilities—attention to radiation hardening and/or operational workarounds has suffered from widespread neglect. Again much was learned during the Cold War. Over the past decade, investments by 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 (EMP) commission and a recent DSB study have taken DOD to task for its neglect of nuclear survivability.[15] Recommendations for remedying the situation have been made and some actions regarding EMP have been recently agreed upon. But the spectrum of concerns extends beyond EMP—potential and declared nation-state adversaries are proclaiming their pursuit of theater and tactical nuclear weapons aimed at countering U.S. conventional military superiority, with a willingness to use such weapons on their own territory if need be; and evidence continues to build of terrorist interest in acquiring a nuclear weapon.

Technology Strategies and Recommendations

The panel's assessment of the maturity and uniqueness of the priority technologies for rapidly tailored effects is summarized in table 13.

The panel 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*, **DOD, in partnership with other key federal agencies, should**:[16]
    - **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

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15. *Report of the Commission to Assess the Threat to the United States of Electromagnetic Pulse (EMP) Attack*, July 2004; and *Defense Science Board Task Force on Nuclear Weapon Effects Test, Evaluation, and Simulation*, April 2005.
16. See Volume II of the *Defense Science Board 2005 Summer Study on Reducing Vulnerability to Weapons of Mass Destruction* for a more complete description of each recommendation.

- **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

Table 13. Rapidly Tailored Effects Technologies Categorized According to Development Maturity

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

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

The task force's recommendations for influence operations are:

- **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 as noted in table 13.

For time-critical conventional strike, the panel recognizes the complexity of the issues associated with the options and recommends that

- **DOD develop a comprehensive plan to evolve time-critical conventional strike capabilities.** 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.

Chapter 8. Technology Push Perspective

Thus far, this report has described a process and results traceable to mission and operational needs balanced against technologies available today, or those that could address those needs with the proper investment. However, 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. As such, a balanced S&T strategy must maintain a healthy "technology push" component, as well as the operational or capability pull.

A focus on technology push has two primary objectives. The first is to discover game-changing capabilities enabled by technology advances—both to exploit new technology opportunities for use by the United States and, equally important, to assure that the nation not surprised by potential adversaries. The most likely sources of new capabilities of this magnitude are the technologies that are changing most rapidly and therefore are least fully exploited for military applications. Those which fit this criterion most obviously today are biotechnology (where DOD also lags well behind other government organizations and the private sector); nanotechnology; and information technology, which continues to expand in spite of the recent decades of advances. DOD must assure the development of potential capabilities based on detailed understanding of these technologies and the military opportunities they might present. Moreover, the synergies among these three areas is starting to manifest itself, such that DOD savvy in less than all three runs the risk of missing some important breakthroughs.

The second objective is to seek further operational advantages in applications of available technologies. This is less likely to produce new game-changers, but it should be a deliberate objective in order to understand how adversaries could exploit the commercial advances and, of course, to better understand the military possibilities.

Figure 11 is illustrative of the bio-nano-info opportunity space. The rectangles indicate the individual technology area with an example of a military capability that might be developed, enabled by that particular technology. The ovals represent capabilities that derive from the synergy of two or three of these high-rate-of-change technologies.

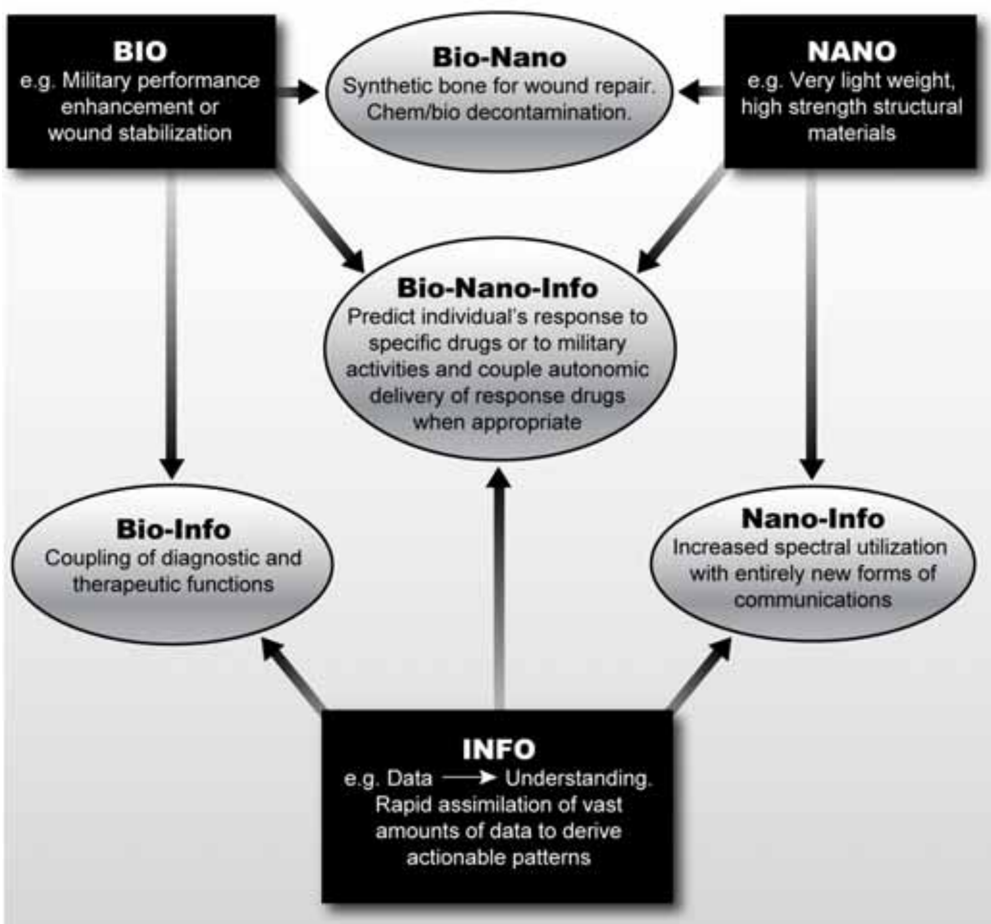

Figure 11. Illustrative "Technology Push" Examples in the Bio-Nano-Info Nexus

Table 13 shows a number of examples for bio and nano that have been proposed as potential derivatives of these technologies and suggest potential for important military capabilities.

Table 13. Potential Military Capabilities Based on Advances in Biology or Nanotechnology

Potential Capabilities in Bio and Nano

Bio[1]

- New stealth characteristics using bio materials
- Identify and track people using biological makers
- Emulate capabilities of nature (biomimetics)
- Performance enhancement—physical performance, enduring sleep deprivation/other extremes
- Autonomic coupling of diagnostics and therapeautic functions
- Wound healing with engineered skin, tissue, organs
- Counteract shock to allow continued functionality
- Cell-based energy systems (biological photovoltaics)

Nano[2]

- IRLO (nano layers, selective optical barriers)
- Personal ISR (nano-enabled air vehicles (1/3 oz)
- Enhanced personal protection (nanofibers strengthening composites and stretching to absorb eneregy
- Identify, track people (nano taggants)
- Radically increased memory scale (giant magnetoresistive memories)
- Major steps in encryption and decryption (quantum computing and communications)
- Improved marine propulsion efficiency (nano-based surfactants)
- Very lightweight structural materials with high strength for improved land-space vehicles

1 "Opportunities in Biotechnology for Future Army Applications," NRC Board on Army S&T, 2001
2 Various publicly-proposed capabilities

The message in table 13 is not what should be emphasized in S&T. Instead, there are many potential military capabilities that might emerge from a well-structured, but broad exploration of these technologies as applied to military problems. The panel is first to admit that the lists are incomplete and may contain some questionable items, but they do illustrate the range of applications that should motivate investments in these rapidly advancing areas

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Chapter 9. Conclusions

Cross-Cutting Outcomes

Upon completion of the panel's examination of critical capabilities, it addressed the question of how the acquisition of these capabilities might impact the fabric of national security beyond enabling the missions they directly support. Three important cross-cutting outcomes emerged as a result of that inquiry.

Improvements in Small Unit Forces

During the long war in which the nation is now engaged, irregular forces and insurgents understand that battle casualties have a huge impact on the level of public support for conflict. It is not too strong to say that a key strategic advantage of today's enemy is its ability to inflict casualties on U.S. forces, regardless of the level of casualties they sustain in doing so. Many of the technologies recommended for development serve to make U.S. forces better able to defeat the enemy in small unit actions, where most U.S. casualties are sustained.

Decision-making and learning tools will sharpen the skills of the junior leaders whose competence is absolutely vital to victory in small unit conflict. Tools for language and cultural understanding will also play a major role in shaping the small unit battle. Human performance enhancement technology will provide the small unit leader with additional sensors and a deeper understanding of his battle space.

The provision of these tools will result in much more capable small units and better small unit leaders, helping to strip away the enemy's strategic advantage of causing casualties in tactical small unit actions.

Avoiding Strategic Surprise

The second cross-cutting outcome is a higher probability of avoiding strategic surprise. The human, social, cultural, and behavior modeling proposed in this report will help in understanding both the micro and macro societies in which U.S. forces will operate. These tools, and those proposed in conjunction with influence operations, will give U.S. forces the ability to model alternative courses of action for kinetic and non-kinetic operations, resulting in better decision-making and a reduction in unintended consequences.

Favorable Shifts in Asymmetries

The third major cross-cutting outcome that will occur is a more favorable balance of current asymmetries. Ubiquitous observation will make it more difficult for the enemy to hide; and ability of U.S. forces to rapidly deliver tailored effects will enable these forces to take immediate advantage of greater enemy visibility. The tools developed for contextual exploitation will give U.S. forces a much better understanding of, and an ability to shape, the perceptual environment.

Summary

The panel's work yielded four critical capabilities:

- **Human terrain preparation**: the ability to much better understand how individuals, groups, societies, and nations behave.
- **Ubiquitous observation and recording**: a shift from long dwell ISR over fixed areas observing "things" to ubiquitous ISR observing individuals.
- **Contextual exploitation**: extracting meaning from floods of data.
- **Rapidly tailored effects**: delivering the type and level of effect to shape the behavior of adversaries and influence the perceptions and actions of partners and neutrals.

The four capabilities do not stand alone and, in fact, interact in myriad interdependent ways. In the view of the panel, these four, with their interconnectedness, define a 21st century transformation of the observed-orient-decide-act loop. No longer should the key capabilities be linked sequentially, and no longer are physical entities alone the drivers for observation and action. The "human terrain" takes center stage and encompasses the full breadth of understanding and shaping the actions of our adversaries, of ourselves, and of all others involved.

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.
Panel Membership

CO-CHAIRS

Name	Affiliation
Dr. Mim John*	Sandia National Laboratory
Gen Mike Williams, USMC (ret)*	LMI

MEMBERS

Dr. Matt Ganz	HRL
VADM Kevin Green, USN (ret)	IBM
MajGen Ken Israel, USAF (ret)	Lockheed Martin
LtGen Rick Kelly, USMC (ret)	LMI
Mr. Zach Lemnios	Massachusetts Institute of Technology/ Lincoln Laboratory
Mr. Larry Meador	MGI Strategic Solutions
Mr. Walt Morrow*	Massachusetts Institute of Technology/ Lincoln Laboratory
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Mr. Jim Shields	Draper Laboratory
Dr. Ann Skalka*	Fox-Chase Cancer Research Center
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Mr. Bob Stein	Private Consultant
Dr. Rich Wagner	Los Alamos National Laboratory
Dr. Dave Whelan	Boeing

**Defense Science Board member*

GOVERNMENT ADVISORS

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COL Kevin Brown, USA	U.S. Army Training and Doctrine Command
Col Ken Byrd, USAF	Headquarters, U.S. Air Force/A5X
Mr. Shane Deichman	U.S. Joint Forces Command
Anh Duong	Office of the Chief of Naval Operations
Mr. Dan Flynn	Central Intelligence Agency
Dr. Brendan Godfrey	Air Force Office of Scientific Research
Dr. Joanna Ingraham	Defense Threat Reduction Agency
LTC Todd Key, USA	Joint Staff, J-8
Ms. Carolyn Nash	Office of the Assistant Secretary of the Army, for Acquisition, Logistics and Technology
LtCol Dave Pere, USMC	U.S. Marine Corps
Mr. Dennis Schmidt	Office of the Assistant Secretary of the Army, for Acquisition, Logistics and Technology
CAPT Dennis Sorensen, USN	Office of Naval Research
Dr. Dave Stoudt	Naval Surface Warfare Center, Dahlgren Division
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STAFF

Tim Cullen	Strategic Analysis, Inc.
Juile Evans	Strategic Analysis, Inc.
Kevin Gates	Strategic Analysis, Inc.

Appendix C. Capability Matrices

This appendix contains supporting data for the mission-to-capability-to-technology systems analysis. The data contained in this appendix are the result of the analyses performed throughout the 10 month summer study.

Capability Prioritization

List of Capabilities

The capabilities in table C-1 resulted from the inputs of all of the members of the summer study. The members were asked to provide their view of the three most important capabilities needed to effectively deal with the five missions upon which the summer study results were based. After removing redundancies and broadening some of the inputs to accommodate similar functions provided by different members under one capability heading, the following 39 distinct capabilities resulted:

Assessing Importance by Mission

The capabilities in table C-1 were each examined with regard to their importance to each of the five missions. Tables C-2, C-3, C-4, C-5, and C-6 contain the results of that examination. A code of 4 means that a capability is critical to that particular mission; 2 means that it is very important, but not absolutely crucial; 1 means that it contributes in a lesser but useful way; and zero means that it does not contribute to the capability.

Table C-1. Thirty-Nine Capabilities Identified by Summer Study Panel Members

Human intelligence
Culture/language understanding
Modeling societal dynamics, stability and influencers
Strategic surprise anticipation
Strategic shaping
Persistent ISR of fixed and mobile targets
Knowledge discovery/data fusion/decision support
Survivable global joint tactical communications
Strategic communication
Medical surge for mass destruction events
Joint precision tailored global strike from sanctuary
Rapid decontamination
Portal chemical, biological, radiological, nuclear (CBRN) detection/identification
Covert penetration operations
Identify & covertly tag, track people and objects globally
Maritime domain awareness
Joint networked command and control
Consequence management
Remote WMD detection
Secure/ render safe WMD
Undersea warfare
Information security/information warfare/cyber supremacy
Space dominance (offensive/defensive)
Efficient power generation and storage
Small unit/soldier protection
Rapid training for quick reaction missions
Strategic corporal/soldier-focused capability
Reduced footprint
Immersive live/virtual/constructive training
Small unit leadership training
Civil affairs and reconstruction
Support/ enforce international treaties/alliances
Broad spectrum medical treatments/preventatives
Air/ land/sea supremacy
Rapid logistics
Rapid task organization and force reconstitution
Rapid strategic decision-making/translation to war plans and operations
Force/ strategic asset protection
Rapid resource delivery to the battlefield

Table C-2. Defeating Terrorist Networks

Capability	Importance
Human intelligence	4
Culture/ language understanding	4
Modeling societal dynamics, stability and influencers	4
Strategic surprise anticipation	4
Strategic shaping	1
Persistent ISR of fixed and mobile targets	2
Knowledge discovery/data fusion/decision support	4
Survivable global joint tactical communications	1
Strategic communication	2
Medical surge for mass destruction events	1
Joint precision tailored global strike from sanctuary	2
Rapid decontamination	1
Portal CBRN detection/identification	0
Covert penetration operations	4
Identify and covertly tag, track people and objects globally	4
Maritime domain awareness	1
Joint networked command and control	1
Consequence management	1
Remote WMD detection	0
Secure/ render safe WMD	0
Undersea warfare	0
Information security/information warfare/cyber supremacy	4
Space dominance (offensive/defensive)	0
Efficient power generation and storage	1
Small unit/soldier protection	1
Rapid training for quick reaction missions	2
Strategic corporal/soldier-focused capability	2
Reduced footprint	0
Immersive live/virtual/constructive training	1
Small unit leadership training	2
Civil affairs and reconstruction	1
Support/ enforce international treaties/alliances	2
Broad spectrum medical treatments/preventatives	1
Air/ land/sea supremacy	2
Rapid logistics	0
Rapid task organization and force reconstitution	1
Rapid strategic decision-making/translation to war plans and operations	2
Force/ strategic asset protection	1
Rapid resource delivery to the battlefield	1

Table C-3. Defending the Homeland

Capability	Importance
Human intelligence	4
Culture/ language understanding	2
Modeling societal dynamics, stability and influencers	2
Strategic surprise anticipation	4
Strategic shaping	2
Persistent ISR of fixed and mobile targets	2
Knowledge discovery/data fusion/decision support	4
Survivable global joint tactical communications	2
Strategic communication	2
Medical surge for mass destruction events	4
Joint precision tailored global strike from sanctuary	2
Rapid decontamination	2
Portal CBRN detection/identification	4
Covert penetration operations	2
Identify and covertly tag, track people and objects globally	4
Maritime domain awareness	4
Joint networked command and control	2
Consequence management	4
Remote WMD detection	4
Secure/ render safe WMD	2
Undersea warfare	0
Information security/information warfare/cyber supremacy	4
Space dominance (offensive/defensive)	1
Efficient power generation and storage	0
Small unit/soldier protection	0
Rapid training for quick reaction missions	1
Strategic corporal/soldier-focused capability	0
Reduced footprint	0
Immersive live/virtual/constructive training	2
Small unit leadership training	1
Civil affairs and reconstruction	2
Support/ enforce international treaties/alliances	2
Broad spectrum medical treatments/preventatives	4
Air/ land/sea supremacy	4
Rapid logistics	0
Rapid task organization and force reconstitution	1
Rapid strategic decision-making/translation to war plans and operations	4
Force/ strategic asset protection	2
Rapid resource delivery to the battlefield	0

Table C-4. Preventing the Acquisition and Use of Weapons of Mass Destruction

Capability	Importance
Human intelligence	4
Culture/ language understanding	2
Modeling societal dynamics, stability and influencers	1
Strategic surprise anticipation	4
Strategic shaping	4
Persistent ISR of fixed and mobile targets	2
Knowledge discovery/data fusion/decision support	4
Survivable global joint tactical communications	1
Strategic communication	2
Medical surge for mass destruction events	0
Joint precision tailored global strike from sanctuary	4
Rapid decontamination	1
Portal CBRN detection/identification	1
Covert penetration operations	4
Identify and covertly tag, track people and objects globally	4
Maritime domain awareness	2
Joint networked command and control	1
Consequence management	1
Remote WMD detection	2
Secure/ render safe WMD	4
Undersea warfare	0
Information security/information warfare/cyber supremacy	1
Space dominance (offensive/defensive)	0
Efficient power generation and storage	0
Small unit/soldier protection	0
Rapid training for quick reaction missions	1
Strategic corporal/soldier-focused capability	0
Reduced footprint	0
Immersive live/virtual/constructive training	1
Small unit leadership training	0
Civil affairs and reconstruction	0
Support/ enforce international treaties/alliances	4
Broad spectrum medical treatments/preventatives	0
Air/land/sea supremacy	2
Rapid logistics	0
Rapid task organization and force reconstitution	0
Rapid strategic decision-making/translation to war plans and operations	4
Force/strategic asset protection	0
Rapid resource delivery to the battlefield	0

Table C-5. Shaping the Choices of Nations at Strategic Crossroads

Capability	Importance
Human intelligence	4
Culture/ language understanding	4
Modeling societal dynamics, stability and influencers	4
Strategic surprise anticipation	2
Strategic shaping	4
Persistent ISR of fixed and mobile targets	2
Knowledge discovery/data fusion/decision support	4
Survivable global joint tactical communications	1
Strategic communication	4
Medical surge for mass destruction events	1
Joint precision tailored global strike from sanctuary	4
Rapid decontamination	0
Portal CBRN detection/identification	0
Covert penetration operations	2
Identify and covertly tag, track people and objects globally	0
Maritime domain awareness	1
Joint networked command and control	1
Consequence management	0
Remote WMD detection	1
Secure/ render safe WMD	0
Undersea warfare	2
Information security/information warfare/cyber supremacy	4
Space dominance (offensive/defensive)	2
Efficient power generation and storage	0
Small unit/soldier protection	0
Rapid training for quick reaction missions	2
Strategic corporal/soldier-focused capability	0
Reduced footprint	1
Immersive live/virtual/constructive training	0
Small unit leadership training	1
Civil affairs and reconstruction	2
Support/ enforce international treaties/alliances	4
Broad spectrum medical treatments/preventatives	1
Air/ land/sea supremacy	2
Rapid logistics	2
Rapid task organization and force reconstitution	2
Rapid strategic decision-making/translation to war plans and operations	2
Force/ strategic asset protection	1
Rapid resource delivery to the battlefield	1

Table C-6. Stability, Security, Transition, and Reconstruction

Capability	Importance
Human intelligence	4
Culture/ language understanding	4
Modeling societal dynamics, stability and influencers	4
Strategic surprise anticipation	2
Strategic shaping	2
Persistent ISR of fixed and mobile targets	4
Knowledge discovery/data fusion/decision support	4
Survivable global joint tactical communications	2
Strategic communication	4
Medical surge for mass destruction events	1
Joint precision tailored global strike from sanctuary	1
Rapid decontamination	0
Portal CBRN detection/identification	1
Covert penetration operations	4
Identify and covertly tag, track people and objects globally	4
Maritime domain awareness	0
Joint networked command and control	2
Consequence management	0
Remote WMD detection	1
Secure/ render safe WMD	1
Undersea warfare	0
Information security/information warfare/cyber supremacy	2
Space dominance (offensive/defensive)	0
Efficient power generation and storage	2
Small unit/soldier protection	4
Rapid training for quick reaction missions	2
Strategic corporal/soldier-focused capability	4
Reduced footprint	2
Immersive live/virtual/constructive training	2
Small unit leadership training	4
Civil affairs and reconstruction	4
Support/ enforce international treaties/alliances	1
Broad spectrum medical treatments/preventatives	1
Air/ land/sea supremacy	4
Rapid logistics	1
Rapid task organization and force reconstitution	1
Rapid strategic decision-making/translation to war plans and operations	1
Force/ strategic asset protection	2
Rapid resource delivery to the battlefield	1

Overall Importance and Relative Priority

Based upon the capability contributions to each mission, the overall relative priority was established by counting the number of missions to which each capability was critical, important, or contributed in some way. Table C-7 is presented in priority order based upon "critical" outweighing "important," and "important" outweighing "contributes."

Prioritized Capabilities and the Four Critical Capabilities

Table C-8 represents the principal association of the 39 prioritized capabilities above with the four critical capabilities—human terrain preparation, ubiquitous observation, contextual exploitation, and rapidly tailored effects—defined by the panel. The addition of the category "other" is required for a few capabilities that do not fit neatly into any of the four critical capabilities. In general these are lower priority capabilities or ones that are not principally associated with the DOD (such as "support/enforce international treaties and alliances").

Mapping into the Tier II JCAs

Table C-9 shows the results of mapping the 102 tier 2 JCAs into the panel's 39 capabilities. The capabilities are ordered by the number of tier 2 JCAs that map into them. As seen from the matrix, the mapping is essentially complete, with only one capability failing to have any corresponding JCA. Two of the panel's capabilities—air/land/sea supremacy and force/strategic asset protection—are noteworthy in that they are ranked relatively low because of their lack of high criticality to the five missions, yet a large number of the JCAs map into them. This is likely driven by the strong JCA focus on war fighting vice the summer study's focus on the more non-traditional missions of the QDR.

Table C-7. Capability Ranking by Mission Contribution

Capability	Crit	Imp’t	Cont.
Human intelligence	5	0	0
Knowledge discovery/data fusion/decision support	5	0	0
Identify and covertly tag, track people and objects globally	4	0	0
Culture/ language understanding	3	2	0
Strategic surprise anticipation	3	2	0
Covert penetration operations	3	2	0
Modeling societal dynamics, stability and influencers	3	1	1
Information security/information warfare/cyber supremacy	3	1	1
Strategic communication	2	3	0
Air/ land/sea supremacy	2	3	0
Strategic shaping	2	2	1
Joint precision tailored global strike from sanctuary	2	2	1
Support/ enforce international treaties/alliances	2	2	1
Rapid strategic decision-making/translation to war plans and operations	2	2	1
Persistent ISR of fixed and mobile targets	1	4	0
Civil affairs and reconstruction	1	2	1
Maritime domain awareness	1	1	2
Remote WMD detection	1	1	2
Small unit leadership training	1	1	2
Secure/render safe WMD	1	1	1
Strategic corporal/soldier-focused capability	1	1	0
Medical surge for mass destruction events	1	0	3
Broad spectrum medical treatments/preventatives	1	0	3
Portal CBRN detection/identification	1	0	2
Consequence management	1	0	2
Small unit/soldier protection	1	0	1
Rapid training for quick reaction missions	0	3	2
Survivable global joint tactical communications	0	2	3
Joint networked command and control	0	2	3
Immersive live/virtual/constructive training	0	2	2
Force/ strategic asset protection	0	2	2
Rapid task organization and force reconstitution	0	1	3
Rapid decontamination	0	1	2
Space dominance (offensive/defensive)	0	1	1
Efficient power generation and storage	0	1	1
Reduced footprint	0	1	1
Rapid logistics	0	1	1
Undersea warfare	0	1	0
Rapid resource delivery to the battlefield	0	0	3

Table C-8. Ranked Capabilities and the Four Critical Capabilities

Critical Capability	Prioritized Individual Capabilities
Ubiquitous observation	Human intelligence
Contextual exploitation	Knowledge discovery/data fusion/decision support
Ubiquitous observation	Identify and covertly tag, track people and objects globally
Human terrain preparation	Culture/language understanding
Contextual exploitation	Strategic surprise anticipation
Scaleable effects	Covert penetration operations
Human terrain preparation	Modeling societal dynamics, stability and influencers
Scaleable effects	Information security/information warfare/cyber supremacy
Scaleable effects	Strategic communication
Distributed	Air/ land/sea supremacy
Scaleable effects	Strategic shaping
Scaleable effects	Joint precision tailored global strike from sanctuary
Other	Support/ enforce international treaties/alliances
Scaleable effects	Rapid strategic decision-making/translation to war plans and operations
Ubiquitous observation	Persistent ISR of fixed and mobile targets
Scaleable effects	Civil affairs and reconstruction
Ubiquitous observation	Maritime domain awareness
Ubiquitous observation	Remote WMD detection
Human terrain preparation	Small unit leadership training
Scaleable effects	Secure/ render safe WMD
Human terrain preparation	Strategic corporal/soldier-focused capability
Scaleable effects	Medical surge for mass destruction events
Scaleable effects	Broad spectrum medical treatments/preventatives
Ubiquitous observation	Portal CBRN detection/identification
Scaleable effects	Consequence management
Distributed	Small unit/soldier protection
Human terrain preparation	Rapid training for quick reaction missions
Other	Survivable global joint tactical communications
Other	Joint networked command and control
Human terrain preparation	Immersive live/virtual/constructive training
Distributed	Force/ strategic asset protection
Other	Rapid task organization and force reconstitution
Scaleable effects	Rapid decontamination
Distributed	Space dominance (offensive/defensive)
Other	Efficient power generation and storage
Other	Reduced footprint
Other	Rapid logistics
Other	Undersea warfare
Other	Rapid resource delivery to the battlefield

Table C-9 Capability Ranking of Tier 2 JCAs

Summer Study Capability	# of JCAs	Missions Critical	Missions Important
Air/ land/sea supremacy	16	1	0
Information security/information operations/cyber supremacy	14	3	1
Covert penetration operations	13	2	3
Urban and stability operations	13	2	1
Force/ strategic asset protection	12	0	3
Knowledge discovery/data fusion/decision support	11	5	0
Culture/language understanding	10	3	2
Joint precision tailored global strike from sanctuary	10	2	1
Support/enforce international treaties/alliances	9	2	2
Consequence management	9	1	0
Strategic surprise anticipation and shaping	8	3	2
Detect and locate targets in cluttered environments	8	3	2
Persistent ISR of fixed and mobile targets	8	2	3
Strategic communication	8	2	2
Modeling societal dynamics, stability and influencers	7	3	2
Rapid strategic decision-making/translation to war plans and operations	7	2	3
Rapid task organization and force reconstitution	7	0	0
Survivable global joint tactical communications	6	0	3
Rapid logistics	6	0	0
Rapid resource delivery to the battlefield	6	0	0
Identify and covertly tag, track people and objects globally	5	4	0
Strategic corporal/soldier-focused capability	5	2	0
Small unit leadership training	5	1	1
Rapid decontamination	4	1	0
Joint networked command and control	4	0	2
Space dominance (offensive/defensive)	4	0	1
Human intelligence	3	5	0
Rapid training for quick reaction missions	3	2	2
Maritime domain awareness	3	1	2
Portal CBRN detection/identification	3	1	1
Broad spectrum medical treatments/preventatives	3	1	1
Undersea warfare	3	0	1
Remote WMD detection	2	2	0
Secure/ render safe WMD	2	2	0
Medical surge for mass destruction events	2	1	1
Immersive live/virtual/constructive training	2	0	2
Small unit/soldier protection	1	1	1
Reduced footprint	1	0	1
Efficient power generation and storage	0	0	1

Technologies

The Capabilities Panel was also tasked to examine and prioritize the technologies required to implement the capabilities discussed above. The data in the tables that follow are the results of the panel's discussions and prioritization of capabilities.

Critical Capabilities, Technology Areas, and Constituent Technologies

Table C-10 lists the association of each of the four critical capabilities with the three most important technology areas for each. Each technology area depends upon a number of "constituent technologies," and the 43 such technologies are shown as well.

Technology Scoring

The technologies listed in table C-10 were scored according to their contribution to the original 39 capabilities. As shown in table C-11, each technology was rated as critical (4), important (2), useful (1) or not applicable (0) against each capability. The individual technology/ capability ratings were then summed, with the technology ratings that applied to a given capability that was critical to two or more missions weighted twice as heavily as one that was critical to only one mission. In turn, the technology ratings that applied to a given capability that was critical to one mission were weighted twice as heavily as one that was not critical to any mission. The overall scoring is given in the last row and provides a useful assessment of the relative importance of each technology as it applies through the appropriate capabilities back to the original five missions.

Table C-12 lists the constituent technologies in priority order based on the scores in the previous table. It also contains an entry code that indicates the development status for each constituent technology as defined below:

- PNW—Promising but immature and still Needs Work
- STC—shows significant progress, investments being made, Stay The Course
- TFC—work largely outside of DOD, Transfer From Commercial when ready
- JDI—development sufficiently mature that it should be in use today, Just Do It

While table C-11 is useful in providing a vehicle to examine the relative importance of the individual technologies, it is not especially helpful in providing a foundation for developing a technology roadmap or development strategy, because those technologies within a given development status category as defined above have to be treated differently then those in the other categories. To make this easier to visualize, table C-12 groups the constituent technologies first by their development category and then, within that category, lists them in rank order. Included also is the critical capability principally serviced by each constituent technology. The technologies within the top overall 50 percent are depicted by the shaded area of each development category.

Table C-10. Association of Critical Capabilities, Technology Areas, and Constituent Technologies

<table>
<tr><th>Critical Capability</th><th colspan="2">Technology Area</th><th>Constituent Technology</th></tr>
<tr><td rowspan="14">Ubiquitous Observation</td><td colspan="2" rowspan="5">Day/night all-weather wide-area surveillance</td><td>Space-based GMTI/SAR</td></tr>
<tr><td>Gigapixel optical imaging</td></tr>
<tr><td>Foliage penetration sensors</td></tr>
<tr><td>Active and passive hyper spectral sensing</td></tr>
<tr><td>High-altitude long-endurance platforms</td></tr>
<tr><td rowspan="5">Close-in sensor and tagging systems</td><td rowspan="3"></td><td>High density packaging</td></tr>
<tr><td>High-performance and high-efficiency signal processing</td></tr>
<tr><td>Stealthy/precision delivery platforms</td></tr>
<tr><td rowspan="6">Soldier as a collector</td><td>Miniature sensor technology</td></tr>
<tr><td>Efficient energy storage technology</td></tr>
<tr><td rowspan="4"></td><td>Body-borne flexible displays</td></tr>
<tr><td>Soldier-centric communication/networking technology</td></tr>
<tr><td>Interactive automated debriefing</td></tr>
<tr><td>All-domain precision geo-location</td></tr>
<tr><td rowspan="12">Rapidly Scalable Effects</td><td colspan="2" rowspan="3">Time critical strike from afar</td><td>Directed energy</td></tr>
<tr><td>Hypersonics</td></tr>
<tr><td>Ballistic missile technology</td></tr>
<tr><td colspan="2" rowspan="5">WMD protection and mitigation</td><td>Standoff active radiation detection</td></tr>
<tr><td>Rapid diagnostics and environmental monitoring</td></tr>
<tr><td>Broad spectrum medical countermeasures</td></tr>
<tr><td>Decontamination technologies</td></tr>
<tr><td>Nuclear weapons effects and impact models</td></tr>
<tr><td colspan="2" rowspan="4">Influence operations</td><td>Kinetic/non-kinetic cause-effect models (environment; infrastructure; socio-cultural; DIME; PMESII)</td></tr>
<tr><td>Campaign planning/targeting/shaping tools (eg, gaming; stochastic estimation; weapon-target pairing; (non)lethal weapon effects)</td></tr>
<tr><td>Decision support tools (complexity, ambiguity)</td></tr>
<tr><td>Storytelling, gisting, advanced visualization</td></tr>
</table>

Table C-10 (continued). Association of Critical Capabilities, Technology Areas, and Constituent Technologies

Critical Capability	Technology Area		Constituent Technology
Contextual Exploitation	Mega-data management		Data management from very diverse sources
		Situation-dependent information extraction	Entity, relationship and pattern analysis
			Multi-level security and accreditation
			Advanced context/concept search, information retrieval and knowledge discovery
			Knowledge discovery (data to information to target recognition)
			Contextual analysis and intent recognition tools
	Human/system collaboration		Natural man machine interface
			Human guided algorithms
			Knowledge representation
Human Terrain Preparation	Human , social, cultural, behavior (HSCB) modeling		Macro HSCB models (structure/trends)
			Micro HSCB (networks/events)
			Integrated coherent micro-macro quantitative/computational models (taxonomies, application programming interfaces, semantics)
	Automated language processing		Foreign-to-English translation (e.g., voice, chat, instant message, e-mails; broadcast, conversational; gisting; summarization; [un]constrained)
			Speech-to-text transcription (eg, Phraselator; voice response translator; speech-to-speech)
	Rapid training/learning methods/aids		Socio-culturally relevant immersive games, training and mission rehearsal tools
			Language/culture/leadership tutoring and coaching tools
			Human/team performance measurement models-tools

Table C-11. Rank-Ordered List of Constituent Technologies

Critical Capability	Constituent Technology	Raw Score	Rank
CE	Contextual analysis and intent recognition tools	31.0	1
CE	Entity, relationship, and pattern analysis	24.8	2
UO	Miniature sensor technology	23.8	3
CE	Knowledge discovery (data to information to target recognition)	23.3	4
UO	Efficient energy storage technology	22.3	5
CE	Data management from very diverse sources	22.0	6
HTP	Macro HSCB models (structure/trends)	21.5	7
SE	Decision support tools (complexity and ambiguity)	21.3	8
UO	All-domain precision geo-location	21.0	9
SE	Kinetic and non-kinetic cause-effect models (environment; infrastructure; socio-cultural; DIME; PMESII)	20.8	10
SE	Storytelling, gisting and advanced visualization)	20.5	11
HTP	High fidelity, socio-culturally relevant immersive fames, training and mission rehearsal tools	20.3	12
HTP	Micro HSCB (networks/events)	20.0	13
SE	Campaign planning/targeting/shaping tools (e.g, gaming; stochastic estimation; weapon-target pairing; effects)	19.8	14
HTP	Integrated coherent micro-macro quantitative/computational models (taxonomies, application programming interfaces, semantics)	19.5	15
UO	Interactive automated debriefing	18.8	16
UO	High performance and high efficiency signal processing	18.3	17
CE	Advanced context/concept search, information retrieval and knowledge discovery	17.3	18
HTP	Foreign-to-English translation (e.g., voice, chat, instant messaging, emails; broadcast, conversation; gisting; summarization; [un]constrained)	17.0	19
UO	Soldier-centric communications/networking technology	16.8	20
STC	Multi-level security and accreditation	16.0	21
UO	High density packaging	15.5	22
HTP	Language/culture/leadership tutoring and coaching tools	15.5	22
SE	Rapid diagnostics and environmental monitoring	15.0	24
UO	Space-based GMTI/SAR	14.3	25
UO	Active and passive hyper spectral sensing	13.8	26
UO	High-altitude long-endurance platforms	13.8	26
HTP	Human/team performance measurement models-tools	13.8	26
SE	Broad spectrum medical countermeasures	13.5	29
CE	Human-guided algorithms	13.5	29
HTP	Speech-to-text transcription (e.g., Phraselator; voice response translator; 2-way speech-to-speech)	13.5	29
UO	Body-borne flexible displays	13.0	32

Table C-11 (continued). Rank-ordered List of Constituent Technologies

Critical Capability	Constituent Technology	Raw Score	Rank
CE	Natural man-machine Interface	13.0	32
SE	Directed energy	12.8	34
UO	Stealthy/precision delivery platforms	12.5	35
SE	Standoff active radiation detection	11.0	36
UO	Gigapixel optical imaging	10.3	37
CE	Knowledge representation	10.3	37
SE	Nuclear weapons effects and impact models	10.0	39
SE	Decontamination technologies	9.5	40
SE	Hypersonics	9.0	41
UO	Foliage penetration sensors	8.5	42
SE	Ballistic missile technology	8.5	42

Note: HTP = human terrain preparation; UO = ubiquitous observation; CE = contextual exploitation; SE = scalable effects

Table C-12. Constituent Technologies Grouped by Development Category

Develop. Status	Critical Capab.	Constituent Technology	Rank
TFC	UO	Efficient energy storage technology/ TRL 5	5
	CE	Data management from very diverse sources/ TRL 5	6
	SE	Storytelling, gisting and advanced visualization)/TRL 2-5	11
	HTP	High fidelity, socio-culturally relevant immersive games, training and mission rehearsal tools/TRL 3-6	12
	SE	Campaign planning/targeting/shaping tools (e.g., gaming; stochastic estimation; weapon-target pairing; [non]lethal weapon effects)/TRL 3-6	14
	CE	Advanced context/concept search, information retrieval and knowledge discovery (data mining)/TRL 2-6	18
	SE	Broad spectrum medical countermeasures/TRL 1-3	29
	CE	Natural man-machine interface/ TRL 2-3	32
	CE	Knowledge representation/TRL 3-5	37
STC	CE	Contextual analysis and intent recognition tools / TRL 3	1
	CE	Entity, relationship and pattern analysis/ TRL 3	2
	CE	Knowledge discovery (data to information to target recognition)/ TRL 2	4
	SE	Decision support tools (complexity and ambiguity)/ TRL 3	8
	UO	All-domain precision geo-location/TRL 4-5	9
	UO	High performance and high efficiency signal processing/ TRL 5	17

Table C-12 (continued). Constituent Technologies Grouped by Development Category

Develop. Status	Critical Capab.	Constituent Technology	Rank
	HTP	Foreign-to-English translation (e.g., voice, chat, instant messaging, emails; broadcast, conversational; gisting; summarization; [un]constrained) /TRL 3-7	19
	UO	Soldier-centric communications/networking technology (waveforms, transmit/receive)/ TRL 5	20
		Multi-level security and accreditation/TRL 3	21
	UO	High density packaging/ TRL 5	22
	HTP	Language/culture/leadership tutoring and coaching tools/TRL 4	22
	UO	Space-based GMTI/SAR/TRL 5	25
	HTP	Speech-to-text transcription (e.g., Phraselator; voice response translator; 2-way speech-to-speech)/TRL 2-6	29
	UO	Body-borne flexible displays/ TRL 4	32
	SE	Decontamination technologies/ TRL 2-6	40
PNW	UO	Miniature sensor technology/ TRL 3-5	3
	HTP	Macro HSCB models (structure/trends)/ TRL 4-6	7
	SE	Kinetic and non-kinetic cause-effect models (environment; infrastructure; socio-cultural; DIME; PMESII)/TRL 2-6	10
	HTP	Micro HSCB (networks/events)/ TRL 2-4	13
	HTP	Integrated coherent micro-macro quantitative/computational models (taxonomies, application programming/interfaces, semantics)/TRL 1-2	15
	UO	Interactive automated debriefing/ TRL 3	16
	SE	Rapid diagnostics and environmental monitoring/ TRL 3-5	24
	UO	High-altitude long-endurance platforms/TRL 3	26
	HTP	Human/team performance measurement models-tools/TRL 3-6	26
	CE	Human-guided algorithms/TRL 2	29
	SE	Directed energy/TRL 3-7	34
	UO	Stealthy/precision delivery platforms/ TRL 6	35
	SE	Standoff active radiation detection/ TRL 1 - 3	36
	UO	Gigapixel optical imaging/TRL 3	37
	SE	Nuclear weapons effects and impact models/ TRL 2-5	39
	SE	Hypersonics/ TRL 4-5	41
JDI	UO	Active and passive hyper spectral sensing/TRL 5	26
	UO	Foliage penetration sensors/TRL 3	42
	SE	Ballistic missile technology/TRL 7-9	42

Note: HTP = human terrain preparation; UO = ubiquitous observation; CE = contextual exploitation; SE = scalable effects

Candidates That Did Not Make Our Short List

Logistics

The panel recognizes the vital importance of logistics across the spectrum of military operations. When examining the subject in light of the five missions, it was determined that better logistics capability is more a matter of using currently available technology than a subject for S&T investment. At the force levels contemplated in the QDR missions and SSTR, the logistics capability of DOD is more than adequate. Much can, and should, be done to adapt commercial technology and supply-chain management to military logistics, but recommendations on these matters are beyond the scope of this study.

Air/Land/Sea Supremacy

Air/land/sea supremacy is the appropriate military goal for major combat operations. The panel's focus, however, was not major combat operations, but rather the insurgency and irregular operations characteristic of the five missions. There is no existing challenge to U.S. sea and air supremacy. The panel believes that the capabilities recommended will go far to ensure the land supremacy needed for the missions studied. Therefore, this subject was not included in the study or report.

Network-Centric Operations

The four capabilities highlighted in this report all rest on a foundation of robust connectivity. Vertical and horizontal integration of data and information is a prerequisite for success. The panel chose to view the network as an integral part of achieving the selected capabilities rather than as a stand-alone capability. Most of the connectivity issues studied were more a matter of policy implementation and resource allocation than research investment. The companion Defense Science Board 2006 Summer Study on Information Management for Net-Centric Operations examined these issues in more detail.

General Force/Asset Protection

The panel took an offensive-oriented view of asset and force protection. The four capabilities recommended for development—preparing human terrain, ubiquitous observation, contextual exploitation, and rapidly tailored effects—will serve force and asset protection needs in the environment of the missions studied. An exception was made in the case of WMD; some recommendations for defensive measures are included in the body of this report.

Information Operations

Information operations involve actions taken to affect adversary information and information systems. The panel came to the conclusion that these operations, though vitally important in major combat operations, had slightly less importance in the kind of operations necessary to prosecute the missions studied. The panel believes that influence operations, designed to get a positive message to an indigenous population of dubious loyalty, were more important than classical information operations, and included them as a substitute. As an aside, it is the belief of the panel that the definition of information operations should be expanded to include influence operations.

Appendix D. Glossary

ASCII	American Standard Code for Information Interchange
BRN	Barisan Revolusi Nasional Melayu Pattani
CBRN	chemical, biological, radiological, nuclear
CLE	combat leader's environment
DARPA	Defense Advanced Research Projects Agency
DIME	diplomatic, information, military, economic
DDR&E	Director, Defense Research and Engineering
DOD	Department of Defense
DSB	Defense Science Board
EMP	electromagnetic pulse
GALE	Global Autonomous Language Exploitation
GAM	Free Aceh Movement
GMIP	Gerakan Mujahideen Islam Pattani
GMTI	ground moving target indication
GPS	Global Positioning System
HSCB	human, social, cultural, and behavior
HTP	human terrain preparation
ISR	intelligence, surveillance, and reconnaissance
JCA	Joint Capability Area
JCIDS	Joint Capabilities Integration and Development System
JI	Jemaah Islamiyah
LAST	Learning with Adaptive Simulation and Training
OODA	observe-orient-decide-act
PMESII	political, military, economic, social, infrastructure, information
POFED	Politics of Fertility, Economics, and Development
PULO	Pattani United Liberation Organization
QDR	Quadrennial Defense Review
R&D	research and development
SAR	synthetic aperture radar
SSTR	stability, security, transition, and reconstruction
S&T	science and technology
TMTI	Transformational Medical Technologies Initiative
TRL	technology readiness level
UAV	unmanned aerial vehicles
VBIED	vehicle-borne improvised explosive device
WMD	weapons of mass destruction