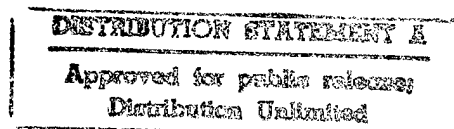1998

DOCUMENTED BRIEFING

New Methods for Robust Science and Technology Planning

Robert J. Lempert, James L. Bonomo

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National Defense Research Institute

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DOCUMENTED BRIEFING

RAND

New Methods for Robust Science and Technology Planning

Robert J. Lempert, James L. Bonomo

Prepared for the
Defense Advanced Research Projects Agency

National Defense Research Institute

PREFACE

In the fall of 1996, RAND researchers conducted a successful proof-of-concept demonstration for the Defense Advanced Research Projects Agency (DARPA) of new methods for science and technology (S&T) planning. These methods exploit new information technologies in order to

- Improve the quality of the S&T planning process by using online computer-assisted decision-support tools that

  — make relevant information more easily available to expert panelists meeting over the World Wide Web

  — help panelists include and compensate for the effects of uncertainty by treating an S&T plan as a portfolio of technology investments hedged against a wide range of plausible futures.

- Provide a lasting electronic archive of the expert discussions and other information that go into building an S&T plan.

- Lower the travel-related costs and scheduling constraints of the current planning process by supplementing face-to-face expert panel meetings with asynchronous meetings over the World Wide Web.

The demonstration made use of two new RAND methodologies: *HyperForum*, a facilitated Web-based collaborative exercise, conducted in a carefully crafted, information-rich, online environment, and *Exploratory Modeling*, a new approach to generating systematic, quantitative comparisons among alternative policy decisions without relying on imperfect predictions of the future.

This documented briefing describes that demonstration. It should be of interest to decisionmakers responsible for choosing, managing, and justifying portfolios of science and technology research projects in the Department of Defense and other federal agencies, and in the private sector. In addition, it should be informative to those readers interested in how new information technologies can provide new methods for planning and decisionmaking under uncertainty. Readers interested in viewing the Web site described in this documented briefing are invited to e-mail one of the authors: **Robert_Lempert@rand.org** or **James_Bonomo@rand.org**.

This research was conducted for DARPA within the Acquisition and Technology Policy Center of RAND's National Defense Research Institute, a federally funded research and development center sponsored by the Office of the Secretary of Defense, the Joint Staff, the unified commands, and the defense agencies.

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New Methods for Robust
Science and Technology Planning

Robert Lempert & James Bonomo

I. INTRODUCTION

This briefing describes a proof-of-concept demonstration of some new methods[1] for science and technology (S&T) planning. RAND researchers conducted this demonstration for the Defense Advanced Research Projects Agency (DARPA) in fall 1996 to show that exploiting new information technologies can supplement the current S&T planning process in useful ways. In particular, it can

- make relevant information more easily available for participants in the planning process

- address uncertainty explicitly

- lower some of the costs associated with the process, especially travel-related costs.

Additionally, the inherent characteristic of the approach—using Web-based technology—provides a lasting record of the discussion and allows later users of the S&T plan a much fuller understanding of the basis for that plan than is possible for paper-based methods.

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[1]A *method* is an orderly procedure for doing something. This report describes two methods, HyperForum and Exploratory Modeling. They can be used individually or together. In the work described in this documented briefing, we used them together.

This document presents the results of our experiment and argues that the two methods used in our approach—HyperForum and Exploratory Modeling—would be useful for the Department of Defense's S&T planning—in particular, for future rounds of the Joint Warfighting Science and Technology (JWS&T) planning process. That process considers primarily the large-scale demonstrations of new technology within the Department of Defense and, as such, has both a continuing need for planning and a need to convey those plans to many audiences.

Robust Planning for Defense S&T
Is Difficult

- **We cannot make accurate predictions of**
  - **Future military missions**
  - **Future technological capabilities**
- **Yet the Director of Defense Research and Engineering (DDR&E) must**
  - **Ensure that his or her S&T plans are robust**
  - **Demonstrate that robustness to various stakeholders**
- **Current planning tools do not support building robust plans**

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Uncertainty complicates S&T planning. We all know that the new national security environment is highly uncertain. We do not know the future uses of U.S. military forces or the capabilities that new technology may provide.

In principle, we know how to handle such uncertainty in the S&T planning activities of the Department of Defense: Since S&T plans stretch far into the future and face great internal uncertainty, an S&T plan should be considered a portfolio of technology investments that is robust[2]—hedging against a wide range of possible futures and well positioned to take advantage of unexpected opportunities.

But traditional methods of S&T planning do not help in realizing this vision. Despite best intentions, S&T plans usually emphasize some best-guess estimate of the future. Most of the attention and effort are focused there, because that is seen as the most likely, and thus most important, case. It is thus difficult to assess whether these plans are robust against other plausible futures.

In addition, current S&T plans are very long and complex documents. The JWS&T Plan[2] is two long volumes with numerous charts and graphs; the

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[2] In relation to a DoD science and technology plan, a *robust* plan is one that will provide the U.S. military with all the most important capabilities it will need, no matter what type of operations it finds itself conducting in the future.

[3] Under Secretary of Defense (Acquisition and Technology) and the Joint Staff, *Joint Warfighting Science and Technology Plans*, Washington, D.C.: Department of Defense, 1996.

Defense Technology Area Plan[4] (DTAP) is longer still (6 volumes). Even if the S&T plans are robust, it is difficult to use such documents to demonstrate that robustness to distant, but still interested, stakeholders such as Congress.

The current process for creating the defense S&T plans and the related documents is also labor-intensive. Like many S&T planning processes, it fundamentally relies upon expert opinion. Through a series of meetings, a group knowledgeable about the technical area reaches some consensus on the future prospects and the appropriate future plans.

The experiment described in this document involved only a part of the overall defense S&T planning process, that involving the Information Superiority segment of the *Joint Warfighting Science and Technology Plan* (JWS&TP). For understanding the implications of our experiment, it is important to understand the basics of the existing process for generating that plan.

The process begins with a set of Joint Warfighting Capability Objectives (JWCOs) developed by the Joint Staff and coordinated with the Office of the Secretary of Defense (OSD) and with the Service science and technology executives. The JWCOs are not intended to be a comprehensive set of objectives that cover all the demands of the Department of Defense for advanced technologies. Rather, they "represent some of the most critical capabilities for maintaining the warfighting advantage of U.S. forces" (JWS&TP, Chapter II, "Vision and Strategy," at **http://www.dtic.mil/dstp/DSTP/97_jwstp/jw2.htm** on October 31, 1997). The JWCOs change in number and content over time. Information Superiority has consistently been an important JWCO, probably because of its obvious importance for future military dominance in most, if not all, types of future operations.

For each JWCO, a panel is created under the oversight of the Defense S&T Reliance Executive Committee (EXCOM). The EXCOM is chaired by the Deputy, DDR&E, and otherwise includes the Deputy Assistant Secretary of the Army (Research and Technology); the Chief of Naval Research; the Deputy Assistant Secretary of the Air Force (Science, Technology, and Engineering); the Deputy Director, Defense Advanced Research Projects Agency; the Assistant Deputy Director for Technology, Ballistic Missile Defense Organization; and the Deputy Director, Defense Special Weapons Agency.

The panel for each JWCO is made up primarily of technical experts in the subject matter of the JWCO. It is chaired by an individual selected by the

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[4] Director, Defense Research and Engineering, *Defense Technology Area Plan*, Washington, D.C.: Department of Defense, 1996.

Office of the Director of Defense Research and Engineering (ODDR&E), and includes the membership of all the above organizations that have relevant expertise, plus representatives from the Joint Staff. These panels hold face-to-face meetings to discuss and, eventually, to fashion a list of future demonstrations—the Advanced Technology Demonstrations (ATDs) and the Advanced Concept Technology Demonstrations (ACTDs). These demonstrations are then used to create Defense Technology Objectives (DTOs) for each demonstration.

It is important to realize that these panels rely almost entirely upon the expertise and knowledge the panelists bring to the deliberations. While these panels can, and do, draw upon relevant analytic work, they have too little time and support to embark on analysis themselves. This leaves their expert opinions as the key input to their decisions.

After these plans are created, a group outside the Department of Defense reviews each technical area to ensure a wide perspective on technical developments. This is the Technology Area Review and Assessment (TARA) process. The TARA teams must have at least two-thirds of their membership from outside DoD. "Most TARA team members are recognized experts from the National Academy of Sciences, the National Academy of Engineering, the Institute of Medicine, the Defense Science Board, the scientific advisory boards of the military departments, industry, and academia. The TARA team is chaired by a senior executive appointed by the DDR&E. The appropriate representatives from the Defense S&T Reliance Technical Panel brief the DoD program as compared to the planning guidance" (JWS&TP, Chapter II, "Vision and Strategy," at **http:/ /www.dtic.mil/dstp/DSTP/97_jwstp/jw2.htm** on October 31, 1997). The results of the TARA process are filtered through the DDR&E–chaired Defense Science and Technology Advisory Group (DSTAG), and the DDR&E ultimately submits suggested changes to the Department of Defense budget decisionmaking process.

Our experiment was designed within this overall framework. That is, we too used expert panels and relied upon the panels' understanding of operational needs and of technical possibilities. While it would be possible to use the S&T planning methods described in this document to link such panels to numerous existing studies or even to tools allowing the panels to *do* technical analysis, that was not our aim here. Instead, we focused on expanding and enhancing the existing methodology of these panels, not on changing their fundamental reliance on expert judgment.

An Experiment Indicated a Solution

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Thesis:

- **New information technologies can provide DoD with analytic S&T planning methods having previously unavailable capabilities**

- **Methods can ease many constraints of traditional planning**

Experiment:

- **Use Web-based HyperForum to gather expert opinions**

- **Use Exploratory Modeling to determine whether S&T strategies are robust across many futures**

Result:

- **Experiment demonstrated feasibility of method**

- **Methods affected planning process itself**

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Our hypothesis was that new information technology can improve the current S&T planning process by providing DoD with analytic planning methods that have previously unavailable capabilities (James Bonomo, "Tools for Strategic Planning at DARPA," unpublished RAND research).

We employed two main techniques, or methods. First, we used the Web to let expert panels work online, reducing the need for face-to-face meetings and increasing the information readily available to them. Second, we used Exploratory Modeling to enable the panelists to consider a large number of future scenarios.

The experiment worked. We showed that these methods can make valuable contributions to S&T planning. We also helped our panelists come to a deeper understanding of the plans they were producing.

Most important, the experiment showed that a robust plan could be constructed, and that the robustness of that plan could be conveyed to at least some people who were outside the planning process.

A HyperForum Helps Groups Work Together on Complex Policy Problems

What is a HyperForum?

- a facilitated, Web-based collaborative exercise, conducted in a carefully crafted, information-rich, online environment

- a set of techniques and technology being developed by RAND, Caltech, and the Markle Foundation.

Using the Web, groups developing technology plans can draw on and convey more information:

- Databases can be searched and manipulated

- Nodes can be linked to other relevant sources of information

- Forums are available to facilitate inputs and buy-in from many stakeholders

RAND

Before we describe our experiment, we need to describe the two methods—HyperForum and Exploratory Modeling.

In addition to the S&T planning HyperForum conducted for DARPA, we also conducted a HyperForum on Sustainability in collaboration with Caltech, the World Resources Institute, and the Santa Fe Institute, in a project funded by the Markle Foundation (see "Internet Changing How Research Centers Work," *New York Times*, June 9, 1997, p. D5, in the Appendix). The name HyperForum is a registered trademark owned by the Markle Foundation.

A HyperForum is a facilitated, Web-based collaborative exercise, conducted in a carefully crafted, information-rich, online environment.[5] It is helpful to differentiate the HyperForum idea from the many other online conferencing efforts that are under way. In contrast to newsgroups, chat rooms, and group work over intranets, a HyperForum is heavily facilitated, embeds, on the site,

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[5] Most current Web site design seeks to make as much unfiltered information available to users as possible, and the amount of information can rapidly overwhelm those users. Rather than using such automation as search engines, autonomous agents, or advanced site maps to prevent this problem, we adopted a more labor-intensive approach that we believe is more appropriate for some policy applications. We carefully chose and limited the information we placed on the site to that information the panelists would find most useful in addressing the tasks we gave them.

The discussions are facilitated by a person in much the same way a face-to-face meeting or conference is facilitated by the chairperson.

a great deal of customized information for the panelists, and organizes the site using a task-oriented rather than a browsing-oriented model.[6] HyperFora draw heavily on commercially available technology (e.g., discussion tools, graphics tools), although we have developed some specialized tools—in particular, custom software required for individual HyperFora.

The HyperForum method helps the technology-planning process draw on and convey more information. In particular, the plans themselves become databases that can be searched, manipulated, and linked to other relevant documents. And the planning process can be opened to inputs and buy-in from many more stakeholders than could attend face-to-face meetings.

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[6] Much like a library, most Web sites are browser-oriented in that their creators are neutral about what information a user will seek and in what order.

A HyperForum is like a face-to-face meeting in that it is designed to help the panelists achieve a specific purpose. Therefore, the information made available when the panelists are at the HyperForum site is governed by a temporal agenda and a specific set of procedures.

Exploratory Modeling Helps Make
Systematic Choices Without Predictions

- **What is Exploratory Modeling?**
    - **A new approach to generating systematic, quantitative comparisons among alternative policy decisions that combines scenario-planning methodologies with quantitative forecasting techniques**
    - **Enabled by today's information technology**
    - **Applied in part here; more fully elsewhere[a]**

- **With Exploratory Modeling, S&T plans can address uncertainty:**
    - **Find robust combinations of plans or identify holes by looking at patterns in the visualizations**
    - **View technology plans as portfolios that take advantage of fortuitous opportunities and hedge against adverse surprises**
    - **Consider adaptive plans explicitly designed to respond as new information becomes available**

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[a]R. J. Lempert, M. E. Schlesinger, and S. C. Bankes, "When We Don't Know the Costs or the Benefits: Adaptive Strategies for Abating Climate Change," *Climatic Change* 33: 235–274 (1996).

Exploratory Modeling, or xM, is the second technology we used in our experiment. A new approach to generating systematic, quantitative comparisons among alternative policy decisions without relying on imperfect predictions of the the future, xM marries today's information technology—networked computer workstations and powerful graphics— to a new concept for supporting decisionmaking under uncertainty. It combines the wide-ranging scope of scenario-planning methodologies with the strengths of the best quantitative forecasting techniques.

The basic concept of xM is to create a database of many (tens to millions) scenarios and then use computer search and visualization techniques to understand the implications these scenarios have for policy choices. This briefing presents an application with only a very small number of scenarios, but the methods can be used to handle several orders of magnitude more scenarios, as we are already doing 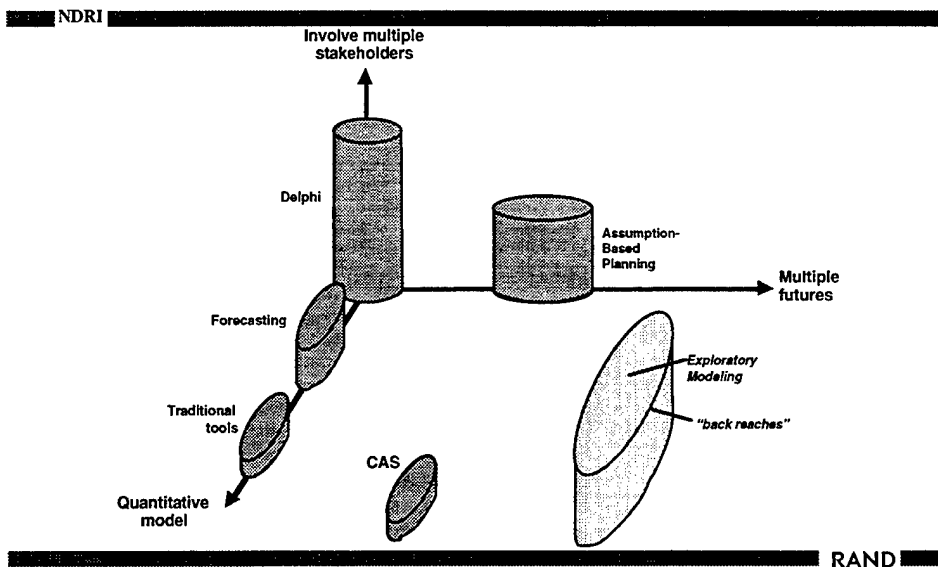in other policy areas, such as our work on climate change (R. J. Lempert, M. E. Schlesinger, and S. C. Bankes, "When We Don't Know the Costs or the Benefits: Adaptive Strategies for Abating Climate Change," *Climatic Change* 33: 235–274, 1996) and weapons procurement (Arthur Brooks, Steve Bankes, and Bart Bennett, *Weapon Mix and Exploratory Analysis: A Case Study*, Santa Monica, CA: RAND, DB-216/2-AF, 1997).

Exploratory Modeling helps the S&T planning process address uncertainty explicitly, identifying holes or finding robust combinations by looking at patterns in visualizations. In addition, we showed how these methods help treat technology plans as portfolios that take advantage of fortuitous opportunities and hedge against adverse surprises.

Comparison with Other Methods

Involve multiple
stakeholders

Delphi

Assumption-
Based
Planning

Multiple
futures

Forecasting

Exploratory
Modeling

Traditional
tools

"back reaches"

CAS

Quantitative
model

Exploratory Modeling draws upon and combines the benefits of many previous methods for making choices about the future. We've chosen to compare these methods along three dimensions: the degree to which a method uses quantitative models to describe the system, the degree to which it considers multiple futures, and the degree to which it involves multiple stakeholders or experts.

Let's start along the quantitative-model axis. Quantitative tools are important because they address "how much" questions (How much should a firm spend on a new technology? What growth rate indicates a new product is a success?) and can yield unexpected insights about the strengths and weaknesses of different decisions.

Delphi is the first method along this axis. It uses iterated, anonymous polling of experts, but uses no quantitative model and yields only one consensual view of the future. Forecasting techniques, such as technology forecasts or market forecasts, employ some variation of trend extrapolation. Forecasting can involve multiple stakeholders but employs quantitative models designed to yield a single "best estimate" about the future. "Traditional tools" is our label for the elegant mathematical machinery built around optimization. These tools assume static outcomes, even for inherently dynamic processes, and then maximize those outcomes. This class includes much of operations research, decision theory, and the cost-benefit tools of neoclassical economics. These techniques generally involve one research team and consider one future.

Some variant of these methods—Delphi, forecasting, and optimization—underlies most prediction-based policy analysis.

There are also several methods for thinking about multiple futures. Assumption-Based Planning is a RAND-developed scenario-planning method (James A. Dewar, Carl H. Builder, William M. Hix, and Morlie H. Levin, *Assumption-Based Planning: A Planning Tool for Very Uncertain Times*, Santa Monica, CA: RAND, MR-114-A, 1993) that is somewhat similar to the scenario-planning techniques most famously employed by Royal Dutch Shell and by Peter Schwartz and his Global Business Network (Peter Schwartz, *The Art of the Long View*, New York: Doubleday/Currency, 1991). Scenario planning usually involves the members of a community or organization in developing a small number of compelling scenarios that reveal the key assumptions underlying the group's plans. Such methods focus on multiple stakeholders and multiple futures but generally have no quantitative model.

CAS, or complex adaptive systems, is often associated with the Santa Fe Institute. CAS uses highly nonlinear mathematics to capture the unpredictability, evolution, and adaptability of systems made of many interacting agents. We show CAS models as being more quantitative than optimization, because the latter makes many assumptions about linearity that are often not true. CAS models will usually generate many futures. The main problem with CAS is that no one has yet figured out how to make useful comparisons among potential decisions using this fascinating mathematics.

Finally, we show Exploratory Modeling as building on the best ideas in the other methods. Exploratory Modeling can employ the quantitative models from the forecasting, optimization, and CAS methods. It can use the models within the multi-scenario, organizational planning process used in the scenario-based planning methods.

The entire region labeled Exploratory Modeling on this chart has not yet been filled in with examples of successful studies. What we have done so far is contained in the back reaches of this space.

Flow of Experimental Planning Process

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Put tools and the existing plans on the Web	◄— Task 1: Create Web site with specialized tools and content
↓	
Expert panels build alternative plans	◄— Task 2: Convene expert panels
↓	
Exploratory Modeling reveals key issues	◄— Task 3: Conduct Exploratory Modeling exercise
↓ ↑	
Experts revisit choices	◄— Task 4: Iterate with expert panels
↓	
Best options for S&T strategy	◄— Task 5: Provide decisionmakers with plan and history

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This chart shows how we organized our experiment for DARPA, using HyperForum and Exploratory Modeling. The experiment follows the flow of an actual planning process.

In this demonstration project, we worked through only the first three steps because of funding limitations. Tasks 1 through 3 are described in Sections 2 through 4. Section 5 discusses the results of the experiment and offers conclusions.

Flow of Experimental Planning Process

Put tools and the existing plans on the Web	Task 1: Create Web site with specialized tools and content
Expert panels build alternative plans	Task 2: Convene expert panels
Exploratory Modeling reveals key issues	Task 3: Conduct Exploratory Modeling exercise
Experts revisit choices	Task 4: Iterate with expert panels
Best options for S&T strategy	Task 5: Provide decisionmakers with plan and history

RAND

2. TASK 1: CREATE WEB SITE WITH SPECIALIZED TOOLS AND CONTENT

Web Site Built from the JWS&T Plan and ABIS

- **Both efforts link from JWCO to technology demonstrations**

- **Plans already supply significant programmatic information**

- **Efforts have significant acceptance in DoD**

In the first task, creating our Web site, we put online the Information Superiority section of the then-current JWS&T Plan (*Joint Warfighting Science and Technology Plan*, 1996; *Defense Technology Area Plan*, 1996). We focused on the Information Superiority section, because we had become familiar with that part of the plan when RAND helped DARPA with the Advanced Battlespace Information System (ABIS) study, which provided much of both the structure and the substance for the Information Superiority section of the JWS&T Plan.[7]

In particular, both the ABIS study and the JWS&T Plan rely upon an explicit connection between operational effectiveness and technology. The connection uses the expert but subjective opinion of the panel building the plan. The panel focused on the comparatively well-defined Joint Warfighting Capability Objective for Information Superiority and estimated how particular demonstrations or technology developments supported part of that JWCO. That connection provided us with the ready-made and accepted method that we needed for our experiment.

Additionally, the JWS&T Plan contains readily available, extensive information on DoD S&T programs, making it a natural source for planning activities. It also has rapidly become a widely accepted document among participants in, and the audience for, our experiment.

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[7] Joint Staff, Director of Command, Control, Communications, and Computers, and Office of the Secretary of Defense, Director, Defense Research and Engineering, *Advanced Battlespace Information System (ABIS) Task Force Report*, Volumes I–VI, Washington, D.C., May 1996.
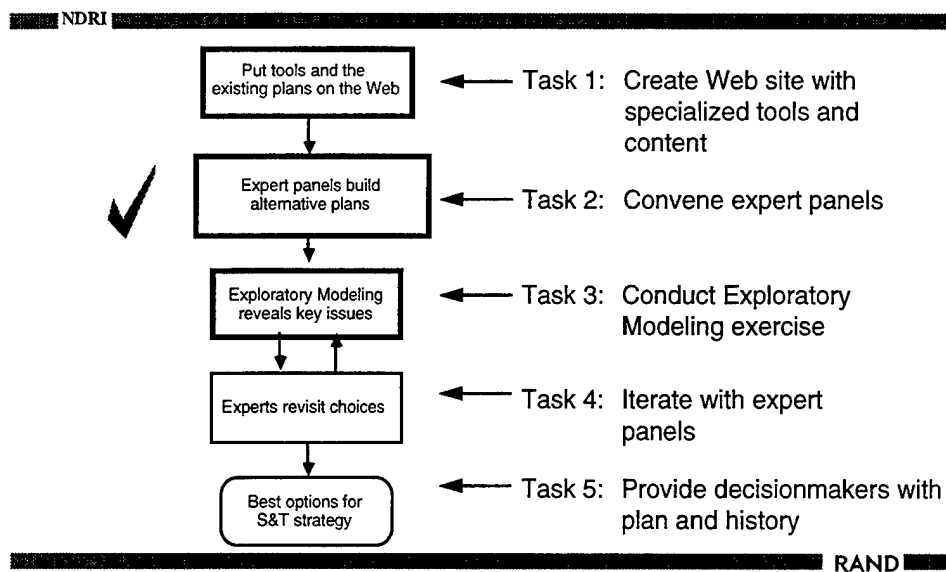
Methods Help Improve on
JWS&T Plan and ABIS

- **Allocate S&T investments as hedges against different possible futures**

- **Consider budgetary trade-offs or constraints**

- **Draw information from experts outside traditional community**

- **Provide an audit trail to trace the effects of changes in assumptions**

We put a variety of software tools on our Web site to help the panelists examine the implications of the JWS&T Plan and explore potential modifications in a way not possible by working on paper and in face-to-face meetings. We describe these tools in more detail in the next section. We then used our HyperForum and Exploratory Modeling methods to demonstrate how the process of creating the JWS&T Plan and ABIS could be improved.

Flow of Experimental Planning Process

NDRI

Put tools and the existing plans on the Web	◄——— Task 1: Create Web site with specialized tools and content
Expert panels build alternative plans	◄——— Task 2: Convene expert panels
Exploratory Modeling reveals key issues	◄——— Task 3: Conduct Exploratory Modeling exercise
Experts revisit choices	◄——— Task 4: Iterate with expert panels
Best options for S&T strategy	◄——— Task 5: Provide decisionmakers with plan and history

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3. TASK 2: CONVENE EXPERT PANELS

After creating our Web site with its specialized tools and content, we next convened our expert panels. Each panelist needed only a standard Web browser (such as a recent version of Netscape Navigator), the URL for our Web site, and a password. All the tools for manipulating plans and communicating to the other panelists were accessible through the browser; the (small) computational load was handled on our UNIX server. This protocol enabled several of our panelists to access the site from simple laptops while traveling.

Convene Expert Panels Online

- Panels charged with modifying the Information Superiority portion of JWS&T Plan to address two new military scenarios, a "No-Warning" MRC and Urban Combat

- Panels met online from November 11 to December 9, 1996
  - Heavy facilitation
  - Kick-off meeting was face-to-face

- Panel divided into two teams:

Team A (No-Warning MRC)	Team B (Urban Combat)
Dr. Ed Brady	Dr. Richard Darilek
Dr. Paul Davis	MAJ Steve Galing (USA)
Lt Col Tom Fossen (USAF)	LtCol Colin Lampard (USMC)
Lt Col Dan McCusker (USAF)	Dr. Dave Ochmanek
CDR Nicholas Trongale (USN)	Dr. John Poindexter

Our expert panel had ten members: five military officers, three members of the RAND research staff (Davis, Darilek, and Ochmanek, who had just returned from the Pentagon), and two consultants (Brady and Poindexter) nominated by DARPA. We divided the panel into two teams of five each. Each team had a member of our project staff serve as a facilitator.

We asked each team to start with the Information Superiority portion of the JWS&T Plan and modify it to provide capabilities the U.S. military would need to conduct successful operations in two new military scenarios in the year 2010—a No-Warning MRC (major regional contingency) and Urban Combat. Each panel first met in an introductory session at RAND in both Santa Monica and Washington, D.C. The first session was a face-to-face meeting. The participants on one coast were connected via telephone with the participants meeting simultaneously on the other coast. The rest of the panel interactions occurred online over the course of one month.

We should emphasize that these panelists were chosen as part of a proof-of-concept exercise. While they represent a broad base of talent and expertise, they did not cover all the substantive areas we would have needed for an actual exercise intended to inform DoD policy choices.

Each Panel Was Charged with Modifying the JWS&T Plan in Discrete Steps

Step 1: Agree on a concepts of operations that would allow the U.S. to prevail in the urban combat scenario. These concepts of operations will be based on the nine Operational Capability Elements (OCEs) described in the JWS&T Plan. Click on the "Step 1" link to discuss these operations with your team members.

Step 2: Modify the JWS&T plan so that it provides the technologies needed to support these concepts of operations. The "Step 2" link below takes you to a short description of this step, to some tools to help you, and to a discussion concerning your team's choice of technology plan. Click on the "Team B: Workspace" link for a large set of tools to view and modify your set of technology plans for that discussion.

Step 3: Assess how well your modified technology plan will support these concepts of operations. Click on the "Team B: Workspace" link in the box on the left for appropriate tools. The "Step 3" link below summarizes the estimated improvement in each OCE resulting from successful completion of the Team B Public plan.

Military Scenario: Urban Combat
Step 1: Agree on Concepts of Operations
Step 3: Assess Technology Plan

Technology Plans

Step 2: Choose Plan

Team B: Workspace

Email: TeamB@rand.org

Technical Support: terry@rand.org

We divided each team's work into two phases. This figure shows the three-step homepage Team B saw during the first phase of their work. Each phase lasted for a few days to a week. The panelists would come to this page for instructions and for an overview of the material on the site. In the second phase, we modified the homepage as described below.

We asked Team B to modify the JWS&T Plan to address future urban combat. Each of the three areas reached by the links—labeled Step 1, Step 2, and Step 3—has tools, content, and discussion space for the task at hand. When one step was complete, the facilitator would ask the participant to move to the next step.

In Step 1, we asked the team to develop concepts of operations for future urban combat. The "Military Scenario" link provides a detailed briefing on an urban-combat scenario, based on prior RAND work (John A. Friel and Bruce W. Don, "Close Support, Scenario and Battlefield Situation Assessment," unpublished RAND research). The "Step 1" link provides a place for the panel to carry on their discussions. In Step 2, we asked the panel to modify the JWS&T Plan so that it would better support these concepts of operations. The "Choose Plan" link provides a discussion area, and the "Team B: Workspace" provides a variety of tools for manipulating various versions of the technology plan. In Step 3, we asked the panel to assess how well the United States could conduct urban-combat operations if this new plan were carried out.

Step 1—Operational Concepts:
History of Discussion Is Maintained and Available

1. The Informational Demands of Robots, and What to Do? (Jim Bonomo, RAND (Panelist No. 17))
   1. Other Approaches (John Poindexter, DARPA (Panelist No. 16))
      1. Other Approaches 2 (Maj. Steve Galing, USA (Panelist No. 13))
      2. An Easy Synthesis on Optical Stealth and Mirages, and More (Jim Bonomo, RAND (Panelist
         1. Untitled (LtCol Colin Lampard, USMC (Panelist No. 14))
         2. Untitled (John Poindexter, DARPA (Panelist No. 16))
         3. Opinion (Maj. Steve Galing, USA (Panelist No. 13))
         4. Untitled (Guest Observer (Panelist No. 20))
   2. How Far Out? (Jim Bonomo, RAND (Panelist No. 17))
      1. Comments on Where We Are _____ (Dave Ochmanek, RAND (Panelist No. 15))
         1. NCA Needs Options (John Poindexter, DARPA (Panelist No. 16))
         2. A Variety of Missions (Jim Bonomo, RAND (Panelist No. 17))
      3. Robots 2 (Maj. Steve Galing, USA (Panelist No. 13))
         1. On Robots (Dave Ochmanek, RAND (Panelist No. 15))
      4. Battlefield robotics and sensor info flow (LtCol Colin Lampard, USMC (Panelist No. 14))
         1. Untitled (Dave Ochmanek, RAND (Panelist No. 15))
      5. An Attempted Summary on Robots (Jim Bonomo, RAND (Panelist No. 17))
         1. "Manipulated sensors" vice "robots" (LtCol Colin Lampard, USMC (Panelist No. 14))
         2. Untitled (John Poindexter, DARPA (Panelist No. 16))
         3. Robot Uses (Maj. Steve Galing, USA (Panelist No. 13))
         4. Untitled (Ed Brady, DARPA (Panelist No. 2))

In Step 1, we asked Team B to develop a concept of operations for urban combat. Shown here is a typical discussion, carried out using a share-ware tool called HyperNews. Each comment has a title, shows the author, and is positioned in relation to the other comments in the discussion. The indentations allow a reader to follow the various threads of the discussion as panelists respond to previous comments or start a discussion on a new topic. The icons appearing before each message title are a standard feature of HyperNews. Their use in voting is described on the chart after next.

Note that panelists respond to the facilitator and to each other. One important role of the facilitator was in fact to keep the different threads of the discussion focused and relevant to the panel's overall goals, so that when an important new idea appeared, the facilitator used that idea to create a new "thread." Creating new threads allowed the discussions on different issues to move forward separately, without becoming confusing.

To ease navigation through those issues, the facilitator would post a "summary" message from time to time. The summary would be announced through a short e-mail message sent separately to the participants. The posted "summary" message would draw attention to important issues in other messages, wherever they had been posted, and included links to them through hyperlinks. The posted message also suggested specific topics that needed discussion.

The resultant threaded arrangement of the comments makes it easy to follow the discussion, both while it is going on and afterwards. One author (Lempert), who did not participate in the panels, worked his way through the discussions after they were completed and found it surprisingly easy to get a good understanding of a complicated and multifaceted debate.

Concepts Are Generated, and Gain Support

◊ Mirage Concept

I wanted to flesh out a bit more my concept of "optical stealth" -- Mirage -- so that we would have something to go on as we address technologies.

In thinking of the problems associated with urban warfare it would seem an alternative or possible adjunct to robots might be a concept of deception to confuse the enemy. It is assumed that in the conduct of this type of warfare one must fight from building to building, street to street rather than razing urban structures. (This might be a bad assumption.) Thus military forces must enter buildings to secure them. It is doubtful in the time frame of Joint Vision 2010 we could develop robots capable of climbing stairwells and doing reasoning sufficient to do room by room searches let alone that required to distinguish fighters from non-combatants. Therefore humans must enter the buildings and we must figure out ways to assist them and make them less vulnerable.

Mirage could be series of tools to deny information and thus provide the elements of surprise, concealment, and deception. One assumption here is that the most significant sensor an enemy will have in an urban environment is the human eye ball. We must either deny that sensor or make it see something that isn't.

Under optical denial there are several possibilities of increasing degrees of technical difficulty:
(1) Mask the scene by some technique that denies visibility to the enemy but not our fighters.
(2) Blind the enemy with some type of wide angle directed energy device.
(3) Make the war fighter optically invisible.

For optical deception the techniques that come to mind are:
(1) Some variations of magician's smoke and mirror tricks
(2) Realistic projected holographic images
(3) . . .

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This is an example of a concept and the depth of discussion that could be engendered. This idea was raised by one of the panelists early in our discussion of urban combat. He called it then "optical stealth" but quickly decided "mirage" was closer to what he had in mind. The concept, which he developed more in the message shown above, appealed in principle to the other panelists. It seemed a natural extension of well-established methods of urban combat, such as the use of smoke.

Naturally, the technical feasibility of this idea was also considered later as the panel built an S&T plan. Here, however, the discussion focused more on the operational implications of plausible technical capabilities. Such discussions always mix issues of feasibility and operational effectiveness. Moreover, in this HyperForum, the permanence of the comments allowed the facilitator to recall any comments on these issues and bring them, again, to the attention of the entire group.

Mechanically, the process of entering a concept, or responding to one, quickly seemed to become second nature to the panelists. After an initial week of learning to use the HyperNews tool, they responded easily and appropriately to the discussion threads.

HyperNews itself facilitated such response with several useful features. It provides a highlighted title, the author's name (we have deleted the name here because we promised our panelists that we would not identify them publicly with their comments), and date of a message. At the bottom of the message (not visible in the image on the facing page), buttons that are clicked on take a reader to a composition page, where he or she can enter comments. Those comments, when finished and submitted, then appear as titles below the message, or on the summary of threads, as in the preceding chart.

Example of Voting on a Summary of an Issue

Re: Urban Combat -- Concept of Operations Discussions
Re: One (Developed) Alternative for Coping with Urban Combat (Jim Bonomo, RAND (Panelist No. 17))
Re: The Informational Demands of Robots, and What to Do? (Jim Bonomo, RAND (Panelist No. 17))
Re: Other Approaches
Re: optical stealth mirage invisible defensive information warfare
Date: Thu, 14 Nov 1996 03:53:45 GMT
From: James_Bonomo@rand.org (Jim Bonomo, RAND (Panelist No. 17))

Everyone who has commented likes the ideas of being "invisible" and of creating false soldiers to confuse an enemy. I am not sure that these ideas fit under "information superiority", but for the sake of argument, we can call them two sorts of defensive information warfare and include them.

The technical difficulty of both ideas is great, but I will begin a thread on that later, under the technology plan discussion. For now, I think we can safely say that these are great ideas in principle.

Are there other "defensive" information superiority ideas which are applicable to urban combat? Other decoys which could work, for example? I would naively think that the short ranges of urban combat would make that hard, but if anyone has an idea, please toss it out.

More | Next | Prev. | Out

Messages [Inline Depth: 1 2 3 All] [Outline Depth: 1 2 3 9 All]

1. Untitled (Lt.Col. Colin Lampard, USMC (Panelist No. 14))
2. Untitled (John Poindexter, DARPA (Panelist No. 16))
3. Opinion (Maj. Steve Geling, USA (Panelist No. 13))
4. Untitled (Guest Observer (Panelist No. 20))

Use of HyperNews in this HyperForum evolved during this short experiment. One of the authors, acting as the facilitator for the urban-combat team, developed a simple method of voting on a summary: First, the facilitator fashioned a terse statement of an apparent consensus within the group. This consensus was then presented, as in the rectangle on the facing page, for the participants to vote on, within one of the summary messages described earlier. The voting method simply used two of the already-available icons supplied by HyperNews. A thumbs-up indicated support, and a thumbs-down indicated disagreement. These icons (which could be used at any time to tag any submitted message) were reserved for this purpose, through a social agreement within the group on their use.

The consequence of such voting was that issues could be resolved by the panelists. More important, each participant was encouraged to take a visible stand on each issue. Most attempts at summaries were in fact agreed on by the panelists, probably because the facilitator waited until there were clear signs of consensus. At other times, an attempted summary prompted a deeper discussion of an issue, such as on the tension between a commander's interest in "drilling down" for (micromanaging) information on the execution of a mission versus a subordinate's interest in avoiding micromanagement.

While all of the examples have concerned the first step of the planning process, developing a concept of operations, the methods of facilitating a discussion described for this step were used in all later steps as well.

Step 2—Create a Technology Plan:
Panelists Can Manipulate Technology Plans Online

[Add New Program]

Demonstration Title	Changes			Budget		Military Contribution	Notes
	Add	Del	Mod	JWS&T	Cur.		
Rapid Terrain Visualization - Mod	x			-	4.5	4	notes
Adaptive Force Package Tailoring	x			-	8.0	3	notes
Joint Theater Information & Spectrum Dominance	x			-	35.0	4	notes
Distributed Situation Assessment			x	23.0	30.0	8	notes
Intelligent Minefield				-	-	4	-
Hunter Sensor Suite				-	-	4	-
Robust Tactical/Mobile Networking			x	23.0	61.5	5	notes
Joint C4I for Rapid Force Projection			x	50.0	110.0	4	notes
Precision Rapid Counter Multiple Rocket Launcher		x	x	90.9	75.9	4	notes

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Once the panelists agreed on concepts of operations, the facilitator asked them to move on to Step 2. Here, we asked the panelists to modify the JWS&T Plan to support the concepts of operations developed in Step 1. It was important that this modified plan fit within the same budget as the original JWS&T Plan. This step differed from the first in its heavy use of online tools.

The chart on the facing page is what an S&T plan looks like on our site. The plan itself is a database that can be manipulated, searched, and shared among panelists. In the left-most column is a list of technology programs. Clicking on a name produces a page with the programmatic information provided in the Appendix of the JWS&T Plan: program description, budgets, and a matrix showing those military operational capability elements (OCEs) supported by the program. The next columns show whether this program has been added, deleted, or modified relative to the original JWS&T Plan. The next columns show the budget.

The military-contribution column shows a rough measure of the program's contribution to military operational capabilities. In the JWS&T process, each program in the technology plan was given a black dot, a white dot, or no dot, representing "strong," "moderate," or "no support"' for each OCE. We assigned a score of 2 to each black dot, a score of 1 to each white dot, and a score of 0 to each "no support." The sum over all the scores for all OCEs gives the total military contribution for each program.

Every time a program was changed in the formulation of some overall plan, the software prompted the person making the modification to explain his reasons. These comments appear under the Notes column.

"Workspace" Gave Panelists
a Variety of Tools

Each panelist could

- edit, duplicate, and delete plans on his private scratch pad

- share technology plans with fellow panelists

- compare two plans' individual programs, overall budgets, and the military capabilities they enable

- assess the contribution a plan makes to future military capabilities

Panelists used alternative plans as exhibits in their discussions.

Facilitators helped each panel reach consensus on a plan and assess its military contributions.

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Each panelist had a workspace on the server, in which he could manipulate versions of the JWS&T Plan. Panelists could edit, duplicate, and delete plans as they could with any standard word-processing document. While working on a plan, they could keep it private on their own scratch pad and then, when ready, share that plan with other panelists. The typical Information Superiority plan contained several hundred programs, so we provided tools that allow a panelist to compare two technology plans and quickly focus on the specific differences between them. Finally, we provided the panelists with tools to assess how well a technology plan contributes to future military capabilities, as we discuss below.

Since these plans were online along with the discussions, panelists could use the plans as exhibits in the discussions. For instance, a panelist could propose modifications to the plan and post them for the other panelists to debate.

With help from the facilitator, each team agreed on a single version of the plan for each team.

Step 3—Assess Performance of Plan:
Panelists Assessed Plans with ABIS "Water Glasses"

Assess "Water Glass" Levels

You assess the impacts of a technology plan by estimating how well the U.S. military will be able to perform each of the nine OCEs in 2010 if the technology plan is successfully completed. Enter your estimates for each of the OCEs below. The numbers in parentheses gives the estimates that accompany the original JWS&T plan.

RANGE: 0 to 1

Effective Employment	Battlespace Awareness	The Grid
Prediction Planning 0.75 (0.75)	Information Acquisition 0.80 (0.75)	Univ. Transactions Serv. 0.42 (0.50)
Integrated Force Mgt 0.72 (0.50)	Battlespace Understanding 0.80 (0.75)	Dist. Environment Support 0.50 (0.50)
Exec. Time Crit. Missions 0.82 (0.75)	Precision Information 0.75 (0.75)	Assurance of Services 0.50 (0.50)

Set Normalization Values

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Once the panelists had agreed on a modified technology plan, the facilitator asked them to move to Step 3, in which they assessed how well the United States could perform the urban-combat mission if the proposed plan were enacted.

In the ABIS study, the team used the "water glass" method to assess how well each Operational Capability Element in that technology plan contributed to future military capabilities. Each OCE was represented by a partially filled water glass. The more full the glass, the greater the contribution of the technology plan to the OCE. In ABIS, all the water glasses were either 1/2 or 3/4 full. We adopted that measure for this work, and adopted those values as a starting point for the discussion.

The ABIS OCEs were identical to eight of the entries in the table on the facing page; within the JWS&T Plan, Information Acquisition was added as another OCE. In ABIS, the acquisition of information had been ruled out of scope, so that the study became focused on the less-studied C4 (command, control, communications, and computers) aspects. We arbitrarily set Information Acquisition to start at 3/4.

In our exercise, we asked that the panelists estimate the contribution of their entire technology plan to each of the nine Information Superiority OCEs interpreted within their scenario and concept of operations. As in ABIS, we asked for that estimate on a 0-to-1 scale. This chart shows the page the panelists used to enter their judgments. The number in each box is entered by the panelists. The corresponding number in parentheses is the ABIS water-glass height for that OCE, or for Information Acquisition, our surrogate.

In an associated discussion area, panelists debated their choices until their team reached a consensus.

Step 4—Assess Plan
Against Other Military Scenario

Step 4: Agree on the concepts of operations that would give the U.S. the best chance to prevail in the urban combat scenario given the technology plan you developed for the No-Warning MRC scenario. Click on the 'Step 4: Agree on Concepts of Operations' link to discuss these operations with you team members. Once you agree on concepts of operations, assess how well your team's technology plan will support those operations using the 'Assess Water Glass Levels' tool on your 'Team B: Workspace' page. To help in this assignment, you can review your previous work and that of Team A's by clicking on the respective 'Concepts of Operations' and 'Assess Technology Plans' links.

Technology Plans	No Warning MRC	Urban Combat
Team A Choose Plan	Concept of Operations	
Team A Public Plan	Assess Technology Plan	
Team B Choose Plan		Concepts of Operations
Team B Public Plan	Step 4: Agree on Concepts of Operations and Assess Technology Plan	Assess Technology Plan
Team B: Workspace		

Email: TeamB@rand.org

Technical Support: terry@rand.org

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Up until this point, each team had worked separately on crafting a technology plan for a particular future military scenario. Once each team had completed this job, we gave it the other team's scenario in order to test the robustness of their plan. We asked Team A to assess how well its technology plan, designed for the No-Warning MRC scenario, would contribute to the Urban Combat scenario. Similarly, we asked Team B to assess how well its technology plan, designed for the Urban Combat scenario, would contribute to the No-Warning MRC scenario.

The figure on the facing page shows the new homepage for Team B at the start of this fourth and final step. We allowed Team B to see the work they and Team A did in Steps 1 through 3. Team B also got a new Step 4, asking them to develop concepts of operations for the No-Warning MRC scenario and to assess how well their Urban Combat technology plan would address this new scenario. It is important to remember that this is an assessment of the plan *with no adjustments* for the new scenario. The search for a plan that works well in both scenarios comes later in the HyperForum.

Note that the site for Team B changes significantly when it moves to Step 4 from Steps 1 through 3. (The Team A site changed similarly.) Changing the site over time is an important feature of the HyperForum. It allows the panelists and facilitator to move systematically through a series of tasks and the information supporting those tasks.

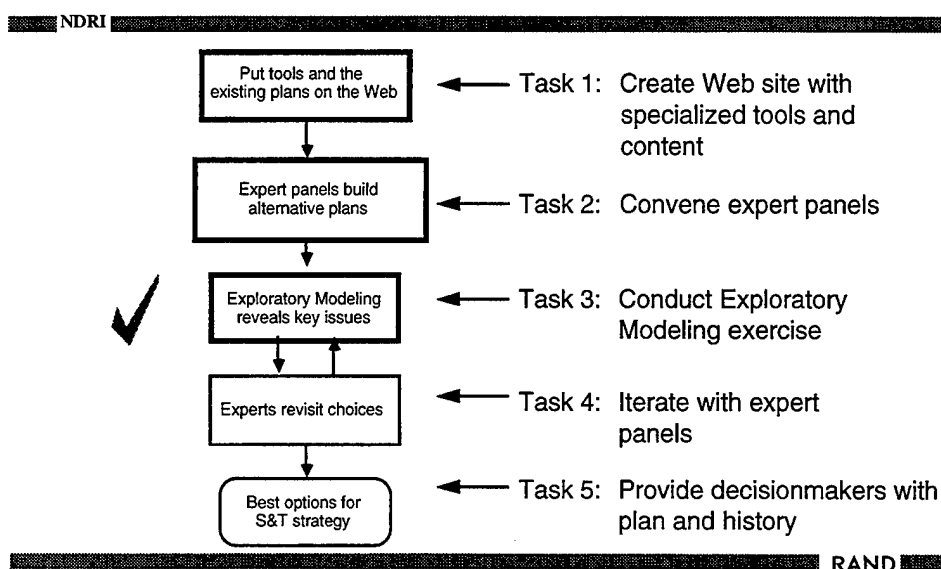# Result Is Both Plans Assessed Against
Both Military Scenarios
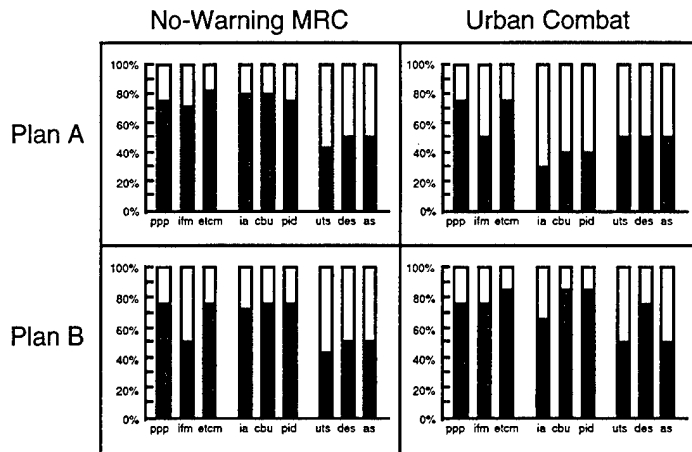
This chart presents a graphic summary of the panels' work showing how each team assessed the military capabilities that would derive from successful completion of their S&T plans. Both scenarios used each of the nine Information Superiority OCEs from the JWS&T Plan. These OCEs are Prediction Planning (ppp), Integrated Force Management (ifm), Execution of Time-Critical Missions (etcm), Information Acquisition (ia), Battlespace Understanding (cbu), Precision Information (pid), Universal Transactions Served (uts), Distributed Environmental Support (des), and Assurance of Services (as).

As we would expect, each plan works best for the scenario it was designed for. The ratings for the off-design scenarios, Urban Combat for Plan A and No-Warning MRC for Plan B, are important for this effort, because they form the basis for the final step: interpolating between plans in a search for robustness.

The detailed changes have an immediately apparent logic. Plan A, developed for the MRC, had the largest estimated decrease in its capability for Battlespace Awareness (the middle three OCE estimates above) when facing urban combat. For instance, Information Acquisition for Plan A drops significantly in Urban Combat compared with the MRC. In the latter scenario, there is no need to look inside buildings; this is an operation essential in urban combat but not in an MRC. Similarly, when facing a No-Warning MRC, Plan B, derived for urban combat, had the largest estimated decrease in its capability to provide integrated force management, reflecting the larger scale of coordination needed in an MRC.
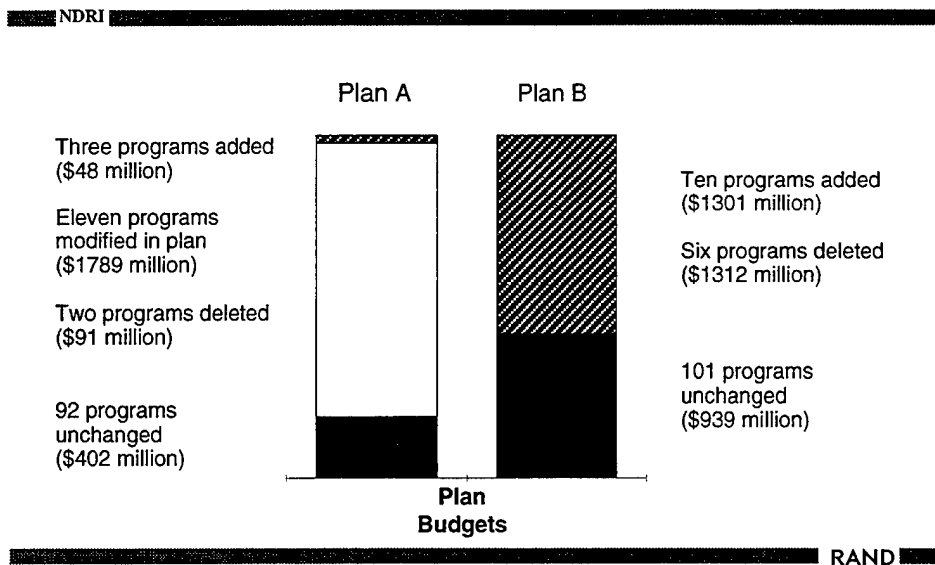
Flow of Experimental Planning Process

Put tools and the existing plans on the Web	Task 1: Create Web site with specialized tools and content
Expert panels build alternative plans	Task 2: Convene expert panels
Exploratory Modeling reveals key issues	Task 3: Conduct Exploratory Modeling exercise
Experts revisit choices	Task 4: Iterate with expert panels
Best options for S&T strategy	Task 5: Provide decisionmakers with plan and history

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4. TASK 3: CONDUCT EXPLORATORY MODELING EXERCISE

The two teams in our expert panel produced two technology plans, each assessed against different future military scenarios. But policymakers need a single technology plan that is robust against multiple futures. In this section of the briefing, we describe a simple application of the Exploratory Modeling ideas to suggest how the two teams' plans can best be combined into a single, robust technology plan.

We describe how we can automatically generate new technology plans that are mixes of the programs from Plans A and B and that have the same overall budget as Plans A and B. We then describe how we can estimate the military contribution of each of these new plans in our two military scenarios. This process is designed to produce a small number of candidate technology plans, successful in both military scenarios, that in a real planning process would be given back to the expert panels to help them recommend a single, robust technology plan.

Team A Modified Existing Programs;
Team B Added New Programs

Plan A   Plan B

Three programs added
($48 million)
                                    Ten programs added
Eleven programs   ($1301 million)
modified in plan
($1789 million)   Six programs deleted
                                    ($1312 million)
Two programs deleted
($91 million)

                                    101 programs
92 programs   unchanged
unchanged   ($939 million)
($402 million)

**Plan
Budgets**

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As a first step in explaining our method of combining technology plans, it
is useful to examine in more detail the results produced by our expert
panel. This slide shows a budgetary summary of how the two teams
modified the JWS&T Plan. The differing shaded areas in the bars indicate
the very different responses of our two teams to their respective scenarios.

The Information Superiority portion of the JWS&T Plan had a total budget
of $2.2 billion. As shown in the figure, Team A added three new programs
costing a total of $48 million, modified eleven programs accounting for
$1789 million, deleted two programs totaling $91 million, and left
unchanged 92 programs totaling $402 million. Team B added ten new
programs costing $1301 million, deleted six programs totaling $1312
million, and left 101 programs totaling $939 million unchanged. Team B
did not modify any programs.

The contrast between these two sets of results makes sense in light of the
different scenarios given to the two teams. Team A's No-Warning MRC
scenario was close to the dominating MRC scenario considered by the
government in creating the original JWS&T Plan. Accordingly, Team A
could focus on modifying existing programs. Team B's Urban Combat
scenario was very different from the situations considered in ABIS and in
the Information Superiority section of the JWS&T Plan. The panelists
responded by creating new programs designed especially for these new
circumstances.

As an aside, it is interesting to note the relatively small budget for the large
number of unchanged programs. This owes to the fact that many
programs in the original JWS&T Plan, especially those beyond the 5-year
budget-planning cycle, had no budget. Consequently, there was no
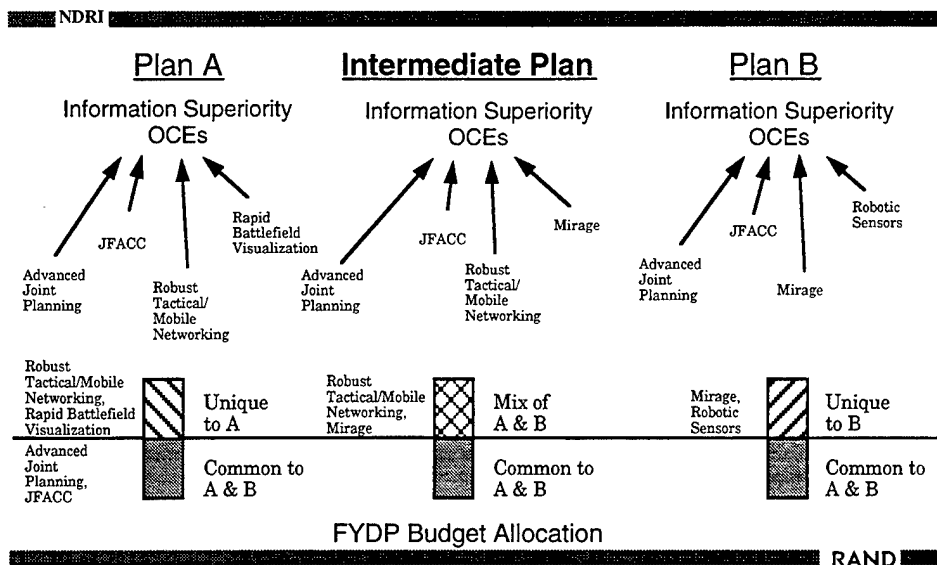incentive to remove or change them.

Changes Made by Teams A and B

Team A

Additions to Plan
Rapid Terrain Visualization - Mod
Adaptive Force Package Tailoring
Joint Theater Information & Spectrum
    Dominance
Modified Programs
Distributed Situation Assessment
Robust Tactical/Mobile Networking
Joint C4I for Rapid Force Projection
Precision Guided Mortar Munition
IW [Information Warfare] Battle Management
Survivable Armed Reconnaissance on the Digital
    Battlefield
Rapid Battlefield Visualization
Battlefield Awareness & Data Dissemination
Operator Intelligence Interface
Small Satellite SAR [Synthetic Aperture Radar]
Counter Camouflage, Concealment, & Deception
Deleted from Plan
Precision Rapid Counter Multiple Rocket
    Launcher
Rotocraft Pilot Associate

Team B

Additions to Plan
MOUT [military operations on urban terrain]
    Command, Control, Comm, Computers and
    Intelligence
MOUT Survivability
MOUT Modeling and Simulation
Full-Scale MOUT Demo
Urban Combat Training ACTD
Netted Sensor ATD
Mirage
Context-based Information Distribution 2
Robotic Sensors
Smart Assistant for the Infantryman
Deleted from Plan
Precision Rapid Counter Multiple Rocket
    Launcher
Precision Guided Mortar Munition
GEODSS [Ground-Based Electro-Optical Deep-
    Space Surveillance System] Upgrade
Small Satellite SAR
Wide Area Tracking System
Context-Based Information Distribution

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This chart names the specific programs added, modified, and deleted by our expert panels. All the modifications made by Team A had to do with the budget, as opposed to the substance, of the programs in question. Team A increased or decreased the budgets of programs to provide more or fewer capabilities. They did not modify or create new programs to provide a significantly different capability. Many of the programs added by Team B were taken from other parts of the JWS&T Plan—specifically, the Military Operations in the Urban Terrain JWCO—rather than being created from scratch. Important exceptions are Team B's Mirage program, which we discussed earlier, and their Netted Sensor ATD, Robotic Sensors, and Urban Combat Training ACTD.

Interpolating Technology Plans

NDRI

Plan A	Intermediate Plan	Plan B
Information Superiority OCEs	Information Superiority OCEs	Information Superiority OCEs

FYDP Budget Allocation

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If we knew with certainty that the future would look like the scenarios given to Team A, we would choose Plan A as our new JWS&T Plan. If we knew with certainty that the future would look like the scenario given to Team B, we would choose Plan B. But since we do not know the future, we want to examine whether some composite of Plans A and B is reasonably robust against both scenarios.

Accordingly, we developed an automated routine for interpolating two technology plans, as shown in this chart. An automated plan is not really necessary with only two plans; however, we wanted to demonstrate our ability to expand in the future to many dozens or hundreds of plans to cover many more futures.

We start by noting that each plan has programs unique to that plan and programs common to both plans. The total budget for the programs unique to A is the same as the total budget for the programs unique to B, since the budgets of the plans common to A and B are the same and both plans have the same total budget.

Any plan intermediate between Plans A and B will have all the programs common to A and B. The remainder of the budget is then used to buy programs unique to A or B for the intermediate plan. For instance, an intermediate plan that is 75 percent A and 25 percent B, uses 75 percent of its "Unique to A or B" budget to buy programs unique to A and 25 percent of the budget to buy programs unique to B. (See the example on page 40.)

Finally, we need to determine the military contribution of the intermediate plan. As shown in the chart, each individual program contributes to some OCEs, as measured by the white-/black-dot weighting discussed above. Assuming there are no *important* synergies[8] among programs, we sum the contributions of each program for each OCE to estimate the military contribution of the intermediate plan.

Note that this process *does not* distinguish contributions in different scenarios. Rather, a contribution of some weight to some OCE, say, Information Acquisition, is the same in any scenario. Although the contribution of any one program is always only a few percent of the total contribution for any OCE and does not have a huge effect, it has some distorting consequences for the method. These consequences are discussed in the chart after next and could be changed with a more elaborate weighting methodology. We adopted this interpolation process because it was, literally, the closest analogy that we could find to the subjective JWS&T methodology. That methodology does not discuss contributions in different scenarios; rather, it presents the entire plan and contributions. Additionally, even this method is time-consuming, so elaboration in this experiment was implausible.

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[8]*Synergies* are enhancements produced in one program by the presence of another. For example, there are synergies between improved long-range weapons and improved long-range battlefield surveillance, since the former are more useful if a military force knows what is in the battlefield to shoot at. Generally, there are synergies among technology programs, although most often they are not considered explicitly in most analyses, including the JWS&T Plan and ours.

Interpolation with
75% Plan A and 25% Plan B

PLAN A PROGRAMS	Score	Budget
Robust Tactical/Mobile Networking	5	$61.5
Context-Based Information Distribution	4	$0.0
Rapid Terrain Visualization - Mod	4	$4.5
Distributed Situation Assessment	4	$30.0
Joint Theater Information & Spectrum Dominance	4	$35.0
Joint C4I for Rapid Force Projection	4	$110.0
Battlefield Awareness & Data Dissemination	4	$225.7
Adaptive Force Package Tailoring	3	$8.0
IW Battle Management	3	$33.0
Wide Area Tracking System	2	$3.0
GEODSS Upgrade	2	$6.6
Counter Camouflage, Concealment, & Deception	2	$25.0
Operator Intelligence Interface	2	$60.0
Rapid Battlefield Visualization	2	$61.3
Small Satellite SAR	2	$546.4
Survivable Armed Reconnaissance on the Digital Battlefield	0	$125.0
~~Precision Guided Mortar Munition~~	~~0~~	~~$611.3~~
		$1,335.0

| PLAN B PROGRAMS	Score	Budget
Full-Scale MOUT Demo	11	$140.0
MOUT Command, Control, Comm, Computers and Intell	11	$295.8
~~Battlefield Awareness & Data Dissemination~~	~~9~~	~~$185.7~~
~~Smart Assistant for the Infantryman~~	~~8~~	~~$100.0~~
~~Mirage~~	~~8~~	~~$230.0~~
~~Urban Combat Training ACTD~~	~~7~~	~~$90.0~~
~~Netted Sensor ATD~~	~~7~~	~~$90.0~~
~~MOUT Survivability~~	~~6~~	~~$27.0~~
~~Robotic Sensors~~	~~6~~	~~$230.0~~
~~Distributed Situation Assessment~~	~~4~~	~~$23.0~~
~~Robust Tactical/Mobile Networking~~	~~4~~	~~$23.0~~
~~Joint C4I for Rapid Force Projection~~	~~4~~	~~$50.0~~
~~Context-based Information Distribution~~	~~4~~	~~$93.9~~
MOUT Modeling and Simulation	3	$4.0
~~IW Battle Management~~	~~3~~	~~$22.0~~
~~Operator Intelligence Interface~~	~~2~~	~~$45.0~~
~~Rapid Battlefield Visualization~~	~~2~~	~~$58.3~~
~~Counter Camouflage, Concealment, & Deception~~	~~2~~	~~$127.5~~
		$435.8

The interpolation routine requires that the programs unique to each plan be prioritized. We employed a simple scheme of ranking the programs in each plan according to their military contribution. We broke ties between programs having equivalent military contributions by ranking those programs with smaller cost higher than programs with higher cost.

This is obviously a crude prioritization scheme, although it is closely based on the assessments used in the ABIS project. In future work, it would certainly be possible to employ other schemes. It is also possible to compare the technology plans resulting from several prioritization schemes, so that the panelists need not come to a consensus on any single ranking of the programs.

Note too that synergies between programs, or dependencies among them, can be captured with elaborations of this method. Although we built tools that can capture such relationships—allowing, for example, one program's failure to "force" the degradation of another—it was clear that our panels had neither the time nor the expertise to use such linkages. Indeed, such relationships are also largely ignored in other planning methods we have seen.

These other methods might be able to capture and to display the implications of such relationships, creating new insights for S&T planning. For now, however, that ability remains a speculation.

Mix of 40–70% Plan B
Gives Most Robust Overall Plan

No-Warning MRC

Urban Combat
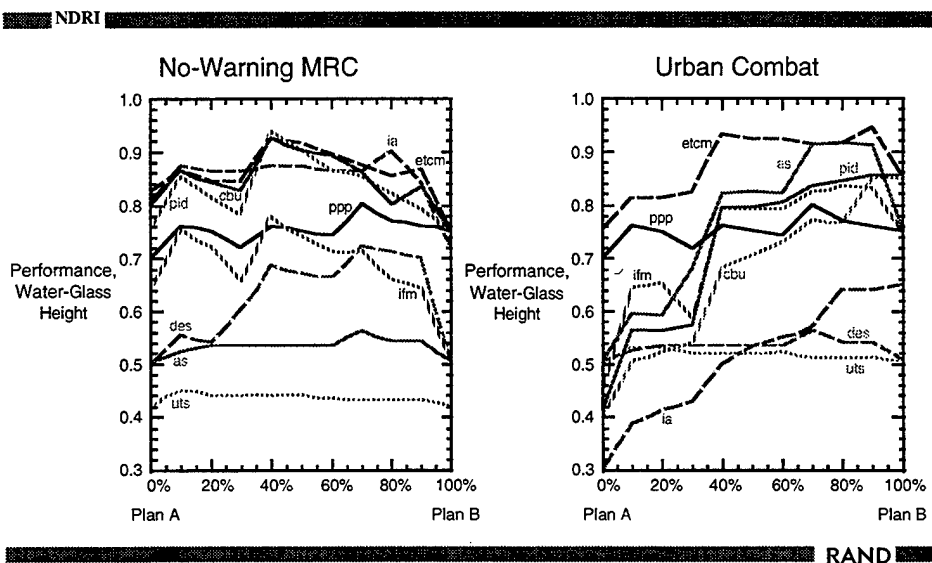
Next, we found the most robust combination of the technology plans produced by our expert panel. The results of our analysis of the combinations is shown in this chart.

The left and right panels show how a variety of intermediate plans perform in the No-Warning MRC and Urban Combat scenarios, respectively. Each curve in the panels represents the performance of one Information Superiority OCE, measured along the 0-to-1 water-glass scale, as a function of the fraction of the "Unique to A or B" budget allocated to Plan B programs. For instance, the Information Acquisition (ia) OCE in the Urban Combat scenario has a score of 0.3 when the entire budget is allocated to Plan A programs and increases monotonically to a score of 0.65 when the entire budget is allocated to Plan B programs. This behavior is not surprising, since the technologies needed to locate enemy forces are quite different for an MRC and for Urban Combat.

This chart shows us that the technology plans most robust against our two military scenarios are those in which 40 to 70 percent of the budget is allocated to Plan B programs. Note that below 40 percent, a technology plan performs relatively poorly in the Urban Combat scenario. Above 70 percent, a plan provides relatively poor performance in the No-Warning MRC scenario.

This represents the final step in our demonstration project. In a real-world planning process, this result would be given the panelists, who would then use this information as a starting point to craft an S&T plan robust against these two military futures.

Note that the OCEs for the No-Warning MRC scenario improve when about 10 percent of the Plan A budget is allocated to Plan B programs and for the Urban Combat scenario when about 10 percent of the Plan B budget is allocated to Plan A programs. The reason is that Plans A and B both have a small number of programs with negligible contribution to the Information Superiority OCEs. Our interpolation scheme replaces these programs with the highest-scoring programs of the other plan, and thus increases the overall performance of the intermediate plans.

This is one example of a potential distortion coming from our simple weighting method. Presumably, the new programs would contribute most in the other scenario, and so give less of a boost when they are added. This effect is also, in part, due to difficulties in the then-current JWS&T Plan, which included programs having low contributions.

Panelists Judged the Exercise a Success

Even without much prior Web experience, most panelists participated without difficulty:

- Most required several hours to come up to speed

- Most were heavily engaged in discussions

Panelists enjoyed flexibility of asynchronous meetings

- But still needed to devote significant time to effort

Compared with face-to-face meetings, HyperForum brought more information into discussions

Facilitator was necessary

5. CONCLUSIONS

After the experiment, we interviewed the participants to learn what they liked and did not like about the experiment.

In general, the panelists were pleased. All had been able to access the site, learn how to use it, and participate in the discussions. All were impressed by being able to conduct detailed, informative, asynchronous discussions. Many reported that their other commitments would have prevented them from participating in the exercise if they had been required to physically attend a series of meetings at a particular place and time. The participants also reported that the online format provided easier access to relevant information than most face-to-face meetings could provide.

Nonetheless, many panelists reported that they spent many hours examining the material on the site and composing their own postings. *Asynchronous* does not imply that little time was needed, only that the schedule for that time was flexible. The facilitators spent even more time than did panelists in sifting and combining the messages in a way that structured the discussion. In general, this HyperForum did not substitute for human knowledge and insights, but provided a different and, in some ways, a superior way to approach a goal cooperatively.

Project Demonstrated
Some Key Capabilities

Technology plans can provide and draw on more sources of information. Plans are

✓ • **Databases that can be searched and manipulated**

✓ • **Nodes linked to other relevant sources of information**

• **Forums with inputs and buy-in from many stakeholders**

Technology plans can embrace uncertainty:

✓ • **Portfolios that take advantage of fortuitous opportunities and hedges against adverse surprises**

• **Adaptive processes designed to respond as new information becomes available**

RAND

Overall, this experiment demonstrated many, but not all, of the key capabilities we believe a method combining HyperForum and Exploratory Modeling can offer. First, it showed that large databases can be searched and manipulated online by individuals with the computer skills of those who typically serve on DoD expert panels. Moreover, these databases can be linked to yet more sources of information online, enabling the panelists to gather much relevant information quickly without the delays inherent in a face-to-face meeting.

Additionally, the method did demonstrate a capability to fashion plans that show robustness to multiple (two) futures. That part of the methodology is easily expanded to as many scenarios as panelists can consider.

We did not show that diverse stakeholders would buy into this method. Our panelists did, but they were not under the same sort of institutional pressures that real-world panelists will always feel. We also did not pursue Exploratory Modeling into the realm of adaptive strategies—that is, strategies explicitly designed to evolve over time in response to new information; rather, this method would simply be used to revise plans as needed (yearly for the JWS&T Plan). Both HyperForum and Exploratory Modeling could be a focus for future work.

Additionally, we found one insight not mentioned in the slides. The weighting plan of the established methodology in the JWS&T Plan discriminates against large programs. Essentially, no program contributes to more than four OCEs, and not "strongly" even to that many.

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Consequently, no existing program has a weight, in our scheme, of more than 9 units. Conversely, every program should have some contribution, which is a minimum of 1 unit. Thus, the dynamic range of different programs' contribution to (all) OCEs was about 10.

In contrast, the budgets of the differing programs varied by well over a factor of 100, which meant that it was *always* better to trade off a large project for a host of smaller ones, from another plan or from some variant plan being considered for just one scenario. For example, the Small Satellite Synthetic Aperture Radar program, which was in the plan for $660 million and had an OCE contribution of 2 units, could easily be traded off for a great number of modeling and simulation programs, which cost, typically, a few million dollars and gain a contribution of 1 or 2 units.

It is important to note that this is *not* a flaw in our methodology or weightings, which we set arbitrarily. Rather, the problem is inherent in the JWS&T Plan itself, which contains such a wide range of program sizes that the judgments of program importance (the weightings or, in the JWS&T Plan, sets of "dots") are overwhelmed. Our computerized method of comparing these programs forced us to confront this issue, which is still present in the JWS&T Plan as it exists today.

Fundamentally, if the estimates of operational importance in the JWS&T Plan are taken seriously, they lead to the cutting of large programs. The leadership of OSD should consider either modifying those estimates of importance to allow them to express a much greater impact from different efforts, or else restrict the JWS&T Plan to consideration of only programs of roughly similar costs.

Methods Offered Interesting Advantages

- **Allow asynchronous, remote involvement**
  - **Lower some costs**
  - **Broaden participation**

- **Provide traceability through discussion**
  - **Generate recognized support for ideas**
  - **Affect deliberations**

- **Create more-robust plan**
  - **Address multiple futures more easily**

- **Articulate robustness to outside audiences**

RAND

Returning to the consequences of our experiment, we found many of the practical advantages we anticipated. The combined method does allow more people to participate and even lowers travel costs. It provides a usable traceability so that decisions or recommendations can be fully understood by others coming to the process later. Combining different plans is possible and creates a more robust hybrid. Finally, that robustness can be communicated with some flexibility to outside audiences.

Next Steps

Apply methods to real-world planning process:

- **Assess robustness of DDR&E's current JWS&T Plan**

- **Assist other federal agencies with S&T planning**

- **Help private-sector firms craft R&D portfolios**

Methods most useful when there is

- **Desire to create portfolios of S&T investments robust against extreme uncertainty**

- **Commitment at the top to augment current planning with new methods**

- **A large number of stakeholders in planning process**

- **Existing planning process, based on expert opinion, in place**

RAND

These S&T planning methods are ready to use as part of a real-world planning effort. From our limited experience, it is hard to generalize on the applicability of the methods used in this proof of concept. However, we think that these methods will be most useful when several conditions are met. First, there must be a need to craft an S&T investment portfolio that is robust in the face of major uncertainties. Without uncertainty, traditional planning methods will probably suffice. Second, there must be a commitment within the organization to exploring new methods to augment current planning methods. Third, the methods will be most useful if multiple stakeholders are involved in the planning process; a small group could just as easily make their plans face-to-face. Finally, as currently configured, our combined method is designed to augment an existing planning process based largely on expert opinion. In the future, however, we hope to expand the methods to combine expert opinion with other types of information.

As an obvious first step in such expansion, these S&T planning methods could be used as part of the next planning cycle, to assess the robustness of some portion of the next JWS&T Plan. If the experience is positive, the methods could then be used to address the full plan.

This combined method could also be used for other S&T planning activities within the Department of Defense—for example, those conducted by the individual Services. In addition, other federal agencies that build S&T plans, such as NASA or the Department of Energy, might also find these methods useful. For instance, the National Science and

Technology Council might use these tools to build consensus among scientists, industry representatives, and environmentalists on a national technology agenda for dealing with the threat of climate change. Finally, private industry might also use these methods to craft technology research portfolios well balanced between protection of their current markets and the challenge of creating new ones.

APPENDIX

Internet Changing How Research Centers Work

By GEANNE ROSENBERG

The year is 2050. The place: Earth. The possibilities: a chaotic world at the mercy of warring factions; a world in which sustainable development is mediated by governmental action; a world in which technology has eliminated the threats posed by global warming, population growth and diminished natural resources. Which future is in store and what, if anything, can or should be done about it?

These questions were collectively addressed by environmentalists, economists, academicians and policy makers. But while the Rand Corporation and the World Resources Institute helped set up the debate, the arena was not a conference room.
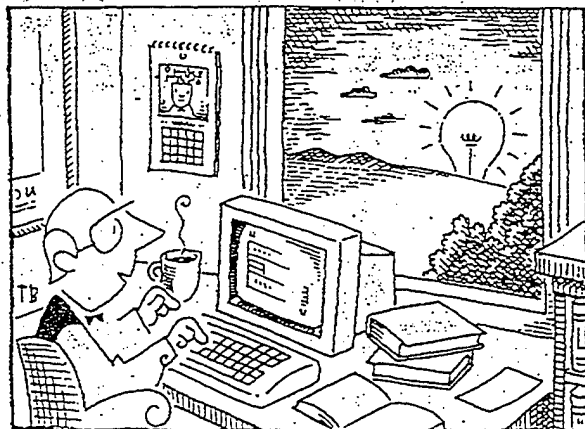
Instead, it was Hyper Forum, a site in cyberspace where experts convened earlier this year to "grapple with the range of plausible futures," said Robert Lempert, a senior scientist at Rand who helped develop Hyper Forum along with others at Rand, the World Resources Institute, the Markle Foundation and Bruce Murray, a professor of planetary science and geology at the California Institute of Technology and Hyper Forum project leader.

At Rand, Dr. Lempert said, "We still have our tank." But the notion of a tankless "think tank" is not an oxymoron — not in cyberspace at any rate. Experts in fields as diverse as politics, economics, the environment, law and business are choosing the Internet as the most efficient forum for policy research.

A case in point is the Cyberspace Law Institute, an Internet-based research group devoted to promoting discussion on the law of cyberspace.

Increasingly, according to Maggie Powell, electronic publishing manager at the World Resources Institute in Washington, the Internet "gives everyone the opportunity to be able to contribute their thoughts without leaving their desks."

Long-distance collaboration has been an organic part of the Internet since it was incubated in academic and Government circles in the 1980's. Businesses have been built around software, like Lotus Notes, which enhances such collaboration.

But now the technology that arose from an academic environment is returning in a new guise: as a tool for research centers to reorganize policy discussions, build agreements among specialists and reach out for new voices and new perspectives.

Hyper Forum provides a clear example of how the Internet is changing the way research centers operate. "The idea is, a forum is a place where people come together to debate," Dr. Lempert said. Group software allowing people to collaborate on complex issues is only one component of Hyper Forum. It contains some of the features of software like Lotus Notes, but adds information, structure and methodology.

In contrast to the face-to-face meetings that research centers have traditionally held, Hyper Forum allows "more stakeholders," or policy makers, to participate and can reach people who otherwise might not contribute, Dr. Lempert said.

Opening the doors when there is free food for thought, however, can draw crowds. David Post, a law professor who co-founded the Cyberspace Law Institute, discovered this virtual reality when his institute played host to a cyberconference for nonlawyers on the law of cyberspace. According to Professor Post, more than 20,000 people participated via E-mail. "There's just not enough time in the universe to deal with that," he said, and not all of the queries could be answered.

"The problem that everyone is trying to deal with with the Web is the information glut," which "degrades the usefulness of the information," Dr. Lempert observed. To resolve this problem, he said, Hyper Forum uses a moderator to guide the discussion.

Roger Hurwitz, research scientist

One problem: on-line conferences attract too many attendees.

at the Massachusetts Institute of Technology, predicted that "the need for collaboration and managing the complexity of collaboration" is going to increase.

Dr. Hurwitz and John Mallery, also an M.I.T. research scientist, have developed software for wide-area collaboration. "Wide-area collaboration is the idea of letting everyone who is relevant within the enterprise work on the material," Dr. Hurwitz explained. His software manages and directs participation.

The Virtual Institute of Information, a search and link network for telecommunications, cybercommunications and mass media research operated by the Institute for Tele-Information at Columbia University has been host to cyberconferences. Topics have included cryptography, electronic publishing and telecommunications law, said Carla Legendre, communications program manager.

Eli Noam, professor of finance and economics at Columbia and director of the Institute for Tele-Information, has experience with radio and video Internet communications. "There's a certain aspect at this point of 'Look

Ma, no hands,'" he said of the emerging technologies. But, he added, what distinguishes the Internet is that "you have the ability to establish very rapidly shifting groups of people to form ad hoc collaborative arrangements."

The Internet is providing "a better, informed and better expressed forum for deliberative discourse," Dr. Murray said, adding: "I think the Web is an amazing revolution. I think it's a millennial change and not just a decennial or centennial one."

While Internet users can chat with each other in real time on line, Dr. Murray believes that electronic correspondence — which, while quick, allows participants a chance to think before they write — is the key to collaboration on complex projects. Dr. Murray compares use of the Net for "deliberative discourse" to Thomas Jefferson's correspondence; through letter writing in that individuals can take the time to analyze a complex situation and carefully construct and communicate their own thoughts, reactions or additions. However, unlike the painfully slow process of written correspondence between two authors in the days before the locomotive, the Internet allows almost instantaneous and simultaneous access to up-to-the-minute updates of huge amounts of information by multiple correspondents in a medium that unlike the penned word, "is particularly well suited for visualizing things."

In addition, he said, while huge amounts of information have previously been organized "in a serial sense," alphabetically, or by number, information on the Net "is defined only in connection with other information" which is "much more the way the human brain works — pattern recognition."

But while the Net may be changing the mode of collaboration at research centers and elsewhere, even Internet aficionados agree that actual meetings are not obsolete.

Charles M. Firestone, director of the Aspen Institute's communications and society program, said the Internet "affects almost every level of what we do."

But, while he concedes that the World Wide Web allows for "more people to participate" in discussions, and "eliminates physical and social barriers" to collaboration, "what you really want to do is have the people whom you want to resolve the problem at the table," he said. "People still want to meet face to face."