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Surveying Relevant Emerging Technologies for the Army of the Future

Lessons from Forecast II

R. E. Darilek, E. M. Cesar, J. A. Dewar,
G. P. Gould, E. D. Harris, J. R. Hiland,
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40 Years 1948-1988

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This study evaluated the U.S. Air Force's survey of emerging technologies of the future, Project Forecast II, for its relevance to the Army's potential requirements for the future, as indicated by the Army 21 Interim Operational Concept. The study concluded that there is a high correlation between the Army's needs and the technologies identified in Forecast II, although the Army could benefit from a poll of its contractors to uncover more Army-relevant technologies. In addition, by using systems as the bridge between projected technologies and specified military capability requirements, as the Air Force did in Forecast II, the Army could take advantage of a valuable means of establishing and gauging the relevance of emerging technologies to future requirements. Keywords → Front

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PREFACE

This study was conducted at RAND as part of an Arroyo Center project on "Future Warfighting Ideas and Technologies." Task two of that project called for RAND to help identify emerging technologies of potential relevance to the Army in the 21st century. In particular, the task required that RAND examine a prior U.S. Air Force effort to identify such technologies for itself—an intensive six-month study in 1985–1986 called Project Forecast II. The results reported here represent an attempt to identify future technologies and systems unearthed by Project Forecast II that could be of potential relevance to the U.S. Army. The authors also attempt to draw some general lessons for the Army based on review and analysis of the Air Force effort.

The research, sponsored by the Deputy Chief of Staff for Technology, Planning, and Management of the U.S. Army Materiel Command (AMC), was carried out in the Applied Technology Program of the Arroyo Center. Throughout the course of this study, RAND researchers worked closely with and benefited from the guidance, assistance, and support of AMC officials—in particular, officials within AMC's Laboratory Command (LABCOM).

The study should be of interest to Army materiel developers throughout AMC. It should also be of interest to other Army and Air Force officials concerned with emerging future technologies because it identifies, based on the Air Force's recent efforts in this field, areas of potential overlap and possible joint collaboration. Moreover, since the study examines the use of notional system concepts as a vehicle for matching technologies with required military capabilities, it should prove interesting to concept developers within the TRADOC community as well as other futures planners throughout the Army.

The Arroyo Center

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The Arroyo Center is housed in RAND's Army Research Division. The RAND Corporation is a private, nonprofit institution that conducts analytic research on a wide range of public policy matters affecting the nation's security and welfare.

Stephen M. Drezner is Vice President for the Army Research Division and Director of the Arroyo Center. Those interested in further information concerning the Arroyo Center should contact his office directly:

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EXECUTIVE SUMMARY

In this study, a group of RAND researchers examined the results and methodologies employed in Project Forecast II, an intensive U.S. Air Force effort aimed at identifying emerging technologies most likely to provide "revolutionary breakthroughs" and "quantum leaps" that would enhance the Air Force's warfighting capabilities in the next century. The object of our study was threefold: (1) to evaluate Forecast II for its relevance to steps the U.S. Army has already undertaken to identify emerging technologies, (2) to extract Army-relevant technologies from the Air Force effort, and (3) to learn some useful lessons from Forecast II that could inform future Army technological policy efforts.

THE ARMY EFFORT

To this end, we first examined two approaches that the Army has developed to identify the technological advances required to meet its 21st century missions. Both approaches were found in or derived from the *Army 21 Interim Operational Concept,* hereafter referred to as "Army 21." The first approach involved the identification and listing by Army 21 planners of "enabling technologies," i.e., comprehensive technologies that hold promise for operational improvements in many elements of the total Army force. The second Army method was to develop lists of specialized military capabilities and specific key technology areas[1] and then cross-reference them to show where such military capabilities (requirements) intersect with such technologies. This approach yields a list of key technology areas that can be related directly to the achievement of particular capabilities.

In our analysis of Army 21's two approaches, we noticed that both were essentially limited to extrapolations from technologies already under study in Army laboratories. Although the second approach involved more of a "requirements-pull" orientation than the first, because this approach was tied so closely to currently emerging technologies, it did not unearth revolutionary new technologies nor the revolutionary new capabilities that such technologies might make possible. Moreover, both approaches seemed to be limited by their failure to identify **future-oriented notional systems** that would enable the

[1]Key technology areas were based on Army estimates of the status of current state-of-the-art technologies in twenty years.

Army to visualize how it might actually use such projected technologies to meet military capability requirements in the 21st century.

FORECAST II

The Air Force effort, Project Forecast II, was avowedly a "technology-push" approach; and it began by attempting to identify or suggest emerging technologies and then considered the military systems in which such technologies would be used and the various warfighting capabilities that would result. Forecast II panel members received 2000 ideas over the course of several months. These were distilled down to a final set of 39 "project technologies" and 31 "project systems" that could be used to support a list of defined Air Force missions or capabilities.

The Air Force then ranked these technologies and systems according to their perceived abilities to contribute to overall future Air Force mission requirements. Moreover, Forecast II provided a framework for relating project technologies to mission requirements (capabilities) *through* the project system concepts. This framework acted as a means for ensuring the relevance of given emerging technologies to military capability requirements.

COMPARING KEY AREAS OF ARMY 21 AND FORECAST II

We examined the technologies identified by Forecast II for their potential relevance to the Army of the future and found that *at least half of Forecast II's project technologies seemed to overlap with or promised to enhance Army 21's list of enabling technologies.* A second comparison involved linking the Forecast II project technologies with the expanded listing of military capabilities (cross-referenced to specific key technology areas) identified from Army 21. In this case we found that *about three-fourths of Forecast II's project technologies promised technology improvements that could enhance particular military capabilities required by Army 21.* Combining both methods, **we concluded that there is a fairly high correlation between the Army's needs, as identified in Army 21, and the technologies identified in Forecast II.**

Next, we attempted to assess the relevance of the final 31 Forecast II project *systems* to Army 21's military capability requirements. We found ten Forecast II systems whose development could potentially enhance Army 21 military capabilities, but because of the lack of more specific definitions for both the systems and the capabilities at this stage, an analysis of their potential relevance must await further clarification of both. We also noted that, although the intersection of Army capabilities with potentially enhancing Forecast II systems is not as great as those identified for the Forecast II technologies (30 percent vs. 50–75 percent), **it would still be in the Army's interest to explore the potential of such systems to enhance Army requirements for the future.**

ARMY-RELEVANT LESSONS AND OBSERVATIONS FROM FORECAST II

The first and possibly most important lesson derived from our analysis of Forecast II's relevance for the Army is that **using systems as the *bridge* between projected technologies and specified military capability requirements provides a valuable means of establishing and gauging the relevance of technologies to requirements.** This use of systems, which was missing in the Army 21 document, would seem to be an important element that the Army should consider adopting for future technology identification efforts. To this end, Forecast II's approach provides a *useful guide* for how to go about combining technologies, systems, and required capabilities.

Our second observation is that it is unlikely that all of the potentially Army-relevant technologies that exist were unearthed by Forecast II because the firms who contributed most heavily to Forecast II's white papers had relatively little involvement with the Army (only 25 percent of these firms had captured 2 percent or more of the Army's FY85 contract awards). Thus we concluded that **the potential exists for more Army-relevant technologies to surface if the Army were to poll its own contractors,** many of whom would likely have new ideas to contribute based on their involvement with the Army.

A third lesson drawn from our analysis is that **Army 21's "concept-based" or "requirements/capabilities" approach would add a missing element if the Army chooses to use the technology-systems-capabilities methodology embodied in the Air Force's Forecast II.** A requirements-based approach will encourage effective system and technology responses to the capability requirements of various Army warfighting doctrines (e.g., AirLand Battle) or the requirements of future evolutionary doctrines. Although the Army's requirements are naturally quite different from the mission requirements identified by the Air Force, the interaction and feedback involved in Forecast II's technology-systems-capabilities approach provide the flexibility to meet such requirements.

Based on RAND's past experiences with the first Project Forecast, and conversations with Forecast II participants concerning their impressions of Forecast II, we developed a series of observations concerning features of the Air Force effort worth emulating and pitfalls worth avoiding, if possible.

One major pitfall involved Air Force expectations of how the initiatives that were to come out of the effort would be funded. There was a sense early in Forecast II that no new funding would be available for the new initiatives; i.e., that one purpose of the effort was to refocus the efforts of the Air Force laboratories. This had a "chilling effect" on the creative process because it meant that ideas identified for development in Forecast II had to compete with established projects for funds. We conclude that if the purpose of a Forecast II-like effort is truly to plumb the "art of the possible," the best way of fostering the creative process is to assume that monies in addition to the current research and development budget will be available for promising ideas.

Other possible shortcomings identified by Forecast II participants were as follows:

- There was less input from academia than in the original Project Forecast study (1964), and some participants felt that Forecast II missed the potential benefits of this participation.
- In retrospect, participants would have preferred that more upper-level management time be spent providing them with day-to-day direction and encouragement.
- The evaluation panels were weighted rather heavily towards Air Force staff representation; this could have been balanced with more participation by "think tanks" and other nonstaff representatives.
- A greater impetus could have been given for industry preparers of technology white papers to include potential systems applications with their technology proposals, because these industry participants were in a good position to conceive of such applications.

ARMY OPTIONS FOR THE FUTURE

Extrapolating from its analyses of the Air Force and Army efforts, our study concludes with a sample of options open to the Army for exploring and identifying the emerging technologies that will be the most viable for it in the future:

1. The Army can pursue Forecast II technologies and systems identified as Army-relevant, presumably in concert with the Air Force.

2. The Army can apply some of the techniques used in Forecast II to its own studies. This could include the polling of Army contractors for future possibilities, the Army's development of notional Army systems based on its own required military capabilities, and the establishment of priorities among systems and technologies after first ranking required capabilities.

3. The Army could choose to conduct its own version of Forecast II, improving upon it as suggested above. In addition, by emphasizing development of an agreed list of required military capabilities and of notional systems to support those capabilities, the Army could add a concept-based dimension to the entire exercise that would move it beyond the possibility of becoming simply a technology-push, materiel-oriented effort.

Finally, as a further illustration of the range of approaches available, we suggest one that developed as a by-product of our analyses of Army 21 and Forecast II. Starting with a list of postulated generic technologies, one can explore how various combinations of the technologies might be useful to the Army of the future in terms of capabilities. Potentially promising technology combinations are then conceptualized into systems, and the expanded capabilities available from using these systems are further investigated. After some promising new systems have been identified using this technique, they can be evaluated in terms of technical feasibility, required breakthroughs, and development times.

There are, of course, many different approaches that the Army may choose to take in identifying and analyzing emerging technologies for the future. Those discussed above relate directly or indirectly to the methodologies of the Air Force Forecast II study and to the Army 21 effort because that was the task of this study. One of the major ideas that should be gleaned from this exercise is that, when thinking about the potential impact of future technologies, it is critical to keep a synergistic perspective in mind, i.e., one that relates technologies to systems, systems to required capabilities, and vice versa.

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Throughout the course of this study, the authors were ably supported in their efforts by Army Materiel Command and LABCOM officials—in particular, John Hansen of LABCOM, who served as project monitor. Thomas Kehoe of the Jet Propulsion Laboratory also contributed invaluably to the effort to understand and interpret the results of Project Forecast II. Both reviewed and commented upon an earlier draft of this report. In addition, we express our appreciation to our RAND colleagues Cullen Crain and Bruno Augenstein, formal reviewers of the report, for their careful attention to our study in its earlier stages and their many helpful suggestions for its improvement.

CONTENTS

Appendix

FIGURES

TABLES

ACRONYMS

ADM	Atomic demolition munition
AI	Artificial intelligence
BIT	Built-in test
BITE	Built-in test equipment
BTF	Battle task force
CBRS	Concept-based requirements system
CCF	Close combat force
COMINT	Communications intelligence
C3	Command, control, communications
C^3I	Command, control, communications, intelligence
ECM	Electronics countermeasures
ELINT	Electronic intelligence
EM	Electromagnetic
EMP	Electromagnetic pulse
FLIR	Forward looking infrared
HALE	High-altitude, long-endurance unmanned aircraft
HF	High frequency
ID	Identify
IEW	Intelligence and electronic warfare
IFF	Identification, friend or foe
IR	Infrared
IR&D	Industrial research and development
LBF	Land battle force
LCD	Liquid crystal display
LED	Light-emitting diode
LIDAR	Laser intensity detection and ranging
LRU	Line replaceable unit
MHE	Munitions handling equipment
MP	Military police
MTI	Moving-target indicator
NBC	Nuclear, biological, chemical
PSS	Personnel service support
RF	Radio frequency
RSTA	Reconnaissance, surveillance, and target acquisition
SIGINT	Signals intelligence
SOF	Special operations forces
STOL	Short takeoff and landing
STOVL	Short takeoff and vertical landing
TRADOC	Training and Doctrine Command (U.S. Army)

TV	Television
VHSI	Very-high-speed integration [circuitry]
VLSI	Very-large-scale integration
VSTOL	Vertical/short takeoff and landing

I. INTRODUCTION

In order to execute its missions in the presence of increasingly sophisticated and diverse threats, as well as to take advantage of future opportunities, the United States Army is exploring both the technological requirements to support operations in the 21st century and new warfighting concepts to define how those operations should be conducted. Both the technological and the conceptual approaches, it is hoped, will result in more effective uses of Army manpower and materiel, not only in the 21st century but also in the intervening years. This study focuses on the technological approach. Its purpose is to address the following major tasks:

- To understand what specific steps the Army has already taken to develop a process for identifying the future technology requirements of its 21st century operations.
- To determine the usefulness to this Army effort of the U.S. Air Force's projection of future technologies in Project Forecast II.
- To outline options by which the Army might significantly improve the quality of its ongoing efforts to identify future battlefield technologies.

METHODOLOGY AND RESULTS

We examined two approaches defined by the U.S. Army for identifying emerging technologies relevant to its projected 21st century military capabilities. These approaches were found in or derived from the *Army 21 Interim Operational Concept,* hereafter referred to as "Army 21."

A panel of RAND researchers with both technological expertise and Army experience took the results of the Army 21 study—the technology areas and military requirements identified as crucial to the Army—and cross-referenced these findings with the results of Project Forecast II. We were looking for Forecast II technologies and systems that seemed to be relevant to the Army. Our estimations of relevance consisted of assessments concerning Forecast II project technology and system areas that appeared to *overlap with or enhance* the future Army technologies and military capabilities defined in Army 21. Because of the brevity of available descriptive material concerning Project Forecast II, and the understandable generality and vagueness of technology and system definitions at this stage of development, it is difficult to speculate on the final configuration such technologies and systems may ultimately attain, and hence, their direct applicability or relevance to the Army. Under such limitations, therefore, we conducted our comparisons and reached the following conclusions.

There is a fairly high correlation between the Army needs identified in Army 21 and the emerging technologies identified in Forecast II. This indicates to us that it would be in the Army's interest to explore the potential of such Forecast II technologies to enhance Army requirements for the future.

We also discovered that it is unlikely that all of the potentially Army-relevant technologies that exist were unearthed by Forecast II. The firms who contributed most heavily to Forecast II's white papers had relatively little involvement with the Army, leading us to suspect that there is substantial potential for more Army-relevant technologies to surface if the Army were to poll its own contractors.

We observed that the technology-systems-capabilities approach used by the Forecast II study is very flexible in that it depends for success to a great extent upon constant communication and feedback between all three levels: technology developers, systems engineers, and systems users. Because of this flexibility, such a methodology could be applied to the Army's capabilities- or requirements-based approach (i.e., its concept-based requirements system—CRBS) as embodied in the Army 21 concept. This methodology (suitably adapted to the Army's particular needs) would generate technologies and systems that are appropriate to the Army's own military requirements. We also observed that Army 21's "capabilities approach" would enable the Army to respond effectively to the capability requirements of different Army warfighting doctrines (e.g., AirLand Battle) or the requirements of future evolutionary doctrines.

ORGANIZATION OF THE REPORT

After the Introduction, Sec. II presents our analysis of the steps taken by the Army thus far to identify the required capabilities and corresponding technologies that seem most relevant to the Army of the future. Then the focus shifts to an explanation of the Air Force's Project Forecast II. The terms and conditions of Forecast II are explained and its methodology is reviewed.

Section III attempts to specify the relevance of Forecast II to the Army. This effort is pursued by taking certain of the future-oriented criteria derived from the analysis of Army 21 in Sec. II and applying those criteria to the results of Forecast II. The result is an identification of the technologies and systems designated by Forecast II as important to the Air Force that might also be relevant to the Army.

Based on RAND's past experiences with the first Project Forecast in 1964 and conversations with Forecast II participants, we developed a series of observations on features of the Air Force effort that should be emulated and pitfalls that should, if possible, be avoided. These are presented in detail in Sec. IV.

Section V concludes the study with a general discussion of Army options for identifying and exploring the emerging technologies that will hold the most potential for it in the future. Finally, as a further illustration of the range of approaches available for considering future warfighting technologies and concepts, we suggest one approach that developed as a by-product of the RAND analyses of Army 21 and Forecast II. It is explained in detail in Appendix C.

Appendix A lists the intersections that the Army found when it linked Army 21 capabilities developed at TRADOC to the key technology areas identified by the Army Materiel Command (AMC). Appendix B presents our listing of the desired military capabilities that are either expressed or implied in the Army 21 concept.

II. BACKGROUND

This section discusses the methodologies used by the Army 21 and Forecast II planners, respectively, to identify critical or revolutionary emerging technologies that could augment their warfighting capabilities in the 21st century.

BACKGROUND OF ARMY 21

We examined two Army-developed approaches for identifying the technological advances required to meet the Army's 21st century missions. Each of these approaches was either found in or derived from the *Army 21 Interim Operational Concept*, Second Coordinating Draft, First Edition, June 1985.[1] We continued to rely on this draft, even though subsequent editions were published, because for our purposes it was more detailed than its successors. We have examined later published versions of the Army 21 concept and, except as noted below, have concluded that none of the subsequent changes substantially alters the observations and recommendations offered in our study.

Identifying Future Technology Directions Using Enabling Technologies

The Army's effort to identify future technology directions in Army 21 began with a listing of enabling technologies, described in the Army 21 document as those technologies that are pervasive in nature and contribute to operational improvements for many elements of the total force.[2] The list of such technologies includes:

- Integrated circuits
- Artificial intelligence
- Materials
- Robotics

[1]U.S. Army, *Army 21 Interim Operational Concept*, First Edition, Second Coordinating Draft, U.S. Army Training and Doctrine Command, Fort Monroe, Virginia, and U.S. Army Materiel Command, Alexandria, Virginia, June 1985. Subsequent editions, including the April 1986 version, were also consulted.

[2]Army 21 used the term "enabling" for technologies that were pervasive and therefore "enabled" many systems of the future. Forecast II, however, used the term "enabling" for a technology that was considered critical for the construction of a *specific* system.

- Biotechnology
- Simulation
- Reliability
- Space technology
- Logistics support technology

The last three enabling technologies were added in later drafts of the Army 21 report. This is the only case that we could identify in which later versions of the Army 21 document contained more that was relevant to our purposes than earlier versions. As stated above, we relied primarily on the second coordinating draft of June 1985 for the bulk of our analysis.

One problem with using the "enabling technologies" approach to identify future technological directions for the Army is that its categories are rather broad and open-ended. On the one hand, this is beneficial, because it does not prematurely restrict future technological search efforts through the use of narrowly defined categories. On the other hand, the categories encompass a wealth of possibilities, not all of them Army-relevant. Deciding which developments within a particular enabling technology category are potentially relevant to the Army becomes a problem.

One solution to the problem, which we employ in Sec. II below, is to look for technological developments in these categories that promise to advance the state of the art in that technology area significantly. This criterion avoids a premature narrowing of the technological possibilities, whereas applying an Army-relevance filter too early in the process might result in failure to explore some that are potentially promising but seem highly remote.

Identifying Future Technology Directions Using Military Capabilities

Army 21 employed a second way of identifying future technological directions that was more complicated than simply providing a list of enabling technologies. First, it developed a comprehensive list of military capabilities that required future technology developments. These capabilities grew from an assessment of future concepts of operation provided by Training and Doctrine Command (TRADOC) schools and centers for their particular functional areas. Army 21 clustered these capabilities into five broad categories:

- firepower
- command, control, communications, and intelligence

- mobility and strategic deployability
- survivability
- support

Within these broad military capabilities categories lie a total of 31 detailed "second-order" capabilities, as illustrated in Fig. 1 below.[3]

While developing the above list of military capabilities from the TRADOC community, a parallel Army effort proceeded to identify major directions for future Army technology. The chosen methodology began with the state-of-the-art technologies then currently under study in the Army Materiel Command's development centers as a departure point. These technologies were extrapolated for a 20-year time period into future "key technology areas."[4] The key technology areas were then cross-referenced by the Army against the 31 second-level military capability subdivisions shown in Fig. 1. An overview of this process is

- Firepower
  - Lethality
  - Extended range
  - Smart sensors
  - Fire control
  - Robotics
- Survivability
  - Detection
  - Hit avoidance
  - Vulnerability
  - Repairability
- Support
  - Supply
  - Maintenance
  - Transportation
  - Field services
  - Simulators and training devices
- C^3I
  - Artificial intelligence
  - Automatic processing/integration
  - Long range beyond line of sight
  - Dispersed operations
  - High capacity
  - Security/electronic counter-countermeasures (ECCM)/electromagnetic pulse (EMP)
  - Sensors
  - All-source analysis
- Mobility
  - Light weight
  - Miniaturization
  - Navigation
  - Robotics
  - Common platforms
  - Propulsion
  - Countermine
  - Gap/obstacle crossing
  - Countermobility

Fig. 1—Army 21 military capability categories

[3]In some cases, we found that items of hardware that are components of larger functioning military systems (e.g., robotics) are identified as second-order capabilities. In other cases, technological capabilities, as opposed to strictly operational capabilities, are also found in the second level subdivisions.

[4]In many cases, we found that items of hardware that are components of larger functioning military systems were identified as key technology areas.

shown in Fig. 2. The results of the cross-referencing produced intersections between future key technologies and the operational requirements put forth by the TRADOC community. Appendix A lists the specific key technology areas that intersected with each second-order military capability subdivision in the Army's cross-referencing.

Although the technologies identified by the key technology areas relate to the military capability requirements defined by Army 21, they are not necessarily limited to those capabilities or to the Army 21 concept. There is considerable agreement among the RAND team of evaluators that the technological requirements identified in the Army 21 concept would be entirely consistent with a broad range of warfighting concepts that attempt to satisfy operational needs on the 21st century battlefield.

One problem we noted with the above approach, however, is that it is heavily based on current technologies already being pursued in Army laboratories (from which the technological inputs to Army 21 came), rather than potentially revolutionary technologies for the future. Thus, Army 21's agenda for science and technology research represented by the key technology areas in Army 21 largely reflects *evolutionary* changes to the existing set of R&D activities. These remain grounded firmly in the present. They do not represent revolutionary

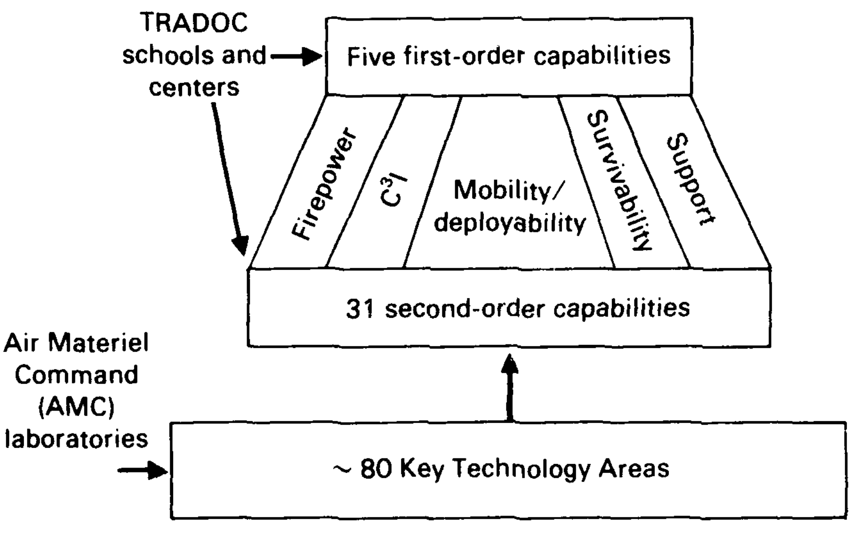


Fig. 2—Army 21 military categories and technologies

breakthroughs or "quantum leaps" forward that could result from future technological progress (e.g., of the kind that the Strategic Defense Initiative may promise or require.)

BACKGROUND OF AIR FORCE PROJECT FORECAST II

Project Forecast II was a six-month project launched by the Air Force expressly to identify those emerging technologies most likely to provide revolutionary breakthroughs and "quantum leaps" that would enhance the Air Force's warfighting abilities. The objective was to produce a list of major warfighting/war-supporting capabilities that would (1) exploit the new technologies and (2) incorporate the technologies into innovative systems concepts. As in predecessor studies—Toward New Horizons (1944) and Project Forecast (1964)—inputs were sought from a wide variety of sources. Participant panels consisted of 175 Air Force and civilian personnel who were carefully picked from major commands and laboratories, as well as participants from the defense industry and academia.

An express aim of the project was to break away from conventional thinking and examine new ideas that might hold promise for the long term. This approach is described in the Executive Summary of Project Forecast II as follows:

> In the summer of 1985, the Secretary and the Chief of Staff of the United States Air Force directed a comprehensive study to identify new technologies with exceptional promise for improving the Air Force's future warfighting capabilities. . . . Ordinarily, the Air Force's Science and Technology program is formulated in response to needs expressed by the Air Force's operational commanders. This "requirements pull" system helps ensure the relevance of the work conducted at the Air Force laboratories. The resulting technological developments tend to be evolutionary—aimed at near-term problems. . . . To make longer-term investment decisions, the Air Force periodically steps back to look for emerging technologies that might revolutionize capabilities—producing quantum leaps instead of evolutionary steps. . . . The aim of Project Forecast II, simply stated, is to provide operational Air Force commanders a menu of the "art of the possible" in future warfare.

Project Forecast II, then, was a "technology-push" effort; that is. it began by emphasizing the identification of emerging technologies. Ultimately, it moved on to a consideration of these technologies vis-à-vis the military systems that would employ them and the warfighting capabilities they would engender.

Figure 3 sketches the flow of Project Forecast II in terms of the distillation of ideas. Approximately 1000 ideas were received over the

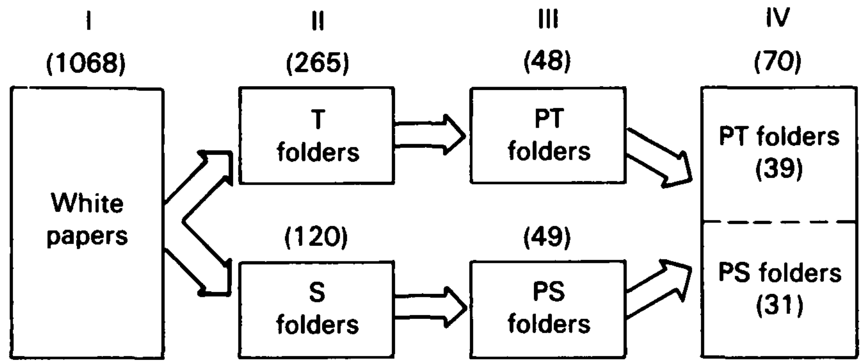


Fig. 3—Project Forecast II flow diagram

course of several months in the form of one or two-page "white papers." These, along with other less formally presented ideas were subjected to 18 technology, mission, and analysis panels for evaluation. Out of those evaluations came technology and system folders representing the distillation of the ideas into 265 generic technologies (with T numbers) and 120 potential systems (with S numbers). A further review, distillation, and combining process brought the technologies and systems into 48 "project technologies" (with PT numbers) and 49 "project systems" (with PS numbers) for more serious consideration.

At this point the technologies and systems were further defined according to sets of instructions. The instructions for developing expanded outlines of the project technology ideas are provided in Fig. 4 below. Instructions for developing the project systems ideas are shown in Fig. 5. These expanded outlines provided a more detailed description of each project technology and project system. The final distillation down to 39 project technologies and 31 project systems was made on the basis of these outlines. Table 1 below lists the final 39 project technologies and 31 project systems concepts that were selected as having exceptional promise for improving the Air Force's future warfighting capabilities.

In preparation for a rank ordering of the importance of the final 39 technologies and 31 systems, Project Forecast II's five mission panels developed a prioritized list of 24 desired military capabilities that were termed "project capabilities" (PCs). The mission panel members consisted of senior representatives of the major Air Force commands and

The following is the outline for a fleshed-out technology folder. Each section (1.0 through 3.2.2) should be included in the folder for each PT. If you feel a specific section does not apply, indicate why in that section in the folder write-up.

1.0 Description of Technology
- 1.1 Overview of technical area in which the specific technology is being proposed.
- 1.2 Detailed discussion of the technology including assumptions, definition of terms, and the development of supporting theories. Presentation of discussion should include graphical and/or tabular data and necessary equations, as required, and should be written at a level which can be understood by a technical manager.
- 1.3 Research which is currently under way (government and industry) including a summary of individuals who are involved in the research.
- 1.4 The relationship of the specific technology to other related technologies.
- 1.5 Completed demonstrations which support conclusion that technology is available.

2.0 Application of the Technology
- 2.1 Range of application of the technology.
- 2.2 Examples of each application including a concept of operations (as appropriate) if the technology is a subsystem of a specific PS (e.g., microwave devices).
- 2.3 Resulting system/capability enhancements (compare to current system/capability).
- 2.4 Vulnerability of the application of the technology to counters by the threat (Red Team/Blue Team).

3.0 Program Plan
- 3.1 Description of the 6.1/6.2/6.3 program
  - 3.1.1 Technical content for each
  - 3.1.2 Major demonstrations for each
  - 3.1.3 Test Facility requirements for each
  - 3.1.4 Major milestones for each
- 3.2 Program cost
  - 3.2.1 Total cost for 6.1/6.2/6.3 for FY (constant FY85$)
  - 3.2.2 Delta over current budget for 6.1/6.2/6.3 by FY (constant FY85$)

Fig. 4—Instructions for project technology folders

The following is the outline for a fleshed-out system folder. Each section (1.0 through 3.2.2) should be included in the folder for each PS. If you feel a specific section does not apply, indicate why in that section in the folder write-up.

1.0 Objectives of the System
- 1.1 What is the system, in general, supposed to accomplish?
- 1.2 Describe how it will contribute significantly to future Air Force capabilities (PC1 - PC24). Identify each capability and how it will contribute.
- 1.3 Postulate expected concepts of operation.
- 1.4 Postulate expected support requirements.

2.0 System Description
- 2.1 A brief description of each system concept being proposed within the generic PS title (e.g., PS-8, Autonomous Antiarmor Weapons, probably has more than one weapon concept to discuss).
- 2.2 Evaluate the comparative advantages, disadvantages, and likelihood of successful development of each concept described.
- 2.3 Identify and describe the key technologies still to be developed which are required to make each alternative system concept work. Evaluate the likelihood of successful development of the technologies and a reasonable time frame for completion.
- 2.4 What other future systems will this system depend on?
- 2.5 How can the utility of each system concept be affected by future threats. Identify likely types of countermeasures that could reduce the system's effectiveness.
- 2.6 Identify currently deployed or programmed systems which each proposed system concept might replace. Identify any other source savings that might be incurred (manpower savings, etc.)

3.0 Program Plan
- 3.1 Description of the 6.3/6.4 program
  - 3.1.1 Technology availability dates
  - 3.1.2 Demonstration
  - 3.1.3 Test Facility requirements
  - 3.1.4 Major milestones
- 3.2 Program cost
  - 3.2.1 Total cost for RDT&E (constant FY85$)
  - 3.2.2 Total cost for production (constant FY85$)

Fig. 5—Instructions for project systems folders

of the Air Staff. The project capabilities they developed represented a "best-guess" projection of the most pressing needs of the Air Force over the next few decades. The outlines submitted for each project capability were required to include the following:

- Mission capability
- Narrative description
- Payoff
- Required systems
- Required technologies
- Operational considerations

The final project capabilities that were chosen are listed in Table 2.

After establishing these project capabilities, the Air Force ranked each of them according to its *relative importance* to overall Air Force mission needs. These "ranking values" varied from .4 to .9 and were determined by averaging the individual subjective assignments made by the group chairman, his deputy, and the five mission panel chairmen.

Project Forecast II then devised a way of determining and illustrating (1) the relative importance of a given project system to individual and overall mission (project) capabilities and (2) the relative importance of a given project technology to a specific project system or to the entire scope of systems.

To illustrate the interactions/intersections of the project technologies, project systems, and project capabilities, the Air Force used a "T-matrix" table. This table (so named because the axes form a T) provided a methodology for several purposes: (1) To identify, as just mentioned, those project systems that contribute the most to the presumed missions (project capabilities) of the future Air Force; (2) to identify the technologies that are most "pervasive" in their effects on potential future Air Force systems; (3) to single out "enabling" technologies that are required for the development of particular systems; and (4) to facilitate analysis of the connection between technologies, the systems to which they might contribute, and the mission or military capabilities that might benefit from those systems/technologies.

An abbreviated outline of the T-matrix is shown in Fig. 6 below to provide a quick grasp of the format. The project numbers and values are hypothetical.

Air Force Project Systems vs. Project Capabilities

As the sample in Fig. 6 shows, the right side of the T-matrix was drawn up with the required project capabilities (PCs) along the horizontal axis and the 31 project systems (PSs) along the vertical. Each

Table 1

FORECAST II AT A GLANCE

Final "Project Technology" (PT) Concepts	
PT-01	High-energy-density propellant
PT-02	Particle-bed nuclear propulsion
PT-03	High-performance turbine engine
PT-04	Combined-cycle engine
PT-05	Space power
PT-06	Advanced deception
PT-07	Rapidly reconfigurable crew station
PT-09	Acoustic charge transport
PT-10	Wafer-level union of devices
PT-11	Photonics
PT-12	Full-spec..um, ultraresolution sensors
PT-13	Fail-soft, fault-tolerant electronics
PT-14	Survivable communications network
PT-15	Adaptive control of ultralarge arrays
PT-16	Smart skins
PT-17	High-temperature materials
PT-18	Broad-spectrum signature control
PT-19	Satellite protection
PT-20	Ultrastructured materials
PT-21	Cooling of hot structures
PT-22	Ultralight airframes
PT-23	STOL/STOVL/VSTOL technology
PT-24	Hypersonic aerothermodynamics
PT-26	Brilliant guidance
PT-28	Directed-energy technology
PT-30	Advanced manufacturing technology
PT-32	Unified life-cycle engineering
PT-33	Smart built-in test (BIT)
PT-34	Robotic telepresence
PT-36	Knowledge-based systems
PT-40	Virtual man-machine interaction
PT-41	Distributed information processing
PT-42	Antiproton technology
PT-43	Ultrahigh software quality and productivity
PT-44	Aircrew combat mission enhancement (ACME)
PT-45	Nonlinear optics
PT-46	Antiterrorism technology
PT-47	Plasma defense technology
PT-48	Low-cost, high-speed military computer technology

Table 1—continued

Final "Project Technology" (PS) Concepts	
PS-01	Intratheater VSTOL transport aircraft
PS-03	Multirole global-range aircraft
PS-04	Supersonic VSTOL tactical aircraft
PS-05	High-altitude, long-endurance unmanned aircraft
PS-06	Hypersonic interceptor aircraft
PS-07	Special operations aircraft
PS-08	Autonomous antiarmor weapons
PS-09	Autonomous high-value target weapons
PS-12	Long-range air-to-air missile
PS-14	Hypervelocity weapons
PS-18	Long-range boost-glide vehicle
PS-21	Tactical low-cost drones
PS-22	Multimission remotely piloted vehicle (RPV)
PS-23	Hypervelocity vehicle
PS-24	Advanced heavy-lift space vehicle
PS-25	Advanced antisatellite system (ASAT)
PS-26	Direct-ascent antisatellite system
PS-27	Manned space station
PS-28	Reusable orbit transfer vehicle
PS-29	Spacecraft defender
PS-30	Distributed sparse array of spacecraft
PS-32	Space-based surveillance system
PS-33	Bistatic radar system
PS-35	Airborne surveillance system
PS-39	Theater air warfare command, control, communications, and intelligence (C^3I)
PS-44	Super cockpit
PS-45	Artificial ionospheric mirror
PS-46	Space object identification system
PS-47	Multirole conventional weapon
PS-48	Battle management processing and display system
PS-49	Imaging system

intersection of the matrix was filled with a number representing a mission panel's rating of the *dependence* of a given project capability upon a given project system, i.e., the project system's importance to that particular capability. Each rating was on a 0 to 1.0 scale, with a zero rating meaning the mission capability did not depend at all upon the project system, and a 1.0 meaning the project system was absolutely necessary to accomplish the mission capability.

To evaluate a system's value or importance to *overall* Air Force mission capabilities, the matrix values for a given project system were multiplied by the "ranking value" of the corresponding project capability. For each system, these products (the values in the PC-PS matrix

Table 2

AIR FORCE FORECAST II: PROJECT CAPABILITIES

PC-01	Survivable enduring strategic aerospace forces
PC-02	Adaptive mission plan/real-time avionics ECM reprogramming
PC-03	Enhanced threat avoidance/enemy airspace penetration
PC-04	Continuous detect/identify/attack hidden buried targets
PC-05	Comprehensive air and missile defense
PC-06	Detect/identify/kill low-observable atmospheric targets
PC-07	Detect/identify/attack orbital targets
PC-08	On-orbit repair/reconstitution of space systems
PC-09	Affordable access to space
PC-10	Global force projection and support
PC-11	Ensured force survivability and sortie generation/theater airpower presence
PC-12	Real-time situational cueing/awareness
PC-13	Unrestrained night/in-weather operations
PC-14	Track/identify/attack multiple airborne targets
PC-15	Mobile surface tactical target detection and destruction
PC-16	Unrestricted air operations in chemical, biological, radiological environment
PC-17	Peacetime near-real-world combat training environment
PC-18	Use of aerospace power in low-intensive conflict
PC-19	Counterterrorism
PC-20	High-technology applications to reduce development/employment/sustainability costs
PC-21	Comprehensive strategic force management
PC-22	Coordinated theater force management
PC-23	Offensive and defensive operations within the EM spectrum
PC-24	Fixed and movable target detection and destruction

times the assigned "ranking factor") were then summed horizontally across all project capabilities to yield a figure representing the weighted importance of that project system to the overall group of project capabilities.

These final sums were normalized by dividing all sums by the value of the largest. This yielded final ranking values between 0 and 1 for each sum (not shown in Fig. 6). Using the ranking system, the project systems were placed from top to bottom in the T-matrix according to their "contributive" value to the total project (mission) capabilities.

Air Force Project Technologies vs. Project Systems

A similar matrix was drawn up on the left side of the T-matrix, with the 31 project systems along one axis and the 39 project technologies along the other. Each intersection of the matrix was then filled with a number to represent the dependence of a project system on a project technology. In this matrix, however, only three values were

Project Technologies (PTs)				Systems (PSs)	Project Capabilities (PCs)			
PT	PT	•••	PT01		PC01	PC02	•••	PC
0.9	0.5	•••	0.1	PS01	0.9	0.6	•••	0.4
0.5	0.5	•••	0.5	PS02	0.4	0.0	•••	0.5
0.5	0.5	•••	0.1	PS03	0.7	0.1	•••	1.0
•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•

Fig. 6—Outline of Forecast II T-matrix

assigned—.1, .5, and .9—corresponding to a low, medium, or high dependency of a given system on a given technology.

The technology vs. systems part of the T-matrix provided information for two types of assessments:

1. A vertical summing of the weighted values for a given technology over all project systems (each value of which was weighted by the overall "rank" of the system, as discussed above) gives an indication of how "pervasive" that technology might be in the Air Force systems of the future, i.e., its overall importance or contributive value to *all* projected systems. In the T-matrix, the project technologies were ranked from highest overall contributive value on the left to lowest on the right.
2. A second assessment of interest to the Air Force consists of enabling technologies. These are technology-system intersections associated with a .9 ranking. The reasoning was that if a given technology were absolutely crucial (indicated by .9) for a given system, that technology must be available for that system to be viable or "enabled."

Current Status of Project Forecast II

The Air Force Systems Command (AFSC), which conducted the Forecast II study, is responsible for implementing the identified initiatives. Several developments in the implementation process since the study was completed are worth mentioning in the context of this report.

The original implementation plan for the Forecast II initiatives was to pursue all 70 initiatives, requiring an increase in research and development funding over current funding projections. Part of the increase was to come from a shifting of funding at the laboratories to Forecast II initiatives. Each laboratory has been directed to commit 10 percent (compounded annually) of non-Forecast program funds to Forecast II initiatives through FY93. This has been done, and no shortfall of expected funding on Forecast II initiatives is expected until FY88 or 89.

The remainder of the funding for Forecast initiatives was to come from an increase in the Air Force research and development budget. The Gramm-Rudman-Hollings measure to cut back the federal deficit, however, caused the research and development budget to be scaled back slightly.

To support the original funding plan, the Air Force had its laboratories prepare implementation plans for each of the 70 initiatives that were constrained only by the progress of technology. The budget required for those plans exceeded even the planned increase in the R&D budget (2.3 percent of Air Force Total Obligational Authority). In light of the Gramm-Rudman cuts, AFSC has now gone back to the laboratories and asked for implementation plans that are fiscally constrained. These plans will be combined with the results of a survey of industry IR&D funding in a Report to the Government that will be used to argue for an increase in the Air Force research and development budget.

Another approach to fund Forecast II initiatives derives from the Packard Commission Report that recommended that the Defense Advanced Research Projects Agency (DARPA) get more heavily involved in prototyping. The Air Force has begun setting up joint programs with DARPA to fund and build prototypes of Forecast II initiatives.

Summary

In general, the T-matrix methodology served two broad purposes. As a rank-ordering device, it provided a framework for establishing which initiatives appeared to have the greatest potential for improving warfighting capabilities, as well as the reason for that potential (enabling technology, pervasive, critical, etc.). As an integrative device, moreover, the T-matrix provided a framework for relating basic technologies to military capabilities *through system concepts*; this became a means for ensuring the relevance of an advanced technology to future Air Force military capabilities.

III. THE RELEVANCE OF PROJECT FORECAST II TO THE U.S. ARMY

We next describe the details and results of our application of the Army 21 criteria identified in Sec. II to the results of Project Forecast II. We were looking for Forecast II technologies and systems that seemed to be relevant to the Army of the future. Our estimations of relevance consist of assessments by a panel of RAND researchers (with both technological expertise and Army experience) of Forecast II project technology and system areas that appear to overlap with or enhance the future Army technologies and military capabilities defined in Army 21, and thus may be of value to future Army efforts.

As noted in Sec. II, Forecast II produced a listing of technologies along with a listing of Air Force-relevant systems which could incorporate advanced technologies. The Air Force labeled the subsets of technologies and systems receiving highest priority as PS (for project system) and PT (for project technology). In our analysis, we attempted to identify potential links between the PS and PT categories from Forecast II and various criteria that we derived from the Army 21 effort.

Our assessment was based on project technology and project system descriptive material contained in two sets of summaries. One set of summaries was produced by the Air Force during Forecast II. The other set was provided by a six-man team of RAND and Army representatives during their review of the Forecast II project folders. Because of the brevity of available descriptive material and the understandable generality and vagueness of technology and system definitions at this stage of development, it is difficult to speculate on the final configuration such technologies and systems may ultimately attain, and hence, their direct applicability or relevance to the Army. It is important to keep in mind that the following comparisons were conducted under these limitations.

Recall from Sec. II that two Army 21 technology lists were extracted from the Army 21 concept. The first is an Enabling Technology list. The second is a listing of Army-identified key technology areas. Below we discuss the methods and results of our attempt to link areas of Army technological interest to Forecast II's PT and PS categories.

FORECAST II TECHNOLOGIES VS. ARMY 21 ENABLING TECHNOLOGIES

A total of 39 Project Technology (PT) proposals survived the Forecast II consolidation and selection process. These are listed in Table 1, Sec. II. We first examined and linked the 39 surviving Forecast II PTs with the Enabling Technologies identified by Army 21. The criteria used to link the two lists, as explained in Sec. II, was whether an effort defined by an Air Force project technology (PT) *promised to advance* the state of the art in a particular enabling technology area, rather than whether the PT proposal would require advances in the state of the art in that area. We used the enabling technologies included in the June 1985 Army 21 draft concept. (As noted in Sec. II, three additional enabling technology areas were added in a later draft: reliability, space technology, and logistics support technology; these were not included in our initial linking process.)

Table 3 summarizes the results of this linking process. The results indicate that about half of the PTs may have a significant impact in Army 21 enabling technology areas. The technological impacts of most of the other PTs either lie outside the defined enabling technology areas or are of an applied-research or a system-oriented nature. Had we included the three additional enabling technology areas noted above—reliability, space technology, and logistics support—the number of potentially significant impacts would have risen, particularly in space technology, which was heavily represented on Forecast II's list of PTs.

The amount of correlation shown here suggests that the Army may find it useful to its own efforts to periodically examine and possibly even support certain Air Force technology efforts.

Note from Table 3 that some Forecast II PT programs are more "robust" than others in relation to Army needs; i.e., they fall into a greater range of Army 21 enabling technology categories (for example, the technology of photonics). Such robust technologies should be of interest to the Army because the potential range of applications they offer means that research money spent on such technologies will be rewarded in a variety of ways—there is "more bang for the buck."

FORECAST II TECHNOLOGIES VS. ARMY 21 KEY TECHNOLOGY AREAS

The second comparison involved linking the technologies identified in Forecast II's PTs to the expanded list of military capabilities and technologies that the TRADOC community identified as critical for

Table 3

SUMMARY OF AIR FORCE PROJECT TECHNOLOGY PROGRAMS RELATED TO ARMY 21 ENABLING TECHNOLOGIES

Army 21 Enabling Technology	Percentage of Total Forecast II PTs that Correlate	Relevant Forecast II PT Programs
Sensors	13	Acoustic charge transport Wafer-level union of devices Photonics Full-spectrum ultraresolution sensors Nonlinear optics
Integrated circuits	10	Acoustic charge transport Wafer-level union of devices Photonics Low-cost, high-speed computer technology
Artificial intelligence	8	Photonics Knowledge-based systems
Materials	13	Smart skins High-temperature materials Broad-spectrum signature control Ultrastructured materials STOL/STOVL/VTOL technology
Robotics	10	Full-spectrum, ultraresolution sensors Fail-soft fault-tolerant electronics Brilliant guidance Robotic telepresence
Simulation	5	Virtual man-machine interaction Aircrew combat mission enhancement
Biotechnology	0	
Not identified	54	

meeting the needs of Army 21. As discussed in Sec. II, the second-level Military Capabilities (Fig. 1, Sec. II) were cross-referenced against Army key technology areas to produce a list of key technology areas that were considered highly relevant for meeting TRADOC's stated military capabilities requirements. These third-level capability/technology area intersections are shown in App. A.

In comparing Forecast II's PTs with the third-level Army 21 key technology areas, we again looked for significant intersections. Where would an effort defined in an Air Force technology program significantly aid in meeting an Army technology need? The criteria that we applied in this case was whether an Air Force project technology proposal could be expected to enhance the technology base that the Army could draw upon to achieve new or improved systems that would significantly increase a specified Army military capability. This process was largely subjective. When in doubt, however, the third-level key technology areas beneath the second-level military capabilities again provided the basis for identifying the intersection of a Forecast II PT and the broadest level Army 21 military capability area. Table 4 shows the results of this comparison. The numbers that occupy the matrix cells are defined in Fig. 1, Sec. II, and illustrate the specific second-level military capabilities where cross-fertilization with a Forecast II PT could occur. For example, a number 2 under Firepower means extended range, and a number 6 under Mobility/Countermobility means propulsion.

Table 5 summarizes the overall number of potential interactions. It shows that about three-fourths of the PTs contained proposed technology improvements that could affect Army 21 military capabilities requirements. The greatest potential impacts are largely in the categories of firepower and C^3I. This degree of correlation again suggests to us that the Army should make an ongoing effort not only to maintain its awareness of potentially enhancing Air Force project technologies, but possibly even to support some of them for the Army's own purposes.

Combining the results of linking both lists—the Army 21 enabling technologies and the Army 21 military capabilities—to Forecast II's PTs simply reinforces the point. Some PTs appear on both lists, but since each list represents a different Army-relevant yardstick, each also identifies particular PTs that the other does not. The net effect of combining them, therefore, is an even broader linkage between Army interests and Forecast II technologies than indicated above. Hence, the potential value or impact of Forecast II's project technologies for the Army, as their future development unfolds, might be considerable enough to warrant exploring the possibility of joint efforts.

FORECAST II SYSTEMS VS. ARMY 21 MILITARY CAPABILITIES

We reviewed the list of 31 Forecast II project systems to determine those that appeared to have significant relevance to the Army. This exercise produced two lists. The first, shown in Table 6 below, identifies 10 of those systems we thought could enhance Army capabilities.

Table 4

LINKING FORECAST II PROJECT TECHNOLOGIES AND ARMY 21 MILITARY CAPABILITIES

	Project Technology	Firepower	C^3I	Mobility/ Countermobility	Survivability	Support
PT-01	High-energy density propellant	2				
PT-02	Particle bed nuclear propulsion					
PT-03	High-performance turbine engine			6		
PT-04	Combined cycle engine	2				
PT-05	Space power					
PT-06	Advanced deception		6		1	
PT-07	Rapidly reconfigurable crew station	4		3		
PT-09	Acoustic charge transport	3	2			
PT-10	Wafer-level union of devices	3	2			
PT-11	Photonics	3, 4	5		3	
PT-12	Full-spectrum ultraresolution sensors	3	7			
PT-13	Fail-soft, fault-tolerant electronics				3	2
PT-14	Survivable communications network		4		3	

Table 4—continued

	Project Technology	Firepower	C^3I	Mobility/ Countermobility	Survivability	Support
PT-15	Adaptive control of ultralarge arrays		6, 7			
PT-16	Smart skins					
PT-17	High-temperature materials			6		
PT-18	Broad-spectrum signature control		6		1	
PT-19	Satellite protection					
PT-20	Ultrastructured materials		7		1	
PT-21	Cooling of hot structures	2		6		
PT-22	Ultralight airframes			1		
PT-23	STOL/STOVL/VTOL technology					
PT-24	Hypersonic aerothermodynamics	2				
PT-26	Brilliant guidance	3		4		
PT-28	Directed-energy technology	1				
PT-30	Advanced manufacturing technology					2
PT-32	Unified life-cycle engineering					
PT-30	Smart built-in test (BIT)					2
PT-34	Robotic telepresence	5		4		

Table 4—continued

Project Technology		Firepower	C^3I	Mobility/ Countermobility	Survivability	Support
PT-36	Knowledge-based systems		1			
PT-40	Virtual man-machine interaction		2			5
PT-41	Distributed information processing		4			
PT-42	Antiproton technology					
PT-43	Ultrahigh software quality and productivity					
PT-44	Aircrew combat mission enhancement (ACME)	4				5
PT-45	Nonlinear optics	3	7			
PT-46	Antiterrorism technology	1				
PT-47	Plasma defense technology					
PT-48	Low-cost, high-speed military computer technology					

Table 5

SUMMARY OF AIR FORCE PROJECT TECHNOLOGY PROGRAMS RELATED TO ARMY 21 MILITARY CAPABILITY CATEGORIES

Army 21 Military Capability	Relevant Forecast II PT Program	
	Number	Percent
Firepower	15	38
C^3I	13	33
Mobility	7	18
Survivability	6	15
Support	5	13
Not identified	10	26

The Army may be interested in developing or procuring such systems for its own use. Whether such efforts would or should be separate-service or joint-service cannot be judged until we know the final configuration requirements of each service.

An additional six Air Force systems (about 20 percent) were assigned to a second list, shown in Table 7. Although these systems appear to clearly support Army interests and should warrant vigorous Army encouragement for their development, we did not view them as systems the Army would necessarily develop or procure on its own—given our understanding of current Army/Air Force roles and missions and the emerging role of the Unified Space Command (USC). We note and list them separately because they seem to support Army interests and because uncertainties remain over future service roles and missions, including those of the Unified Space Command.

We then arrayed the project systems of Tables 6 and 7 against 35 Army 21 (first- and second-level) military capability requirements, and noted the intersections where the project systems seemed likely to contribute significantly to enhanced Army capabilities. While admittedly subjective, these assessments represent a consensus of judgment by a panel of six to seven RAND project personnel, comprising a wide range of experience and expertise, after sometimes lengthy deliberation at each intersection of a matrix. The results of this exercise are shown in Table 8. Five of the systems *may* contribute to enhanced IFF capabilities (see question marks) but the vagueness of both the IFF requirement in general and these project systems in particular precluded a more definitive assessment. The broad categories of firepower, command-control-communications and intelligence, and survivability

Table 6

ARMY-RELEVANT AIR FORCE SYSTEMS

PS-05	High-Altitude, Long-Endurance Unmanned Aircraft (HALE) Small and large aircraft Days to weeks endurance Continuous surveillance/targeting, common linking, ECM
PS-08	Autonomous Antiarmor Weapons Indirect fire-and-forget Aircraft launched Terminally guided Parafoil delivery capability Point and area warheads
PS-21	Tactical Low Cost Drones Built with low-cost materials and non-mil-spec components Expendable Lethal attack, jamming, surveillance, reconnaissance, and community relay
PS-22	Multimission Remotely Piloted Vehicle (RPV) Takes off and lands as RPV—drone mission HALE capability Theater-level SIGINT, ELINT, COMINT Communications relay Reconnaissance photos of large areas
PS-33	Bistatic Radar Survivable—all weather Battlefield surveillance Covert targeting for strike operations
PS-35	Airborne Multispectral Surveillance Multimission surveillance on HALE RPV Up or down surveillance—radio-frequency and optical bands All-weather battlefield surveillance Wide area surveillance of atmospheric targets
PS-44	Super Cockpit Modular crew station Three-dimensional virtual situational information to pilot Allows system control by visual line of sight, voice and other psychomotor responses
PS-45	Artificial Ionospheric Mirror Direct high-power microwave energy into atmosphere Enhance performance of over-the-horizon radars Possibly enhance communications and IFF
PS-47	Multirole Conventional Weapons Consolidate current munitions into four basic types: Airborne and suppression of enemy air defenses (SEAD) Surface hard targets Surface soft targets Surface hard mobile Ultimate objective: one missile and one bomb
PS-48	Battle Management Work Station Interactive work station Configured for varying user and system demands Advanced display, decision aid, and simulation technology

Table 7

AIR FORCE PROJECT SYSTEMS ABLE TO SUPPORT JOINT OPERATIONS

PS-01	Advanced Intratheater VSTOL Transport Aircraft
	Survivability
	Rapid response
	Army 21 conflict area employment
	Long range, worldwide deployment
	SOF (special operations forces) use without airfields
	Advanced propulsion
	Advanced landing gear
	Passive terrain-following/avoidance; avionics
	Larger than a C-130
PS-03	Multirole Global Range Aircraft
	Large weight/volume, supersonic
	Long unrefueled range
	Transport outsized equipment
	High efficiency propulsion
PS-07	Special Operations Aircraft
	VTOL/STOL/STOVL
	Long range
	Low-observable radar, IR, and acoustic signatures
	Covert/clandestine infiltration/exfiltration worldwide
PS-30	Distributed Sparse Array of Spacecraft (SWARM)
	Wide area surveillance of air and ground targets
	Survivable
	Battlefield surveillance
	Tactical communications
	SIGINT, ELINT, COMINT
PS-39	Theater Air Warfare C^3I System
	Software and hardware
	Receive, analyze, and fuse intelligence data
	Provide intelligence with battle management decision aids to all C^3 nodes in usable format, real-time situation awareness

contained the preponderance of intersections. This may reflect a not surprising commonality of enhanced capability requirements between the Air Force and the Army in these three areas. Six project systems were not evaluated because of the uncertainties noted above concerning future service roles and missions.

In the end, we found that there were some Forecast II project systems whose development could potentially enhance Army 21's military capabilities, but the developmental domain of such systems is unclear at this time. The correlation between required Army capabilities and their Forecast II project system counterparts is not as high as those found between the Air Force project technologies and either Army 21's enabling technologies or its military capabilities/key technology areas. Nevertheless, it is our belief that the "enhancing" potential of such

Table 8

AIR FORCE PROJECT SYSTEMS VS. ARMY 21 MILITARY CAPABILITY REQUIREMENTS

	Project System	Firepower	C^3I	Mobility/ Countermobility	Survivability	Support
PS-01	Advanced Intratheater VSTOL Transport Aircraft	Not evaluated				
PS-03	Multirole Global Range Aircraft	Not evaluated				
PS-05	High-Altitude, Low-Endurance Unmanned Aircraft (HALE)	Fire control Targeting	Communications Intelligence Electronic warfare IFF (?)		Detection Warning	
PS-07	Special Operations Aircraft	Not evaluated				
PS-08	*Autonomous Antiarmor* Weapons	Field artillery				
PS-21	Tactical Low Cost Drones	Field artillery Fire control Targeting	Communications Intelligence Electronic warfare IFF (?)	Mapping Obstacle detection Countermobility	Detection Warning	
PS-22	Multimission Remotely Piloted Vehicle (RPV)	Fire control Targeting	Communications Intelligence Electronic warfare IFF (?)		Detection Warning	
PS-26	Direct Ascent ASAT	Not evaluated				

Table 8—continued

	Project System	Firepower	C^3I	Mobility/ Countermobility	Survivability	Support
PS-30	Distributed Sparse Array of Spacecraft (SWARM)	Not evaluated				
PS-33	Bistatic Radar	Fire control Targeting	Intelligence IFF (?)		Detection Warning	
PS-35	Airborne Multispectral Surveillance	Fire control Targeting	Intelligence IFF(?)	Obstacle detection	Detection Warning	
PS-39	Theater Air Warfare C^3I System	Not evaluated				
PS-44	Super Cockpit	Fire control Targeting		Operational and tactical maneuver Navigation	Detection Warning	Training
PS-45	Artificial Ionospheric Mirror		Communications			
PS-47	Multirole Conventional Weapons	Air defense artillery/ antitactical missile Field artillery		Strategic deployability		Supply maintenance Field services Training
PS-48	Battle Management Work Station	Fire control Targeting	Command and control			Training

future Air Force systems for Army capabilities is a subject that the Army should not overlook as it strives to identify and develop future technologies and systems.

IV. LESSONS LEARNED FROM OUR ANALYSIS

In this section we discuss some of the conclusions of our analysis and comparison of both the Army 21 and the Forecast II approaches to identifying promising future technologies, systems, and military capabilities. We also introduce our own variation of such an identification process.

LESSON 1: THE NEED FOR NOTIONAL SYSTEMS

We believe that one important lesson to be learned from Project Forecast II is that projected or "notional" systems provide a useful way of matching or comparing required military capabilities to appropriate technologies. In Sec. II we saw how Forecast II, a predominantly "technology-push" exercise, went about describing emerging technologies and then used systems to relate those technologies to required capabilities. An overview of the Forecast II process is shown on the left side of Fig. 7 below. The formal methodology for this relational process involved the use of the T-matrix.

A different approach was taken by the Army. Army 21 was a requirements-based or "concept-pull" document that attempted to link required capabilities directly to technologies. An overview of this process is shown on the right-hand side of Fig. 7. We recognize that this requirements-based orientation derives from the way the Army organized and processed its operational requirements in Army 21 and that this, in turn, derives from an overriding interest in having operational concepts drive requirements for technologies, rather than having

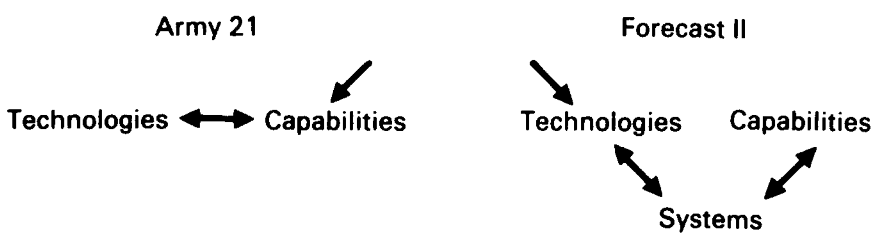


Fig. 7—Army 21 vs. Forecast II methodologies

technologies drive both the requirements and the concepts. We also recognize that the Army has begun its own efforts to relate technologies to systems through the use of the Mission Area Material Plan process, and is beginning to take strides to articulate both next-generation and notional concepts through this process. Nevertheless, we believe that in Army 21 a premature attempt was made to establish a direct connection between Army operational concepts (the "capability categories" in Fig. 1, Sec. II) and potentially supporting technologies (key technology areas). This attempt omitted descriptions of the necessary potential (notional) operational systems that could *use* such technologies to attain the projected military capability. Our experience has shown such omissions to be less than optimal.

In our view, developed on the basis of this and other Arroyo Center projects, the matching of requirements and technologies must include the conceptualization of one or more "notional systems" inserted between the military requirement and the candidate technology, and the entire process should ideally be an interactive rather than a serial, incremental, or iterative process.

Figure 8 is a sketch of a model for matching technologies with operational requirements using notional systems. The model can be employed in a bi-directional way, that is, through a technology-push *or* requirements-pull approach. The operational requirement supplies the warfighting concept, which takes into account the operational environment, threat, operational constraints, and the forces that will be employed. The technologies describe actual or potential capabilities and their technical limitations. The notional system describes how a given technology might be applied, how the system will be used to achieve a range of results in different environments and against various threats. Such a model, using notional systems as the bridge between requirements and technologies, shows how systems can originate from the "capabilities" side as readily as they can from the "technology"

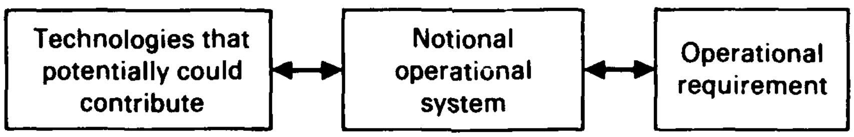


Fig. 8—Model for matching technology to operational concepts

side. These two approaches[1] to systems development are described as follows:

1. The "technology-push" approach to systems development is first to examine a particular technology, or some set of technologies that can fit together to create a particular system, and, second, to conceptualize a notional system that would employ these technologies. Then, by studying the operational concept, see if there is a requirement for the system. For example, robotics technology combined with artificial intelligence and a particular type of propulsion might be a useful combination for an unmanned ground combat vehicle.
2. The "requirements-pull" approach is to study the operational concept first and glean from it all the requirements for operational systems needed to support the concept. Then, one would look for specific technologies with which to build such systems. For example, the required capability for an unmanned ground combat vehicle might lead to combining robotics technology with artificial intelligence and a particular type of propulsion, or a completely different set of technologies might be used to satisfy the requirements.

Using the Two Approaches

When a new kind of technology is being considered, one for which there is little or no operational experience, it seems best to employ the technology-push approach. This allows a creative range of system ideas for the technology to be proposed and examined; systems developed in this way can then be compared with the list of required capabilities to see if there is a useful match.

In instances where the basic technology is already understood and is being advanced in some new form or way, the requirements-pull approach may produce better results. Using such an approach, notional systems for each Army 21 requirement (such as the one demonstrated below) can be created.

The development of a notional system using the requirements-pull approach follows four major steps: (1) identifying an Army 21 capability requirement; (2) conceptualizing a notional system that satisfies the requirement; (3) visualizing and exploring the concept idea; and (4) exploring variations of the idea. An example of this process is given below, using a notional concept that we developed.

[1]A third, hybrid method was experimentally created by RAND analysts as a way of applying notional systems within the technology-push orientation of Forecast II. It is discussed further in Sec. V, and is outlined in App. C as a stimulus for further notional system thinking.

Example: Developing the Battlefield Probe Concept

The Army-required capability we identified is that of providing near-real-time battlefield information to commanders about enemy activities deep beyond the forward line of own troops (FLOT), a capability that would be available to commanders on demand. We opted to explore designs for a missile-launched battlefield probe.

The nature of the imagery to be collected would be determined by the sensor package flown on the probe. For example, imagery data can be collected by flying an infrared or electro-optical camera payload, or SIGINT and ELINT data may be collected by carrying an alternate payload. Also, if a moving-target indicator (MTI) radar payload is available, an all-weather capability to detect vehicle movements is a possibility. Thus, we found that the options for collecting data in the deep operations area depend highly on sensor echnologies. Delivering the payload in a timely manner and transmitting the data also draw on special technologies such as rocket propellants, motor designs, stabilization, and control systems, onboard data processing, power systems, and communications systems. A list of the types of technologies used in the battlefield probe concept is shown in Table 9.

The next step was the integration of these technologies into a system concept, as shown in Fig. 9. This step combined the physical requirements of the situation with the potential solutions supported by the available technologies. In the case of the battlefield probe concept, it was observed that the desired operational capability could be achieved if a sensor payload could be placed high enough so that a favorable viewing geometry could be achieved of the deep battle area. Such a payload must be placed there rapidly and be maintained in the viewing area long enough to collect the necessary surveillance data.

Combining these factors led to the generation of the battlefield probe concept shown in Fig. 10. In this concept, a transporter-erector-launcher (TEL) launches a payload on a suborbital trajectory. The TEL is survivable, permits launch on demand, and is Army controlled. The payload could consist of any of the necessary sensors mentioned above. Operationally, the system is launched whenever the corps commander decides that he needs an update on enemy activities, or in response to a cue from a space-based intelligence sensor.

In the original conceptualization of the battlefield probe, the lightweight sensor payload was launched vertically behind the FLOT and recovered using a parachute. The payload contained sensors for viewing out to the corps area of interest (i.e., 200 km beyond the FLOT), and the data were transmitted directly to a mobile ground-based data processor. The concept was considered survivable because it would represent a target for the enemy only for a brief period of time.

Table 9

TECHNOLOGIES FOR BATTLEFIELD PROBE CONCEPT

Sensors	
	Infrared
	Television and electro-optical
	Radar
Onboard data processing	
	Very-high-speed integrated circuitry (VHSIC)
	Gallium arsenide semiconductor
Position location	
	Mini-Global Positioning System
	Stabilization: platform/sensor
Power	
	High-energy density
Data Link	
	Secure
	Modulation schemes
	Antenna design
Inflatable designs	
	Inflation system
	Plastics
Deceleration devices	
Launch vehicles	
Lauchers	

Generally, the process of creating a notional system does not end with one concept. In the fourth step of this process, as one continues to analyze a concept, alternatives naturally evolve. Figure 11 illustrates this evolution for the battlefield probe concept. The concept began with a "vertical probe," but because of interest in shortening the sensor range requirements, we added the "ballistic probe," which flew directly over the area of interest. Both concepts provided adequate (albeit short) viewing time. To lengthen the viewing time over the target, we included the balloon probe, which was inspired by a recently flown Russian Venus atmospheric probe experiment. We included the inflatable glider probe concept to allow several hours over the target and recovery of the payload. Thus a series of notional system concepts can be spun off a central idea that is conceived to satisfy a given set of capability requirements.

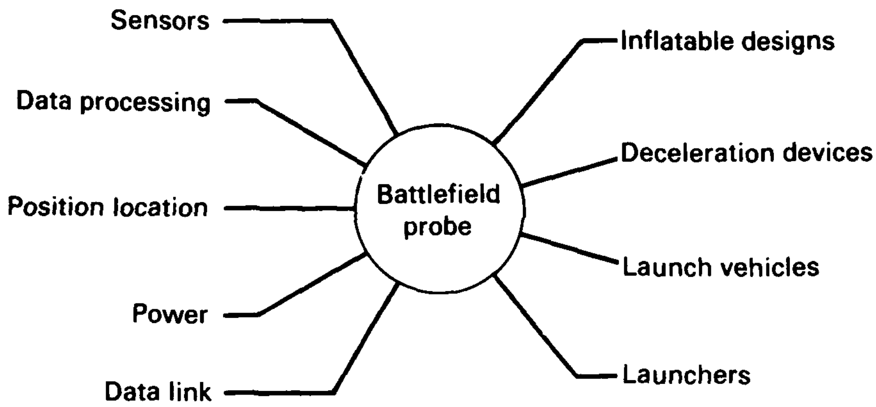


Fig. 9—Systems-oriented approach to technology development

To reiterate, using the above notional system process is an excellent way to foster interactive dialogue between technology creators and users; we recommend its use for all identified Army capability requirements.

Conclusion

The first lesson drawn from our study is that Forecast II's T-matrix methodology, which uses systems as a bridge between technologies and requirements, is valuable because systems can theoretically originate from the capabilities side of the T-matrix as readily as they can from the technology side. The T-matrix approach can be useful to the Army (further discussion of this point follows in Lesson 2), and the Army should build upon it in ways that it has already begun to explore. The Army Materiel Command's "Next Generation Notional Systems" is a move in this direction.

LESSON 2: THE NEED FOR A CAPABILITIES-ORIENTED APPROACH

The second conclusion to be drawn from an examination of Forecast II results is that an Army-relevant survey of emerging technologies using Forecast II's T-matrix (that is, relating technologies both to systems and to required military capabilities) can and should originate

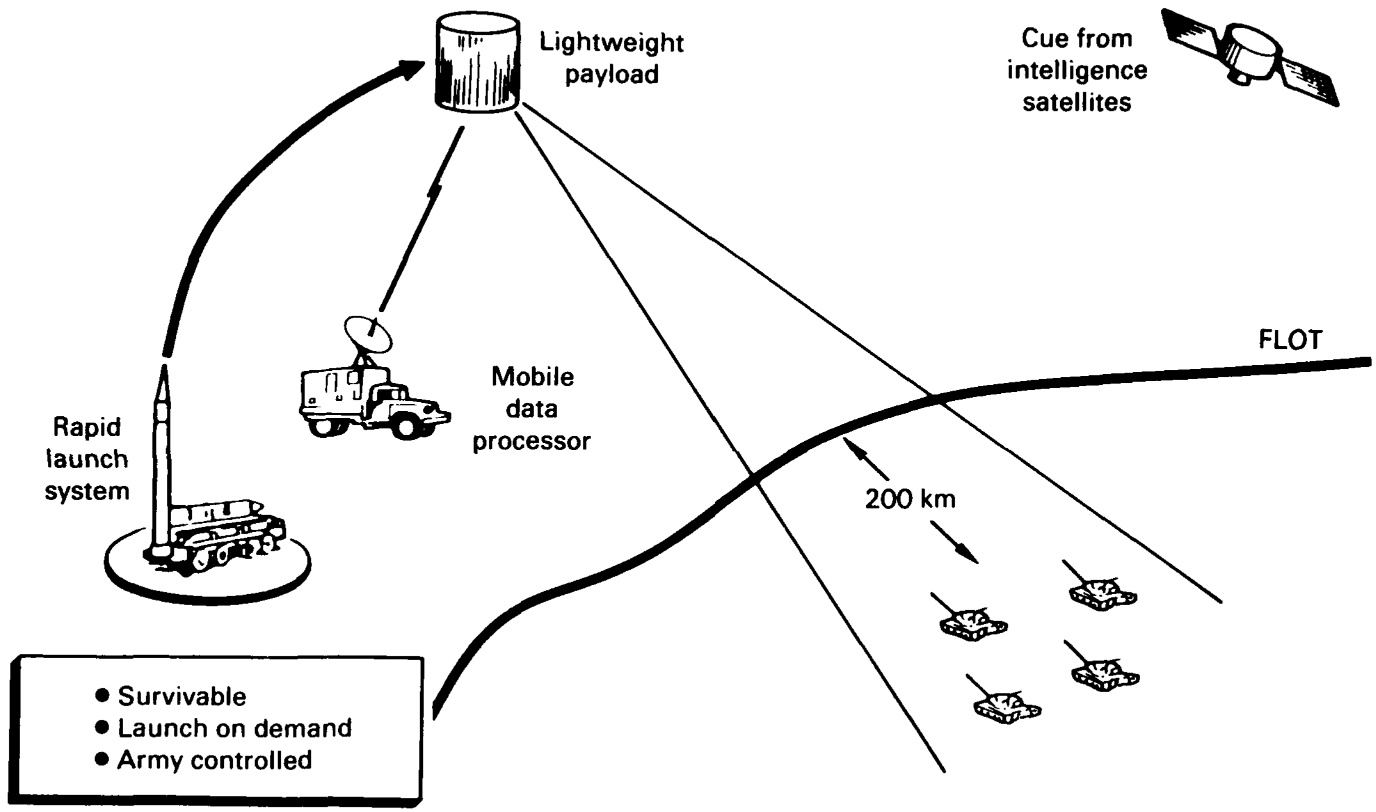


Fig. 10—Battlefield probe concept

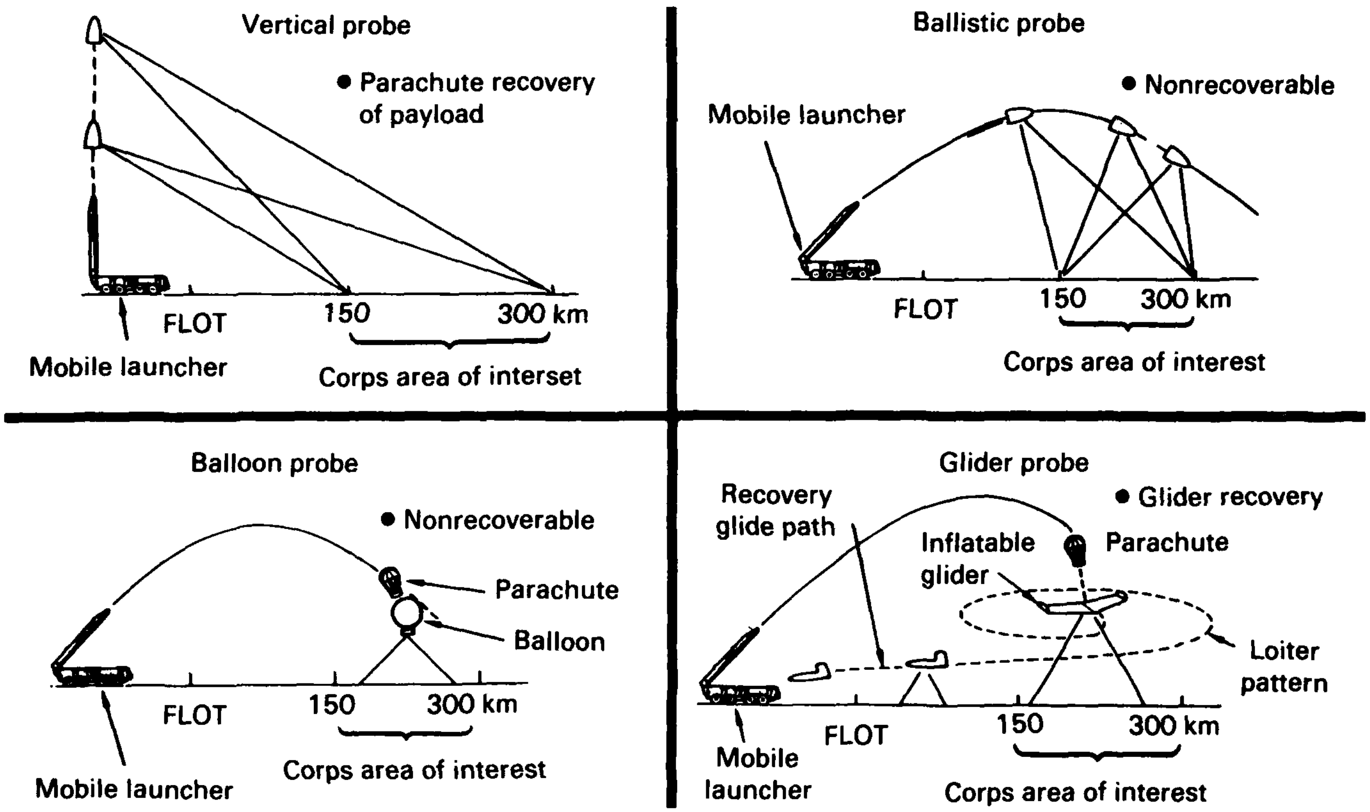


Fig. 11—Battlefield rocket probe options

from the capabilities side of the matrix, i.e., as part of a "requirements-pull" approach. If the Army were to undertake its own Forecast II study, for example, the results could be displayed in a T-matrix format similar to that used by the Air Force.

However, the central and obvious limitation to the Army's use of the actual Air Force T-matrix is that the Army and Air Force require different military capabilities to perform their respective missions. To confirm this point, compare the military capabilities derived from Army 21 (Fig. 1, Sec. 1) with Forecast II's Air Force capabilities identified in Table 2, Sec. II. They are fundamentally different, with any overlaps occurring primarily in the area of C^3I.

Furthermore, drawing on Army AirLand Battle doctrine, we would expect that additional Army military capabilities might be identified and that they will differ from those derived solely from Army 21. We might even derive additional or different required capabilities from Army 21 itself. There may be more capability requirements than Army 21 has identified, or the number could be less if certain ones are combined. This situation signifies a need to take into account the additional Army-unique military capabilities that can be derived from both existing and proposed Army doctrine.

To explore whether a more comprehensive list of military capabilities required to support Army 21 was possible, we read the interim operational concept closely and gleaned its expressed and implied requirements for military capabilities independently from the exercise discussed in Sec. II. The requirements we developed are listed by category in App. B. We think this list represents a more rigorous "capabilities-oriented" formulation of future requirements than the Army 21 technology-capability hybrid discussed in Sec. II. As a consequence of additional possible Army-relevant capabilities, the right-hand portion of the Forecast II (Fig. 11) T-matrix would be expanded somewhat, as shown in Fig. 12 below.

For the Army to obtain such military capabilities, moreover, will often require Army-unique military systems that differ from the systems identified by the Air Force in Forecast II. If nothing else, differences between existing and proposed Army doctrines can be expected to introduce the need for new and different systems. For example, Army 21 envisions a much greater emphasis on mobility in delivering firepower than does the AirLand Battle doctrine; therefore, new and different systems may be required to deliver the firepower.

The impact of Army system considerations on the Air Force's Forecast II T-matrix is shown in Fig. 12; this figure includes, among other illustrations, the arraying of Army 21 and other Army systems along the vertical portion of the T-matrix. As discussed in Sec. III, our

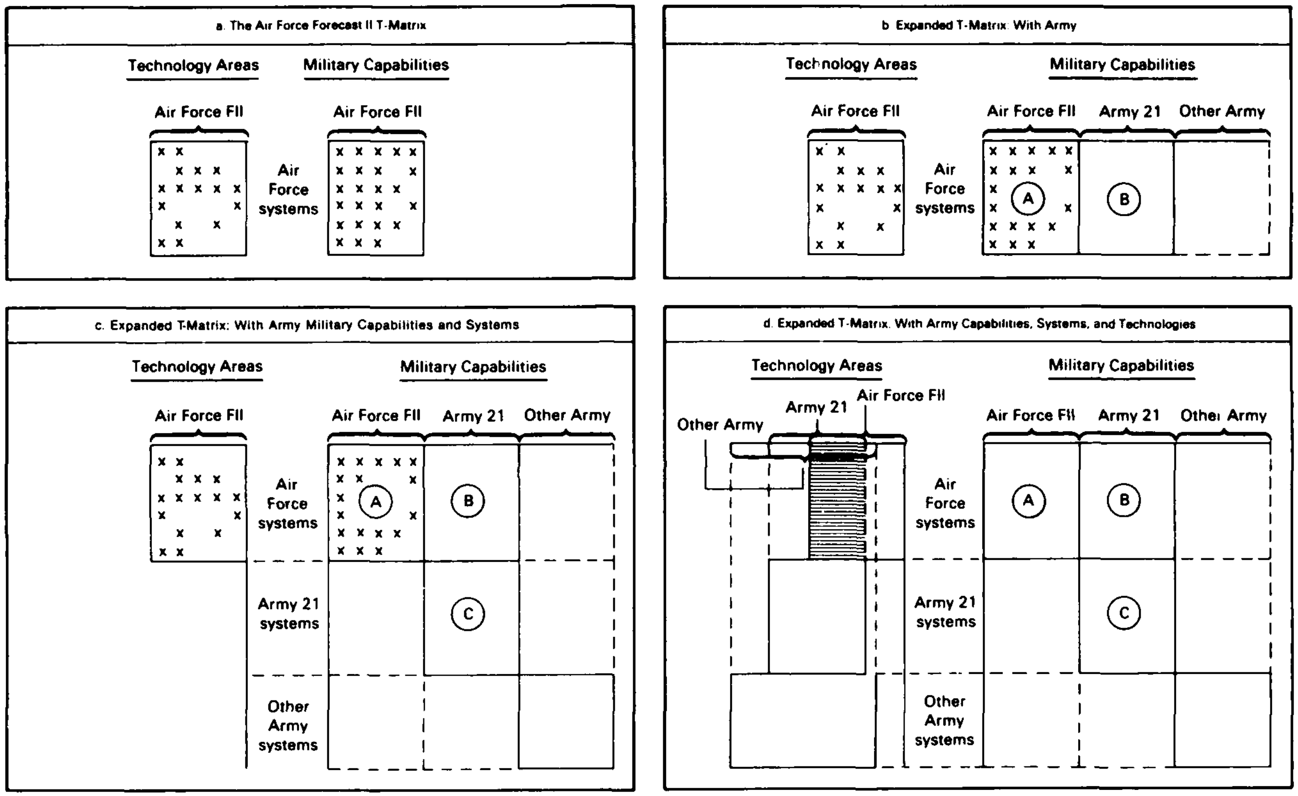


Fig. 12—Military capability-system-technology T-matrix

investigation of the utility of the Air Force's Forecast II found that 10 of the final 49 Air Force systems could possibly be used by the Army to perform some of their Army 21 derived military capabilities. As a consequence, in Fig. 12b the "B" portion of the expanded T-matrix, which corresponds to Table 3 in Sec. III, is more sparsely filled than the "A" portion that comes directly from the Air Force's Forecast II study. Although we have not attempted to fill out any other portions of the right-hand side of the expanded T-matrix, one would expect that the Army 21 systems could be rank-ordered using a procedure similar to that used by Forecast II in ordering preferred Air Force systems.

As discussed in Lesson 1, we believe that notional systems are the key to relating technologies and capabilities. Given a notional system, further expansion of the T-matrix could help identify the technologies needed to support an Army-unique version of that system. In Sec. III we observed (in the absence of clearly defined Army systems) that roughly half of the technologies identified by Forecast II could be relevant to the Army.[2] This is illustrated schematically by the shaded area on the left-hand side of the T-matrix shown in Fig. 12d. We would expect, however, that a specific list of Army systems would result in a greater degree of differentiation between the technologies needed for the Army systems and those required for Air Force systems.

Since system definitions are needed to differentiate among technologies, it would probably be a mistake to assume that an Army technology plan should emphasize those technologies that are outside the overlapping area in Fig. 12d, or that the Army should depend upon the Air Force to develop the technologies within the overlapping area. In the area of robotics, for example, there are a large number of possible Air Force and Army applications, many of which require significantly different technological advances. Until we identify the specific areas of robotics that Army systems require, we cannot rely completely on an Air Force robotics research program to generate the technology needed to fulfill the Army's needs.

To fully address the Army's technology needs, therefore, the Air Force's T-matrix could be expanded significantly to include both a "capabilities" and a "systems" approach keyed to Army military requirements. Such an expanded T-matrix would help to identify and differentiate between the specific technologies needed by each notional system.

[2]From 50 to 75 percent depending on the basis of the comparison.

LESSON 3: THE NEED FOR ONGOING DIALOGUE

A third lesson gleaned from our study is that to be truly effective in identifying relevant new technologies, systems, and capabilities, a complete and ongoing interaction must take place between technology developers and users. To illustrate this point, let us employ some imaginary dialogue between two principals, the Technologist and the Operator.

> TECHNOLOGIST: "I have an idea for a new widget that can do this and that. Can you think of a use for it?"
>
> OPERATOR: "That sounds interesting. I have a requirement for an operational capability that would provide the following."
>
> TECHNOLOGIST: "This widget won't quite do what you want, but in some ways it will give you another capability that you haven't asked for that might also be useful. Perhaps you could modify your operational plan to accommodate it."
>
> OPERATOR: "Yes, I believe I can. How about enhancing this aspect more and playing down that aspect a bit because of (weight, complexity, cost, environmental) considerations?"

Conversely, the dialogue could begin with the operator stating his requirement.

> OPERATOR: "I have a requirement to insert forces deep and protect them and be able to extract them at will."
>
> TECHNOLOGIST: "How about an armored bus?"
>
> OPERATOR: "I need something that is highly mobile and doesn't produce much, if any, physical or electronic signature."
>
> TECHNOLOGIST: "The laboratories have been working on lightweight composite materials and a new type of fuel for high-speed propulsion."
>
> OPERATOR: "I need to visualize a particular system so I can understand how the various technologies you offer can be combined operationally."

Such a give-and-take approach is crucial to the process. While either approach can produce results, it is essential to understand the importance of the notional system as an *intermediary step* between the operational concept and the potential applied technology. This step appears to be lacking in the current Army 21 concept development process.

With respect to the second dialogue above we note that the process of first stating a requirement and then attempting to match that requirement with suitable technologies can be dangerous: Many interesting or even revolutionary potential capabilities may be missed simply because there is no formal requirement for them. Requirements, once formalized and approved, tend to take on a life of their own and become difficult to change, even in the face of revolutionary breakthroughs in technology.

It is possible, of course, to conceptualize a great many notional systems, since there can be a variety of system approaches to any given requirement. Such systems can be proposed by potential users (or their representatives in TRADOC) as well as by potential developers in the Army Materiel Command or industry. However, to retain an emphasis on feasibility, an extended give-and-take between operators and technicians is necessary—not only to come up with additional systems, but to spot the ones among them that seem most feasible. In other words, more interactive work between users and developers, conceptualizers and technologists, TRADOC and AMC, can help define future Army systems; this dialogue is the necessary complement to a systems-oriented approach.

LESSON 4: UNEARTHING MORE ARMY-RELEVANT TECHNOLOGIES

In examining the utility of Forecast II for the Army, we asked the question: To what extent did Forecast II unearth all potentially Army-relevant technologies? To answer this question, we examined the list of contractors who submitted the original white papers with which Forecast II began, and attempted to assess their contractual involvement with the Air Force and the Army. Presumably, one would obtain better ideas from companies that understand and deal with the Army on a regular basis. If such firms were not involved in Forecast II, this would signal the potential for Army-relevant technology inputs from those firms.

At the outset of the Air Force Forecast II study, the Air Force solicited industry participation by requesting technology and system ideas in the form of white papers. A total of 1068 white papers were received and integrated with inputs from other sources such as the Air Force laboratories. Table 10 illustrates the participation in Forecast II of the top 20 Air Force FY85 contractors. These contractors accounted for over 50 percent of the white papers, which is somewhat less than their total percentage of FY85 Air Force contracts (67.5 percent).[3]

Although our data base was not as complete as we would have liked (e.g., we were unable to obtain information on the sizes of individual contracts or the company division to which a given contract was awarded), we made three aggregate comparisons to partially answer this question.

Table 11 shows the first comparison—the participation levels in Forecast II of the top 20 Army FY85 contractors. At the corporate

Table 10

PARTICIPATION IN FORECAST II OF TOP 20 AIR FORCE FY85 CONTRACTORS

Air Force Top Contractors (FY85)	Percent of Total Air Force FY85 Contract Awards	Air Force Forecast II White Paper Submissions	
		Number	% of Total
1. Rockwell International	11.4	109	10
2. Boeing	8.4	19	1.8
3. Lockheed	5.9	66	6.2
4. General Electric	5.8	8	0.8
5. General Dynamics	5.7	3	0.3
6. McDonnell Douglas	5.7	62	5.8
7. United Technologies	3.9	186	17
8. Martin Marietta	2.6	61	5.8
9. Westinghouse Electric	2.2	26	2.4
10. ITT	2.2	2	0.2
11. Northrop	2.1	14	1.3
12. Howard Hughes Medical Instruments	2.0	9	0.8
13. CFM International	1.7	0	0
14. Eaton	1.7	0	0
15. TRW	1.4	0	0
16. Textron	1.1	7	0.7
17. General Motors	1.1	7	0.7
18. Pan American World Airways	0.9	0	0
19. Honeywell	0.9	0	0
20. IBM	0.8	0	0
Total	67.5		53.8

SOURCE: "The Top 200 Defense Contractors: Best of Times, Worst of Times," *Military Logistics Forum*, Vol. 3, No. 1, July/August 1986.

[3]Based on "The Top 200 Defense Contractors: Best of Times, Worst of Times," *Military Logistics Forum*, Vol. 3, No. 1, July/August 1986.

level, we found a high degree of participation for these firms, i.e., the top 20 Army contractors contributed about 40 percent of the Air Force white papers. These firms represent about 43 percent of the Army's FY85 contract awards.

Second, we examined the top 20 industrial white paper contributors to Forecast II, to ascertain their contractual involvement with the Air Force and the Army. In tabulating their market shares of Air Force and Army FY85 contracts (see Table 12), we found that about 50 percent of the top white paper contributors did a substantial amount of business for the Air Force—each received more than 2 percent of the Air Force's FY85 contract awards, or more than one billion dollars each. However, only 25 percent of these firms captured 2 percent or

Table 11

PARTICIPATION IN FORECAST II OF TOP 20 ARMY FY85 CONTRACTORS

Army Top Contractors (FY85)	Percent of Total Army FY85 Contract Awards	Air Force Forecast II White Paper Submissions	
		Number	% of Total
1. Raytheon	4.2	0	0
2. General Dynamics	3.9	3	0.3
3. McDonnell Douglas	3.4	62	5.8
4. Martin Marietta	3.4	61	5.8
5. LTV	3.2	41	3.8
6. Howard Hughes Medical Instruments	3.0	9	0.8
7. Textron	2.8	7	0.7
8. General Motors	2.5	7	0.7
9. Honeywell	2.1	0	0
10. Boeing	2.0	19	1.8
11. United Technologies	1.9	186	17
12. General Electric	1.8	8	0.8
13. Ford Motor Co.	1.5	0	0
14. Food Machinery and Chemical (FMC)	1.3	0	0
15. Oshkosh Truck	1.1	0	0
16. Canadian Commercial	1.0	0	0
17. ITT	0.9	2	0.2
18. Federal Republic of Germany (FRG)	0.9	0	0
19. Teledyne	0.9	4	0.4
20. Hercules	0.8	17	1.6
Total	42.6		39.7

SOURCE: "The Top 200 Defense Contractors: Best of Times, Worst of Times," *Military Logistics Forum*, Vol. 3, No. 1, July/August 1986.

Table 12

AIR FORCE AND ARMY INVOLVEMENT OF TOP 20 FORECAST II CONTRIBUTORS

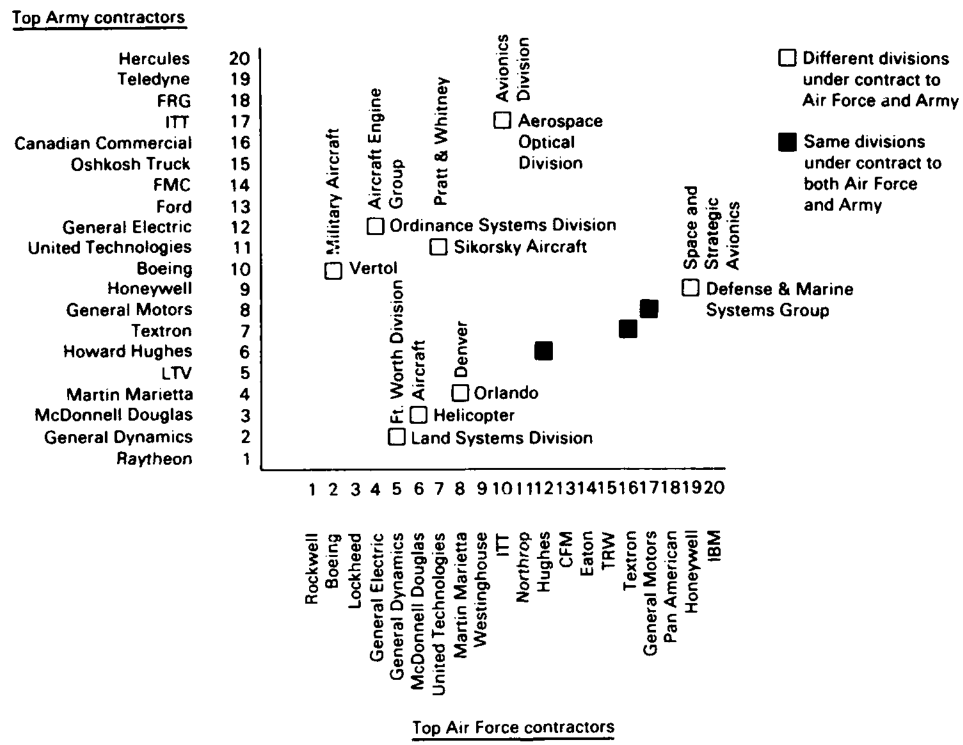
	White Papers Submitted		Percent of Total FY85 Contract Awards	
Top Contractors Ranked by Number of White Paper Submissions	Number	% of Total	Air Force	Army
1. United Technology (including Pratt & Whitney)	186	17	3.9	1.9
2. Rockwell International	109	10	11.4	0.4
3. Lockheed (Space & Missile Co.)	66	6.2	5.9	<0.3
4. McDonnell Douglas	62	5.8	5.7	3.4
5. Martin Marietta	61	5.8	2.6	3.4
6. LTV (Aero Defense Division)	41	3.8	0.6	3.2
7. Sandia	41	3.8	<0.2	<0.3
8. Morton Thiokol	29	2.7	0.2	0.5
9. Westinghouse	26	2.4	2.2	<0.3
10. Gencorp (Aerojet)	21	2.0	0.6	0.5
11. Boeing	19	1.8	8.4	2.0
12. Hercules	17	1.6	0.5	0.8
13. Allied-Signal (Garrett)	15	1.4	0.8	0.8
14. Mitre	15	1.4	0.5	<0.3
15. Northrop	14	1.3	2.1	<0.3
16. Rocket Research	13	1.2	<0.2	<0.3
17. Grumman	12	1.1	<0.2	<0.3
18. Marquardt	10	.9	<0.2	<0.3
19. Howard Hughes Medical Instruments (Hughes Aircraft)	9	.8	2.0	3.0
20. General Electric	8	.8	5.8	1.8
Total	774	71.8	<54.0	<24.1

SOURCE: "The Top 200 Defense Contractors: Best of Times, Worst of Times," *Military Logistics Forum*, Vol. 3, No. 1, July/August 1986.

more of the Army's FY85 contract awards.[4] This comparison suggests there was considerably less involvement of Army contractors in Forecast II.

Our final comparison, in Fig. 13, provides a partial basis for supporting the above observation. In this comparison, we arrayed the top 20 Army contractors along the y-axis and the top 20 Air Force contractors along the x-axis. Square symbols designate firms that had contracts with both the Air Force and Army. For example, Boeing was the

[4]Two percent of the Army FY85 contract awards is equal to about $700 million.



SOURCE: "The Top 200 Defense Contractors: Best of Times, Worst of Times," *Military Logistics Forum*, Vol. 3, No. 1, July/August 1986.

Fig. 13—Top 20 Air Force and Army contractors for FY85: by division

number two contractor for the Air Force in FY85 and number ten for the Army. An open square for Boeing indicates that different divisions of the company supported the Air Force and the Army, e.g., the Military Aircraft Division was the principal supporter of the Air Force, whereas the Vertol Division was the principal supporter of the Army. Of the firms shown in Fig. 13, only 11 did business with both the Air Force and the Army in FY85, and only three with the same principal supporting divisions (as represented by the filled square): Hughes, Textron, and General Motors. The total white paper contribution of these three firms to Forecast II was 23 out of 1068 or about 2 percent.

The general conclusion from this rough comparison is that, because of the low involvement of Army contractors in Forecast II, not all Army-relevant technologies were necessarily unearthed by Forecast II. If the Army wishes to discover all the potentially relevant technologies available to it, it should, at a minimum, poll its own contractors. As we have shown, these contracts for the most part comprise a different set of firms, or separate divisions of larger firms, from those who participated most actively in Forecast II.

LESSON 5: COMMENTS ON FORECAST II METHODOLOGY

We talked with several participants in Project Forecast II to obtain their impressions concerning the good and bad points of the process or methodology of Forecast II. We then combined those impressions with RAND's first-hand experience with the original Project Forecast to inform the Army in the event that it should choose to do something similar. Our consolidated observations can be broken down roughly into two categories: "Features to be Emulated" and "Pitfalls to be Avoided."

Features to be Emulated

The T-matrix approach was generally considered to be difficult to implement, but well worth the effort. Its virtues have been extolled above. There were, in addition, three other features of the Air Force approach that were generally regarded as good ideas.

The first of these features was a lesson learned from the original Project Forecast effort: It is important, in such an intense endeavor, to isolate the participants from day-to-day concerns. In the case of Forecast II, the participants were physically removed to offices at the ANSER Corporation in Crystal City, Virginia for the duration of the exercise. This enabled them to concentrate on the task at hand. Moreover, the physical proximity of the staff's offices fostered the speculative, cooperative, synergistic thinking that such a project demands.

Another aspect of the process that elicited positive comments was the quality of the staff working on the project. Forecast II's directors made the conscious decision to go after the best people they could find and, having generally succeeded, were pleased to note later that the benefits were worth the costs of pulling the best people away from their posts for several weeks. Participants agreed that support at the level of the Office of the Secretary of the Air Force was crucial in enabling the directors to request and receive the services of the best people.

The third feature relates to the size and composition of the team that performed the final "cut" from 97 project technologies and systems down to the 70 that were to receive funding and serious attention. Six of the most broadly focused technologists and systems engineers undertook these deliberations and made the final selection. One of the participants in the process indicated that more than six would have made it more difficult to achieve consensus and that fewer than six would not have been sufficient to offer the relevant breadth of expertise.

Pitfalls to be Avoided

The Air Force's intent in Project Forecast II was apparently to use the effort both to refocus activities at the Air Force laboratories and to add money to the AF research and development budget to pursue initiatives that Forecast II identified. The Gramm-Rudman-Hollings measure to cut back the federal deficit, however, effectively thwarted that strategy by freezing spending levels. This generally dictated that near-term spending for Forecast II initiatives had to come from funds shifted away from current science and technology efforts.

Several participants indicated that this had a chilling effect on the creative process because it meant that any idea identified for Forecast II had to compete with current projects for funds. There was also an indication that this effect percolated throughout the Forecast II process from the white papers to the final science and technology selection process. If there is a lesson to be learned here, it is that the best results from a forecasting process such as this are to be obtained when there are resources specially earmarked and carefully set aside to fund the initiatives that are expected to come out of the process.

Two other features of the Forecast II process were prominently mentioned as having been different from (and not as satisfactory as) earlier features in the original Forecast process.

- There was less academic involvement in Forecast II. Participants and observers indicated that relatively more academic input contributed to the original project and that it benefited by comparison. Several thought this might have been a result of funding problems.
- The original project had, according to participants, more day-to-day management at the top than the Forecast II exercise. This, too, was thought to be a result of the funding situation. Participants agreed that although they had been sufficiently isolated from their day-to-day concerns, not enough upper-level management time was spent "in the trenches" with them to provide direction and encouragement. Another problem here was that the physical offices of management and staff, although both located at the ANSER Corporation, were in separate buildings, contributing to manangement insularity.

Two final items are worth mention. The first is that there was some concern that the evaluation panels were too heavily "blue-suited," i.e., Air Force staffed. This was thought to have slanted the project's ideas toward current capability shortfalls rather than futuristic notions. On the other hand, if the panels are too heavily staffed with members from industry, industry may be reticent to bring proprietary notions before the panels. A delicate balance must be struck between the two types of representation. The original Project Forecast apparently bypassed this problem by picking several of its panel members from think tanks and other non-staff sources.

Finally, some participants indicated that greater incentive should have been given to technology proposers for including potential systems applications with their technologies. Such proposers are in the best position to suggest appropriate applications of those technologies. It was believed that the candidate systems, while acceptable as a whole, could have been improved by a continuing dialogue with industry concerning potential technology applications.

V. CONCLUDING OBSERVATIONS

The objective of this study was to identify emerging technologies of relevance to the U.S. Army—in particular, technologies identified by the U.S. Air Force in Project Forecast II. The process of examining Forecast II, however, led to more than simply identifying Army-relevant technologies and systems. In that process, we also identified certain limits to the relevance of Forecast II to Army concerns (e.g., its polling of primarily Air Force, as opposed to Army, contractors for their suggestions of future technologies and systems), and we have indicated various strong points of Forecast II. Chief among the latter was Forecast II's use of "systems" as the bridge between technologies (researchers and developers) and required capabilities (users).

At this point, it would seem, the Army has various options open to it. One is simply to take what has been identified as Army-relevant among the Forecast II technologies and systems and focus upon those emerging possibilities. Another is to improve upon certain aspects of the Forecast II effort, especially in areas where limitations for the Army have been identified. This could include the polling of Army contractors for future possibilities; development of notional Army systems based on its own required military capabilities; or the establishment of priorities among systems and technologies after rank ordering the Army's required capabilities.

A third option is for the Army to conduct its own version of Forecast II. This would encompass all of the above options, including them in an overall effort that would attempt to unearth, identify, and prioritize all emerging technologies and systems of potential relevance to the Army. Such an all-Army effort could be modeled after Forecast II, especially its linkage of technologies to requirements via systems. This T-matrix approach would provide useful guidelines for organizing a large-scale project of this kind. The Army's project, moreover, could take advantage of the lessons learned from Forecast II to ensure (1) adequate representation of academic and other third-party participants on its various evaluation panels, (2) continuing dialogue with the authors of white-paper proposals to derive as many unsuspected implications of the proposals as possible, and (3) removal of project staff from other day-to-day responsibilities to the maximum extent feasible. In addition, the Army, by focusing on development of an agreed list of required military capabilities—whether derived from Army 21, as here, or from some other source—and of notional systems to support those capabilities, could add a concept-based dimension to the entire exercise that would move it beyond the possibility of becoming simply a technology-push or materiel-oriented effort.

These options are only a few among many different approaches that the Army could take in identifying and analyzing emerging technologies for the future. The options relate directly or indirectly to the methodologies of the Air Force Forecast II study and to the Army 21 effort because that was the task of this study. A completely different approach, which surfaced as a by-product of our Forecast II analysis, is presented in App. C. This approach cross-references some of the results of our Forecast II efforts, as well as the Army's key operational capabilities, but relies on neither Forecast II nor Army 21 categories and methods to produce its own results.

Briefly, with this approach, one starts with a list of postulated advanced generic technologies and then thinks about how various combinations of these technologies might affect the Army of the future. Many of these represent existing capabilities taken to a future extreme, and do not require qualitative revolutions in the technologies themselves. However, potentially dramatic implications for future warfare may exist in the *new capabilities* derived from combinations of the technologies.

For example, advances in satellite technology, data processing, communications, and directed energy could combine to create an extremely lethal battlefield, leading possibly to the demise of expensive manned combat vehicles. Advances in robotics could also contribute to this trend. Some of the combinations result in novel outcomes. For example, improvements in data processing linked to artificial intelligence and advanced communications capabilities could result in "super-realistic" training simulators.

After some promising new capabilities have been identified as a result of combining various technologies, such new "system" capabilities can then be evaluated in terms of technical feasibility, required breakthroughs, and development times. Appendix C further illustrates the process. The examples shown there are meant to convey only a few of the combinations possible. The principal idea is to stress that, when thinking about the potential impact of future technologies, it is critical to keep a synergistic perspective in mind.

Appendix A

INTERSECTIONS OF ARMY 21 MILITARY CAPABILITIES WITH KEY TECHNOLOGY AREAS

This appendix lists the future "key technology areas" identified by AMC that the Army found to be relevant to the 31 second-order capability requirements established by TRADOC. The five first-order capabilities are listed with Roman numerals, followed by their second-order capabilities listed as A, B, C, etc. Beneath these capabilities are numbered third-order headings that list the specific key technologies that intersected with those capabilities. Fourth- and fifth-order headings are included in some cases.

I. FIREPOWER

A. Lethality

1. Explosive warheads: advanced dual/tandem shaped-charge warheads; nonaxisymmetric self-forging fragment systems for top attack; reactive fragments; optical and radio frequency sensors for fuzing.
2. Penetrating warheads: gun propulsion techniques including light gas, liquid propellant, electromagnetic propulsion, hypervelocity rockets, rocket-assisted penetrators.
3. Chemical warheads: added capability for existing projectiles; binary technology for improved storage and safety; adjustable lethality and persistence levels.
4. Directed energy: lasers, high-power microwave and particle beams; research on fundamental physics, engineering, and atmospheric problems; small particle accelerators, high-power radio-frequency (RF) sources, high-efficiency small-sized power generation equipment.

B. Extended Range for Guns

1. Electromagnetic propulsion including rail gun yechnology, erosion and plasma arc technologies, and hybrid combination of electromagnetic and conventional propulsion.
2. Travelling charge concepts.
3. Consolidated charge technology for volume constrained guns with regenerative liquid propellant technology.

4. In-course correction based on tracking information of target's position after launch.
5. Improved recoil systems and precision aiming techniques; improved propellants; atmospheric effects correction techniques.

C. Extended Range for Missiles

1. Integral rocket/ramjet technology; terminal guidance or submissiles; throttlable concepts using gas propellants or solids.
2. High-burning-rate solids.
3. Fiber-optics (closed-loop) guidance.

D. Smart Sensors

1. Target acquisition:
   a. Ground-based sensors for air defense against fixed wing aircraft and missiles will integrate passive RF FLIR, TV, and acoustic sensors into a lightweight mobile package. Sensors to provide noncooperative identification for C^3. Modular gun or missile kill mechanisms as possible add-on.
   b. Ground-based sensors for ground targets will use seismic, acoustic, and FLIR technologies. Complement to existing millimeter-wave radar.
   c. Heliborne sensors for ground targets will use polarimetric processing, millimeter-wave radar, acoustic recognition; passive RF, and laser locators to extract targets from ground clutter.
2. Terminal guidance:
   a. Passive RF and IR sensors for air defense suppression
   b. Polarimetric seekers for adverse weather
   c. Coupling laser semiactive guidance with FLIR and millimeter-wave
   d. Fiber optics

E. Fire Control

1. Computers: improved by VHSI/VLSI and ultra-high-speed integrated circuits; self-healing redundant architectures to improve reliability; materials to improve EMP hardening.

2. Optical correlation or photonic computers: analog devices to simultaneously process an input scene against hundreds of references; development of hybrid digital/analog components with integration to provide optical processing capability.

3. Algorithms and software: faster problem-solving techniques; improved software reliability; artificial intelligence.

F. Robotics

1. Semiautonomous and autonomous systems.

2. Applications to autoloaders; autotracking and cueing; automated mine laying and weapons platforms; sensor control; target acquisition and target engagement.

II. COMMAND, CONTROL, COMMUNICATIONS, AND INTELLIGENCE

A. Command, Control, and Communications

1. Artificial intelligence

a. Logic and algebraic mechanisms that model cognition

b. Controlling network communications from any point

c. Systems that simulate warfare

2. Automatic processing and integration

a, Integration of advanced software, graphic displays of NBC contamination and advanced data transfer including voice, data, facsimile, displays.

b. Automatic control of all RF frequencies and gateways between frequency systems using communication protocols compatible with computer protocols.

c. Display technologies such as cathode ray tube (CRT), plasma, thin film electroluminescent (TFEL), flat CRT, LCD, LED, direct current, high resolution, flat panel non-CRT, touch-activated video screens.

3. Long-range beyond line of sight (overcome distance, maintain link)

a. Satellite terminals

b. High-flying platforms with relay networks, antijam sensors

c. HF burst communications

d. MBC (meteor burst communications)

e. Small, inexpensive radio units

f. Automated radios capable of relay, alternate routing, and internet gate waiting

4. Dispersed Operations

5. High capacity

a. Data filtering based on information content and data fusion based on information abstraction

b. Packet-switching technologies

c. Source data reduction by compressed speech, compressed video, voice authentication, information overlay, extended stored data bases

6. Security, jam resistance, EMP

a. Interactive graphics to secure communications when using encryption devices

b. Solving technical barrier problems

c. On-line embedded encryption on communication equipment

d. Automatic encryption key

e. Full automatic authentication

B. Intelligence

1. Sensors—situation and target development:

a. Improvement in location accuracy of enemy targets

b. Expand frequency availability by moving higher on spectrum with continuous tuning capability

c. Ability to handle complex modulations

d. Increase sensor sensitivity to increase range of coverage

e. Operability in all weather and in man-made battlefield obscuration conditions

f. Maximize sensor automation

g. Processing speed and capacity

h. Produce weather intelligence describing weather's effect on friendly/threat sensors

2. Sensors—NBC detection:
   a. Automated reporting and warning capability providing near-real-time information
   b. Technology for improved reconnaissance, detection, and identification techniques including atmospheric effects; remote sensing for vehicles:
      1. ion mobility spectroscopy
      2. mass spectroscopy
      3. immunochemistry
      4. coated microsensors
   c. Technology for biological agents
      1. pattern recognition
      2. ultraviolet recognition
      3. single particle mass spectroscopy
   d. Technology for remote detection
      1. differential absorption LIDAR
      2. differential scattering LIDAR
      3. laser induced fluorescence
      4. passive IR
      5. topological reflectance spectroscopy
3. Sensors—artificial intelligence: Smart sensors that can recognize tactical scene, select target automatically, and cue sensor to gather intelligence or target acquisition information.
4. Sensors—robotic technology: Application of sensors to robotic instruments that can enter areas too dangerous for soldiers.
5. All source analysis: Correlation and fusion of information from many sources made possible by enhanced computer capability.

III. MOBILITY AND STRATEGIC DEPLOYABILITY

A. *Weight and Size Reduction*

1. Lightweight structural materials, electronics, and communications equipment from development of composite materials.

2. Organic-matrix composites; metal-matrix composites; ceramic and glass-matrix composites; research on self-propagating high-temperature synthesis.

3. Reduce weight of electronics and communications equipment by:

   a. Using VHSIC, thin film electroluminescent (TFEL) multifunction displays

   b. Integrating communications, navigation, and identification equipment

   c. Using hybrid processors

   d. Technology developments with waveguide carbon-dioxide lasers

B. Miniaturization

1. Materials engineering.

2. Technologies to reduce size, weight, and bulk of ammunition propelling charges and casings.

C. Navigation

1. Automated route-planning with inputs like:

   a. Computer-stored local terrain map

   b. Sensor-provided information on obstacles and threats

2. Hierarchical controller software to determine most feasible route, issue vehicle piloting instructions, check sensor inputs, revise route plans as necessary and update map.

3. Autonomous mobility using long-range large-feature sensor coupled with short-range narrow-beam radar or ultrasonic device.

4. Improved Integrated Internal Navigation System; substitution of Global Positioning System (GPS) for the external update function currently provided by Tactical Air Navigation (TACAN); substitution of strapdown inertial navigation unit (INU) with more reliable ring laser gyro technology.

5. Laser-based radar for navigation in areas of low visibility at low altitude over short ranges. Functions include:

   a. Wire/obstacle detection
   b. Terrain following
   c. High-resolution three-axis doppler velocity sensing for low-altitude navigation/hover
   d. Target detection and identification
6. Hybrid common or shared aperture system to provide both course and fine resolution; processor included with sensor to fuse data from other sensors.
7. Fiber-optic cable, single mode with heterodyne capability.
8. Focal plane array and multispectral imaging guidance devices to provide adverse-weather, low-altitude flight capability.
9. Digital map technology to:
   a. Generate digitally based topographic display
   b. Generate automatic, continuous position updating of doppler navigator via terrain correlation
   c. Generate all symbolic data for nap-of-earth pilotage

D. Robotics

1. Major applications for unmanned aerial vehicles (UAV), remotely piloted vehicles (RPV), and programmed performance drones include:
   a. Surrogate satellite drones and radio relays
   b. RPV internetting
   c. Real-time battle situation assessment beyond lines of contact and into second echelon
   d. Autonomous operation of ground systems
2. Machine vision with necessary processing power and algorithms.

E. Common Platforms

1. Commonality of engines, transmissions, dynamic components.
2. Similar airframes and hulls for families of vehicles to present identical signatures and to simplify maintenance and logistics.

F. Propulsion

1. Improved reliability, maintainability, engine size and weight.
2. Higher pressure ratios, improved performance through compressors, ceramic coatings for thermal barriers, ceramic bearings needing no lubrication, cooling improvements, electronic fuel controls.

G. Countermine

1. Mine clearing and mine neutralization
2. Technology directed toward:
   a. Remote minefield detection
   b. Close-in mine detection
   c. Mine neutralization systems for use with armored vehicles
   d. Maximum use of robotics, intelligence information processing, and position/navigation techniques

H. Gap/Obstacle Crossing

1. Assault crossing technology concepts
2. Counterobstacle vehicle
3. Rotorcraft

I. Countermobility

1. Mines
   a. Safe and arm, sensor, antidisturbance
   b. Countermeasure hardening, self-destruct functions
   c. Lightweight compact configuration
2. Demolition
   a. Chemical energy enhanced
   b. Lighter weight, smaller size, easy emplacement
3. Advance barrier concepts

IV. SURVIVABILITY

A. Detection

1. Deception—false signature throughout sensor spectrum through

- a. Visual decoys
- b. Thermal infrared
- c. Aural, olfactory
- d. Communication and noncommunication electronics

2. Camouflage—clutter enhancement techniques and decoys
   - a. Retroreflectors
   - b. Radar-scattering cloths
   - c. Doppler spectrum spreaders
   - d. Polarizers
3. Signature reduction
   - a. Thermal signatures
     1. Thermal suppression of electric generators
     2. Thin coatings to prevent distinguishing tactical equipment from natural thermal background
     3. Multilayer systems of thin metallic IR-reflecting films to reduce target-to-background contrast
     4. Ultralow penalty engine suppressors
     5. Heat transfer techniques
   - b. Radar signatures
     1. Coatings to absorb RF radiation
     2. Fabrication of coatings effective over broad frequency range
4. Smoke and obscurants
   - a. Infrared screening compositions
   - b. Atmospheric effects
   - c. Multispectral screening compositions
   - d. IR-emissive smokes
   - e. Aerosols to protect against high-energy lasers
   - f. High-power microwave weapons
   - g. Advanced dissemination concepts
   - h. Smoke elimination concepts
   - i. Real-time obscurant characterization
   - j. Nontoxic smoke/obscurants

B. Hit Avoidance

1. Electronic countermeasures

   a. Increased frequency range capability

   b. Greater power output at all frequencies

   c. Simultaneous multisignal jamming capability

   d. Gas technologies, integrated pulse, and continuous wave

   e. IR jammers to defeat multispectral missile guidance

2. Flares and chaff

   a. Improved packaging techniques for cartridges for application to smart dispenser

   b. RF expendables for integration into the same smart dispenser

3. Antiradiation missile countermeasures

   a. Low peak power and sophisticated processing

   b. Digital beamforming for phased-array antennas

C. Vulnerability Reduction

1. Protection

   a. Individual

      1. Chemical and biological protection

      2. Integrated protective clothing system

      3. Vulnerability to conventional and nuclear effects

   b. Collective

      1. NBC protection

      2. Standard family of shelters

      3. Hardening

2. Ammunition—low vulnerability to reduce probability of detonation

3. Field fortifications

   a. Combat excavators capable of digging emplacements from 2 to 18 feet wide

   b. Combat excavators with soil-handling capability of 500 cubic yards per hour

4. Armor

5. Nuclear survivability
   a. Nuclear weapons effects technology base
   b. Nuclear weapons effects threat environments
   c. Nuclear weapons effects system applications
6. Directed energy
   a. Screening smoke to defeat target acquisition and pointing
   b. Screening smoke to defeat the damaging beam

D. Repairability
1. Decontamination
   a. Self-decontamination
      1. Liquid jet optimization
      2. Radiative techniques
      3. Microencapsulation technology
      4. Polymer bound catalysts
      5. Robotic decontamination and biotechnology
   b. Sacrificial coatings
      1. Microencapsulation technology
      2. Polymer bound catalysts
      3. Biotechnology
   c. Individual decontamination kits
      1. Microencapsulation technology
      2. Polymer bound catalysts
   d. Universal decontamination—all purpose nonaqueous
      1. Hot air decontamination techniques
      2. Radiative techniques
      3. Solid phase decontaminants
      4. Enzymatic decontaminants
   e. Food and water decontamination
      1. Biotechnology
      2. Reverse osmosis processes
2. Battle damage repairs/spare parts for combat

V. SUPPORT

A. Supply

1. Ammunition resupply

   a. Mechanical/robotic materials handling to handle palletized unitized loads at combat position supply area

   b. Mobile ammunition transporters compatible with combat vehicle in use

   c. Survivable aerial resupply capability for deep-strike maneuvers

2. Rations and food service equipment

   a. Development of Nutrition Sustainment Modules (NSM)

   b. Food technologies such as infusion, compression, extrusion

3. Water supply

   a. Production

   b. Treatment

   c. Storage

   d. Distribution

B. Maintenance

1. Redundancy in critical circuits
2. Self-diagnostic equipment
3. Condition report forwarded to central, crew-monitored console

C. Field Services

1. Tactical energy—generators/mobile electric power sources
2. Graves registration

D. Simulators and Training Devices

E. Transportation

1. Fuels and fuels handling

   a. Receiving

   b. Storage

   c. Land transfer

   d. Filtration
   e. Testing
   f. Dispensing
   g. Integrated systems
2. Airdrop
   a. Low-altitude high speed
   b. Soft landing for heavier cargo
   c. Capability to drop SOF personnel with supplies from aircraft as high as 40,000 feet and at offset distances between 50–100 kilometers

Appendix B

ARMY 21 REQUIRED MILITARY CAPABILITIES

The following represents our compilation of a nonprioritized listing of the desired military capabilities within the TRADOC functional areas, as expressed or implied in the Army 21 concept.

AUTOMATIC DATA PROCESSING

ADP-FS-15 Ability to perform accounting and requisitioning functions continuously and with automation to update friendly unit status and support requirements.

ADP-IEW-4 Ability to perform document translation utilizing automation.

ADP-IEW-5 Ability to analyze threat data and perform threat projections employing automation.

ADP-IEW-9 Ability to integrate and fuse data employing automation.

ADP-MP-4 Ability to process and integrate Military Police technical data (provided by MP reconnaissance teams, sensors, and unattended aerial vehicles) employing automation.

ADP-PSS-2 Ability to interface the soldier data tag with portable automated data base and other automated systems.

ADP-PSS-3 Ability to provide mobile computer Personnel Service Support (PSS) data bases for the Land Battle Force (LBF), Battle Task Force (BTF), and Close Combat Force (CCF).

ADP-PSS-4 Ability to provide mobile, automated administrative center, support center capability.

ADP-SFS-1 Ability to provide automated, real-time asset visibility for logistics management and decisionmaking.

ADP-SFS-2 Ability to perform automated predict' .tus reporting for short- and long-term logistics planning.

AVIATION

AVN-AVN-1 Ability to destroy enemy air and ground elements employing combat aviation.

AVN-AVN-14 Ability to provide aircraft, the structural systems of which are lightweight, have high strength, and are capable of high temperature operation.

BARRIERS

BAR-CLC-11 Ability to emplace and enhance barriers and obstacles.

BAR-MP-8 Ability to easily erect portable fences to form obstacles to enemy ground movement.

BAR-SFS-24 Ability to create barriers and obstacles employing explosives, chemicals, and such deception materials as foam.

BAR-SFS-25 Ability to create hasty barriers with integrated sensor systems.

BREACHING

BRC-NUC-19 Ability to rapidly breach nuclear Atomic Demolition Munitions (ADM) obstacles.

COMBAT SERVICE SUPPORT

CSS-CCL-6 Ability to provide enhanced combat service support that is less manpower intensive than current methods and are as mobile and survivable as the force they support.

CSS-CCL-7 Ability to provide organic combat service support to: fire support, air defense, communications, engineering, intelligence and electronic warfare (IEW), aviation, military police, and other combat support and combat service support elements.

COMMAND AND CONTROL

CC-CC-1 Ability to streamline command and control and decision-making processes.

CC-CC-2 Ability to perform command, control, communications, and intelligence functions in a distributed (as contrasted with centralized) manner.

CC-CCL-4 Ability to perform maneuver, target acquisition, attack, battle control, and target attack assessment functions.

CC-IEW-6 Ability to produce and acquire distributed intelligence data bases.

CC-NUC-8 Ability to perform command, control and communications functions employing systems that are highly mobile, resistant to jamming, hardened against nuclear effects, and have indistinct physical, electronic, and electrical signatures.

COMMUNICATIONS

COM-AVN-6 Ability to perform secure and jam-resistant short distance air-to-air communications.

COM-CC-4 Ability to communicate employing instantaneous switching.

COM-CCL-15 Ability to perform enhanced automatic switching and relaying functions at communications terminals.

COM-CLC-30 Ability to communicate without using metallic "wires."

COM-CLC-31 Ability to communicate with the use of lasers.

COM-CLC-32 Ability to communicate employing the ultraviolet spectrum.

COM-CLC-33 Ability to communicate employing automated data transmission.

COM-COM-1 Ability to communicate employing enhanced and automated trunking.

COM-COM-2 Ability to communicate employing enhanced local area networks.

COM-COM-4 Ability to communicate employing enhanced communications control.

COM-COM-5 Ability to provide enhanced communications security.

COM-COM-6 Ability to provide enhanced communications terminals.

COM-COM-7 Ability to provide enhanced communications support.

COM-FS-2 Ability to provide enhanced, jam-resistant communications having low probability of intercept.

COM-IEW-12 Ability to provide enhanced IEW mission support communications.

COM-IEW-21 Ability to provide communications with automated, integrated voice recognition capability in radios, thus negating the need for manual authentication procedures.

COM-SOF-1 Ability to provide communications capabilities that are continuous, worldwide, rapid, and secure.

COM-SOF-3 Ability to provide secure communications that permit deployed Special Operations Forces elements to function with minimal exposure.

COM-TRN-5 Ability to perform communications that permit transportation elements to exchange movements data employing devices onboard vehicles.

CONSTRUCTION

CON-EMW-3 Ability to perform enhanced fixed and float bridging.

CON-EMW-7 Ability to perform enhanced combat engineer construction capabilities, e.g., prepackaged repair kits and preassembled building components.

CON-EMW-8 Ability to perform enhanced engineer damage repair.

CON-EMW-9 Ability to perform enhanced rapid runway construction.

CON-FS-4 Ability to perform enhanced fail-soft, fault-tolerant electronics system functional capabilities, also with redundant circuits.

CON-IEW-15 Ability to create electromagnetic barriers and to penetrate barriers.

CON-SFS-42 Ability to conduct hasty burial of materiel, also with capability for location.

DECEPTION

DCP-CLC-7 Ability to make equipment stealthy.

DCP-CLC-14 Ability to conduct enhanced deception and counter-deception including electronic deception.

DCP-IEW-13 Ability to perform electromagnetic signals obscuration.

DCP-IEW-14 Ability to penetrate enemy-imposed obscuration.

DCP-IEW-16 Ability to perform electronic signature simulation.

DCP-IEW-17 Ability to perform electro-optical signature simulation.

DCP-IEW-18 Ability to perform enhanced physical signature simulation.

DCP-IEW-19 Ability to perform enhanced infrared signature simulation.

DCP-IEW-20 Ability to perform holographic signature simulation.

DCP-NBC-26 Ability to perform enhanced support for deception operations.

DECONTAMINATION

DEC-HS-7 Ability to provide soldier and patient decontamination.

DEC-NBC-15 Ability to provide decentralized decontamination.

DEC-NBC-16 Ability to determine when decontamination is complete.

DEC-NBC-17 Ability to perform personal decontamination.

DEC-NBC-41 Ability to perform vehicle and area decontamination.

DEC-SFS-41 Ability to provide decontamination for human remains (utilizing robotics, automation, etc.).

DETECTION

DET-CCH-16 Ability to provide advanced NBC countermeasures, self-identification, and detection.

DET-CLC-6 Ability to automatically detect, identify, and engage enemy targets.

DET-HS-11 Ability to perform rapid NBC identification.

DET-MP-11 Ability to validate vehicles at checkpoints to establish positive identification of personnel (perhaps by employing holography).

DET-NBC-3 Ability to detect, identify, mark, and avoid contaminated areas.

DET-NBC-6 Ability to perform standoff and remote detection for warning and for locating contaminated areas.

DET-NBC-37 Ability to perform rapid diagnosis of NBC casualties.

DET-NBC-42 Ability to perform chemical agent detection and monitoring to identify and locate contamination on personnel and equipment and evaluate completeness of decontamination.

DET-NBC-43 Ability to perform detection and identification of contaminating agents in order to pinpoint and delineate them to enable selective decontamination.

DET-NBC-9 Ability to detect and identify biological agents.

DET-NUC-12 Ability to detect nuclear bursts for location and yield determination in order to rapidly determine the extent of nuclear effects.

DET-NUC-17 Ability to detect and measure individual radiation exposure.

DIRECTION FINDING

DF-IEW-29 Ability to perform tactical direction-finding and target acquisition systems with sufficient accuracy for first-shot kill.

DISPLAYS

DIS-AVN-11 Ability to display data and information on instrument panels and with helmet-mounted and heads-up displays and improved control devices.

DIS-EMW-5 Ability to provide hardcopy and electronic graphic displays and other topographic products in the field environment.

DIS-NBC-28 Ability to process information and communications to provide visual displays and overlay printouts of appropriate NBC reports and areas of predicted or actual NBC contamination.

DIS-PSS-5 Ability to record and play back audio/video data in battlefield environment employing advanced hand-held equipment.

ENERGY

EN-AMM-6 Ability to provide continuous operation with reliable, passive energy sources.

FUEL

FL-SFS-10 Ability to provide alternative multipurpose fuel systems.
FL-SFS-15 Ability to provide renewable source fuel systems.
FL-SFS-17 Ability to provide fuel distribution systems that are ballistic hardened.
FL-SFS-20 Ability to provide integrated and standardized systems for refueling vehicles.
FL-SFS-21 Ability to provide portable laboratory kit for fuel testing (to replace base and mobile laboratories).
FL-SFS-22 Ability to provide fire-resistant fuel for all equipment.
FL-SFS-30 Ability to provide fast laying, flexible, lightweight, automated fuel pipeline system.

IDENTIFICATION, FRIEND OR FOE

IFF-IEW-7 Ability to identify friend-or-foe on the battlefield.

JAMMING

JAM-AD-5 Ability to disrupt the enemy's capability to effectively employ his electronic warfare systems to target high-value assets.
JAM-IEW-25 Ability for units to perform jamming and direction-finding (DF) with organic capabilities.
JAM-IEW-30 Ability of IEW systems to DF, collect, or jam while mobile.

MAPPING

MAP-EMW-4 Ability to perform topographic mapping with digitized terrain data base.

MATERIAL HANDLING

MAT-CLC-10 Enhanced ability to handle material and rearm and refuel vehicles.

MEDICAL

MED-HS-2 Ability to medically protect against (prophylaxis) and pretreat for chemical warfare agents.
MED-HS-3 Ability to enhance immunity against threat agents.
MED-HS-4 Ability to medically protect against (prophylaxis) and pretreat for biological warfare agents.
MED-HS-6 Ability to medically enhance soldier performance.
MED-HS-8 Ability to medically enhance acclimatization.
MED-HS-16 Ability to provide medical-grade oxygen.
MED-HS-17 Ability to enhance homeostatic pharmaceuticals.
MED-HS-22 Ability to provide and maintain combat health records.
MED-NUC-20 Ability to provide radiation medicine for individual soldiers to alleviate the symptoms of acute radiation exposure.

MANEUVER

MNV-NBC-5 Ability to relocate units to uncontaminated areas.

MINES

MNE-CLC-12 Ability to emplace mines and clear obstacles.
MNE-EMW-1 Ability to provide enhanced mines.
MNE-EMW-2 Ability to perform improved countermining.

MISSILES

MSL-AD-4 Ability to conduct area air defense employing long-range, fire-and-forget, surface-to-air missile systems.
MSL-CLC-20 Ability to counter tactical missile systems.
MSL-MSL-1 Ability to ensure highly reliable missile system operations employing BITE and BIT which fault-isolate malfunctioning LRUs with 100 percent accuracy.
MSL-MSL-2 Ability to provide missile systems with a prognostic capability.
MSL-MSL-4 Ability to harden missile systems and associated support equipment against NBC and EMP effects.

MUNITIONS

MUN-AMM-3 Ability to provide munitions that meet the following requirements:

- Interface with advanced robotics/MHE systems (both within the ammunition system, logistics support vehicle, the combat vehicles, and weapon system).
- Are lightweight with minimum mass.
- Are easily handled by the individual soldier.
- Are easily decontaminated.
- When stored, are impervious to nuclear/chemical/biological contamination/EMP effects.
- Require no special handling.
- Have user-oriented packaging with minimum residue.
- Are fire-and-forget.

MUN-AMM-4 Ability to provide munitions that are self-diagnostic to identify unserviceable munitions.

MUN-ANV-17 Ability to provide missile warheads and seeker systems that are multipurpose, permitting a single missile to attack armor, air defense, or airborne targets.

MUN-CCH-14 Ability to provide smart, precision-guided munitions that are fire-and-forget and have autonomous target acquisition capabilities.

MUN-FS-1 Ability to provide brilliant munitions that seek out and destroy specific types of moving and stationary targets.

MUN-NBC-19 Ability to provide enhanced chemical munitions.

MUN-NUC 3 Ability to provide nuclear munitions with insertable nuclear component.

MUN-NUC-2 Ability to provide nuclear munitions capable of producing tailorable effects, to include enhanced blasts, enhanced radiation, and variably patterned geometric effects.

MUN-NUC-23 Ability to provide improved conventional munitions that can approximate nuclear effects (blast and EMP).

MUN-NUC-24 Ability to provide man-portable nuclear munitions.

MUN-SFS-29 Ability to provide complete round munitions with dial-for-effect capability.

NAVIGATION

NAV-AVN-10 Ability to navigate aircraft at night.

NAV-AVN-8 Ability to provide global positioning with terrain correlation combined with high accuracy, worldwide, secure navigation capability.

NAV-CCL-11 Ability to provide position location that does not emit a unique electronic signature.

OBSCURANTS

OBS-NBC-20 Ability to provide enhanced production of smoke and other obscurants.

OBS-NBC-23 Ability to degrade enemy sensors.

OBS-NBC-44 Ability to suppress enemy fire by providing protection against infrared homing and laser weapons as well as visually sighted weapons and target acquisition system.

OBS-NBC-45 Ability to provide obscurants that significantly enhance defense against enemy ground, air, and space-based systems.

OBS-NBC-49 Ability to disperse obscurants and suppress enemy-induced obscuration.

OBS-NBC-50 Ability to provide nontoxic obscurants and do not require eye or respiratory protective items to be worn during combat or in training.

PACKAGING

PKG-AMM-1 Ability to provide automated, user-oriented packaging.

PKG-CLC-29 Ability to provide improved ammunition packaging.

PKG-MP-9 Ability to provide time release storage, e.g., bins to hold and sustain enemy prisoners of war or U.S. military prisoners.

PKG-NBC-30 Ability to protect packaged contents (munitions, supplies, and subsistence) from NBC contamination.

PLATFORMS

PLT-CCL-1 Ability to provide enhanced strategic mobility of the light close combat forces.

PLT-CCL-24 Ability to provide lightweight individual lift system for reconnaissance, obstacle bypass, and casualty evacuation.

PLT-CCM-13 Ability to perform silent individual lift by air platform.

PLT-CLC-1 Ability to rapidly deploy close combat forces.

PLT-CLC-2 Ability to provide enhanced highly mobile and maneuverable platforms.

PLT-CLC-38 Ability to perform soft-land airdrop with internal guidance for inserting material.

PLT-HS-20 Ability to perform enhanced search, rescue, and evacuation.

PLT-IEW-33 Ability to perform high-altitude loiter and collection.

PLT-SFS-35 Ability to perform tactical personnel assault by parachute.

PLT-SFS-38 Ability to conduct enhanced low-level, high-speed delivery.

PLT-SOF-4 Ability to perform enhanced ingress and egress.

PLT-SPC-1 Ability to perform space control operations.

PLT-SPC-2 Ability to perform space support operations.

POL

POL-SFS-9 Ability to provide fuel pipeline operations with systems that can be easily emplaced, recovered, and moved.

POWER

PWR-CC-5 Ability to provide quiet (electromagnetic and acoustic) power generation.

PWR-EMW-10 Ability to generate and distribute electrical power.

PWR-SFS-13 Ability to provide solar-generated electrical power.

PWR-SFS-14 Ability to convert nuclear energy to electrical power.

PWR-SFS-16 Ability to provide portable electrical power systems with high-power, low-bulk, and low-fuel-consuming long-life power packs.

PWR-SFS-19 Ability to provide automatic electrical recharging (battery power systems).

PROPULSION

PPL-AVN-13 Ability to provide advanced propulsion.

PPL-CLC-23 Ability to employ liquid propellant for propulsion and munitions.

PPL-CLC-24 Ability to provide electromagnetic propulsion.

PPL-SFS-31 Ability to provide new engine systems that use other than fossil fuels.

PROTECTION

PRT-CCH-10 Ability to employ stealth techniques and electronic signature reduction to battlefield equipment.

PRT-CCH-6 Ability to enhance armored protection by employing a combination of add-on or applique armor.

PRT-CCH-7 Ability to protect critical components and human-engineered crew compartments against directed, chemical, and kinetic energy munitions.

PRT-CCL-22 Ability to protect the eyes, e.g., goggles that provide protection from sun, wind, dust, small ballistic objects, and lasers.

PRT-CCL-23 Ability to provide individual survivability, e.g., man-portable rapid foxhole digger.

PRT-CCM-10 Ability to lighten the individual soldier's load and enhance personal protection.

PRT-CLC-21 Ability to counter directed-energy weapons.

PRT-CLC-27 Ability to provide collective personnel and equipment protection.

PRT-CLC-28 Ability to provide individual protection against NBC effects and personal decontamination, e.g., lightweight combat uniforms and individual protection.

PRT-MNT-1 Ability to provide duplicate or back-up equipment systems that automatically become effective when one is disabled; the alternate system would be switched so the original equipment's function continues.

PRT-MP-3 Ability to provide lightweight shelters with low visibility to infrared, radar, and laser sensors.

PRT-NBC-14 Ability to provide NBC preventive measures and supplementary devices; antidotes, immunizations, medications, skin barriers, and other NBC prophylaxis systems.

PRT-NBC-2 Ability to limit the spread of NBC contamination.

PRT-NBC-21 Ability to suppress precision-guided missiles and infrared homing, laser-designated, and directed-energy weapons.

PRT-NBC-29 Ability to provide sacrificial coatings with special agent resistant and neutralizing covers to protect supplies and equipment.

PRT-NBC-31 Ability to protect electronics against NBC contamination and decontaminants.

PRT-NBC-35 Ability to provide personal cooling to reduce degradation caused by extended wearing of or vigorous activity in protective ensembles.

PRT-NBC-38 Ability to provide mass-producible NBC protective systems and treatment items for enemy prisoners of war, and host nation support activities.

PRT-NBC-40 Ability to provide controlled and protective environment systems that are an integral part of all combat and support vehicles that are lightweight and use low power.

PRT-NUC-18 Ability to provide radiation masking to shield individuals from nuclear radiation emissions.

PRT-NUC-22 Ability to shield critical Army installations, vehicles, and personnel against the effects of nuclear radiation.

PRT-NUC-9 Ability to protect command posts, enabling them to operate when dispersed with hardened, undetectable interior communications, e.g., portable, nuclear-hardened shelters.

PRT-SOF-2 Ability to enhance survivability of personnel and units when deployed.

PSYCHOLOGICAL WARFARE

PSY-SOF-7 Ability to enhance psychological warfare operations.

ROBOTICS

ROB-CCH-2 Ability to emplace and clear ground obstacles employing robotics.

ROB-CCH-3 Ability to perform reconnaissance and target acquisition and engagement functions employing robotic vehicles.

ROB-CCL-16 Ability to provide programmable squad point robot capability with built-in target detection, identification, and automatic engagement system.

ROB-CCL-17 Ability to provide small direct-fire vehicle robot capability with close-in weapons system.

Appendix C

ONE APPROACH TO IDENTIFYING ARMY-RELEVANT EMERGING TECHNOLOGIES

A RAND-developed approach to identifying Army-relevant emerging technologies is illustrated in the following charts. Tables C.1 presents a list of generic technologies and postulated advances in emerging technologies. The next eight tables, Tables C.2 through C.9, show how various combinations of advanced technologies might have an impact on the Army of the future if applied to the eight key operational capabilities designated by the Army as deserving of special attention:

- Reconnaissance, Surveillance, and Target Acquisition (RSTA)
- Command, Control, and Communications
- Battlefield Lethality
- Battlefield Sustainment
- Soldier and Unit Performance
- Lighten the Force
- Deep Battle
- Low Intensity Conflict

The potentially promising technologies are combined on the charts to produce new "system" capabilities, and the implications of these new combinations are shown. Any potential relationships to Forecast II technologies or systems are indicated, as are prospects for, as well as obstacles to, their potential realization in the future.

Table C.1

ADVANCES IN TECHNOLOGY

Data processing	× 10^n increase in speed/memory, power/size reduction, photonics
Artificial intelligence	Decision aids, knowledge-based systems
Robotics	Unmanned vehicles, sensing devices, automated service support
Brilliant sensors	Multispectra for shape/motion/vibration, pattern recognition
Communications	Lasers, 60 GHz, fiber optics, antijam, encryption
Stealth	"Zero observable" aircraft, vehicles, mobile command posts
Satellites	Real-time reconnaissance/surveillance at multiple frequencies and in all weather
Unmanned aerial vehicles	Long endurance/autonomous operations platforms
Lightweight materials	Transportable weapon/support systems, lightweight armor
Biotechnologies	Controllable biological weapons, "bionic man," medical support
New manufacturing processes	Mass proliferation, highly reliable, flexible response production, computer-aided design, computer-aided manufacturing
Directed-energy weapons	Lethal jamming/sensor damage capability
New propulsion	High-performance engines, low fuel consumption designs
Aerodynamics	VSTOL, air cushion vehicles
Navigation	Reliable, cheap, precise, compact positioning/navigation

Table C.2

POSSIBLE IMPACT OF ADVANCED TECHNOLOGIES ON RECONNAISSANCE, SURVEILLANCE, AND TARGET ACQUISITION

Technology Combination	New System Capability	Implications	Potentially Relevant Forecast II Technologies/Systems	High, Medium, Low Prospects (and Obstacles)
Robotics Stealth Data processing Communications Navigation	Unmanned forward observers/ designators, robotic surrogates	Fewer scouts, forward observers, combat service personnel	PT: 7, 9, 10, 11, 12, 13, 20, 22, 23, 26, 34, 36, 40, 48 PS: 21, 22	High
Data processing Brilliant sensors Satellites Communications	All-weather, real-time, global surveillance[a]	Reliable intelligence	PT: 5, 9, 10, 11, 12, 13, 15, 19, 20, 36, 43 PS: 24, 30, 33	Medium to low (Cost, data processing)
Brilliant sensors New propulsion Communications Data processing	Battlefield probe giving on-demand real-time, high-resolution surveillance	"See deep"	PT: 9, 10, 11, 12	High

[a]Also applicable [illegible]ghten the Force.

Table C.3

POSSIBLE IMPACT OF ADVANCED TECHNOLOGIES ON COMMAND, CONTROL, AND COMMUNICATIONS

Technology Combination	New System Capability	Implications	Potentially Relevant Forecast II Technologies/Systems	High, Medium, Low Prospects (and Obstacles)
Data processing Communications Satellites UAVs Navigation	Real-time transfer of survivable command and control information	Fewer command echelons (e.g., theater commander controls battalions)	PT: 6, 9, 11, 13, 14, 15, 19, 41 PS: 45	High
Data processing Artificial intelligence Communications	Real-time, reliable battlefield data fusion	Operational intelligence	PT: 7, 11, 14, 36, 40, 41, 43, 48 PS: 39, 48	Medium (Data processing)
Artificial intelligence Data processing	Failure-free electronics[a]	More autonomy, increased sustainability	PT: 10, 11, 13, 48	High

[a]Also applicable to Battlefield Sustainment.

Table C.4

POSSIBLE IMPACT OF ADVANCED TECHNOLOGIES ON BATTLEFIELD LETHALITY

Technology Combination	New System Capability	Implications	Potentially Relevant Forecast II Technologies/Systems	High, Medium, Low Prospects (and Obstacles)
Brilliant sensors Satellites Data processing Communications Directed-energy weapons	"If you are seen, you are dead"	Demise of expensive manned combat vehicles	PT: 9, 10, 11, 12, 19, 26, 28, 36, 45, 48 PS: 8, 21	Medium (Countermeasures)
Biotechnology Stealth UAVs	Effective delivery of deadly toxins	Demise of unprotected fixed facilities in the battle area	PT: 16, 18, 22 PS: 7	Low (Controllability)

Table C.5

POSSIBLE IMPACT OF ADVANCED TECHNOLOGIES ON BATTLEFIELD SUSTAINMENT

Technology Combination	New System Capability	Implications	Potentially Relevant Forecast II Technologies/Systems	High, Medium, Low Prospects (and Obstacles)
Data processing Artificial intelligence Communications Robotics	Accurate, timely logistics information and support	Rapid repair/ ammunition delivery	PT: 11, 13, 33, 34, 36 PS: 3	High
New manufacturing process AI/robotics Data processing	Flexible production of highly reliable weapon systems	Less inventory, more self-sufficiency	PT: 11, 13, 30, 32, 36	High
New manufacturing processes Lightweight materials	Modular weapon systems	Flexible forces/force structure (e.g., small modular units)	PT: 30 PS: 47	Medium (Engineering compromises)

Table C.6

POSSIBLE IMPACT OF ADVANCED TECHNOLOGIES ON SOLDIER AND UNIT PERFORMANCE

Technology Combination	New System Capability	Implications	Potentially Relevant Forecast II Technologies/Systems	High, Medium, Low Prospects (and Obstacles)
Data processing Artificial intelligence Communications	"Super realistic" ground simulators for training	Permits extensive training at home	PT: 7, 9, 11, 36, 40, 43, 44	High
Biotechnology Communications	Superhuman capabilities	Increased effectiveness of troops, less reliance on reserves/medical support	None	Medium to low (Side effects, political constraints)

Table C.7

POSSIBLE IMPACT OF ADVANCED TECHNOLOGIES ON LIGHTENING THE FORCE

Technology Combination	New System Capability	Implications'	Potentially Relevant Forecast II Technologies/Systems	High, Medium, Low Prospects (and Obstacles)
Robotics Lightweight materials Brilliant sensors Directed-energy weapons	Transportable weapon systems	Highly capable light forces, comparable to today's heavy forces	PT: 1, 3, 11, 17, 20, 22, 26, 28, 48	Medium (Material limitations)

Table C.8

POSSIBLE IMPACT OF ADVANCED TECHNOLOGIES ON DEEP BATTLE

Technology Combination	New System Capability	Implications	Potentially Relevant Forecast II Technologies/Systems	High, Medium, Low Prospects (and Obstacles)
Brilliant sensors Satellites Data processing Communications Navigation	Long-range standoff weapons with surgical deep attack capability[a]	Increased role of standoff weapons, decreased close in battle	PT: 1, 4, 9, 10, 11, 12, 18, 19, 20, 22 PS: 18	Medium (Target acquisition)

[a]Also applicable to Battlefield Lethality.

Table C.9

POSSIBLE IMPACT OF ADVANCED TECHNOLOGIES ON LOW INTENSITY CONFLICT

Technology Combination	New System Capability	Implications	Potentially Relevant Forecast II Technologies/Systems	High, Medium, Low Prospects (and Obstacles)
Aerodynamics Robotics New propulsion	Alternatives to current helicopter designs[a]	Better intertheater lift, close air support	PT: 3, 7, 11, 13, 16, 18, 22, 23 PS: 1, 7	Medium (Propulsion, materials)
Satellites Navigation Directed energy	Novel weapons[b]	Global strike capability	PT: 5, 19, 28, 45 PS: 24	Medium (Political constraints)

[a]Also applicable to RSTA, Battlefield Lethality, and Battlefield Sustainment.
[b]Also applicable to Battlefield Lethality, Lighten the Force, and Deep Battle.