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INSTITUTE FOR DEFENSE ANALYSES

Survey of Long-Term Technology Forecasting Methodologies

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PREFACE

This work was supported by a Central Research Program (CRP) task at the Institute for Defense Analyses (IDA).

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EXECUTIVE SUMMARY

Technology forecasting can be a valuable tool in determining future threats or exploring possibilities for new capabilities. This document presents the results of a preliminary survey of technology forecasting techniques that can be applied to the military's needs. We review some methodologies that have been used to forecast future technologies. The primary focus is on the longer term (approximately 50 years in the future) and on potentially applicable military technologies.

This effort has been carried out under the Institute for Defense Analyses (IDA) Central Research Program (CRP). As a caveat, this IDA CRP was a limited effort, and we have not made any claims about the comprehensiveness (or evenhandedness) in reviewing past studies or in gaining insight into the current thinking of professional futurists. However, although we have not conducted any studies of our own, we have gained some impressions and opinions that will be useful to those considering such studies. The enormity of the field precluded comprehensiveness, but the effort was of sufficient scope to draw some general and specific observations about forecasting.

A. GENERAL OBSERVATIONS ON FORECASTING

Technology forecasting can be used in two important ways:

1. To assess the military (or other) applicability of emerging technologies
2. To seek new or breakthrough approaches for solving existing problems.

Both uses can be valuable, can use similar analytical approaches, and can lead to new awareness and to expanded research and development (R&D) efforts.

Technology applicability studies tend to be nearer term and are widespread. These studies should not be conducted in isolation because military technologies and political alignments evolve and, at times, even change rapidly. Breakthrough approaches for solving existing problems may be sought, but we have no assurances that these approaches can be accelerated or even identified.

In general, forecasting studies call for "out-of-the-box" thinking by asking participants not to be restrained by current technological constraints. Such thinking, however, is not easy to attain. Participants, even in longer-term studies, tend inevitably to be influenced by current events, current societal problems, peer pressure, and perhaps self-interest. Special efforts are needed to achieve freedom from these influences.

B. SPECIFIC OBSERVATIONS ON FORECASTING

Forecasting methodologies can be discussed in terms of formal and informal approaches. Formal approaches include brainstorming, the Delphi technique, and the Horizon Mission Methodology (HMM), Service studies, and organizational studies. These approaches are well structured and have been applied by government agencies, the Services, and industry organizations to identify areas for future research. Informal approaches include those used in science fiction literature. Science fiction writing offers freewheeling predictions of the future that may provide insight into new technologies unrelated to commonly held beliefs.

1. Formal Approaches

a. Brainstorming

In this approach, a group gets together to examine issues and seek alternatives. The participants incorporate principles that appear to have been adopted by most idea-seeking groups (e.g., freewheeling ideas, no negative feedback, and so forth). Usually, these efforts are short term and consider a specific problem.

b. The Delphi Technique

The Delphi technique is a formalized procedure that has evolved over the past 50 years. It can involve a large number of expert participants over a substantial period of time, with iterations and feedbacks as problems are explored. In our opinion, Delphi is best suited for evaluating the alternatives of some definable although not necessarily narrow issue (e.g., the near-term industrial investments for a nation) in which the experience of experts is of particular value. It is likely that the Delphi technique's emphasis on consensus minimizes its utility for predicting far-future capability.

c. Horizon Mission Methodology (HMM)

HMM is a relatively new procedure in which new technological approaches are explored through a technique that forces out-of-the-box thinking. The participants assume that they are living in some future time during which some breakthrough technology is being used. They are then asked to project backwards toward the present and speculate on the genesis of this technology. This approach offers the possibility of minimizing conformist thinking and promotes the development of imaginative concepts. The National Aeronautics and Space Administration (NASA) has used this approach in seeking new concepts for propulsion for space travel. Air Force-sponsored and other studies have also incorporated a broad HMM concept.

d. Service Studies

The Services continue to sponsor a large number of futures-oriented studies and develop "think pieces" and "white papers" on various subjects. Many of the technology studies have been application oriented (examining the applicability of new technologies to new weaponry). In 1992, the National Research Council (NRC) carried out an Army-sponsored study called the *STAR 21: Strategic Technologies for the Army of the Twenty-First Century*. This study was a thoughtful evaluation of recognizable new or emerging technologies and was credibly free of vested interests. The approach, which appears particularly useful for technology evaluation, employed committees of recognized non-Army experts in a carefully structured way. These committees used their knowledge of technology and Army inputs to develop the evaluations. Other studies, in particular the *Air Force 2025*, have developed multiple potential scenarios to examine Air Force roles. The Navy has also conducted studies that explore its role in potential future conflicts. However, these Navy studies appear to be more useful for force structuring or mission development than for technology evaluation. The Navy has also conducted studies that explore its role in potential future conflicts.

e. IDA and the Militarily Critical Technologies (MCT) Process

IDA is evaluating emerging technologies and their criticality to the United States. The MCT approach uses Technology Working Groups (TWGs) to evaluate U.S. and foreign technologies. This information will obviously be of value in future applicability studies.

2. Informal Approaches

Science Fiction

Science fiction, as a genre, permits true out-of-the-box thinking. Indeed, the term "science fiction" could be applied to much of the future-oriented work described previously. Sir Arthur C. Clarke, the well-known scientist and science fiction author, strongly defends reading science fiction as a means of expanding one's thinking processes. In retrospect, science fiction has proposed many now-recognizable technology advances [e.g., long-duration submarines, nuclear weapons, infrared (IR) lasers, and so forth] that have become realities. Other concepts (e.g., Buck Rogers' disintegrator ray) have not yet appeared. Clearly, for realizable concepts, the yield is low; however, as some have argued, envisioning is a first step in any accomplishment.

C. NEXT STEPS

The techniques for analysis discussed here can be applied to broader areas and other questions of relevance to the military—not just technology forecasting. For instance, HMM has also been applied to social issues and civilian questions; thus, the use of HMM as a threat analysis tool provides several interesting challenges and opportunities. Clearly, forecasting can be used to track the development of individual technologies and the potential use of combinations of technologies in several time frames. Several methodologies have been presented here, all of which can be used for threat analysis, but the choice of the specific technique (or combination of techniques) will depend strongly on the goals of the analysis in question.

In light of the events of September 11, 2001, we need to take a broader look at terrorism and a more imaginative approach to the various threat scenarios possible. We have to step "out of the box" and think like terrorists and not be constrained by our own philosophies, morals, and inhibitions. For this, HMM is ideally suited as an approach. For example, consider a workshop using the HMM approach—with the participation of a blend of technical and military experts to provide information on what has been done and a group of free thinkers (e.g., young scientists, terrorism experts, students, artists and inventors) to provide bold ideas about what can be done: this workshop could provide more imaginative scenarios to determine what terrorists may be thinking.

Use of forecasting for establishing basic research investments is another application of the techniques discussed in this document. This could have major impact on technology development by identifying science research areas (at an early stage of their development) that could provide paradigm shifts in the future

I. INTRODUCTION

Governments, industry, and military organizations have often undertaken studies to predict the future course of technology, and the reason for this is easy to understand. The ability to predict the course of technology gives one the upper hand in devising investment strategies and in determining the use of the technology for defense, economic, and social activities.

The Department of Defense (DoD) and all the Services have attempted to predict the course of future technologies. The present study was undertaken to find out

- Systematic approaches that exist for predicting future technologies
- Approaches that are most useful to the military
- The success of past studies in using these approaches predict the future.

During this study, we were able to compare some detailed predictions of the technologies that would develop over the span of some 50 years with the actual technology developments. This information is useful for selecting approaches to study future technologies and for estimating the uncertainties encountered in such studies.

This document reviews various methodologies that have been used in attempts to forecast what technologies may develop in the "long-term" future[1] and how these developments might affect the military. For our purposes, forecasting is not prediction; instead, it is a process used to describe a range of possible developments, some of which could ultimately have profound effects on the military. These efforts can be used to evaluate and suggest applications for emerging technologies [e.g., applications of microelectromechanical systems (MEMS) technology] or to seek new approaches to solve existing problems. Such descriptions serve the dual purpose of alerting warfighters to possible technological surprises and alerting weapons developers to possible opportunities. Initially, such forecasts tend to impact current programs at a low level, perhaps leading to the initiation of programs that might otherwise never get started but may grow as the years pass.

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1 We define the long-term future as a period of some 25 to 50 years from the present.

In recent years, future-planning activities—not those necessarily limited to technology—have become increasingly popular in the Services, in other parts of the government, and in industry. For example, the Department of Energy (DOE) Office of Industrial Technologies (OIT)[2] has solicited proposals for joint chemical research projects essentially aimed at saving energy. These projects are based on the agenda in its *Technology Vision 2020: Report of the U.S. Chemical Industry*, which was a 2-1/2 year study. Also, Section 241 of the 1999 National Defense Authorization Act (NDAA) (see Figure I-1) contains a provision that requires DoD to issue quadrennial reports that detail the impacts of emerging technologies on future DoD concepts and those of our potential adversaries.

SEC. 241. QUADRENNIAL REPORT ON EMERGING OPERATIONAL CONCEPTS

(a) IN GENERAL.—Chapter 23 of title 10, United States Code, is amended by adding at the end the following new section:

¶ 486. Quadrennial report on emerging operational concepts

"(a) QUADRENNIAL REPORT REQUIRED. Not later than March 1 of each year evenly divisible by four, the Secretary of Defense shall submit to the Committee on Armed Services of the Senate and the Committee on Armed Services of the House of Representatives a report on emerging operational concepts. Each such report shall be prepared by the Secretary in consultation with the Chairman of the Joint Chiefs of Staff.

"(b) Each such report shall contain a description, for the four years preceding the year in which the report is submitted, of the following:

"(1) The process undertaken in the Department of Defense, and in each of the Army, Navy, Air Force, and Marine Corps, to define and develop doctrine, operational concepts, organizational concepts, and acquisition strategies to address:

"(A) the potential of emerging technologies for significantly improving the operational effectiveness of the armed forces;

"(B) changes in the international order that may necessitate changes in the operational capabilities of the armed forces;

"(C) emerging capabilities of potential adversary states; and

"(D) changes in defense budget projections.

"(2) The manner in which the processes described in paragraph (1) are harmonious to ensure that there is sufficient consideration of the development of joint doctrine, operational concepts, and acquisition strategies.

Figure I-1. SEC 241, 1999 National Defense Authorization Act (NDAA): Quadrennial Report on Emerging Operational Concepts (In Part) (Source: Ref. 1)

[2] See http://www.oit.doe.gov/.

For many years, DoD and the military Services have sponsored substantial work devoted to identifying future trends in systems and technologies. Appendix A provides a partial list of recently completed activities. For example, the RAND Project Air Force (PAF)[3] has been identified with such efforts ever since it began. While some of the products from these efforts may have been extrapolations and some may have been wish lists, the old cliché that the military "always prepares for the last war" has not gone unheeded. In fact, potential changes in military affairs and in their operational environments have generated a field of specialized study. The "Revolution in Military Affairs," or simply RMA, has become the all-encompassing term used to describe the changing military future and has received attention at the highest levels. For example, in 1994, the *Defense News* (Ref. 2) reported that then-Defense-Secretary William Perry spoke of RMA as one of his legacies. He eventually formed a large RMA study group within DoD. Since RMA, in general, is broader in scope than this work is, we have not attempted to review that literature. A 1994 paper prepared at the Army War College by Mazar (Ref. 3) discusses RMA's effect on defense planning.

Technology forecasting in the wider society has also been a major enterprise. Germany, Japan, Korea, and other countries have undertaken large-scale forecasting efforts using the Delphi approach to develop forecasts and to structure national research and development (R&D) efforts. Other examples of technology forecasting in the wider society include articles, books, and organizations. (Refs. 4, 5, 5a, 5b, 5c, 5d, 5e).

Time frames for technology or weapon system advances vary with the technology and/or item involved. For example, changes to electronic items occur more rapidly than changes to ships or artillery, and aircraft and can have surprisingly long operational lifetimes Some items, in short, remain useful for many decades and may not change significantly in the 25- to 50-year time frame we have selected. Changes in roles and missions or some other factor (e.g., environmental impact), rather than advances in technology, may cause obsolescence. Some of these changes occur with surprising suddenness. For example, the Kosovo air campaign indicated to the Army—a strong proponent of advanced thinking and always concerned with logistics—that it was not well configured for rapid-response requirements. More recently, the terrorist attacks on the World Trade Center in

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3 PAF, originally know as Project RAND, was established in 1946 by General H.H. "Hap" Arnold as a way of retaining for the Air Force the considerable benefits of civilian scientific thinking that had been demonstrated during World War II. PAF's mission is to conduct an integrated program of objectively analyzing issues of enduring concern to Air Force leaders.

New York and the Pentagon near Washington, DC, have forced us to reconsider our operational procedures for homeland defense and the technology requirements needed to meet the challenge. We have learned that innovative approaches are required to deal not only with weapon systems improvements, but also with the challenges posed by our human enemies (e.g., the terrorists).

Technologies and the weapon systems employing these technologies tend to be useful primarily for the purposes for which they were originally intended, and restructuring can be a long and expensive process. Technological forecasting methodologies should consider all these factors.

Finally, as noted earlier, technology forecasting can be viewed in at least two ways, both of which are valuable:

- One approach investigates some recognized emerging technology, such as MEMS or nanotechnology (both perhaps somewhat beyond "emerging") and determines how this technology might be used to solve existing problems or create new capabilities. This approach also can lead to new R&D efforts.
- Another approach selects a problem (e.g., the need for radically improved propulsion for space travel) and seeks new ways to solve this problem. This approach attempts to generate entirely new R&D approaches in what some might view as a stagnant technology area.

Appendix B provides an Institute for Defense Analyses (IDA)-generated briefing on technology forecasting. This briefing has been presented to various government agencies.

II. STUDY SCOPE AND ORGANIZATION

A. SCOPE

Technology forecasting can be a valuable tool in determining future threats or exploring possibilities for new capabilities. This study is a preliminary survey of technology forecasting techniques that can be applied to the military's needs. This document reviews some methodologies that have been used in attempts to forecast future technologies. The primary focus is on the longer term (approximately 50 years in the future) and on potentially applicable military technologies.

This document reports on a limited effort, funded at the level of approximately one person-month and carried out as part of a Central Research Program (CRP) sponsored by IDA. No claim is made concerning its comprehensiveness or evenhandedness in reviewing past studies or in gaining insight into current thinking of professional futurists. No original forecasts have been attempted. However, we have gained some impressions and opinions that may be of interest to those who may be considering similar forecasting efforts. The enormity of the field precluded comprehensiveness, but the effort was of sufficient scope to draw some general and specific observations about forecasting.

B. ORGANIZATION

In Section III, we turn to the main topic of this document, which includes a review, description, and commentary on various formal and informal forecasting methodologies. Formal approaches include brainstorming, the Delphi technique, the Horizon Mission Methodology (HMM) [as used by the National Aeronautics and Space Administration (NASA)], Service studies, and IDA's involvement in the Militarily Critical Technologies (MCT) process. We then turn to anecdotal, informal procedures, as exemplified by science fiction, and comment on some of the ideas presented in this area.[4]

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[4] We note, incidentally, that we have no data on their success ratio (i.e., the ratio of successes to failures).

Finally, we offer some observations as to which methodologies are the most appropriate for particular applications.

Most forecasting efforts are not successful. Some of the reasons for these failures are important, and we have outlined them in Appendix C.

III. REVIEW OF FORECASTING METHODOLOGIES

A. INTRODUCTION

In this section, we review forecasting methodologies. We divide the discussion into "formal" and "informal" approaches. Formal approaches include brainstorming, the Delphi technique, HMM (as used by NASA), Service studies, and IDA's involvement in the MCT process. Informal approaches include those used in science fiction.

For the informal approaches, we know of no formal methodology. However, both approaches use free-form imagination, possibly carried out by an individual or a group. The principal requirement is that the concept be interesting and credible enough to convince a target group (a requirement that has its parallel in larger and more sophisticated studies).

B. FORMAL APPROACHES

1. Brainstorming

The origin of brainstorming is unclear, but it is associated with World War II and the period thereafter. Brainstorming enjoyed a considerable popularity in the 1950s and 1960s and is still used today. Organizations and software exist to pursue this approach (Refs. 6, 7).

The concept involves getting a group together to seek solutions to some problems. The participants use freewheeling thinking and avoid criticism of others' ideas or other individuals. VanGundy (Ref. 6) boils the principles down to "defer judgment, build on ideas, freewheeling is welcome, generate as many ideas as possible." VanGundy, whose firm is associated with brainstorming workshops, also notes that unstructured brainstorming sessions are less productive than those in which a facilitator is present. Obviously, the outcome of any such effort depends heavily on the individuals involved and their personalities. Basically, VanGundy argues that at least some of the participants should be trained in idea generation, that formal techniques for idea generation should be included, that a "fun" atmosphere should be present, and that the effort all carried out under time-limit constraints.

The Brainstorming 101 Global Service Project offers "Brainstorming 101" software free to non-profit organizations (Ref. 7). It is primarily directed toward brainstorming for new business products and not toward advances in technology. Nevertheless, some of the principles may apply. "To survive and grow, your organization needs ideas. You need to be ready to respond to any challenge, any time. Brainstorming was originally developed as a tool that everyone in an organization could use to be more effective. *Brainstorming 101, Ideas for Excellence* teaches the tools and skills to create real-world ideas. It is a practical guide that can help you solve problems, develop new services, and boost productivity" (Ref. 7).

2. The Delphi Technique

a. Background

Delphi has been used widely for many years and merits considerable discussion. Various definitions of the Delphi technique can be found. Reference 8 gives a succinct definition:

> The Delphi survey is a way of finding ideas, forming opinions, and making forecasts which systematically determine the insights and assessments of selected specialists. The survey results are presented to the experts involved once or several times to allow them to examine their views in the light of the other experts' opinions and, if necessary, correct any deviations.

The Delphi process uses written surveys and feedback in an iterative process, which leads toward convergence; however, the method is intended to eliminate the problems associated with direct debate, as described by Gordon and Helmer (Ref. 9) in a 1964 long-range forecasting study (a RAND paper that generated worldwide interest):

> The method which we have employed for the systematic solicitation of expert opinions is the so-called Delphi Technique. [Reference 10 is cited.] Instead of using the traditional approach toward achieving a consensus through open discussion, this technique eliminates committee activity altogether, thus . . . reducing the influence of certain psychological factors, such as specious persuasion, the unwillingness to abandon publicly expressed opinions, and the bandwagon effect of majority opinion. This technique replaces direct debates by a carefully designed program of sequential individual interrogations (best conducted by questionnaires) interspersed with information and opinion feedback derived by computed consensus from the earlier parts of the program.

A large amount of literature exists on the Delphi technique. The term "Delphi" comes from the mythical oracle, and the technique is aimed at producing what might be called Delphic wisdom through the formalized interaction of knowledgeable groups. The

RAND Corporation (the Air Force think tank) is credited with the Delphi technique's first reported use, in 1948, in an experiment to improve betting scores at horse races (Ref. 11). The RAND research was directed at improving the use of expert predictions in policy-making. Procedures were improved and used by RAND in a series of 14 studies from 1950 to 1963 (Ref. 11).

Woudenberg's (Ref. 11) 1991 evaluation of the Delphi technique noted that Delphi was "used mainly to make quantitative assessments (forecasting dates and estimating known parameters)" in the 1950s and 1960s, whereas in the 1970s the "stress was more and more put on the educational and communicational possibilities of Delphi." Some authors began to call Delphi a "communication device," measured qualitatively according to the satisfaction of the participants. Woudenborg carefully noted that his evaluation was of the quantitative Delphi. Even with this caveat, however, his evaluation was largely negative (Ref. 11):

> The literature concerning quantitative applications of the Delphi method is reviewed. No evidence was found to support the view that Delphi is more accurate than other judgment methods or that consensus in a Delphi is achieved by dissemination of information to all the participants. Existing data suggest that consensus is achieved mainly by group pressure to conformity, mediated by the statistical group response that is fed back to all participants.

Other reviewers have expressed more positive views. In 1994, Ono and Wedemeyer (Ref. 12) evaluated the validity of the Delphi technique when used to assess issues in the communications field as predicted some 16 years earlier. They found that the trend forecasts were significantly correlated with the trend assessment and had accurately forecast approximately half the events that could be evaluated as of 1991. Ono and Wedemeyer argued that the results of their study lent "support to the use of the Delphi technique in long-range forecasting . . . in forecasting the development in communication in Hawaii" (Ref. 12).

Lang (Ref. 13) cites various authors who note where Delphi should be used. Predictive issues, such as forecasting the occurrence of new events and forecasting point values and trends of key parameters, are among the applications endorsed.

H. Sackman at RAND (Ref. 14) probably wrote the most authoritative evaluation of Delphi, at least up to that time (1974). Sackman's final recommendations included two options: Delphi should be upgraded with more scientific methods or, in effect, be dropped altogether.

Sackman (Ref. 14) argued, among other points, that

> The evidence adduced in this study clearly indicates that the massive liabilities of Delphi, in principle and in practice, outweigh its highly doubtful assets.
>
> As the preferred alternative to conventional Delphi, professionals, funding agencies, and users are urged to work with psychometrically trained social scientists who can apply rigorous questionnaire techniques and scientific human experimentation procedures tailored to their particular needs. It is recommended that conventional Delphi be dropped from institutional, corporate, and government use until its principles, methods, and fundamental applications can be experimentally established as scientifically tenable.

While controversy continued, interest in the technique expanded on a worldwide basis, with studies in Germany, India (Ref. 15), Japan, South Korea (Ref. 16), and elsewhere. Some applications have involved efforts that have included a large number of participants and have been carried out over a considerable period of time.

The South Korean Delphi application (Ref. 16) had the ambitious objective of providing a 20-year forecast and framework for R&D in the entire South Korean economy. The effort took place from June 1992 to September 1994 and cost about $150,000 (U.S.). The study, which was termed a technology forecasting (TF) study, proceeded according to Figure III-1. It was undertaken in three stages: preliminary, pre-foresight, and main foresight. The scope of the effort was massive. For the preliminary stage, 25,000 experts were asked to send in their 20-year forecasts for 1,200 technological topics. In the end, about 5,000 experts produced about 30,000 ideas. Out of these ideas, 9,000 topics were selected and rearranged into 15 areas. These topics were then evaluated and winnowed by a series of steps. (Reference 16 gives the details.) The results were used to establish a long-range science and technology (S&T) plan. The South Korean study also compared its results with studies conducted in Japan and Germany.

The study in India (Ref. 15) was smaller than the South Korean study. It involved some 370 experts nationwide. The more restricted subject area was limited to electronics and information technology. The authors state that

> . . . The modified Delphi methodology for technology forecasting proposed in this article is thus a combination of scenario writing, Delphi questionnaire, and response analysis using additional written inputs to develop a roadmap for India, fine tuning and short listing through a seminar for implementation. This methodology is considered unique for rapidly changing technology with all pervasive applications like electronics and information technology aiming at sustainable development.

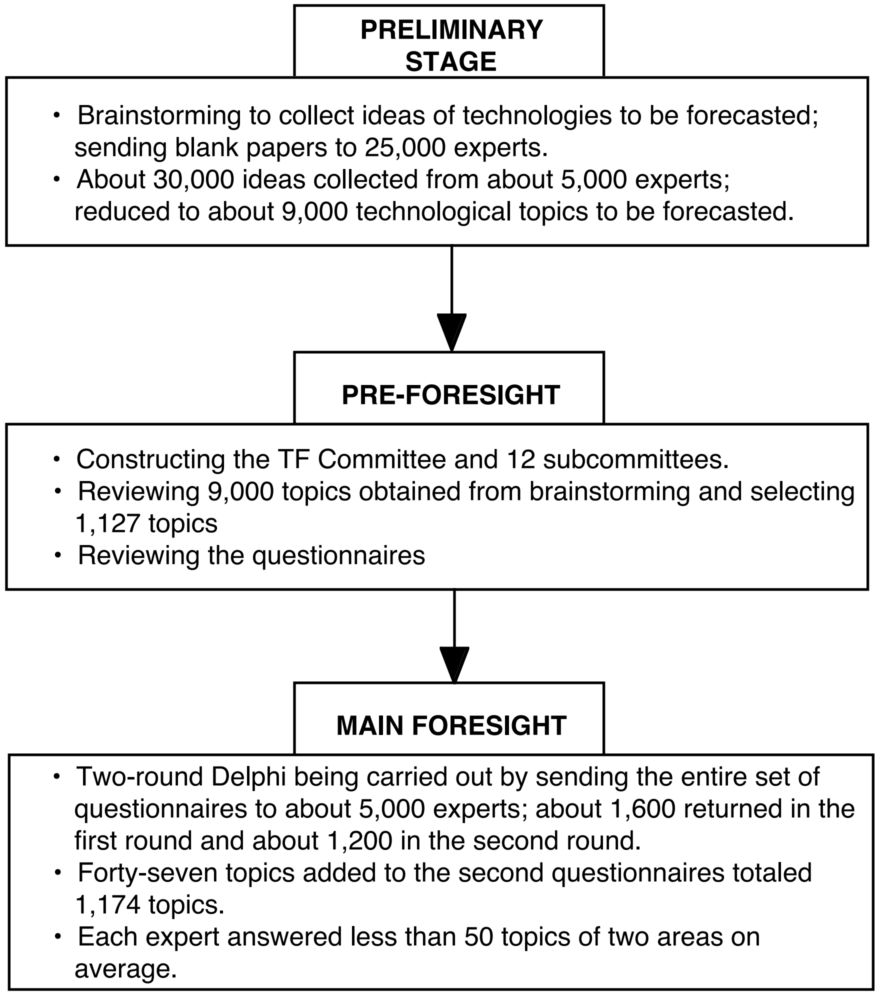

Figure III-1. South Korean Delphi Procedure (Source: Ref. 16)

The study in India developed specific short-term (to 2000), mid-term (2001–2005), and long-term (2006 and beyond) recommendations in nine areas. The time frames associated with some of the items can be argued (in fact, some look highly questionable), but the concepts are of interest. One intriguing concept (for 2006 and beyond) was that of fully automatic translation facilities. We have not seen this concept discussed elsewhere, but it would seem to have enormous applicability to the military in future peacekeeping roles (and to the civilian world in general). Typically, future military forecasting emphasizes instant communication among friendly participants in the battle, and the assumption seems to be that they would all speak the same language. However, that notion is becoming increasingly unsupportable. This technology is under development by several organizations, including the Defense Advanced Research Projects Agency (DARPA) and the Army.

b. Application to Military Technology

The various assessments of the Delphi technique cited previously cover a wide range of applications and are probably indicative of applications in which Delphi might be expected to produce useful results. Whether this approach could be expected to produce useful results in our particular application of interest—namely, long-range technological forecasting directed to military needs—is not really addressed.

In exploring this question, we examined a fairly old (1964) but pertinent RAND long-range (10–50 years) forecasting study by T. J. Gordon and O. Helmer (Ref. 9). This study was undertaken at a time when most, if not all, of the technologies we recognize today (e.g., computers, solid-state electronics, lasers, nuclear fission and nuclear fusion, satellites, man-in-space, and so forth) were known. Forecasts in these areas at least required "nerve" but not necessarily "imagination," to use Arthur Clarke's[5] terminology. The study, however, was not limited to these known technologies, and some of the more interesting predictions had nothing to do with technology per se. Enough time has passed (35 years) to provide some evaluation of the effort.

The Summary of the Gordon and Helmer report (Ref. 9, p. v) gives the justification for such efforts, as follows (in part):

> Prediction-making is a fundamental part of technological, military, commercial, social, and political planning in the modern world. Relatively short-term forecasts of events of, say, the next 24 hours, next year, or even trends of the next decade are often accurate enough to be of demonstrably practical use. But, as the period of concern is moved further and further into the future, uncertainties multiply, confidence in prediction is degraded, and the scientific theories and techniques of forecasting increasingly give way to intuitive judgment. The fact remains, however, that for better or for worse, trend predictions—implicit or explicit, "scientific" or intuitive—about periods as far as 20 or even 50 years in the future do affect current planning decisions (or lack of same) in such areas as national defense, urban renewal, resource development, etc. Thus, almost anything further we can learn about the basis, the accuracy, and the means for improving such long-term forecasts will be of value.

The intent of the effort, which was considered "an experiment in forecasting," took place over a 12-month period and is described as follows (Ref. 9, p. 1):

> Substantively, our interests lay in assessing the direction of long-range trends, with special emphasis on science and technology, and their probable

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5 Sir Arthur Clarke is a well-known scientist and science fiction author.

effects on our society and the world. Here, by "long-range" we had in mind something of the order of ten to fifty years.

The authors also noted a "near vacuum" in tested techniques and hoped "to sharpen the few systematic methods" available.

The RAND study sought to cover topic areas encompassing "the most important determinants of the society of the future" and finally decided on six topics (Ref. 9, p. 2):

1. Scientific breakthroughs
2. Population control
3. Automation
4. Space progress
5. War prevention
6. Weapon systems.

All of these items have some relevance to future military forces; however, the sixth item was of most interest to our study.

This study used experts and questionnaires, without committee activity. Six panels of experts were selected. Each panel answered 4 sequential questionnaires, spaced approximately 2 months apart.

In the first "scientific breakthroughs" questionnaire, panel members were asked to list "major inventions and scientific breakthroughs in areas of special concern to you which you regard as both urgently needed and feasible within the next 50 years." Collation and paring of the responses led to a list of 49 items, which were presented to the panel in the second round. The second round focused on the probability actually implementing the item in each of nine time periods: 1963–1965, 1965–1968, 1968–1972, 1972–1978, 1978–1986, 1986–1997, 1997–2013, later than 2013, and never. Statistical evaluation of the responses led to an estimate of the year in which the item had a 50-percent probability of occurring. On the basis of these findings, it was judged that the panel members had reached a consensus on 10 of the 49 items. This consensus was forwarded to the experts in the third questionnaire, which asked them to take exception if they disagreed and to state their reasons. Of the remaining 39 items, 17 were deemed to be worthy of further evaluation, and these were also forwarded to the panel. The emphasis again was on the year in which the occurrence was judged to be 50-percent probable. If there was disagreement with the consensus, the panel members were to state why. The fourth questionnaire was similar to the third. The outcome of this entire exercise was a "reasonably narrow" consensus of *when* some item would occur with some estimated probability. An example illustrates the outcome (based on information in Ref. 9, pp. 6–10):

Item B1. Feasibility of chemical control over hereditary defects through molecular engineering. The results were given as median (2000) and quartiles (1990–2010). This meant that one quarter of the respondents thought this had an even chance of occurring by 1990, one half thought it had an even chance by 2000, and one quarter thought it would have an even chance only post 2010 (i.e., three quarters thought it had an even chance by 2010).

Figures III-2, III-3, and III-4[6] give the results in Topic Area 1 (Scientific Breakthroughs), Topic Area 4 (Space Progress), and Topic Area 6 (Weapon Systems). In each case, the quartiles and median values are shown, along with the topical areas. For weapon systems (Figure III-4) additional information is presented. A "feasibility" parameter and an "effectiveness" parameter are given, and two sets of forecasts are included. The gray-hatched forecasts are for a "status-quo" approach, and the light bars are for a "crash-program" approach. (The significance of the gaps that appear in some of the forecast results is unclear but is unimportant for our purposes.)

The results in the figures are interesting in terms of topical areas and time frames. An observation is that predictions involving known principles or extensions of existing programs tended to be overly optimistic concerning when the events would occur. Most of the forecasts had to do with events expected to occur in the next 15 years or so, which is well before the current time (2002). The longest-term forecasts had to do with scientific breakthroughs (see Figure III-2), but, even here, 19 of the 31 forecasts were expected to occur (median) by the year 2000. Then-current programs and controversies also heavily influenced the forecasts. Evidently, decoupling oneself from the current newspaper environment was difficult.

The space progress panel (see Figure III-3) almost correctly forecast the then-programmed plan to put a man on the moon in 1969—forecasting that this event would take place in 1970. However, the essentially political nature of this program was unrecognized, and so a temporary lunar base was forecast by 1975, a permanent lunar base was forecast by 1982, and a manned Mars landing and return was forecast by 1985. Solid-core nuclear propulsion [the Nuclear Engine for Rocket Vehicle Applications (NERVA) program,[7] which was then underway] was expected by 1975.

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6 These figures appear on pages III-10–III-15.

7 Despite the fact that nuclear propulsion has consistently come up as one of the most promising propulsion concepts for human missions beyond Earth orbit, little more than study has been done since the NERVA program was suspended in 1972.

Similarly, in weapon systems (see Figure III-4), using lasers for range sensors was expected by 1970 and has certainly been realized, beginning around that time frame. Also forecast by 1978 was an effective terminal defense by ground-launched antimissiles, which may or may not have been related to the SPRINT missile system, which had a nuclear warhead and was deployed at one site and then (along with the SPARTAN missile system) deactivated in the early 1970s. Effective nonnuclear defense against ballistic missiles is, of course, still being pursued. Longer duration aircraft [presumably those of the Aircraft Nuclear Propulsion (ANP) program], "perhaps nuclear-powered," were forecast by 1972. Some "farther out" concepts were still expected much too soon [e.g., weather manipulation for military purposes—possible with a crash program by 1980 but expected by 1990—and directed energy weapons (DEWs) by about 1980].

The various forecasts can be interpreted in several ways, in part, because of ambiguity. It might be argued (see Figure III-2, Sheet 2 of 2, Item 7) that the scientific panel forecast the Internet because the "operation of a central data storage facility with wide access for general or specialized information retrieval" was forecast by 1980. The Internet is distributed (one of its strengths), and widespread data retrieval is possible.

c. An Appraisal of Delphi

The purpose of the RAND study (Ref. 9) was presumably to aid in policy formulation, but we have no way of knowing whether it did. Much of the thinking was heavily oriented toward then-current problems, such as the Soviet threat and other world events. No one had forecast the demise of the Soviet Union, and no one expected that manned exploration of the solar system would not continue more or less immediately. We saw no mention of stealth technology (although possibly an unmentionable at that time), the Global Positioning System (GPS), or the increases in computational capabilities and their implications for precise targeting of weapons. We are not optimistic that a repeat of the exercise today would do any better. It appears that the Delphi technique, with its reliance on groups of experts and its systematic pressure for convergence, is probably more suitable for predicting near-term trends in known systems (e.g., communication systems) than it is for predicting developments beyond or outside current known concepts. It is undoubtedly also useful as a communication medium—an argument made with regard to the Korean study.

For long-term forecasting, some approach other than Delphi is needed. One of the "other" approaches, obviously still unproven by any long-term results, is HMM. NASA has used this concept, and other studies incorporate it to a degree.

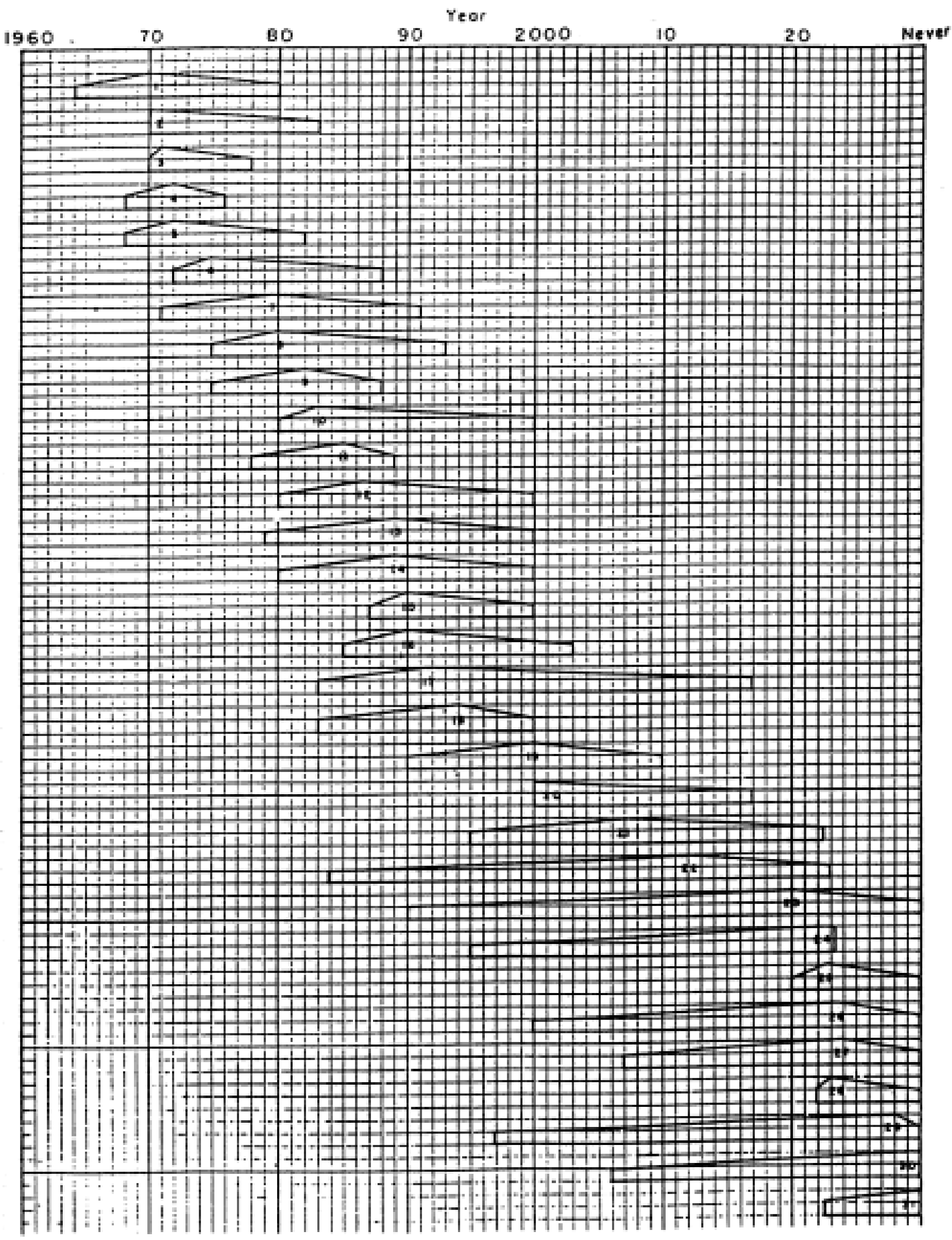

Figure III-2. Consensus of Panel 1 on Scientific Breakthroughs (Medians and Quartiles) (Sheet 1 of 2) (Source: Ref. 9)

1. Economically useful desalination of sea water
2. Effective fertility control by oral contraceptive or other simple and inexpensive means
3. Development of new synthetic materials for ultra-light construction
4. Automated language translators
5. New organs through transplanting or prosthesis
6. Reliable weather forecasts
7. Operation of a central data storage facility with wide access for general or specialized information retrieval
8. Reformation of physical theory, eliminating confusion in quantum-relativity and simplifying particle theory
9. Implanted artificial organs made of plastic and electronic components
10. Widespread and socially widely accepted use of nonnarcotic drugs (other than alcohol) for producing specific changes in personality characteristics
11. Simulated emission ("lasers") in X and Gamma ray region of the spectrum
12. Controlled thermo-nuclear power
13. Creation of a primitive form of artificial life (at least in the form of self-replicating molecules
14. Economically useful exploitation of the ocean bottom through mining (other than off-shore drilling)
15. Feasibility of limited weather control, in the sense of substantially affecting regional weather at acceptable cost
16. Economic feasibility of commercial generation of synthetic protein for food
17. Increase by an order of magnitude in the relative number of psychotic cases amenable to physical or chemical therapy
18. Biochemical general immunization against bacterial and viral diseases
19. Feasibility (not necessarily acceptance) of chemical control over some heredity defects by modification of genes through molecular engineering
20. Economically useful exploitation of the ocean through farming, with the effect of producing at least 20% of the world's food.
21. Biochemicals to stimulate growth of new organs and limbs
22. Feasibility of using drugs to raise the level of intelligence (other than as dietary supplements and not in the sense of just temporarily raising the level of apperception)
23. Man-machine symbiosis, enabling man to extend his intelligence by direct electromechanical interaction between his brain and a computing machine
24. Chemical control of the aging process, permitting extension of life span by 50 years
25. Breeding of intelligent animals (apes, cetaceans, and so forth) for low-grade labor
26. Two-way communication with extra-terrestrials
27. Economic feasibility of commercial manufacture of many chemical elements from subatomic building blocks
28. Control of gravity through some form of modification of the gravitational field
29. Feasibility of education by direct information recording on the brain
30. Long-duration coma to permit a form of time travel
31. Use of telepathy and ESP in communications

Figure III-2. Consensus of Panel 1 on Scientific Breakthroughs (Medians and Quartiles) (Sheet 2 of 2) (Source: Ref. 9)

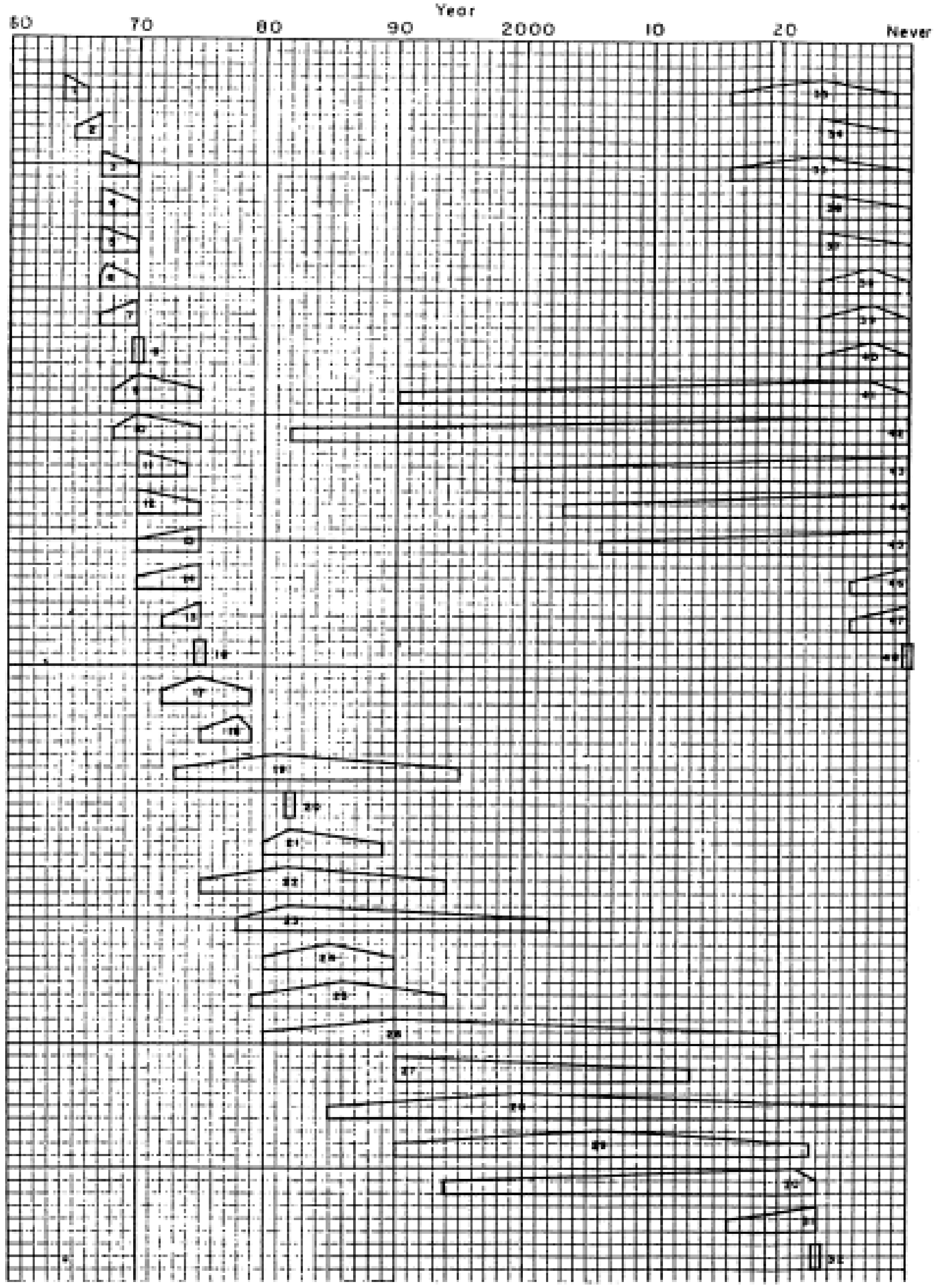

Figure III-3. Consensus of Panel 4 on Space Progress (Medians and Quartiles) (Sheet 1 of 2) (Source: Ref. 9)

1. S.U. orbital rendezvous
2. U.S. orbital rendezvous
3. Increased use of near-earth satellites for weather prediction and control
4. Unmanned inspection and capability for destruction of satellites
5. S.U. manned lunar fly-by
6. Establishment of a global satellite communication system
7. U.S. manned lunar fly-by
8. Manned lunar landing and return
9. Rescue of astronauts stranded in orbit
10. Operational readiness of laser for space communications
11. Manned co-orbital inspection of satellites
12. Manned scientific orbital station – 10 men
13. Development of reusable booster launch vehicle
14. Solid core nuclear reactor propulsion
15. ionic propulsion (nuclear-generator powered)
16. Temporary lunar base (2 men, 1 month)
17. Development of reusable maneuverable orbiting spacecraft
18. Manned Mars and Venus fly-by
19. Reexecution of critical experiments in deep space (Michelson-Morely, speed of light, equality of gravitational and inertial mass, and so forth)
20. Permanent base established on the Moon (10 men, indefinite stay)
21. Manufacturing of atmospheres suitable for human beings on the Moon or planets (no implication of surrounding entire Moon or planet with atmosphere is intended)
22. Deep space laboratories and observatories for high-vacuum, zero-g, and space research
23. Earth weather control: having a highly reliable ability to cause precipitation from certain types of clouds
24. Manned landing on Mars and return
25. Probes (small instrumented unmanned payloads out of the solar system
26. Manufacturing of propellants and raw materials on the Moon
27. Establishment of permanent research stations on near planets
28. Commercial global ballistic transport (including boost-glide techniques)
29. Establishment of permanent Mars' base (10 men for an indefinite period)
30. Manned landing on Jupiter's moons
31. Pluto fly-by
32. Inter-galactic communication
33. Long-duration coma to permit form of time travel
34. Manned multi-generation mission to other solar systems
35. Extra-terrestrial farming
36. Regularly scheduled commercial traffic to lunar colony
37. Communication with extra-terrestrials
38. Competition for planetary raw materials
39. Non-rocket space drive—anti-gravity
40. Manned Venus landing
41. Manned maneuverable geocentric bombardment fleet
42. Space hydrogen ram jet
43. Military force on the Moon
44. Sweeping up Earth-trapped radiation zones
45. Pulsed nuclear propulsion
46. Lunar-based laser beam for use on space vehicle propulsion
47. Heliocentric strategic fleet
48. Radiation immunization (through pills or other means)

Figure III-3. Consensus of Panel 4 on Space Progress (Medians and Quartiles) (Sheet 2 of 2) (Source: Ref. 9)

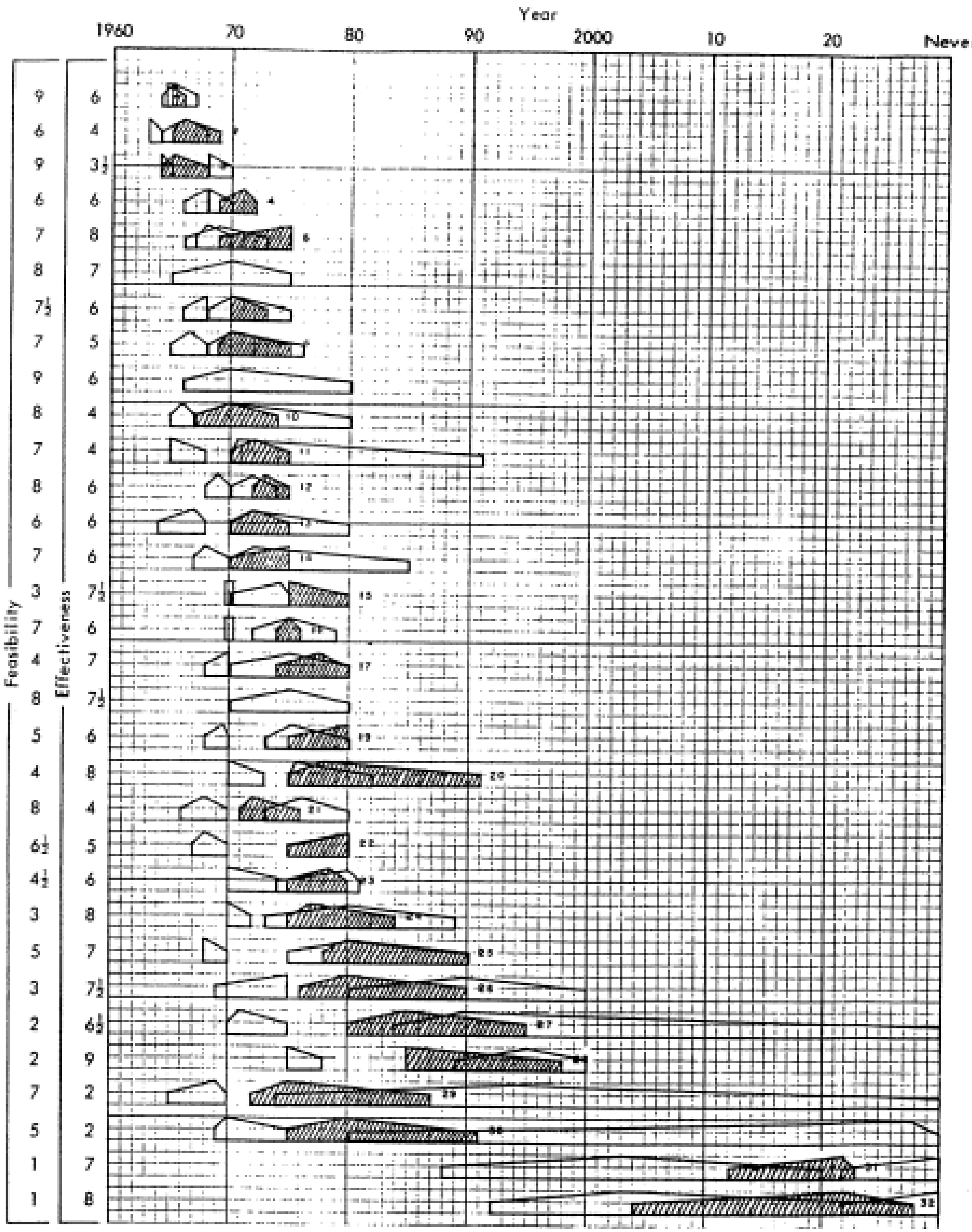

Figure III-4. Consensus of Panel 6 on Future Weapon Systems (Medians and Quartiles) (Sheet 1 of 2) (Source: Ref. 9)

1. Tactical kiloton nuclear weapons for use by ground troops
2. “Economic showmanship”; new foreign-aid techniques to influence nations
3. Extensive use of devices that persuade without killing (water cannons, tear gas, and so forth)
4. Miniature improved sensors and transmitters for snooping, reconnaissance, arms control
5. Rapid mobility of men and light weapons to any point on Earth for police action
6. Incapacitation chemical (as opposed to biological) agents
7. Use of lasers for radar-type range sensors, illuminators, communications
8. Incapacitating biological agents
9. Low-cost lightweight rocket-type personnel armament (silent, plastic, match-lit projectiles capable of single or gang-firing)
10. Lethal biological agents
11. Perishable counter-insurgent arms
12. Orbiting space reconnaissance station
13. Advanced techniques of propaganda, thought control, opinion manipulation
14. Accurate intelligence correlation through use of computers
15. Effective anti-submarine capability, at least against contemporary submarines
16. Longer-endurance aircraft, perhaps nuclear-powered, for logistic supply or bombardment
17. Biological agents destroying the will to exist
18. Penetrating nuclear weapons for deep cratering
19. Automated tactical capability (battlefield computers, robot sentries, TV surveillance)
20. Effective terminal defense by ground-launched anti-missiles
21. ICBMs with other than nuclear warheads (such as snipers)
22. Rapidly mobile public-works and logistics units to war recovery and refugee support
23. Deep-diving submarines made of materials that decrease detection probability
24. Directed-energy weapons (electro-magnetic radiation, particle beams, lasers)
25. Massive civilian defense and post-war recovery plan
26. Weather manipulation (for military purposes)
27. Effective terminal defense by air-launched anti-missiles
28. Effective terminal defense by directed energy beams
29. Large orbiting satellite weapons for blackmail
30. domesticated porpoises or dolphins for anti-submarine reconnaissance
31. Mass-hypnotic recruitment of forces from enemy population
32. Mind reading

Figure III-4. Consensus of Panel 6
on Future Weapon Systems (Medians and Quartiles) (Sheet 2 of 2)
(Source: Ref. 9)

3. HMM

a. Introduction

HMM is much newer than the Delphi technique, and no retrospective examination of its long-term success is possible. NASA's John L. Anderson (Refs. 17, 18) has described the concepts involved. In short, a study group is asked to put themselves into a future time frame in which some technology is assumed to be commonplace. Then, the group is asked to "backcast" to determine how this technology had been accomplished. The general or broad concept of HMM (assuming some future time frame and certain societal organizational characteristics and then looking back to the present) seems to be in fairly wide use in describing future societies [e.g., in *2025* (Ref. 4) and in Air Force studies to be described]. It is not unlike approaches used in science fiction writing.

The focus of Anderson's work using HMM has been on space travel [see also Millis (Refs. 19, 20)], but the concepts involved, as suggested previously, are not limited to this technology area. Anderson (Ref. 17) notes that the HMM method is (or was then, in 1993) being explored as a tool for strategic planning, alternative mission and space system design and analysis, technology requirements analysis and definition, development of investment strategies for basic research, technology assessments and forecasts, and the study of technology innovation. The HMM's objective is to seek breakthrough technology options (BTOs) by moving beyond current technological concepts. In some applications, for example, solutions to problems (e.g., faster-than-light travel) might be sought even though experts would view such travel as violating known principles of physics.

The principles behind HMM are worth noting in some detail. HMM is built up from the concept that (Ref. 17)

> Typical human evaluation of new ideas such as BTOs appears to be governed (and limited) by "inner models" of reality defined as paradigms. A paradigm is an internal frame of reference that performs at least two cognitive functions: it sets forth the "game" being played, the boundaries for what is allowed (or feasible), and the rules for successful operations (problem-solving) within those boundaries; it also acts as a physiological filter—literally—screening the vast flow of incoming data to permit passage only of data perceived to be "relevant" to current "game." We humans use these paradigms to evaluate new ideas, bound our problem-solving approaches, and determine our decisions and actions relating to our circumstances and goals. However, the very nature of an innovative idea places it outside current paradigms, specifically outside the framework of current engineering practices and technology evaluation rules. Thus new ideas are always evaluated by old models. . . . If BTOs are to be analyzed and evaluated comparably to conventional advances in technology, methods are

needed to overcome these blocks, the Horizon Mission Methodology was devised for this purpose.

The HMM method poses a problem that is difficult, or even impossible, to solve with existing technology or reasonable extrapolations. To solve this problem, the study group must "look outside the box" (i.e., open their minds and consider other possibilities). Figure III-5 illustrates the concepts. The inventors (e.g., NASA) visualize a plane on the left as representing all the present knowledge available to prophets by the shaded area. The information that is unavailable to the prophet because it is unknown is contained in the rest of the plane. The plane on the right represents all the future knowledge. The beam emanating from the left plane represents a subset of knowledge in the present known to the prophet. It projects into the future to irradiate an area of knowledge that can be extrapolated from the present. Outside of this circular area is the rest of the future plane. It contains solutions to future problems not imagined by strict projections from the present, using physical laws known at present and reasonable extensions into the future.

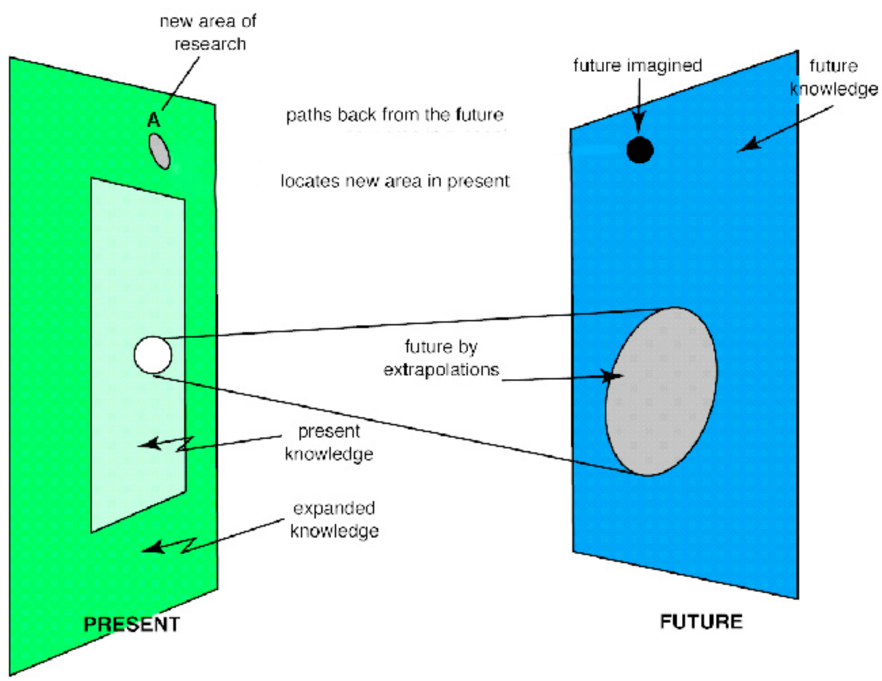

Figure III-5. Predicting the Future—A Graphical Explanation of HMM (Source: NASA)

Consider a concrete example. Suppose the year is 1950 and ideas are being sought to find materials that would be superconducting at much higher temperatures than those currently known (presumably, in 1950, liquid helium temperatures.) The right-hand plane would represent the year 2000. The gray ellipse in the center of this plane would illustrate projections of current (1950) approaches. This area is larger than that in 1950 but is still within the conceptual boundaries. It would be assumed that much higher temperatures could be achieved by operating outside these boundaries, as suggested by point A, which, by speculation, might represent ceramics rather than metals. The concept is backcast to A, the area of research on Cu-oxide ceramics that eventually led to high-temperature superconductivity in 1986. Had the HMM approach been used, high-temperature superconductivity might have been achieved earlier than 1986. This example is easy to accept because it can be related to historical events. However, some other physical limit, deeply rooted in theory and well established experimentally (e.g., the speed of light in a vacuum) is more daunting.

Nevertheless, HMM might ask the question, Can travel that is faster than the speed of light be possible in the future and be represented as a spot on some future plane, such as the dotted one shown? Can it be connected to some research work in the present? HMM would argue as follows: Looking toward the future, we usually just extrapolate from the present as represented by the center beam and the projection of area in Figure III-5. What we see is what our paradigms and single extensions of our present limit allow us to see and tell us is possible. The rest of the future is reachable only by "jumping out of the box" or using different paradigms. If we are to be more successful in predicting the future of technology, we must imagine new concept possibilities and pathways.

Anderson (Ref. 17) outlines the steps by which an HMM study is carried out:

- Identify or define hypothetical "horizon" space missions whose performance requirements exceed extrapolations of known technologies
- Determine mission function, capability, and performance requirements
- Identify the implicit (and limiting) engineering assumptions associated with the requirements
- Develop alternative engineering assumptions (AEAs)
- Identify and evaluate BTOs that enable AEAs
- Identify the practical BTOs and determine their technology requirements based on analogous functional needs of nearer term missions.

HMM participants are asked to be visionary and to entertain—at least for the duration of the process—the notion that the breakthroughs identified can indeed be achieved. The breakthroughs are required to enable the future scenario to exist. At the same time, sound and tangible research approaches are asked for "credible progress toward incredible possibilities." In addition to the critical unknowns and make-or-break issues associated with the ideas, any curious effects (confirmed or unconfirmed) that may support the goals are requested. Participants are also required to suggest present research projects that could evolve into the technology of the future.

b. NASA's Applications of HMM

Two types of activities using HMM are evident from the NASA-published literature. One activity, in workshops organized by John L. Anderson (NASA Headquarters), focused on the theoretical development of HMM and its application to various issues. The topics addressed by these workshops were

- Advanced technology for robotic and human exploration and development of the solar system
- Health sensors for humans and animals in space
- Design of radically new space and aeronautics vehicles
- Biomedical capabilities in 2025
- Near-term value and future potential of new ideas
- Space propulsion applications of theoretical and experimental anomalies in quantum and relativistic physics
- Biological metaphors for future electronic products
- Radically new "human-intelligent" machine combinations for a lunar territory
- Human relational concepts for global problem-solving
- Restructuring technology research programs
- Defining a new organizational mission, future, market, or product through new metaphors.

The other activity, led by Marc G. Millis [Glenn Research Center (GRC)],[8] focused on the space travel issue. The objective of this activity was to identify research projects that could conceivably provide revolutionary propulsion systems for space travel (interplanetary and interstellar). The program is called the NASA Breakthrough Propulsion Physics Program, for which NASA sponsored a workshop in August 1997 (Ref. 20). The objective of the workshop was

> . . . to assess the prospects emerging from physics that might lead to creating the ultimate breakthroughs in space transportation: propulsion that

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8 John H. Glenn Research Center (NASA; formerly Lewis Research Center, Cleveland, Ohio).

> requires no propellant mass, attaining the maximum transit speeds physically possible, and breakthrough methods of energy production to power such devices. Because these propulsion goals are presumably far from fruition, a special emphasis was to identify affordable, near-term, and credible research that could make measurable progress toward these propulsion goals. Experiments and theories were discussed regarding the coupling of gravity and electromagnetism, vacuum fluctuation energy, warp drives and wormholes, and superluminal quantum tunneling.

A series of presentations and poster sessions followed. Appendix D provides details about this workshop. About 80 specific research task ideas were generated to make progress toward propulsion breakthroughs. Research approaches were identified and arranged according to the three program goals. Intriguing phenomena and theories, critical issues, and candidate approaches for each program goal were proposed. Funding decisions were expected in July 1999.

c. A Preliminary Appraisal of HMM for Technology Advancement

The HMM process is appealing because it provides a procedure that allows participants to abandon their conventional thought processes and permits the identification of possible scientific "surprises" and technical breakthroughs. In our view, these desirable characteristics are less well embedded in the Delphi process and are not formally recognized in classical brainstorming. Our primary reservation, perhaps, is that too much might be expected of the process, and this could lead to early disillusionment and perhaps premature rejection of the approach. We also suspect that fundamental breakthroughs are more likely the result of some genius' lone pondering, such as Einstein's work on relativity, rather than that of a workshop and that these breakthroughs cannot be forced or hurried. However, a workshop might stimulate the genius, who might then pursue the concept privately.

4. Service Studies

a. Air Force Studies

The Air Force, like the other Services, forecasts and projects on a continuing basis at various security levels. In our limited effort, we will not make any attempt to conduct a comprehensive review of these efforts but will instead focus on two:

- The Air Force 2025 project (Ref. 21)
- SPACECAST 2020 (Ref. 22).

The Air Force 2025 Project

The objectives of the Air Force 2025 project, which was one of several long-range planning initiatives then under way within the Air Force, were promulgated by the Air Force Chief of Staff in a tasking message to the Commander, Air University (AU), Maxwell Air Force Base, Alabama, in December 1994 (Ref. 23):

> The study team will generate ideas and concepts on the capabilities the United States will require to possess the dominant air and space forces in the future. . . . The final product will be a collection of white papers detailing findings regarding air and space capabilities required for future warfare, new or high-leverage concepts for employing air and space power, and the technologies required to enable the capabilities envisioned.

The key metric for the study was the avoidance of surprise. The approach used took particular efforts to avoid linear thinking (i.e., to "think outside the box" and to avoid the pitfalls of simple projections) and is worth describing in detail here. The approach used is most easily and perhaps best described by quoting from a research paper that Col Joseph A. Engelbrecht et al. presented to Air Force 2025 (Ref. 24):

> **Approach**
>
> The Air Force is embarked on a mission to improve its long-range planning. An important aspect of that mission is to envision the future so the Air Force can position itself to provide the required capabilities. This chapter discusses how the Alternate Futures team derived visions of six alternate futures. To accomplish this, ***2025*** study participants analyzed current trends, studied the work and methods of respected futurists and scientists, and considered possible impacts of "wild cards" or surprises. This review provided a foundation from which to begin analyzing possible "drivers"—the factors which will drive major changes in the world over the next 30 years. The interactions of these drivers produced an infinite number of worlds; six were selected as the most interesting or stressful for the customer. Plausible histories and descriptions of unique features provided detail to these futures and linked them to today. This approach created viable futures which stepped beyond mere extrapolations of current trends. The steps of the alternate futures process are:
>
> 1. selecting the drivers,
> 2. defining the drivers,
> 3. creating the strategic planning space,
> 4. naming and selecting worlds of interest,
> 5. describing the "nature of" and features of each world, and
> 6. developing plausible histories.

Metrics for Success

Good strategic planning meets three requirements. First, the alternate futures created should adequately stress the systems of interest. Secondly, the alternate futures must contain sufficient detail and richness to be useful for planning. Finally, the vision of the future should be broad enough to ensure the entire range of challenges are adequately captured; in other words, ensure the customer is not surprised by the future.

Selecting the Drivers

The first step in creating the alternate futures was identifying the drivers that would be most influential in shaping the future. Drivers are physical or virtual forces or vectors which are expected to be a significant cause of or contributor to change. A driver should also be beyond the strategic planner's (customer's) control—the customer's only viable option must be adaptation to the change produced by the driver. Correct driver selection was fundamental to creating alternate futures.

This process began with dividing the 225 study participants at the Air University (AU) into 14 seminars. Each seminar then used a combination of scientific and nonscientific methods to develop a list of potential drivers. The scientific methods involved analyzing various trends, conducting research on various topics, interviewing respected futurists and scientists, and completing affinity diagrams. The nonscientific methods involved creative thinking techniques such as brainstorming, "exploring," and "artistry." All told, over 100 candidate drivers were generated by this process. One or two individuals were then nominated from each seminar to evaluate all of the potential drivers. These individuals comprised the ***2025*** Alternate Futures group.

This group's initial task was to identify drivers that were relevant to the customer and would significantly impact the future. The group accomplished this task by using affinity diagrams to coalesce the initial list into a smaller number of drivers. A variety of quality concepts and brainstorming techniques narrowed the initial list to five major candidate drivers. These candidate drivers were the U.S. world view, the environment and level of resources, economic forces, technology issues including proliferation, and the nature of global power.

The group's goal was to consolidate these five candidate drivers into three drivers. For three months, the Alternate Futures group extensively analyzed trend data, conducted research, brainstormed, and discussed the merits of these drivers. The study group determined economic forces could be expressed in a multifaceted driver which captures the essence of world power. The study group also concluded that the state of the environment and resources would be an important factor in the future, but not as relevant to air and space power as other drivers.

In the paper that Col Engelbrecht et al. presented to Air Force 2025, the three drivers are further named and described as follows (Ref. 24):

- **American World View.** America's view of its role in the world is an important driver in terms of the military's role. Its dimensions are Domestic and Global. If this view is focused on the Domestic, it will be less concerned with global affairs. Conversely, if this view is focused on the Global, it will be less concerned with domestic affairs.
- **ΔTeK.** This cryptic designation covers not only the ability to employ technology, but also the differential in the rate of growth in technological proliferation and sophistication. ΔTeK is further broken into Constrained and Exponential dimensions, which relate to the rate of growth in technology and the extent of its application. In the Exponential ΔTeK version, new technologies may become obsolete even before they are fielded.
- **World Power Grid.** This concept incorporates the generation, transmission, and distribution of political, military, economic, or informational power throughout the world. It is further divided into Concentrated (with few actors controlling) and Dispersed (with thousands of actors controlling).

These three drivers in their combinations formed eight worlds. These worlds were given colorful but descriptive names, which formed in "strategic planning space" the corners of a cube, as shown in Figure III-6.

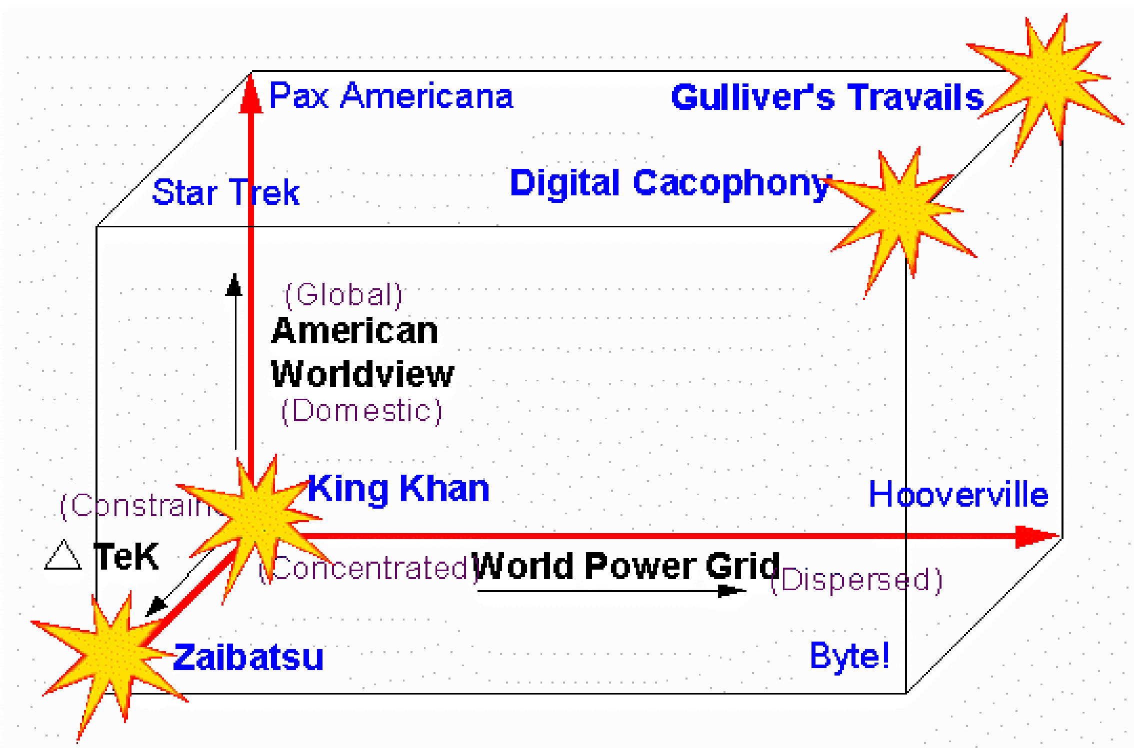

Figure III-6. Strategic Planning Space With Named Worlds at Extremes (Source: Ref. 24)

Of these eight worlds, four were considered to be the most interesting: Gulliver's Travails, Zaibatsu, Digital Cacophony, and King Khan. These worlds were then given "flavor," adding richness to the worlds in terms of economic activity, international politics, news gathering, entertainment, hopes and fears, and so forth. Plausible "histories" were then created by backcasting to determine how such worlds had developed. For example, in Gulliver's Travails, it was postulated that that the American World View became more global following a major terrorist attack in the early 21st century.

At the midpoint of the study (January 1996), the Alternate Futures team briefed this work to Air Force 2025 students, faculty, executive committee, and so forth. Feedback from this briefing led to two additional alternative futures: one being at the "midpoint" of each driver and in the other the world of 2015, in which a strategic crossroads were encountered, leading to a fork in the road. This led to six worlds in all, which provided a complete and robust set of planning environments that were used to stimulate the development of new concepts and technologies.

The conclusions reached, which are general in nature, noted that the alternative worlds developed provide an excellent framework for analysis and recommended using these futures in long-range planning. It is stated that the "synthesis has created what the authors believe is the most robust and comprehensive futures methodology developed to date within the U.S. Government" (Ref. 25).

SPACECAST 2020

In May 1993, the Chief of Staff of the United States Air Force directed AU to identify capabilities for the period 2020 and beyond and the technologies to enable the Air Force to support the security of the United States. A 10-month study resulted, during which time the study team examined the full vertical dimension, including the transatmosphere. The study is reported on the Internet (Ref. 22) and provides more in the way of technical detail (and perhaps less in the way of methodology) than does the Air Force 2025 project (Ref. 21). The study was actually carried out in 1994 and included over 350 participants, including AU faculty, Air Force Institute of Technology (AFIT) scientists and technologists, and the many personnel from vastly different backgrounds. SPACECAST 2020's stated goal was (Ref. 26)

> . . . to energize thinking and imagination to produce a set of possibilities refined and integrated so that senior leadership could adopt all, some, or none of its major ideas. They could select any of these ideas with reasonable

confidence that they are important issues that the U.S. must address if it is to play a dominant role in space in the twenty-first century.

SPACECAST 2020 created—or more precisely, contracted the preparation of—and examined eight alternative futures at some length. The methodologies ("drivers") employed appear to be similar to those used in the Air Force 2025 project. The document entitled *The SPACECAST 2020 Process* stated that "SPACECAST set out to understand the operating environment of 2020, space power, and the space capabilities and hardware required for national security in the first half of the 21st century. SPACECAST met those objectives" (Ref. 27). Overall, there appears to have been less emphasis on the future societies and more emphasis on how systems might develop and be applied. The study did not "pretend to provide the vision of the future" (Ref. 28) (in which, presumably "the" implies one expected future), arguing instead that the participants could speculate in an informed fashion on the technologies that would be of most value and that are not beyond plausibility. The HMM, with Dr. John L. Anderson's participation, was used to examine far-future lift systems. The AFIT sought the creativity of the entire staff and student body in attacking the same problem. It was concluded that no "magic bullet" exists.

Three types of technology were noted:

1. Fast-track technologies characteristic of industry and the private sectors (e.g., computers, electronics and communications)
2. Hybrid public and private ventures in which government investment has been important and commercial spin-offs are possible
3. Large, complex technologies (e.g., weapon systems and space lift), which require large investments and have no immediate civilian applications.

The arguments continue, summarized by the statement that "inexpensive space lift is the enabling element which makes the other aspects a reality" (Ref. 29) and calling for government support on a large scale.

Several papers that explored various aspects of what are termed Global View, Global Reach, and Global Power[9] were prepared. Various discussions are provided regarding topics encompassed by these concepts, including space traffic control, space modular systems, counterforce weather control, and even planetary defense (asteroid interception). The systems called for include an integrated demand information architecture, a TransAtmospheric Vehicle (TAV), and development of a space-based laser (SBL) system

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9 See http://tuvok.au.af.mil/Spacecast/TOC1.html.

for surveillance and counterforce operations. Enabling technologies, many lacking much specificity (e.g., optics, lasers, liquid rocket propulsion, and so forth) were noted. Supporting critical technologies included high-performance computing, micromechanical devices, and materials technology. More specific recommendations were made in some tasking areas (e.g., unconventional space lift, which examined concepts such as nuclear propulsion, orbiting elevators and so forth and resulted in a recommendation for research into high energy-density fuels, high strength-to-weight materials, nuclear engine design, and the dynamics of tether systems).

SPACECAST 2020 offers some lessons learned (Ref. 30):

- Begin with a very specific purpose and a clear vision of the desired end state
- Designate only one individual as the critical node in the study network
- Build and publish all milestones in advance
- Do not pass up opportunities, but do not deviate from the schedule unless a deviation provides extraordinary advantages
- Be open to discovery
- Remain aware that history is being made
- Continue.

The SPACECAST 2020 process led to new ideas, new funding, and new research projects. "By standing in the far future and looking backward to the present, SPACECAST helped plot the course into the future. How that future turns out, of course, cannot be known until 2020. One thing is certain: the SPACECAST process worked" (Ref. 31).

We would add only one final comment. Gen. Michael P.C. Carns, USAF (Ret.), in his Closing Remarks at the SPACECAST 2020 Symposium, called for the "operationalization of space" (Ref. 32). Afterwards, he was asked whether he foresaw the Air Force giving up the F-22 for the TAV. His answer, "Bottom line: we need both" (Ref. 32). Studies of the long-term future are primarily directed toward the initiation of new and usually small-scale efforts and cannot be expected to address the viability of ongoing weapon systems.

b. Army Studies

The Army War College's Strategic Studies Institute (SSI) at Carlisle, Pennsylvania, has a history that dates back to 1947. It "continues to provide an analytical capability within the Army to address strategic and other issues to support Army participation in national security formulation" (Ref. 33). It also has a long list of publications,[10] many of which are thoughtful studies by individual authors (all specialists) related to various aspects of the Army and its missions. For example, *Future Warfare: Anthology*, by MG Robert H. Scales, Jr. (Ref. 34) includes several thought-provoking articles on the history of warfare and on the role of technology (and its limitations). MG Scales points out that dominant technologies (or approaches such as firepower vs. mobility and so forth) change with time as armies learn to adapt.

One prominent study topic was the Army After Next (AAN)[11] (Ref. 35), which was intended to project the Army some 30 years in the future (presumably allowing 15 years for today's Army and 15 years for the next Army). The Chief of Staff of the Army and the Commander, Training and Doctrine Command (TRADOC) established the AAN project in February 1996 (Ref. 35). In his own words, MG Scales says:

> The AAN Project has become a laboratory—part technology-oriented, part military science—in which the Army works with other Services and agencies of government, academic institutions, and civilian industry to build ideas about the future. AAN differs perhaps from the efforts of other futures groups in that its participants take extra care to subject ideas to both the considered experience of military history and the analytical rigor of state-of-the-art gaming (Ref. 34, p. 143).

AAN clearly involved similarities to other studies because the participants were asked to visualize 2025 and the types of battles that may take place in this future world. Technology, the topic of most interest, was viewed as "the path to knowledge and speed" (Ref. 34, p. 165). Information technology was used to create a "knowledge-based Army . . . to act on its superior knowledge by building into its structure the physical agility to move rapidly and adroitly across a larger and more lethal battlefield" (Ref. 34, p. 165). Unmanned aerial vehicles (UAVs) were one important aspect of the information technology goal.

While technology was viewed as one of the key ANN elements, an earlier study sponsored by the Army and conducted by the National Research Council (NRC), is more specifically directed to that topic. *STAR 21: Strategic Technologies for the Army of the Twenty-First Century* (Ref. 36) was published in 1992 and projected 30 years into the future. This book summarized emerging developments in robotics, brilliant munitions,

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10 See http://carlisle-www.army.mil/usassi/ssipubs/catalogs/Catalog.htm.

11 The Army is no longer pursuing the AAN study.

medical support, laser sensors, biotechnology, novel materials, and other key areas. It identified new systems and emerging technologies that offered the greatest payoff for the Army and addressed a host of important military issues, including the importance of mobile, rapidly deployable forces and how commercial technology may help the Army stay ahead of potential opponents. It also provided technology-relevant lists, Army technology base key emerging technologies, and tables that list defense critical and national critical technologies.

The manner in which the STAR 21 study was organized is also interesting. Independence of effort was a key requirement. The Army's cooperation was solicited to provide the perspective of technology users, but the NRC insisted that such cooperation could not compromise the independence of the study. The views and conclusions are entirely those of the STAR 21 study members.

In carrying out the STAR 21 study, the NRC organized a Committee on STAR, composed of nine S&T groups and eight systems panels. Three subcommittees were set up:

1. A Science and Technology Subcommittee
2. A Technology Management and Development Planning Subcommittee
3. An Integration Subcommittee.

These three subcommittees reported directly to the study chairman.

The Science and Technology Subcommittee and its nine S&T groups were responsible for preparing forecast assessments, which were published separately. The eight systems panels projected technological opportunities into systems capabilities thought to be important to the Army in the next 20 to 30 years, using military context from the Technology Management and Development Planning Subcommittee. The Integration Subcommittee examined the future operational environment in which the Army might find itself.

The STAR 21 effort appears to have found a good balance between scenario development (alternative future worlds) and technology projections. Many of the technology goals seem to be focused correctly—even now, some 10 years since their preparation—although some currently "hot" technologies (e.g., MEMS) are not recognized. Not all quarters may have appreciated some of the STAR 21 policy recommendations [e.g., that the Army should take over leadership of the ballistic missile defense (BMD) effort]; however, the NRC, being independent, was presumably not constrained by concerns about impacts on ongoing large-scale weapon systems programs, as might be the case with some agencies closer to such programs.

c. Navy/Marine Corps Studies

In 1992, the Navy released a paper called *…From the Sea: Preparing the Naval Service for the 21st Century* (Ref. 37).[12] This paper defined the operational and strategic concept for naval warfare in the 21st century. It was developed in the wake of the Cold War and reflected a broad reevaluation of purpose and direction for the Navy and Marine Corps. The paper emerged because of a major shift in national security policy that President George H. Bush announced at the Aspen Institute in 1990. This new National Security Strategy presented fundamental changes in military priorities. The new policy emphasized preparing for regional conflicts as opposed to preparing for global threats. Rather than defend against possible global war, the military would be used to stabilize regions critical to national security.

…From the Sea: Preparing the Naval Service for the 21st Century represented the Navy's effort to be full participants in this modified vision of global order. It described the Navy of tomorrow as expeditionary, with an emphasis on controlling littoral (coastline) areas throughout the world. The Navy identified four central elements for their new strategy (Ref. 37):

1. Strategic deterrence and defense
2. Forward presence
3. Crisis response
4. Reconstitution.

While this paper served as a major strategic document, specific technologies that might be used in this new theater did not receive much attention. It did describe some general capabilities that will be crucial in the future (e.g., sealift), but, overall, it was more a statement of purpose. The document forms the conceptual framework for all future forecasting within the Navy.

Forward…From the Sea (Ref. 38), the follow-up to the Navy/Marine Corps White Paper, *…From the Sea: Preparing the Naval Service for the 21st Century*, expanded upon

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12 See http://www.chinfo.navy.mil/navpalib/policy/fromsea/fromsea.txt for the complete text of this Navy/Marine Corps strategy statement.

the concepts outlined in *…From the Sea* to address specifically the unique efforts of future Naval forces. This paper [*Forward…From the Sea* (Ref. 38)] emphasized the importance of flexibility for new naval units and the ability to participate in joint force operations. As with *…From the Sea*, it did not discuss specific technologies that may be critical in the new Navy; rather, it discussed the general capabilities that will be necessary to protect the new ideas of national security.

Another paper to emerge from the new national security policy is *Operational Maneuver From the Sea*, or OMFTS, (Ref. 39). This paper described in more detail the possibilities for the Navy under the new doctrine, including an example future scenario. One of the more interesting portions of the document described the threats in future society. The breakdown of world order was identified as the next great threat to security (Ref. 39, p. 5):

> Though there is much war in the news, there is very little mention of "soldiers," those who belong to the regularly constituted armed forces of established states. Instead, most of the fighting is done by people in the much broader category of "fighters." At a time when most states are reluctant to risk casualties among their well organized and well paid regular forces, there seems to be no shortage of men who are willing to pick up a weapon and defend the cause of their ethnic group, religion, clan, or tribe usually as an unpaid volunteer

The OMFTS paper also described the potential for the rapid emergence of another major superpower and the impact that this would have on the United States. It included a sample scenario, with a description of the new doctrine. It also provided a list of capabilities that will be crucial in the future (Ref. 39, pp. 14–15):

- **Mobility.** Mobility will include high-speed, long-range, maneuverability, with the flexibility to transition from sea to land and vice-versa.
- **Intelligence.** Intelligence includes rapid dissemination of information, with the capability to predict enemy actions.
- **Command and Control (C2).** Command personnel will be educated and trained under the new doctrine, which will be different previously developed techniques.
- **Fires.** Sea- and shore-based fire systems must be developed to provide the increased range, accuracy, and lethality necessary for effective fires.
- **Aviation.** Aircraft must be capable of operating from a variety of ships and bases and landing on several different surfaces.

- **Mine Countermeasures.** Mine/obstacle reconnaissance, mine marking and clearance, and mine neutralization capabilities must be improved.
- **Combat Service Support (CSS).** Sustaining fast-moving, powerful armed forces as they deploy from a ship to a shore-based objective will be difficult. CSS flow must be efficient and timely.

The Navy's forecasting effort that has developed from the *…From the Sea*, *Forward…From the Sea*, and *Operational Maneuver From the Sea* papers seems to focus heavily on scenario development. Much less attention is paid to the issue of technology projections. In addition, although these papers do not detail the methodologies used for developing these scenarios, the scenario development has proved to be fairly accurate in recent years. The Navy clearly has a vision of what battles will be like in 2025, but these studies have not focused on what new technologies will be used in these battles.

5. IDA and the MCT Process

IDA is evaluating emerging technologies and their criticality to the United States. For example, MCT Part III (Ref. 40) has the objective of identifying technologies that will produce "increasingly superior performance of military systems or maintain a superior capability more affordably"—looking beyond the usual DoD 5+ year planning period as far into the future as is reasonable. The MCT approach uses Technology Working Groups (TWGs) composed of technical experts to generate these advances, which must be identifiable and not simply dreams or wish lists. These objectives are consistent with MCT goals, which must involve realism and credibility.

MCT Part III covers 20 technical areas.[13] When finalized, this listing should cover much of the identifiable advanced technology that will be important to DoD in protecting its current lead in advanced weaponry. Any individual or group that is interested in advanced technology should review the MCT documents. However, in MCT Part III, readers should

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[13] **Section 1:** Aeronautics Technology, **Section 2:** Armaments and Energetic Materials Technology, **Section 3:** Biological Technology, **Section 4:** Biomedical Technology, **Section 5:** Chemical Technology, **Section 6:** Directed and Kinetic Energy Systems Technology, **Section 7:** Energy Systems Technology, **Section 8:** Electronics Technology, **Section 9:** Ground Systems Technology, **Section 10:** Information Technology, **Section 11:** Lasers and Optics Technology, **Section 12:** Manufacturing and Fabrication Technology, **Section 13:** Marine Systems Technology, **Section 14:** Materials and Processes Technology, **Section 15:** Nuclear Systems Technology, **Section 16:** Positioning, Navigation, and Time Technology, **Section 17:** Sensors Technology, **Section 18:** Signature Control Technology, **Section 19:** Space Systems Technology, and **Section 20:** Weapons Effects Technology. See http://www.dtic.mil/mctl/.

not look for advances that might involve new principles or interactions that would likely be considered outside current paradigms.

C. AN INFORMAL APPROACH: SCIENCE FICTION

1. Past and Current Contributors to Science Fiction

We can debate whether what is termed "science fiction" has any methodology. Thus, its inclusion in this discussion may need some defense. Science fiction, as its name suggests, is fiction. As a result, it is not a reliable method of predicting technology. However, a key element of science fiction is the creative use of imagination and the creation of scenarios in which standard societal rules may not apply—a conceptual situation not too dissimilar from those employed in some of the alternative future scenarios described previously.

Science fiction is not without its scientific or philosophical merits; therefore, its history and some of its results seem worthy of discussion. Certainly, Sir Arthur C. Clarke (1917–Present) strongly defends science fiction as a means of "expanding" thinking and for considering alternative futures. Clarke (Ref. 41) states that:

> A critical—the adjective is important—reading of science fiction is essential training for anyone wishing to look more than 10 years ahead. The facts of the future can hardly be imagined *ab initio* by those who are unfamiliar with the fantasies of the past.

Broadly interpreted, "science fiction" is old. Mother Shipton's Prophecies might be noted.[14] Leonardo da Vinci (1452–1519) had many solid technological concepts, including helicopters, which, at times, lacked only adequate power sources. Jonathan Swift (1667–1745), in *Gulliver's Travels* (1726) satirized science, scientists, and society in general and created artificial societies in which to do so. Michel de Nostradame (1503–1566), more commonly known as Nostradamus, the astrologer and seer, is probably a bit too mystical to include.

Jules Verne (1828–1905) and Herbert George (H.G.) Wells (1866–1946) are also notable examples of science fiction authors who have either forecast or suggested impor-

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14 Mother Shipton reputedly was born Ursula Sontheil in 1488 in Norfolk, England, in her now famous riverside cave at Knaresborough. She spoke of the discovery of gold in a far-off land as yet unknown, the great fire of London, the defeat of the Spanish Armada, and the wonders of modern technology. She even forecast her own death at the stake in 1561.

tant developments in science or technology. Science fiction, whether in movies, comic strips, or books, has expanded in scope since the days of Verne and Wells to the point that thousands of authors now consider themselves members of the genre. Obviously, some of these authors are simply writers with creative minds. However, science fiction contains a host of well-researched, theoretically plausible technologies.

Jules Verne described rockets to the moon and long-duration submarines and in his classic books *From the Earth to the Moon* (1866) and *20,000 Leagues Under the Sea* (1870). H.G. Wells, in *War of the Worlds* (1898), described a beam weapon that was uncannily similar to an infrared (IR) laser. Nuclear weapons postulated in science fiction articles in the 1930s were sufficiently close to the technology that caused concern during the early 1940s. In some cases, science fiction was so accurate in predicting technologies that patent lawsuits were occasionally filed. H.G. Wells attempted to sue the British government in 1916 when armored tanks were first developed. He claimed that he had developed the idea for tanks in his work *The Land of the Ironclads* (1903).

One science fiction author who has attempted to tie technology and science fiction together is Dr. Robert L. Forward (1932–Present).[15] Dr. Forward's books, short stories, and technical articles discuss antimatter, neutrino communication, black holes, starships, space warps and time machines, and other intriguing matters. Dr. Forward believes that the technology often moves faster than people realize (Ref. 42):

> Nowadays, the distance in time where future science fades into future magic is only decades away. The best example is spaceflight. Who, in 1929, in the bleakest days of the depression [sic], would have thought that in four decades there would be a man walking on the moon? Here we are today, living among and using these magical wonders that were so impossible that our parents and grandparents couldn't even imagine them. What will be the magic in our future? It is impossible to predict, because as soon as we can tell exactly how it can be done and when it will be done, then it is no longer future magic, but future technology.

We have the benefit of time to evaluate older science fiction forecasts. The more difficult task is attempting to predict which technologies in science fiction will emerge in time. From a technology perspective, much current science fiction, including works by Arthur Clarke, has evolved into what some would consider pure fantasy. However, this perception could be shortsighted. What surely seemed like fantasy in the late 1800s and early

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[15] Dr. Forward, in his own words, is "a Physicist first, Gravitational Engineer second, Aerospace Engineer third, Science Writer fourth, and Science Fiction writer fifth." His website address is http://www.whidbey.com/forward/.

1900s is now standard technology. Although we are currently engulfed in one of the largest technology revolutions in history, we have no way of telling just what the future of technology holds.

2. Science Fiction as a Predictive Tool

Measuring or quantifying the success rate of science fiction as a predictive tool is impossible. However, by examining technologies that were first described in science fiction, we can gain a greater understanding of what it has to offer. In addition to technologies that have been successfully predicted by science fiction, a host of other technologies, while not yet fully implemented, could emerge as major developments over the next 50 years.

a. Transportation

Transportation is an area which science fiction has made multiple technology predictions. From travel at light speed to warp drives to teleportation devices, transportation is a key facet of science fiction. Space travel of any kind, especially intergalactic or interstellar travel, requires major technological developments, many of which are difficult and expensive but not impossible. Changing vehicles and incredible propellants will revolutionize high-speed travel (at less than light speed) in the next century.

If the evolution of the transportation industry in the 20th century is any indication, interplanetary journeys in reasonable amounts of time will indeed be possible within the next 50 years. Edward Elmer (E.E.) "Doc" Smith (1890–1965), one of the seminal figures in science fiction, discussed in early science fiction one of the methods for high-speed travel. He described an "inertia-less drive," which used manipulated gravitational fields to achieve very high velocities for vehicles. A propulsion system that used gravitational fields would be able to overcome the massive accelerations and decelerations needed for high-speed travel. Propulsion without mass expulsion (see Appendix D) was another idea introduced by science fiction. Norman Loramer Dean (1902–1972) went so far as to receive a patent for his "Dean Drive," (Ref. 43) which supposedly converted rotary motion into linear directional motion without expelling mass.

High-speed travel will ultimately make travel between planets a relatively trivial task. Traveling between stars, however, will require speeds that approach the speed of light. The foreshortening of perceived time at speeds close to light speed would allow interstellar travelers to visit distant solar systems without aging to the same degree as a stationary person on earth. This concept of "slower" time adds an entirely new dimension to transportation as we know it. The concept of moving at speeds at or above the speed of light is one that even some science fiction authors are not ready to accept as possible. Warp speed and hyperspace from the *Star Trek* television series (1966–1969) and the *Star Wars* movie (1977) may never be realized.

Arthur Clarke, in his book *Profiles of the Future* (Ref. 41), has this to say regarding interstellar travel:

> One day—it may be in this century, or it may be a thousand years from now—we shall discover a really efficient means of propelling our space vehicles. Every technical device is always developed to its limit . . . and the ultimate speed for spaceships is the velocity of light. They will never reach that goal, but they will get very close to it. And then the nearest star will be less than five years' voyaging from the earth.

So, while light-speed travel or travel beyond light speeds may be outside our eventual reach, interstellar and interplanetary travel for humans may well be attainable. Teleportation devices, as described in the movie *The Fly* (1998) and on *Star Trek*, will clearly require technological advances that we cannot begin to conceive today. Devices like these are often described in science fiction but are not foreseeable in the near (less than 50 years) future.

b. Biological Sciences

Science fiction has made several predictions in the area of biological sciences. Biological engineering first appeared with the release of Mary Shelley's *Frankenstein* (1817), considered by many to be the first true science fiction novel. *Frankenstein* dealt with several technological concepts that were well ahead of its time, including xenotransplantation, asexual reproduction, and the use of electricity to stimulate the human brain.

H.G. Wells, in addition to his remarkably prophetic technological descriptions in *War of the Worlds*, was also the first science fiction author to describe the concept of genetic engineering. Wells' classic tale *The Island of Dr. Moreau* (1896) describes a reclusive genius that develops "superanimals" through experimentation with what we know today to be deoxyribonucleic acid, or DNA. With the development of cloned animals and modern discussions of selectively altering the genetic makeup of unborn children, the concept of genetic engineering is emerging as one of today's hottest technology topics. Genetic engineering has been further extrapolated into recent movies such as *Gattaca* (1997), where humans are genetically engineered to fit predetermined roles in society. Aldous Huxley (1894–1963) addressed similar concepts in his novel *Brave New World* (1932). While this extension of genetic engineering is clearly still over the horizon, it is an excellent example of a plausible capability predicted by science fiction that could be of extraordinary—if frightening by U.S. contemporary standards—military utility.

Another example of a biological advance that is used extensively in science fiction is "stasis," the process of preserving someone's body over a long journey or for a long period of time. Robert Ettinger first introduced cryonics (freezing humans to prolong their lifespan) in his book *Prospect of Immortality* (1964). This idea was also used in the *Lost in Space* television series (1965–1968), where several of the characters were cryogenically frozen to preserve their bodies for a long intergalactic voyage. Some institutions today claim to have the capability to freeze terminally ill patients so that they can be regenerated later when medical science has advanced to the point of curing them. While these claims are largely unproven, a current effort to develop this technology is clearly in progress.

c. Communications

The communications field is another area in which science fiction has projected potential technologies. The famous Dick Tracy wristwatch, a two-way, voice-activated videophone that fits around a wrist, was first described in 1946 (Ref. 44) and is now approaching feasibility because of new microelectronics technologies. Also, the wireless communication systems used extensively on *Star Trek* in the 1960s are now appearing on the market. Current wireless phones are shrinking in size so fast that it is not inconceivable to envision a small, pin-shaped instrument for two-way communications worn on the shirt. The major limitation for future communications is not so much the size of the instruments used but the speed at which we can send signals. Without the ability to send a communications signal at a speed faster than light, interplanetary conversations will be practically impossible. Communications with the moon have a 2-1/2 second lag time. Communications signals with colonies on Mars would require 3 minutes to make the journey. Ultimately, communications faces the same barrier that transportation faces: light speed.

d. Colonization

Colonization of other planets and worlds is an idea as old as science fiction itself. While older descriptions of "other-world" colonies were merely fanciful, creative ideas, the modern science fiction writers have made several attempts to describe the creation of other colonies. In *Blue Mars* (1996), the final book of Kim Stanley Robinson's massive epic about the colonization of Mars, Robinson attempts to describe scientifically the possibility of forming a Martian colony through the use of "terraforming," where the weather, atmosphere, and general environment are manipulated to create conditions suitable for colonization. Ray Bradbury also describes the idea of colonization in his *Martian Chronicles* (1950). Arthur Clarke agrees that colonization off of earth's surface will eventually be possible. In an article in *Launchspace* (Ref. 45), Clarke predicted that some day a ring around the Earth in geostationary orbit would be permanently inhabited. Clarke's book, *3001: The Final Odyssey* (1999), has this ring is in place.

The colonization predictions are perhaps the most difficult to realize since few current efforts are in progress in this area. Colonization is not an impossible mission, but one that will require great innovation, and ultimately, great expense.

e. Computing and Artificial Intelligence (AI)

Computing and AI are technologies that receive much attention in modern science fiction. The concept of AI and robots is evident throughout the history of the genre.

Isaac Asimov (1920–1992) is perhaps the most notable author who described a future with intelligent robots. In his *Foundation* series (begun in 1951), he describes a world populated with intelligent machines. This concept has been used in many other works, including *2001: A Space Odyssey* (1968), *Star Wars* (1977), and more recent movies, such as *WarGames* (1983) and *Terminator 2* (1991). AI is an evolving idea that modern industry is beginning to implement in a basic form. It is certainly foreseeable that autonomous "intelligent" machines, or cyborgs, could be implemented in the next century. Clearly, this would have explosive ramifications for the military.

Another aspect of computing that has become a popular topic in science fiction is the idea of computer-generated alternate realities. This concept is depicted in an earlier movie, *Tron* (1982), and in more recent movie, *The Matrix* (1999). The closest current approximation to this capability is virtual reality (VR). With the seemingly unbounded advances in computing, this capability could be used in future training and educational activities.

3. A Final Thought

Science fiction has made implicit "predictions" about thousands of technologies. Many of these technologies do not exist and never will. However, some have already been invented, and hundreds more have at least some promise of emerging within the next century. Arthur Clarke defends science fiction as a means of "expanding" the mind. While science fiction cannot be relied on for accurate forecasting, it is certainly a useful tool that could stimulate insight into future technology.

IV. OBSERVATIONS

A. PERSPECTIVE ON TECHNOLOGY FORECASTS

Technology forecasts and speculations can be important factors in the development of future armed forces, but these forecasts and speculations are only an input to the more important and broader problem of how societies will evolve and what purposes the military will serve. Societies, or at least an aggregation such as the Former Soviet Union (FSU), can change as a threat with surprising rapidity—much more rapidly than a large institution (e.g., one of the Services). Perceptions of the importance of an obvious technological breakthrough (e.g., the development of atomic weaponry) on budgets and the structuring of the various Services can also be important.

At best, technology forecasts cannot be expected to have much impact on near-term programs because of the risks associated with acting on uncertain future projections and because of institutional inertia and the ponderous acquisition cycle. Nevertheless, we view these efforts as a providing a valuable means of examining contingent futures and as providing support for initiating new R&D efforts when emerging technologies are recognized as being potentially valuable.

B. APPLICABILITY OF THE VARIOUS METHODOLOGIES

The following comments on applicability of the various methodologies are impressions developed from the survey of techniques.

1. Brainstorming

Brainstorming seems to be applied best by a small group that has to meet some particular objective over a brief time frame. The concepts behind brainstorming, which call for unfettered suggestions without critical comment, seem to be accepted widely. Indeed, to a degree, brainstorming is an element of most technology forecasts.

2. The Delphi Technique

The Delphi technique allows large numbers of experts (including, in some cases, those of an entire nation) to provide, via several iterations, reasoned input to a particular problem area, without being brought together physically. The approach develops a consensus view while noting other views.

The Delphi process appears to be more suited to reasonably well-defined, near-term issues (e.g., the future of a telecommunications industry) than to speculations on long-term future capabilities.

3. Horizon Mission Methodology (HMM)

HMM uses an assumed future in which some currently unknown capability or technology exists. The HMM approach looks back ("backcasts") to see how this technology might have arisen. It removes any embarrassment that might arise from considering "far out" ideas (i.e., outside existing paradigms and limitations).

HMM is relatively new, compared with the Delphi technique. It appears to be promising, even though its long-term utility has not been established. Indeed, like brainstorming, it may be becoming a common philosophical element in studies of future technologies.

A highly preliminary and notional list of issues where the HMM, or something akin to this process, might be used for DoD studies is as follows:

- Real-time location and health sensing of individuals
- Self-repairing systems
- Energetic materials (explosives) based on isomeric nuclei
- Isomers as power sources
- Small-scale, safe nuclear energy source for soldiers
- Nanoscience and nanotechnology
- Nano-micro transitional technology
- Robotics.

These ideas have various degrees of possible implementation.

4. Service Studies

Our sampling of these studies has been spotty, and our observations may be correspondingly unrepresentative. The Air Force 2025 study is noteworthy for the magnitude of the effort to cover future possibilities through the creation of a set of alternative futures. This aim of effort was primarily to evaluate the possible institutional roles of a future Air Force rather than to evaluate technology needed to fulfill these roles. In a sense, it carried the HMM into creation of future societies. The SPACECAST 2020 Air Force study devoted more effort to recognizable advances in technology but placed less emphasis on possible breakthrough approaches.

The Army's STAR 21 study, which was conducted by the NRC, is of particular interest because it decoupled the institution of the Army from the group that projected future technologies. The NRC STAR 21 report (Ref. 36), while arguably overly straightforward and perhaps unimaginative, strikes us as the most balanced and thorough approach for wide-ranging studies of the potential of what might be termed identifiable advanced technologies.

5. IDA and the MCT Process

The MCT approach focuses on the recognized emerging technologies that may be militarily critical to the United States. It is not intended as a means of generating new ideas or new approaches.

6. Science Fiction

Science fiction exists in books, magazines, and comic-book form. The genre has a long history of providing concepts well before their time of realization. Most of these workable ideas are recognized only in hindsight, and the fraction of ideas that represent good ideas is probably small. Arthur Clarke, a science fiction author and a scientist, strongly defends reading science fiction as a means of training the mind to move beyond current thinking and constraints (again, moving "outside the box"), which is also the purpose of the HMM and much of the other futures work.

C. ADDITIONAL COMMENTS

A preliminary impression is that groups charged with looking at the far future and continually belabored to think beyond current paradigms tend to be influenced heavily by what might be termed the news or issues of the day. Thus, as the RAND Delphi work in the 1960s shows, anticipation of the moon landing led to predictions of moon colonies, Mars landings, and so forth. Also, concern about BMD led to forecasts of breakthroughs in defense using lasers and other high-technology approaches. The Cold War threat was usually forecast to go on indefinitely. These, perhaps, can be classified as failures of imagination.

Another observation, which seems to have been noted in several studies, is that the process may be at least as important as the product. This notion seems to be consistent with the view held by some [as noted by Woudenborg (Ref. 11)] with regard to the Delphi technique: that Delphi is a “communication device,” with participant satisfaction being one measure of success. This argument seems reasonable because seeking ideas and the intercommunication generated by a futures study should have value in itself. It is of interest that South Korea’s economy has recently achieved a “remarkable turnaround” following its recent downturn (Ref. 46), a fact that may or may not have been influenced by a broad internal awareness of its relative strengths and weaknesses, as achieved through the Delphi study. We note also the points suggested after the SPACECAST 2020 study had been completed: that the process, once started, would (and should) continue in some form because of its impact on the participants and their continuing interest in the outcomes.

A cautionary note also seems appropriate with regard to the much-used term “thinking out of the box.” In general, “going outside the box,” implies a departure from conventional thinking. This departure is generally discomfiting in relationships with one’s peers and tends to be neither career enhancing in the military nor grant producing in the scientific world. For these reasons, setting up a formal structure, such as the HMM, is desirable. In this way, all participants are forced into nonconventional ways of thinking and are nonstigmatized in the process.

V. SUMMARY

In this document, we examined several procedures or approaches identifying technologies that could be important in the future both for civilian and military applications. Although we considered several approaches, for completeness and generality, we focused ultimately on two well defined and systematic approaches: the Delphi technique and HMM (Horizon Mission Methodology).

Delphi has been used by several institutions, including U.S. government agencies, foreign governments, and industries to examine technologies with future potential. These exercises were considered important for planning purposes. Many of these studies followed narrow interests of the sponsors, but some were more general in scope. Some of the reports published detailed technology projections and assigned time windows for when they would become important. In one case, we were able to match the detailed predictions of a study to the actual evolution of technology and the directions society took.

HHM, on the other hand, is a relatively new technique, developed and used by NASA in many studies. Not enough time has passed to evaluate capably the success of the studies using HMM.

Table V-1 provides broad-brush comparisons between the methodologies examined in this document. Each study method is best suited for different goals, time frames of interest, and resource constraints. In general, the HMM and science fiction literature seem to be best suited for considering longer term scenarios, while the Delphi method seems to produce shorter term, "safer bet" forecasts.

Forecasting exercises and methodologies need to be viewed from several perspectives. In general, forecasting will not yield quantitative predictions of the future, mostly because of the difficulty in predicting the revolutionary advances that have pushed the scientific frontier in the past. Detailed forecasts require detailed scientific and technical information and, as a result, tend to be limited to shorter time frames.

Table V-1. Methodology Comparisons

Method	Pros	Cons	Time Frame (Best)	Best Applications
Brainstorming	• Quick • Not costly	Lack of depth	Any	Quick turnaround studies
Delphi	• High-tech expertise • Produces safe bets • Applicable to a wide range of problems	• Linear extrapolation only • Not “out of the box” • Expensive, slow • Controlled by experts’ interests	Short term Mid term	Variety of topics (technical goals, national goals, social issues)
HMM	• Structures “out of the box” • High-tech expertise	• Expensive • Directed by experts’ interests but with nonexpert component • Not useful for short term	Mid term Long term	Search for new concepts and technical breakthroughs
Science Fiction Literature	• Completely “out of the box” • Not costly	• High false-alarm rate • Lack of technical depth, usually with major exceptions depending on background of the writer	Long term Far-out term	Idea source

Despite these limitations, the forecasting exercises described in this document can be still useful for several types of organizations for a variety of reasons. The exercises can be structured to force the staff to think “outside the box,” which often leads to the generation of new ideas and the identification of new threats and opportunities. During this process, identifying fundamental (often hidden or ignored) flaws in even well-established institutions may be possible.

In general, for these forecasting methodologies to produce any useful outcomes, three things are critical:

- First, the inhibitions of the participants must be eliminated so that new and radical ideas can be discussed and refined.
- Second, participants need to be rewarded for their participation and creativity in the process.
- Third, the participants must be technically competent and realistic, but not overly pessimistic. The pessimism will tend to limit the generation of new ideas and defeat the point of the whole exercise.

The use of these forecasting methods as a threat analysis tool provides several interesting challenges and opportunities. Clearly, forecasting can be used to track the development of individual technologies and the potential use of combinations of technologies in several time frames. Several methodologies have been presented here, all of which can be used for threat analysis, but the choice of the specific technique (or combination of techniques) will depend strongly on the goals of the analysis. Finally, since threat analysis must account for more than merely technical factors, the exercise must have access to a variety of data sources and expertise, including social and political.

One critical aspect of the analysis will be the information that flows into the selected methodology. Databases of foreign and domestic capabilities (such as those developed by the MCT Program) will be useful in developing threat projections. However, the design of a threat forecasting method must include the input of nontechnical information—as well as a careful selection of methodology. Of course, as with all analytic tools, a clear understanding of the tool and its advantages and limitations for the problems posed is critical.

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   5b. In 1997, Joseph Coates, John Mahaffie, and Andy Hines authored a book that has the simple title *2025* but is subtitled *Scenarios of U.S. and Global Society Reshaped by Science and Technology* (see Ref. 4). This book suggests the widespread interest in possible effects of S&T on society.

   5c. In 1997, Michio Kaku authored a book entitled *Visions: How Science Will Revolutionize the Twenty-First Century* (see Ref. 5). This work envisions the impact of advances in genetic coding, robots, expert systems, MEMS, and more.

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GLOSSARY

AAN	Army After Next
AEA	alternative engineering assumption
AFB	Air Force Base
AFIT	Air Force Institute of Technology
AFRL	Air Force Research Laboratory
AI	artificial intelligence
ANP	Aircraft Nuclear Propulsion
AU	Air University
BMD	ballistic missile defense
BNL	Brookhaven National Laboratory
BPP	Breakthrough Propulsion Physics
BTO	breakthrough technology option
C2	command and control
CRP	Central Research Program
CSS	Combat Service Support
DARPA	Defense Advanced Research Projects Agency
DEW	directed energy weapon
DNA	deoxyribonucleic acid
DoD	Department of Defense
DOE	Department of Energy
ESP	extrasensory perception
Fermilab	Fermi National Accelerator Laboratory
FSU	Former Soviet Union

GPS	Global Positioning System
GRC	Glenn Research Center
HMM	Horizon Mission Methodology
IAF	International Astronautical Federation
ICBM	intercontinental ballistic missile
IDA	Institute for Defense Analyses
IR	infrared
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
LANL	Los Alamos National Laboratory
LEO	low earth orbit
LRC	Langley Research Center
MCT	Militarily Critical Technologies
MEMS	microelectromechanical systems
MG	Major General (Army)
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NDAA	National Defense Authorization Act
NERVA	Nuclear Engine for Rocket Vehicle Applications
NRC	National Research Council
NSIA	National Security Industrial Association
OIT	Office of Industrial Technologies (DOE)
OMFTS	Operational Maneuvers From the Sea
ORNL	Oak Ridge National Laboratory
R&D	research and development
RMA	revolution in military affairs

S&T	science and technology
S.U.	Soviet Union
SBL	space-based laser
SSI	Strategic Studies Institute
STAIF	Space Technology and Applications International Forum
STAR 21	Strategic Technologies for the Army of the Twenty-First Century
STAR	Strategic Technologies for the Army
STIC/TAC	Science and Technology Intelligence Committee Technical Advisory Committee
TAV	TransAtmospheric Vehicle
TF	technology forecasting
TM	technical manual
TRADOC	Training and Doctrine Command (U.S. Army)
TWG	Technology Working Group
U.S.	United States
UAV	unmanned aerial vehicle
USAF	United States Air Force
VR	virtual reality

APPENDIX A
A PARTIAL LISTING OF GOVERNMENT FUTURES-ORIENTED STUDIES

FUTURE U.S. MILITARY WARFIGHTING CAPABILITIES

RESOURCE BASE

NEAR TERM

- QUADRENNIAL DEFENSE REVIEW (QDR), 1997
- DEFENSE PLANNING GUIDANCE, FY 1999-2003
- JOINT WARFIGHTING S&T PLAN, 1996
- DEFENSE S&T STRATEGY
- DEFENSE TECHNOLOGY AREA PLAN (DTAP), 1996
- DEFENSE BASIC RESEARCH PLAN, 1996
- FIVE YEAR DEFENSE PROGRAM (FYDP), 1997
- DEFENSE REFORM INITIATIVE, NOVEMBER 10, 1997

21st CENTURY

10-20 YEARS

- NATIONAL SCIENCE AND TECHNOLOGY COUNCIL (NSTC), NATIONAL SECURITY SCIENCE AND TECHNOLOGY STRATEGY, 1995
- JOINT CHIEFS OF STAFF (JCS) JOINT VISION 2010, 1996
- ARMY VISION 2010, 1996
- STRATEGIC ARMY OF THE EARLY 21st CENTURY TRADOC 525-5, 1994
- ARMY FUTURE OPERATIONAL CAPABILITY, TRADOC 525-66, 1997
- ARMY SCIENCE AND TECHNOLOGY MASTER PLAN, FISCAL YEAR 1997
- CHIEF OF NAVAL OPERATIONS (CNO) SCIENCE AND TECHNOLOGY REQUIREMENTS GUIDANCE (STRG), 1996, 1997
- ONR S&T INVESTMENT PLAN, 1997
- AIR FORCE MAJOR COMMAND MISSION AREA PLANS (MAP), 1997
- AIR FORCE NEW WORLD VISTAS - AIR AND SPACE POWER FOR THE 21st CENTURY, 1990

30-40 YEARS

- A NATIONAL SECURITY STRATEGY OF ENGAGEMENT AND ENLARGEMENT, WHITE HOUSE 1996
- ARMY AFTER NEXT (AAN), 1996
- FORWARD ... FROM THE SEA, THE NAVY OPERATIONAL CONCEPT, CNO, 1997
- CHIEF OF NAVAL OPERATIONS (CNO) STRATEGIC STUDIES GROUP CONCEPT GENERATION TEAMS, 1997
- MARINE CORPS SEA DRAGON CONCEPTS, 1996
- AIR FORCE PROJECT 2025, 1996
- TRANSFORMING DEFENSE, NATIONAL DEFENSE PANEL, DECEMBER 1997
- AIR AND SPACE POWER IN THE NEW MILLENNIUM, CSIS 1997

DEPARTMENT OF DEFENSE GUIDANCE SOURCES

- Defense Planning Guidance: FY 1999-2003
- Report of the Quadrennial Defense Review, May 1997
  - http://www.defenselink.mil/pubs/qdr/
- National Military Strategy
  - http://www.dtic.mil/jcs/nms/
- Joint Vision 2010
  - http://www.dtic.mil/doctrine/jv2010/jvpub.htm
- National Security Science and Technology Strategy
  - http://www.whitehouse.gov/WH/EOP/OSTP/nssts
- TECHNOLOGY PLANNING DOCUMENTS
  - http://www.dtic.mil/dstp/DSTP/mil_index.html
- Transforming Defense: National Security in the 21st Century
  - http://www.dtic.mil/ndp/

MILITARY DEPARTMENT GUIDANCE SOURCES

- ARMY
  - *Force XXI*
  - *The Army After Next*
  - Army Vision 2010
    - http://www.army.mil/2010/
- NAVY
  - *From the Sea*
  - *Forward…From the Sea*
    - http://www.dtic.mil/doctrine/jv2010/navy/b014.pdf
  - *Navy Operational Concept*
  - *Marine Corps Operational Maneuver from the Sea*
    - http://www.dtic.mil/doctrine/jv2010/usmc/omfts.pdf
- AIR FORCE
  - *Global Engagement: A Vision for the 21st Century Air Force*
    - http://www.xp.hq.af.mil/xpx/21/nuvis.htm

INFORMATION SOURCES FOR SCIENCE & TECHNOLOGY (1)

- DEFENSE LINK
  - http://www.dtic.dla.mil/defenselink/index.html
- DEFENSE RESEARCH & ENGINEERING
  - http://www.dtic.mil/ddre/
- LINK TO MOST DoD LABORATORIES "LABLINK"
  - http://www.dtic.dla.mil/lablink/
- SERVICE/AGENCY PAGES
  - ARMY: http://www.arl.army.mil/ and http://www.aro.ncren.net/
  - NAVY: http://www.onr.navy.mil/ and http://www.onr.navy.mil/links.htm
  - AIR FORCE: http://www.af.mil/ and http://web.fie.com/fedix/afosr.html
  - DARPA: http://www.darpa.mil/
  - BMDO: http://www.acq.osd.mil/bmdo/bmdolink/html/bmdolink.html
  - DSWA: http://www.dswa.mil/

INFORMATION SOURCES FOR SCIENCE & TECHNOLOGY (2)

- DEFENSE SCIENCE AND TECHNOLOGY PLAN
  - http://www.dtic.mil/dstp/ (REGISTRATION)
  - http://www.dtic.mil/dstp/DSTP/index.html (DIRECT)
- VISION 21: PLAN FOR DoD LABORATORIES & TEST CENTERS
  - http://www.dtic.mil:80/labman/vision21/index.html
- DUAL-USE APPLICATIONS AND COMMERCIAL PROGRAMS
  - http://www.acq.osd.mil/es/dut/
- STRATEGIC ENVIRONMENTAL RESEARCH & DEVELOPMENT
  - http://www.serdp.gov/
- DEFENSE MODELING & SIMULATION OFFICE
  - http://www.dmso.mil/
- OTHER SCIENCE & TECHNOLOGY LINKS
  - http://www.dtic.mil/ddre/st_websites.html

INFORMATION SOURCES FOR MATERIALS (1)

- SERVICE/AGENCY PAGES
  - ARMY: http://www.arl.mil/~staulbee/wmrd.html and http://www.aro.ncren.net/matsc/
  - NAVY: http://www.onr.navy.mil/ and http://www.onr.navy.mil/links.htm
  - AIR FORCE: http://www.ml.wpafb.af.mil/ and http://web.fie.com/htdoc/fed/afr/afo/any/text/any/structur.htm
  - DARPA: http://www.DARPA.mil/DSO/rd/index.html
- DEFENSE SCIENCE & TECHNOLOGY PLAN
  - http://www.dtic.mil/dstp/97_docs/dtap/mp/contents.htm
- ADVANCED COMPOSITES INSERTION REPORT (TO CONGRESS)
  - http://www.dtic.mil/ddre/index.html (under "S&T Programs")
  - http://www.dtic.mil/ddre/docs/adcom.pdf (the report itself)
- NATIONAL SCIENCE & TECHNOLOGY COUNCIL - MATERIALS TECHNOLOGY SUBCOMMITTEE
  - http://www.oit.doe.gov/mattec/mattec.htm

INFORMATION SOURCES FOR MATERIALS (2)

- NATIONAL MATERIALS ADVISORY BOARD
  - http://www2.nas.edu/nmab/
- ADVANCED MATERIALS AND PROCESSES INFORMATION ANALYSIS CENTER
  - http://rome.iitri.com/amptiac/
- NONDESTRUCTIVE INSPECTION INFORMATION ANALYSIS CENTER
  - http://www.ntiac.com
- *Aging of U.S. Air Force Aircraft*, National Research Council, NMAB-488-2, 1997
  - http://www2.nas.edu/nmab/25ba.html
  - http://www.nap.edu/readingroom/books/aging/
- MIL-HDBK-17 ON COMPOSITE MATERIALS
  - http://www.ccm.udel.edu/army/

APPENDIX B
TECHNOLOGY FORECASTING BRIEFING

TECHNOLOGY FORECASTING

7 February 2001

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This briefing was delivered by B. Balko to the Science and Technology Intelligence Committee Technical Advisory Committee (STIC/TAC) Working Group. The STIC/TAC serves as a coordinating committee for threat analyses and is focused on science and technology (S&T) and the development of methodologies and tools to support those analyses. G. Boezer, R. Oliver, and A. Seraphin participated in the development of this briefing.

Agenda

- Technology Forecasting
- IDA Study on Forecasting Methodologies
  - Delphi method
  - Horizon Mission Methodology
- Threat Perspective

This briefing provides some historical perspective on the use of technology forecasting, especially for military applications. It reviews a recent IDA study on methodologies for Far Future Technology forecasting, with particular emphasis on two specific forecasting methodologies—the Delphi method and the Horizon Mission Methodology (HMM)—and assesses the applicability of various forecasting methodologies to threat analyses.

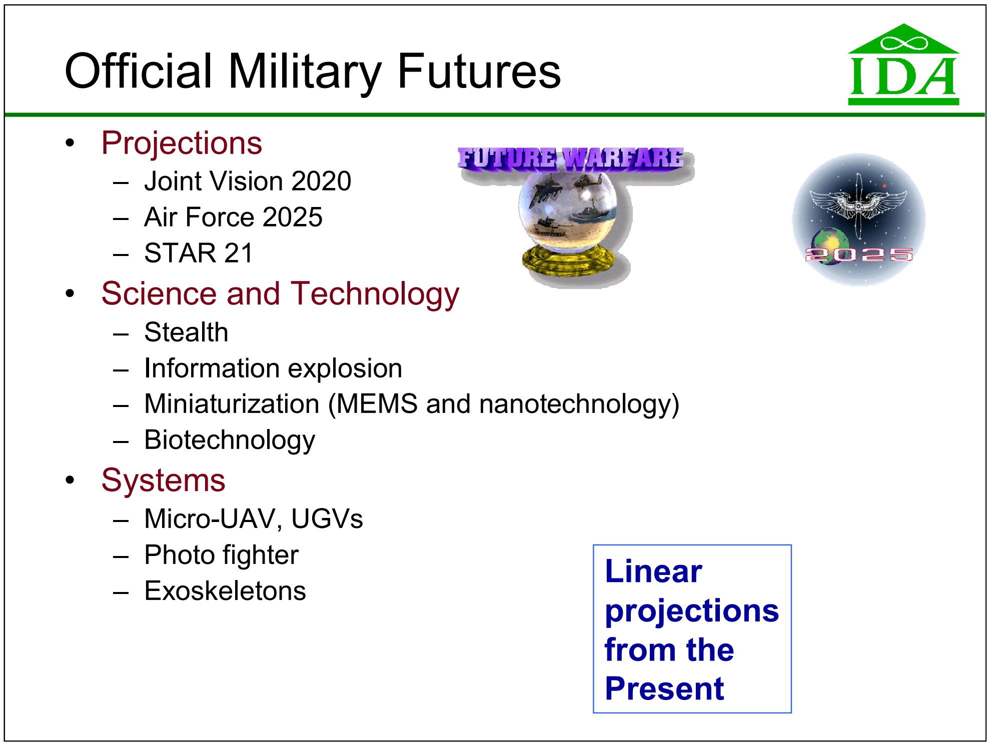
Technology Forecasting

- "Long-Term Technology" Forecasting
- Time Frames
  - Short term: 0–5 years out
  - Mid term: 5–25 years out
  - Long term: 25–50 years out
  - Far-out term: 50+ years out
- What are "Technologies"?
  - Includes sciences, devices, technologies, systems, concepts of operations…

Long-term technology forecasting is becoming an area of interest in a wide variety of circles in both the public and private sectors. Forecasting the development and impact of S&T can be critical to national security, civilian public policy, and investment strategies. It also plays a central role in the development of an understanding of threats in the far future.

We have roughly divided forecasting time frames into four major groups: short term (0–5 years out), mid term (5–25 years out), long term (25–55 years out), and far-out term (50+ years out). IDA's original interest in forecasting focused on the long term, but it has become clear that there is value in forecasting in a range of time frames and that the methodologies used and the types of forecasts made are strongly dependent on the time frames being analyzed.

For this briefing, we are using a very broad definition of technology to include scientific knowledge, devices, systems, and even concepts of operations or social organizations.

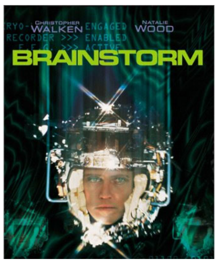


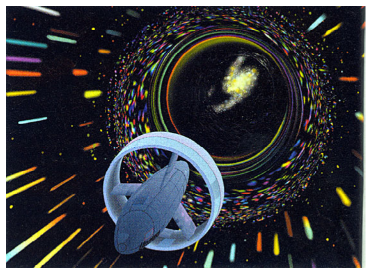
The Department of Defense (DoD) is, of course, extremely interested in understanding the future of S&T developments so as to better understand future threats and develop the best systems to meet those threats. As a result, the defense agencies and the Services have sponsored several studies to examine particular aspects of the future of S&T in a variety of time frames. These often large-scale exercises have examined several different scientific disciplines, including microelectromechanical systems (MEMS), nanotechnology, and biotechnology, and have postulated a variety of future defense systems, including advanced robotic vehicles.

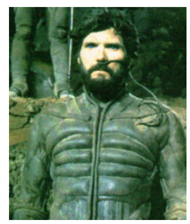
For the most part, however, these projections have been limited to linear projections from present scientific understanding or political and cultural climates. Although this type of forecasting can be very useful, it is questionable whether it can adequately explore the rich universe of technological possibilities.

Future Military Systems?

- Space Travel Using Warp Drive
- Superluminal (FTL) Communication
- Mind Control/Thought-Controlled Systems







It is important that forecasting, especially for the military, be able to envision very nontraditional futures so as to give decision-makers the widest possible breadth of policy and funding choices. This slide lists and pictures several such futures in areas such as travel and power generation. Some of these ideas have even been generated from sources such as science fiction literature. During forecasting exercises, accessing nontraditional sources is critical, although these sources must be strongly tempered with technical analyses and physical realities.

Predicting the Future is Hard

Clarke's First Law:
"When a distinguished but elderly scientist states that something is possible he is almost certainly right. When he states that something is impossible, he is very probably wrong."

- Forecasting gets harder as time frames expand
  - Linear projections from the present break down
  - New discoveries alter path of technology development
- Technologies not predictable in 1950
  - Infrared (IR)
  - Laser

Although forecasting can be a valuable tool for many types of organizations, it also can be difficult to do accurately or usefully.

The noted science fiction writer Arthur C. Clarke has written extensively on technology forecasting. In his book *Profiles of the Future,* he states one of his laws of forecasting, which he derived from numerous examples from the past. Roughly stated, experts who claim something will never be possible are almost always wrong, while an expert admitting something is possible will generally be correct.

Forecasting also gets more difficult as the time frames of interest expand, especially when relying on linear projections of current technological capabilities. As time passes, unforeseen discoveries are likely to alter the path of technology development and usage and render any linear projection incorrect.

Infrared (IR) and laser, two technologies of critical importance in society today, are examples of the difficulties of technology forecasting. In 1950, would it have been possible to predict the widespread impact of IR technology and lasers on society in 2001?

Predicting the Future in 1950

- IR Systems
  - Basic science known: Maxwell’s equations, Planck’s law
  - Missing technology: 10+ μm IR detectors with high (LN_2) operating temperatures
  - Military impact—Sidewinder (1963), Night Vision (1980)
- Lasers
  - Basic science known: Stimulated emission (Einstein, 1917)
  - 1951 maser development
  - 1961 laser development
  - Military impact—range finders, guided bombs, directed-energy weapons

In 1950, the basic science needed to understand the generation and detection of the IR part of the electromagnetic spectrum was known. Maxwell's equations and Planck's law had been in the scientific literature for a long time. Simple detectors were available but were too slow for military use. To develop applications like heat-seeking missiles or night-vision systems, fast detectors sensitive to the 10-μm or longer wavelengths were required. Also, sensor materials operating at higher, more easily attainable temperatures (liquid nitrogen or even better, room temperature) were required.

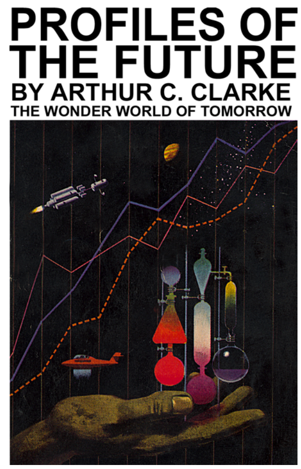
During World War II, Britain made an attempt to develop IR technology but gave up in favor of developing radar. After the war, the United States examined a captured German IR detector, which gave impetus to our own IR program. A special committee (the Metcalf Committee), which included three Nobel laureates, examined the potential of IR technology and proposed several applications. The era of night vision and heat-sensing seekers had begun.

In 1950, the basic phenomena of stimulated emission of electromagnetic radiation was also understood. Einstein described the mechanism of stimulated emission in a 1917 paper. Even after the development of a maser in 1951, however, the potential applications of a laser were still not understood. After the development of the ruby laser in 1961, the significance of laser technology started to become apparent. In a memo, the Army called the laser the most significant development since the atomic bomb. Soon after the development of the laser, concepts for laser range finders, laser-guided bombs, and directed-energy weapons (DEWs) employing lasers were put forth and eventually became part of the military arsenal. Civilian applications from laser pointers (~ mW) to laser welding tools (~ kW) became commonplace, along with lasers for dental work, surgery, and diagnostics.

In these examples, as in many others that could be cited, prediction of the utility of the technology as seen today was not made, as far as we know, even though the underlying science was understood.

Hazards of Prophecy

- Failure of Nerve
  - All relevant facts are available
  - Analyst cannot see inescapable conclusion
  - Need to follow all extrapolations to their logical conclusion
  - Example: U.S. ICBM development
- Failure of Imagination
  - Available facts applied correctly
  - Some vital fact yet undiscovered
  - Analyst draws logical, but incorrect conclusion
  - Example: Rutherford discounts use of nuclear energy



Arthur Clarke categorizes two of the major difficulties or hazards of prophecies as the failure of nerve and the failure of imagination.

Failure of nerve occurs when an analyst is presented with all the facts necessary to make an accurate prediction but still fails to draw the correct, inescapable conclusion. This is a failure to assess accurately the existing data or admit all the extrapolations that the data enable. An example is the development of intercontinential ballistic missiles (ICBMs) in the United States and the Union of Sovier Socialist Republics (USSR). After World War II, the military and scientific communities in both countries knew that it might be possible to deliver nuclear weapons across the globe using missiles as the means of delivery. At the time, atomic bombs weighed 5 tons, which would have required a 200-ton rocket to deliver it over intercontinental distances. Faced with these facts and the need to develop a rocket bigger than anything yet conceived, the United States abandoned the development of long-range rockets for almost half a decade. On the other hand, the Russians went ahead and attempted to build the needed 200-ton rocket. In the end, reduction in weapon sizes made the huge rockets unnecessary for weapons delivery, but the American failure of nerve gave the Russians a huge lead in the development of rockets integral to the exploration of space. This story also points out the need to understand both technical and nontechnical factors in evaluating the course of technology development. Given the same technical realities, the financial and cultural pressures put on the Pentagon and the Services by the tax-paying public moved them in the direction of strategic bombers, as opposed to ICBMs.

A failure of imagination occurs when an analyst manages to apply all available facts correctly in the forecasting process but still reaches an incorrect conclusion. Here, a yet undiscovered vital fact changes the course of technological development and renders any prophecy incorrect. For example, the world renowned chemist, Lord Rutherford, discounted potential uses of nuclear energy and made fun of those who predicted a future ability to harness that energy. Only 5 years after his death, the first chain reaction was started. Rutherford could not have known that a nuclear reaction would be discovered that would release more energy than that required to start it.

This failure of imagination also points out that even the best technical experts will fail at forecasting, often because their extensive knowledge and experience stifles their creativity and imagination.

Hazards of Prophecy

	TECHNOLOGY	OBJECTIONS
Failure of Nerve	Electric Light Bulbs	“Subdivision of the electric light is an absolute ignis fatuus.”—Sir William Preece, Engineer in charge of British Post Office.
	Space Flight	Serious idea presented before 1920 by Tsiolkovsky (Russia), Goddard (United States), and Oberth (Hungary). “This foolish idea of shooting at the moon is absurd speculation.”—Prof. A. W. Bickerton, 1926. “Airspace travel is utter bilge.” — Dr. Wooley, Astronomer and later Royal Advisor on space research.
Failure of Imagination	Astronomy	“We can know about heavenly bodies their forms, distances, bulk motions, but not anything about their chemical/mineralogical structure.” — Auguste Comte (1835), who couldn’t imagine spectroscopy, radio astronomy, theoretical breakthroughs, astrophysics
	Nuclear Energy	Lord Rutherford ridiculed people who suggested energy in nucleus could be released. 1937-first chain reaction (5 years after his death).

This chart (derived from Clarke) highlights more examples of the failures of nerve and imagination, as well as the danger of blindly following expert advice on the future of technology.

Predicting Is Not Impossible

SUCCESSFUL PROPHETS

- Vannevar Bush (*Atlantic Monthly,* 1946)
  - Advances in electronics technology
    - » tape recording
    - » fast reproduction—electrical copiers
    - » information compression (Britannica the size of a matchbox)
    - » multimedia
    - » personal computers
- Richard Feynman (*Eng. and Science,* February 1960)
  - Nanotechnology
    - » information compression (Bible on the head of a pin)
    - » molecular motors
    - » molecular electronics
    - » building devices atom by atom

It is important to note that technology forecasting may be difficult, but it is not necessarily impossible.

Two excellent examples of successful forecasting come from two of the greatest names of the scientific community of the last century: Vannevar Bush and Richard Feynman. Bush was successful in predicting how advances in electronics technology would lead to revolutions in recording, data compression, and computing. Feynman predicted the use of nanotechnology in data storage, and the extension of his ideas led to the development of molecular motors and atomic-scale manipulation—technologies that are at the forefront of science today.

This is not to say that even these experts were perfect in their predictions. Bush is also noted to have been completely wrong in his predictions on future use of ICBMs.

IDA Study

- Corporate Research Project: Long-Term Technology Forecasting Methodologies
- GOAL: Review methodologies which have been used in attempts to forecast future technologies, with the primary focus on longer term … and on technologies potentially applicable to the military.
- Science and Technology Division
  - B. Balko, R. Oliver, D. Calhoun, A. Seraphin
- Report: "Methodologies for Long-Term Technology Forecasting as Applied to Military Needs," 2001

Our brief review of past forecasting attempts led us to ask several questions, including:

- Is it necessary to have geniuses like Feynman and Bush around to get useful forecasts?
- Are there more structured methodologies available to perform technology forecasts?
- Are there forecasting methodologies particularly suited for use in predicting far-future military applications?

The Institute for Defense Analyses (IDA) funded an internal study in its Science and Technology Division to take a preliminary look at some of these questions. A report of this study is currently in preparation.

Forecasting Methodologies

- Brainstorming
  - Freewheeling ideas, no negative feedback
- ✓ **Delphi** (50 years of worldwide use)
  - Large number of expert participants
  - Iterations and feedback used
  - Formalized procedure
- ✓ **Horizon Mission Methodology** (new—1990s)
  - Forces "out-of-the-box" thinking
  - Starts with "breakthrough" technology in future
  - Projects back to present and current science/technology
  - Identifies research goals and programs
- Science Fiction Literature
  - Permits "true" out-of-the-box thinking
  - Early manifestation—technology projections
  - Science fiction writers often scientists
  - High false-alarm rate

The IDA study examines four forecasting methodologies in detail: brainstorming, the Delphi method, HMM, and science fiction literature. The Delphi Method and HMM will be covered in more detail later in this presentation.

The use of science fiction literature as a forecasting methodology has both significant advantages and disadvantages. Science fiction literature has an excellent track record of predicting the development and usage of several technologies, partially because science fiction writers are often technically trained. Science fiction literature also permits true out-of-the-box thinking, which may reduce the chances of falling into traps of failure of imagination and over-reliance on linear projections. Unfortunately, the science fiction literature also includes many proposals and ideas that are completely technically unrealistic or have no hope of occurring because of social or economic factors. This high false-alarm rate makes science fiction literature an unattractive option for most applications.

Delphi Method

- General Observations
  - Objective: Achieve convergence of expert opinions
  - Widely used for 50 years
- Usage
  - RAND Delphi study (1964)
  - International usage for prediction of R&D advances and to inform budget decisions
    - » Germany, India, Japan, S. Korea
    - » S.Korea—25,000 experts, 1,200 topics, 20-year forecasts
    - » India—370 experts, electronics and information technology
- Method
  - Depends on technical expert analyses
  - Surveys of expert opinions
  - Repeat survey process iteratively to reach convergence

The Delphi methodology (named after the mythical oracle) is a systematic way of determining the insights and assessments of groups of experts. The process uses surveys (usually written), with feedback in an iterative process, to reach consensus conclusions.

The process has been widely used for 50 years. Several foreign governments have used Delphi-style studies to develop national research and development funding strategies, including Germany, Japan, India, and South Korea.

We will focus on a large Delphi study undertaken in 1964 by the Rand Corporation to explore the methodology and to try and determine some of its strengths and weaknesses.

RAND Delphi Study (1964)

- Focused on "The most important determinants of the society of the future"
  - (1) Scientific breakthroughs
  - (2) War prevention
  - (3) Weapons Systems
- Approach: Expert Panels Achieving Narrow Consensus
  - (1) Major inventions and scientific breakthroughs
  - (2) time frame (9 time periods: 1963–2013)
  - (3) Probability of occurrence
- Results

Examples from future weapon systems forecasts

Concept	Predicted	Achieved
Extensive use of devices which persuade without killing (water cannons, tear gas, etc.)	1968 ± 3	Some use
Use of lasers for radar-type range sensors, illuminators, communicators.	1970 ± 5	OK
Effective terminal defense by ground-launched missiles.	1982 ± 8	Not yet
Weather manipulation for military purposes	1985 ± 15	Not yet

The 1964 Rand study attempted to analyze "the most important determinants of the society of the future." The study focused on six areas—scientific breakthroughs, population control, automation, space progress, war prevention, and weapon systems. Six panels of experts answered four sets of questionnaires over a period of approximately 8 months. The expert panels eventually achieved a narrow consensus forecasting the probability of occurrence of major inventions and scientific breakthroughs, as well as determining a probability of occurrence for each.

Examples of future weapon systems forecasts from the study are shown. As could be expected, some of these were relatively accurate (e.g., the use of nonlethal weapons), while others (e.g., missile defense) were largely incorrect. Because of the complexity of the issues covered, some of these incorrect forecasts can be blamed on technical issues, while others are completely controlled by political or social forces.

Evaluation of Delphi Method

- RAND Delphi(1964) Shortcomings:
  - Heavily oriented toward then-current problems (1964)
    - » Soviet threat
  - No mention of stealth technology
  - No mention of GPS
  - No mention of the Internet (World Wide Web)
  - Wrong on expectation of immediate exploration of solar system
- Delphi Methodology Problems:
  - Reliance on experts only
  - Systematic pressure on convergence

The Rand forecast failed to account for a number of events and breakthroughs that have occurred since the mid 1960s. For example, although the forecast was very much a function of its time and focused heavily of the Soviet threat, the breakup of the Soviet Union was not predicted. The forecasters also failed to identify key technology developments of the past 3 decades, including stealth, the Global Positioning System (GPS), and the Internet (World Wide Web).

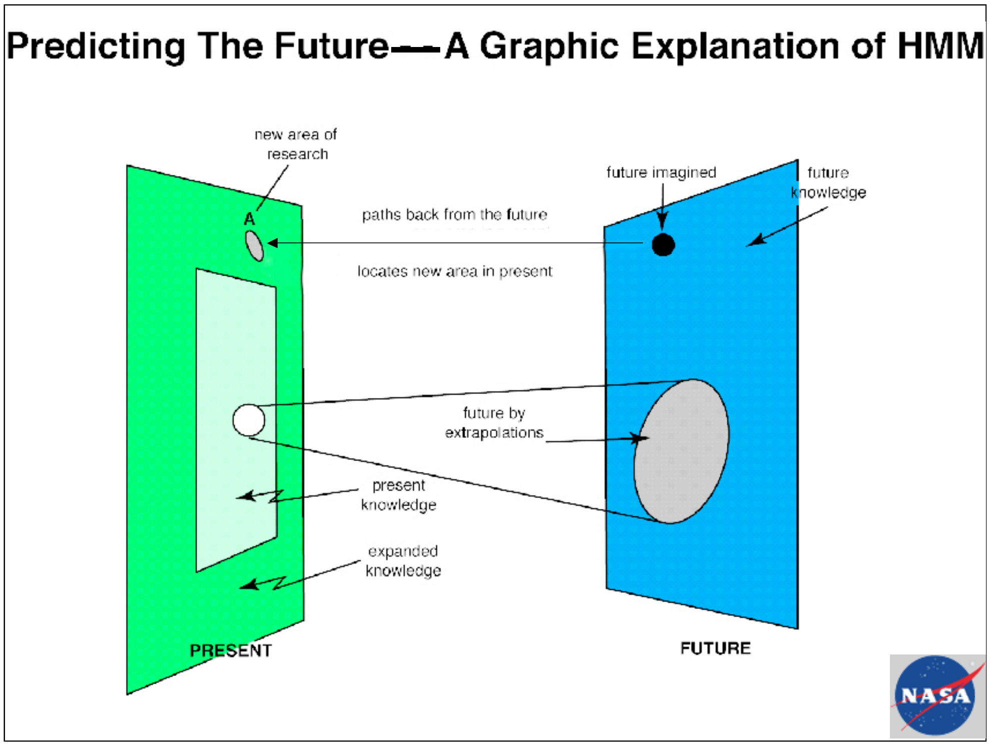
These failures highlight some of the problems with the Delphi methodology in general. A methodology that relies so heavily on experts and on convergence is likely to produce results that are very conservative. As a consequence, the focus on then-current problem is to be expected. The methodology's inherent conservatism will also drive it toward producing linear projections rather than novel new approaches. Even so, the public need and socioeconomic and political factors in the future are hard to predict. They can stifle developments in some directions and promote them in others.

Horizon Mission Methodology

- General Observations
  - Objective: Identify current activities with high specific payoffs
  - Systematic approach to thinking out of the box
- NASA Efforts Using HMM (http://spacescience.nasa.gov/osstech/horizon.htm)
  - (1) Theoretical development and general applications (J. L. Anderson)
  - (2) Space travel (Marc G. Millis)
- Method
  - Pose a problem that is difficult (even impossible) to solve with existing technology
  - Solve the problem using imagined future technology (out-of-the-box solution)
  - Project future technology backward to the present
  - Devise current programs which will lead to required future technology

The Horizon Mission Methodology, or HMM, was developed by the National Aeronautics and Space Administration (NASA) to identify near-term research activities with high specific future payoffs. It is constructed to be a systematic approach to thinking out of the box. It has been used by NASA to identify basic research projects to support future missions that have been funded because of the forecasting exercise.

The methodology involves posing a problem that is technically impossible using current knowledge. Experts from a variety of technical fields and experience levels are then invited to imagine future technologies that could solve the problem and work backward from the future to identify current research areas that could eventually produce technical solutions to the problem.



A graphical representation of the HMM produced by NASA is shown.

Here, the plane on the left represents the present, and the plane on the right represents the future. The light green shaded area represents the current state of knowledge. The expanding circle from within this plane represents a linear projection of knowledge from the present to the future.

The HMM puts the forecasters at an imagined future and forces them to work backward to the present. In terms of "knowledge space," this often leads to an area that requires new research in the present. These new areas will then be those more likely to project into the future a desired solution. These new areas become targets for investment of research dollars.

HMM Studies: NASA Breakthrough Propulsion Physics Program

- Workshop organized by Marc G. Millis, August 1997
- Goal: Assess the emerging physics that could be used to obtain breakthrough methods of energy production and propulsion.
- Method Elements
  (1) Technical participants: government, industry, academia
  (2) Invited presentations to review emerging physics
  (3) Poster papers to provide thought-provoking ideas
  (4) Breakout sessions to produce research tasks
- Resulting Funded Project Areas
  - Engineering the vacuum (zero-point field) (Casimir effect)
  - Investigating weight loss during acceleration (Woodward effect)
  - Gravity modification (EMF effects)
  - Superluminal speeds in exotic materials

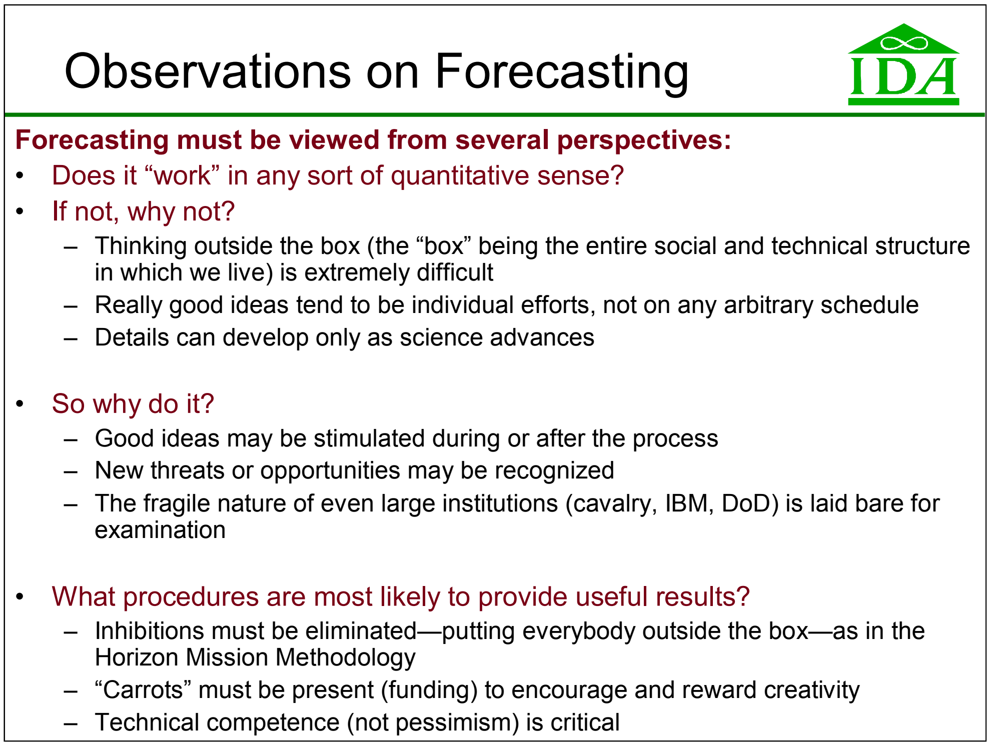
NASA organized a workshop using HMM to identify research areas in physics that would support the development of breakthrough methods for energy production and propulsion. NASA invited a mix of technical participants from a variety of backgrounds (industry, government, academia) and experience levels (graduate students to senior managers). Technical talks and posters during the session presented emerging physics from scientific literature as well as less established thought-provoking ideas. Several breakout sessions were used to identify present day research tasks.

NASA has used the output of this workshop to fund research in several new areas, including investigating the Casimir effect and studying weight loss during acceleration.

Methodology Comparison

	Method	Pros	Cons	Timeframe (best)	Best Applications
1	Brainstorm	- Quick - Cheap	-Lack of tech depth	Any	Quick turnaround studies
2	Delphi	- High tech expertise - Produces safe bets - Applicable to wide range of problems	-Linear extrapolation only - Not out of the box - Expensive, slow - Controlled by experts' interests	Short Term Mid Term	Variety of Topics (Technical, National Goals, Social Issues, …)
3	HMM	- Structured out of the box - High tech expertise	- Expensive - Directed by experts' interests but with high non-expert component - Not useful for short term	Mid Term Long Term	Search for new concepts and technical breakthroughs
4	Science Fiction Literature	- Completely out of the box - Cheap	- High false-alarm rate - Lack of tech depth usually with major exceptions depending on background of the writer	Long Term Far-out Term	Idea source

This chart attempts to provide broad-brush comparisons between the methodologies examined in the IDA study. Each of the study methods is best suited for different goals, time frames of interest, and resource constraints. In general, HMM and science fiction literature seem to be best suited to look out at longer term scenarios, while the Delphi method seems to produce shorter term, "safer bet" forecasts.



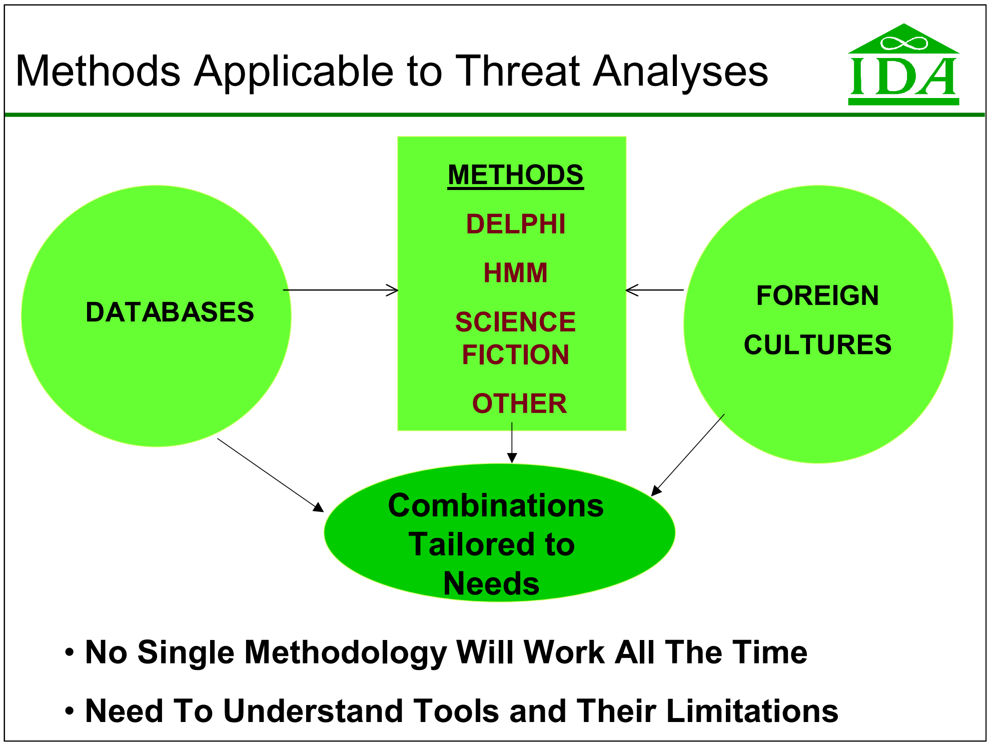
In conclusion, forecasting exercises and methodologies need to be viewed from several perspectives. In general, forecasting will not yield quantitative predictions of the future, mostly because of the difficulty of predicting the revolutionary advances that have pushed the scientific frontier in the past. Detailed forecasts require detailed scientific and technical information and, as a result, will tend to be limited to shorter time frames.

Despite these limitations, the forecasting exercises described in this briefing can be still useful for several types of organizations for a variety of reasons. The exercises can be structured to force staff to think outside the box, which often leads to the generation of new, good ideas and the identification of new threats and opportunities. During this process, it may be possible to identify fundamental (often hidden or ignored) flaws in even well-established institutions.

In general, for these forecasting methodologies to produce any useful outcomes, three things are critical. First, the inhibitions of the participants must be eliminated so that new and radical ideas can be discussed and refined. Second, participants need to be rewarded for their participation and creativity in the process. Third, the participants must be technically competent and realistic but not overly pessimistic. Pessimism will tend to limit the generation of new ideas and defeat the point of the whole exercise.

The use of far future forecasting as a threat analysis tool provides several interesting challenges and opportunities. Clearly, forecasting can be used to track the development of individual technologies and the potential use of combinations of technologies in several time frames. Several methodologies have been presented here, all of which can be used for threat analysis, but the choice of the specific technique (or combination of techniques) will depend strongly on the goals of the analysis in question.

Finally, since threat analyses must account for more than merely technical factors, the exercise must have access to a variety of data sources and expertise, including social and political.



One critical aspect of the analysis will be the information that flows into the selected methodology. Databases of foreign and domestic capabilities [such as those developed by the Militarily Critical Technologies (MCT) program] will be useful in developing threat projections; however, the design of a threat forecasting method must include the input of nontechnical information, as well as a careful selection of methodology. Of course, as with all analytic tools, a clear understanding of the tool and its advantages and limitations for the problems posed is critical.

APPENDIX C
FORECASTING FAILURES

APPENDIX C
FORECASTING FAILURES

In a near-classic book published in 1963 (Ref. C-1), Sir Arthur C. Clarke (1917–Present), the physicist and science fiction author (who was credited with inventing synchronous communication satellites in 1945), stated that:

> It is impossible to predict the future, and all attempts to do so in any detail appear ludicrous within a very few years. This book has a more realistic yet at the same time more ambitious aim. It does not try to describe the future, but to define the boundaries within which possible futures must lie.

Clarke goes on to note that (Ref. C-1):

> With few exceptions, scientists seem to make rather poor prophets; this is rather surprising, for imagination is one of the first requirements of a good scientist. Yet, time and again, distinguished astronomers and physicists have made utter fools of themselves by declaring that such-and-such a project was impossible.

His statement that forecasts appear ludicrous within a few years is borne out by the examples he cites, some of which are included below. However, his 1963 forecasts of the future or the "boundaries" within which he felt the forecasts must lie are, to us, of less interest than the philosophical discussion he offered regarding forecasts. We view his remarks as being highly pertinent to any effort to forecast future developments.

Clarke analyzes why forecasts have failed and divides such failures into two classes: failures of nerve and failures of imagination. Failures of nerve are more common and occur when the prophet cannot see that forecasts lead to an inescapable conclusion—despite having all the relevant facts. As an example of failure of nerve, he cites those nay Sayers who could not see the growth of air travel even after aircraft had already been flown. Clarke views failures of imagination as less blameworthy but more interesting. These failures occur when all the available facts are appreciated and marshaled correctly but when the vital facts are still undiscovered and the possibility of their existence is not admitted. He cites Lord Rutherford, who "more than any other man laid down the internal structure of the atom" (Ref. C-1) and ridiculed anyone who thought that the energy locked up in the atom could ever be harnessed. He also cites "Clarke's Law," which he states as follows and which should be remembered by all those who attempt to forecast the future (Ref. C-1):

> When a distinguished but elderly scientist states that something is possible, he is almost certainly right. When he states that something is impossible, he is very probably wrong.

He also notes that "elderly" in physics, mathematics, and astronautics means over 30. In other disciplines, it might be delayed until one's 40s.

Tables C-1 and C-2 give some examples of failures of nerve (prophet cannot see the inescapable conclusion) and failures of imagination (all available facts used correctly, vital facts still undiscovered) as described by Clarke.

Table C-1. Hazards of Prophecy: Failure of Nerve (Source: Ref. C-1)

Technology	Objections
Electric light bulbs	"Subdivision of the electric light is an absolute *ignis fatuus*." *Sir William Preece, Engineer in Charge of British Post Office*
Airplanes	"Heavier than air flight is impossible" (shortly before Wright Brothers flight)" and "Flying machines might be a marginal possibility but of no practical importance" (after hearing of Wright Brothers flight). *American Astronomer Simon Newcomb*
Spaceflight	"This foolish idea of shooting at the moon is . . . absurd . . . speculation. . . ." Prof. A.W. Bickerton, 1926. "Space travel is utter bilge." *Dr. Wooley, Astronomer, later Royal Advisor to British Government on Space Research*
ICBM	" . . . impossible for many years," " . . . leave it out of our thinking." *Vannevar Bush (1945), Civilian Director of U.S. Scientific War Effort*

Table C-2. Hazards of Prophecy: Failure of Imagination (Source: Ref. C-1)

Technology	Objections
Astronomy	"We can know about heavenly bodies their forms, distances, bulk motions, but not anything about their chemical/mineralogical structure." *Auguste Comte (1835)* Comte could not imagine spectroscopy, radio astronomy, and theoretical breakthroughs.
Nuclear energy	Lord Rutherford ridiculed people who suggested energy in nucleus could be released. It is interesting to note that the first chain reaction was accomplished in 1937 (5 years after his death).

REFERENCES

C-1. Arthur C. Clarke, *Profiles of the Future. The Wonder World of Tomorrow,* Harper and Row, February 1963. (Incorporates material prepared earlier). See also Arthur C. Clarke, "*Profiles of the Future: An Inquiry Into the Limits of the Possible,"* New York: Holt, Rinehart, and Winston, 1984.

APPENDIX D
AN IMPLEMENTATION OF THE HORIZON MISSION METHODOLOGY (HMM)

APPENDIX D
AN IMPLEMENTATION OF THE HORIZON MISSION METHODOLOGY (HMM)

The National Aeronautics and Space Administration (NASA) Breakthrough Propulsion Physics (BPP) Project (Workshop, October 1997)

The NASA BPP Project was established in 1996 to examine emerging physics that could provide propulsion breakthroughs to propel spacecraft farther, faster, and more efficiently. Topics of interest have included experiments and theories regarding the coupling of gravity and electromagnetism and hyper-fast travel.[16]

To get a good start on reaching the desired goals, a "brainstorming" session (based on the HMM format) was organized to produce a list research tasks that are of relatively short duration and address the immediate questions raised by the emerging physics and program goals.

Specifically, the goals of the workshop were to

- Discover new propulsion methods that eliminate or dramatically reduce the need for propellant (mass) by manipulating inertia or gravity or by any other interactions between matter, fields, and space time
- Reduce travel times by discovering how to attain the ultimate achievable transit speed
- Identify new modes of energy generation to power these propulsion devices.

PARTICIPANTS

To have a manageable number of people and still provide a constructive mix of physicists, government researchers, and thought-provoking innovators in the breakout sessions (a maximum of 15 participants for each of the six groups), the number of participants

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[16] See http://www.lerc.nasa.gov/WWW/bpp/index.htm.

was limited to less then 90. A total of 84 participants actually attended the workshop: 16 from universities, 28 from industry, 11 from government labs, 17 from NASA, and 12 students.

The following government laboratories were represented:

- The Los Alamos National Laboratory (LANL)
- The Oak Ridge National Laboratory (ORNL)
- The Fermi National Accelerator Laboratory (Fermilab)
- The Brookhaven National Laboratory (BNL)
- The Air Force Research Laboratory (AFRL) from Edwards Air Force Base (AFB) and Kirtland AFB.

The following NASA laboratories were represented:

- The Glenn Research Center (GRC) at Lewis Field
- The Langley Research Center (LRC)
- The Marshall Space Flight Center (MSFC)
- The Johnson Space Center (JSC)
- The Jet Propulsion Laboratory (JPL).

PROCEDURAL DETAILS

The workshop consisted of three major elements:

1. Breakout sessions to produce research tasks
2. Invited presentations to review emerging physics
3. Poster papers to provide thought-provoking ideas.

Breakout Sessions

The attendees were divided into six breakout groups (Groups A–F). Two groups addressed each of the program's three goals—a process that lasted through five 1-1/2-hour sessions. At the beginning of each session, the goals and ground rules of the workshop were reviewed, with special emphasis placed on the rules of engagement. The group was directed to try to combine vision with credibility.

To begin soliciting visionary ideas that focused on the program goals, an "imagery" technique was used. Seemingly impossible proposals were carefully discussed but were not rejected out of hand because previous experience had shown that even nonviable ideas could trigger other more viable ideas. Three ideas/questions were then posed, each being submitted to two of the six groups:

1. Assume a priori that the physics breakthroughs needed to create practical interstellar travel are achievable. Imagine that you are far enough into the future so that these breakthroughs have been realized, and you are trying to figure out how they work.
2. What are the critical unknowns and make-or-break issues associated with the ideas from step one, or what are some curious effects (confirmed or unconfirmed) that may support the goals of breakthrough propulsion?
3. Building on the critical issues from the ranked themes, what experiments, theoretical analyses, or further theoretical developments are needed to resolve these issues? Transform objections into research objectives. What laws of physics currently present barriers to these goals, and how might these laws be incomplete or limited in their scope? (For example, consider how Newton's laws were augmented by special relativity for velocities approaching light speed.)

Groups A and B were then asked, How could you propel vehicles without any propellant or with a bare minimum of propellant? Groups C and D were asked, How do you think you could propel a vehicle faster than light or at least up to light speed? Groups E and F were asked, How do you think you could power such devices? Where does the energy come from, and what happens to the energy in the conversion process?

Invited Presentations

The intent of these presentations was to provide credible overviews of where we stand today in physics and introduce the unknowns and unresolved issues. Reference D-1 provides a list of the presentations, including authors and affiliations. Some of the topics covered were

- Propellantless propulsion
- Superluminality
- Quantum nonlocality
- Extraction of energy from the vacuum
- Casimir effect
- Electromagnetic zero-point contributions to mass

- Modification of spacetime geometry
- Low-energy nuclear reactions.

Poster Papers

Poster papers were used to provide imaginative material to help provoke discussion. In the words of the organizers, "In pioneering work, it can be difficult to distinguish between the crazy ideas that will one day evolve into breakthroughs and the more numerous, genuinely crazy ideas. Even though many ideas proposed for this subject are likely to be incorrect, they can still be useful by provoking other, more viable ideas." It was in this spirit that ideas beyond the conventional were invited. A total of 29 poster papers resulted.

REFERENCES

D-1. M.G. Millis, "NASA Propulsion Physics Program," NASA TM-1998-208400, 1998 (see http://www.grc.nasa.gov/WWW/bpp/TM-1998-208400.htm). Also available in *Missions to the Outer Solar System and Beyond,* Second IAA Symposium on Realistic Near-Term Advanced Scientific Space Mission, Aosta, Italy, June 29–July 1, 1998, International Academy of Astronautics, G. Genta (Ed.), pp. 103–110.

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14. ABSTRACT
Technology forecasting can be used in two important ways: to assess the military (or other) applicability of recognized emerging technologies and to seek new or breakthrough approaches for solving existing problems. This document reviews some methodologies that have been used in attempts to forecast future technologies. These methodologies include formal approaches [e.g., brainstorming, the Delphi Technique, the Horizon Mission Methodology (HMM), Service studies, and the Institute for Defense Analyses involvement in the Military Critical Techhnologies (MCT) process] and informal approaches (e.g., science fiction). The primary focus is on the longer term (perhaps 50 years in the future) and on potentially applicable military technologies.

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