STUDY PLAN TO IDENTIFY LONG TERM NATIONAL TELECOMMUNICATIONS NEEDS AND PRIORITIES APPLYING DELPHI TECHNIQUES

HANDBOOK

JULY 1974

PREPARED UNDER CONTRACT NO. NAS5-24011;
MODIFICATION NO.6
(WORK ORDER NO. 5)

For

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

CSC
COMPUTER SCIENCES CORPORATION

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EXECUTIVE SUMMARY

This handbook explains the basic Delphi methodology and discusses modified Delphi techniques to identify long-term national telecommunications needs and priorities. Also addressed are the selection of communications experts to participate in such a study, the construction of questionnaires on potential communications developments, and requisite technology. The handbook does not recommend any one of the many modified Delphi approaches as preferrable. No two modified Delphi studies have been the same, which reflects the flexibility and adaptability of this technique. Each study must be specifically tailored to the particular case.

The Delphi method, originally developed and applied at the Rand Corporation, was defined as the iterated interrogation of a panel of experts to obtain a systematic consensus of informed opinion.

The procedure consists of seeking a consensus of opinion among experts about a particular subject and attendant conditions that may prevail in the future. The main features of the Delphi method are:

1. No member of the panel of experts knows what another member of the panel says about a particular question (anonymity of voting). However, this does not mean that the identity of the other members is not known or at least their backgrounds.

2. Questions are asked in two or more iterations (four is often preferred). They may be the same on each round and thus force a reexamination of views from the members of the panel; or they may consist of new questions raised by earlier responses.

3. At each iteration, additional information is given to the participants, in the form of statistics on the earlier responses of the group as a whole, or the answers and comments themselves. This feedback mechanism might also include additional data obtained outside the group.

The Delphi method is an important attempt to bring rigor and logic to forecasting by obtaining the consensus of a number of experts in a climate that eliminates the influence of personalities. Where hard fact or collected data are lacking, the best source of information is the expert. Delphi is a proven method for systematic gathering of estimates and opinions.

Delphi techniques have been applied in a number of long-range forecasting studies, projecting future events or developments, and their impact. These studies cover a wide range of social, economic, political, scientific, and technological subjects. Several pertinent Delphi studies were included as illustrative examples in this handbook.

While none of these Delphi examples employed a computerized approach the use of computers is discussed in detail. A computerized approach to the Delphi study could significantly shorten its duration. However, caution must be exercised to prevent the overlapping of answers in response to one iteration of questions with another. This is essential due to the sequential iterative approach inherent in the Delphi method.

While properly managed Delphi exercises have been considered to be highly successful and, whereas, the Delphi process appears to be one of the most promising approaches developed for social, political, and technical forecasting, it is certainly not advanced as a panacea.

There are several fundamental limitations to be aware of in performing a Delphi study. The administrators of the study may be knowingly or unknowingly biased. This bias can be reflected in the selection of experts, the composition of the questionnaires for the experts to respond to, and in the evaluation and presentation of a round of answers to the questions. Questions can be designed to cope with bias on the part of experts but minimizing bias on the part of study administrators is more difficult.

The experts to serve on the panel must be selected with the utmost care, not only to assure informed and knowledgeable responses but, to minimize the possibility of some experts "going along with the crowd." This could prevent the study from reaching a valid consensus (or possibly equally valid, a lack of consensus).

A further consideration to note is that the assumption in Delphi of linear independence between forecasts or one set of answers and another may not be valid. If the likelihood of a certain event occurring changes, given the occurrence of another event, then, the events are not independent and the conditional probabilities associating these events should be considered in the statistical analysis of answers to questions regarding these events. Cross-impact analysis, discussed in some detail in this handbook provides a method for addressing the latter situation.

To protect against the foregoing deficiencies, the final results of the study to determine long-range national telecommunications needs and priorities might well be reviewed by higher level management personnel outside of as well as within NASA.

The statement of work guiding the development of this handbook is reproduced in the following paragraphs.

The contractor shall perform a study to develop a plan for identification of long-term national communications needs and priorities by use of a modified Delphi technique. The study will include the following tasks:

1. The plan will describe the basic Delphi technique. References to a relevant recent bibliography on the Delphi technique will be collected and identified along with the mathematical basis for the Delphi technique. Modifications to adapt the technique to the discipline of communications technology will be specifically addressed.

2. The plan will present the objectives that will provide for informing a panel of communications experts in the actual implementation of the Delphi study technique. The methodology presented will be directed toward the simplification of the initiation, implementation, and feedback controls for the NASA Plan Leader. Sources for identifying potential communications developments and requisite technology will be suggested by the contractor as a result of a search of literature and other information media. Sources for social, political, and economic indicators will also be suggested. Examples of charts and statistical extrapolations will be included.

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3. The plan will include modification of the original Delphi technique and its later revisions, such as:

   a. Suggestions on personal probability assessments in relation to future communications technology will be presented. Techniques for scaling of verbal phases associated with numerical probability will be included.

   b. Provisions for protections against a spurious concensus of multi-disciplinary judgments will be provided as caveats to the Planning Leader. Feedback – both critical and favorable – on past Delphi studies will be noted to avoid past errors.

   c. A discussion on cross-impact analysis will be included to assure recognition of interdependence among anticipated telecommunications developments. Uses of Monte Carlo simulation in Delphi sensitivity analysis will also be addressed. Risk Analysis Technology will be integrated into the overall plan.

4. The plan will include typical condensed analyses and evaluations of Delphi applications to offer insight into problem areas that may arise.

5. The plan will include the detailed procedures to be used for performing the actual Delphi planning activity. Included will be procedures for selecting the experts to be used and their desired characteristics.

6. The plan summary and recommendations for its implementation will be included.

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SECTION 1 - INTRODUCTION

1.1 PURPOSE OF STUDY PLAN

The purpose of this study plan is to provide NASA with a handbook to facilitate implementation of a program to identify long-term telecommunications needs and priorities in the national interests by use of a modified Delphi technique. National telecommunication needs are not confined to the 50 conterminous states but also include elements interactive with other nations.

1.2 SCOPE OF STUDY PLAN

This study plan focuses on the use of the Delphi method with selected modifications or developments in the prediction of long-term (1985-1995) national telecommunication needs and priorities in general and communication satellites in particular. The Delphi technique was evolved at the RAND Corporation by Dr. Olaf Helmer in collaboration with Dr. Norman C. Dalkey.[1] Originally it was developed and applied as a method for deriving a consensus of expert opinion. The first application of the method to a major long-range forecasting study[2] was by Dr. Helmer and Theodore J. Gordon of Douglas Aircraft under the auspices of RAND Corporation. The Delphi method was defined at RAND as a set of techniques for soliciting and collating the opinion of experts in order to arrive at the most reliable consensus. The method's most distinctive features are anonymity, statistical summaries of information provided by the control group, regulated feedback, and an iterative process that permits and encourages the reassessment of initial judgments. Delphi techniques, both basic and modified, are presented in this study plan with added emphasis on selection of communications experts and construction of questionnaires on potential communications developments and requisite technology. A number of Delphi studies are subsequently presented which illustrate selection of experts and types of questions, i.e., in structure and in communications subject content.

Key terms used in defining the scope of this study plan are elaborated in the following sentences.

By "prediction" we mean the declaration beforehand of events, implying inference from facts or accepted laws of nature. A prediction is a statement made about the future or an as yet unobserved event: a reasonably definite forecast about the future.

"Long-term" implies long-range forecasting as well as characterizing an enduring need. Predicting the precise form that technology will take at a future date is not reasonably to be expected. A "long-term" look helps to evaluate the probability and significance of possible future developments (circa 1990) so that present managers can make better decisions.

The term "national" pertains to the United States and the aggregation of people having like institutions and customs and a sense of social homogeneity and mutual interest therein. Also implied is a national level of viewpoint rather than state or local, e.g., national goals or national objectives.

"Telecommunications" is communications at a distance. Here we mean a broad sense of any transmission, emission, or reception of signals, writing, images, sounds, or intelligence of any nature by wire, radio, visual or other electromagnetic systems. The terms telecommunication and communication are often used interchangeably.

"Needs and priorities" implies a hierarchy of imperatives for achievement. As posed here "need" is the central determinant of technological forecasts in the communications field. This expresses a teleological view that processes of technological changes in communications should be interpreted as being responsive to external stimuli rather than self-generating or "inner-directed" as in the ontological view. Further, such viewpoint tacitly assumes that technology is only utilized if it responds to a need. Recognizing that breakthroughs are essentially unpredictable, the central position of "needs" in forecasting relies on the expectation that major technological contributions in communications will result from applied, mission-oriented research. Statement of communications needs will strongly reflect the experience and expertise of the originator, which may be both a strength and a weakness. Interaction of social scientists and communications technologists are vital in developing needs.

In summary, the scope of this handbook is to explain the Delphi method and illustrate its application in identifying communications experts and stating communications expectations which may be reflected in questionnaires.

1.2.1 Context of the Delphi Method

There are a number of forecasting tools that may be used to predict the technology and hardware that will be of major concern in the future. Four tools are generally described; Delphi fits into the last of these techniques:

- **Morphological analysis** is a method for systematic examination of all possible inventions, strategies, policies, or outcomes emphasizing fundamental structural differences and/or similarities rather than functional or performance features.

- **Extrapolation of trends** is the estimation of future values or magnitude by assuming smooth, continuous progression from present states or trends. Underlying causal mechanisms are not necessarily known.

- **Heuristic forecasts** are based on explicit "models" of a dynamic process leading to or of the future, involving a greater degree of understanding of some causal mechanism than for a simple extrapolation.

- **Intuitive forecasts** of future developments encompass flashes of genius, brainstorming, games, scenarios, consensus devices (Delphi), etc. System and order may be applied to such sources to improve results.

Most practitioners of forecasting agree that long-range forecasting is not merely an extension of short-range forecasting. At the present time only intuitive techniques have been suitable for long-range forecasting. For this purpose, the Delphi method and scenarios have been most useful. When properly applied the Delphi technique will provide long-term insights to aid decisionmakers in formulating long-range plans. Coordinated information on the future in social, economic and technological areas is normally sought to indicate trends or patterns. Separate Delphi panels may be formed and addressed to cover all three areas. On the other hand, supplementary studies or

the application of other techniques may provide the additional information to be used in conjunction with a technological Delphi exercise.

1.3 APPLICATION OF DELPHI TECHNIQUES TO LONG-TERM NATIONAL TELE-COMMUNICATIONS NEEDS AND PRIORITIES

1.3.1 <u>Application of Delphi.</u> Delphi techniques can be used in any situation where opinions are sought from experts (or knowledgeable persons) on a particular subject or issue. This technique has been developed, tested, and found to be an extremely effective method of forecasting future events in both business and government activities. Its success depends critically on the choice of experts to serve on the panels, the formulation of questions, and the way in which the technique is implemented. Delphi has been applied to a forecast survey of Japan's scientific and technological developments up to 2000 A.D., which included some space and communications programs (see the example, in Paragraph 6.1).

1.3.2 <u>Requirement for Long-Range Planning.</u> As with other ongoing activities NASA can engage in long-range communications planning to identify the major decision points well in advance of their occurrence for the decisionmaker in order to prevent piecemeal decisions and to illuminate the long-term consequences of his decisions. In general, NASA programs span long time scales; communications developments face the same extended R&D cycle as the other programs. In this framework, long-range planning is needed to provide communication programs that are viable alternatives to other programs - all within projected budgetary levels. Intelligent long-range planning requires insight into the social and military environments, as well as into the technology that will exist in the future. In fact, the practice of forecasting is deeply woven, explicitly and implicitly, in our national system.

1.3.3 <u>Telecommunication Needs.</u> A first step in NASA's long-range communications planning process is determination of long-term needs, from which concrete goals are derived for achievement. Forecasting technological advancements in communications is essential to this determination. Nearly everyone who looks into long-range forecasting must face the fact that a large part of the activity is at least within the area of

opinion. The opinion of communications experts appears to be a likely source for indicating the features of the communications future. The Delphi technique is a useful way of eliciting and organizing this expert opinion. In recent literature much has been written about the revolution in communications, projections on the future of communications, and communications needs. (Appendices B and C discuss anticipated developments further.) A caution is in order because even widely recognized needs do not necessarily call forth invention; a need is not always reflected in a market.

1.3.4 Management of Delphi Application. In the application of Delphi techniques, the administrative/analytic group maintains constant control over the iteration of questionnaires, processing of responses, and controlled feedback. Although this group must exercise extreme care to avoid introducing its own biases, such control is essential to reduce ineffectual results and incorrect actions based on low-quality forecast information. The final forecast information is assembled by the analytic group in usable form for making statistically valid decisions. This information can then be reviewed by higher level NASA management in order to make suggestions on its validity, content, and recommended usage. Finalized Delphi forecast information would then be submitted to top-level planners to use in conjunction with other decision data and aids in developing and issuing specific plans and strategies.

1.3.5 Delphi Technique Should Avoid Gross Errors. Some experts are so immersed in the problems of developments in their field that they tend to be overly conservative on what may reasonably occur in the future. Delphi tends to stimulate and interest the participants by the feedback and iteration of questions, by the requests for justification of outlier opinions to the responses of the group of experts, and by permitting a respondent to change his mind. The outlier opinion may turn out to be the correct interpretation. Delphi should encourage the expression of insights and not be deflationary to egos of panel members.

Arthur C. Clarke[3] has collected a number of examples where the individual expert has made a particularly bad forecast. A few of these are worth noting.

The first was an essay by the astronomer Simon Newcomb, who stated that "the demonstration that no possible combination of known substances, known forms of machinery, and known forms of force can be united in a practical machine by which man shall fly long distances through the air, seems to the writer as complete as it is possible for the demonstration of any physical fact to be." Newcomb was convinced (as were Euler, Stokes, Kirchhoff, and Rayleigh before him) that the physics of lift and drag on finite three-dimensional bodies moving in a viscous fluid (air) were such as to rule out any possibility of powered flight by heavier-than-air craft. Although the relevant physical laws were previously known in general, the correct deduction (i.e., calculation) from them was not made until after a successful powered flight was actually demonstrated by the Wright brothers in 1903.

A second instance was occasioned by the publication of a book called "Rockets through Space" by Cleator in 1936. A review of the book, written by R. v. d. R. Wooley and published in Nature, dismissed the notion of space flight as "essentially impractical." In 1956, a year before the first Sputnik, Dr. Wooley was appointed Astronomer Royal. When he was interviewed by the press he confirmed his earlier opinion with the remark, "Space travel is utter bilge." The author of this opinion became, ex officio, a member of the committee advising the government of the United Kingdom on space research.

Aeronautical engineer Nevil Shute Norway (later famous as author Nevil Shute) was chief calculator for the R-100 Airship and a cofounder of Air Speed Ltd., subsequently merged with DeHavilland's in 1940. In 1929, he was very much an optimist about the future of civil aviation, yet he firmly predicted that by 1980 commercial aircraft would be limited to a cruising speed of 110 to 130 mph, a range of 600 miles, and a payload capacity of 4 tons out of 20 tons total weight. (On the other hand, in a novel written in 1948,[4] he accurately anticipated the problems of catastrophic structural failure due to metal "fatigue" which later plagued the Comet and the Lockheed Electra, among other aircraft.)

1.4 ORGANIZATION OF HANDBOOK

The balance of this handbook is divided into six major sections and three appendices.

- Section 2, Management of Delphi Procedure, describes the planning for implementation of Delphi techniques: the scheduling, technical control, and budgeting of a Delphi program.

- Section 3, Delphi Methodology, presents the historical development of Delphi and definition of the basic method. An illustration of a Delphi application is given to involve the reader so that he may acquire an overview of the essential steps. Finally, the principal advantages and limitations of the Delphi method are discussed.

- Section 4, Procedure for Delphi Application to Long-Term National Telecommunications Needs, sets forth an explanation of needs, how to select experts, how to generate pertinent questions, the processing and iteration of questionnaires, associated statistical analyses, and presentation of results.

- Section 5, Development of Delphi Modifications, describes techniques that various practitioners have evolved in applying Delphi methods with the aim of making results more accurate and valid. Several of these are associated techniques and not necessarily Delphi per se.

- Section 6, Examples of Delphi Method Applications, presents four abstracts of Delphi studies, illustrating the flexibility, style, and usefulness of the method.

- Section 7, Utilization of Delphi-Obtained Data, points out several systematic methods for evaluating the results of a Delphi effort as additional insights in the decisionmaking process.

- Appendix A, Mathematics of Delphi Methods, provides details of mathematical techniques useful in the Delphi process.

- Appendix B, Summary of the Telecommunications Future, highlights the areas of expected developments in the communications field as reported in recent literature and as expressed in preliminary discussion with a few knowledgeable communications experts.

- Appendix C, Literature Survey of Future Telecommunications Technology, discusses recent literature which provides additional perspective and previews of future telecommunications developments.

SECTION 2 - MANAGEMENT OF DELPHI PROCEDURE

2.1 PLANNING OF PROGRAM

The many planning activities and questions that must be considered in the course of managing a Delphi exercise or a Delphi conference are outlined below, in the approximate order in which they arise in any given exercise. Many of the questions affect each other, however, so the ordering is somewhat arbitrary.

1. The exercise design and monitor team must be selected. Turoff[5] recommends two to five professional people and about the same number of secretarial support people for a questionnaire-type exercise with 10 to 50 people in the respondent group. The size of the design and monitor team is roughly proportional to the size of the respondent group. If a Delphi conference is used instead of a Delphi exercise, the number of secretarial support people could be drastically reduced. Throughout this document a Delphi exercise will generally imply the use of mimeographed or printed questionnaires distributed and returned by mail and tabulated manually; whereas, a Delphi conference will imply the use of interactive remote access computer terminals, such as teletypes, connected by phone to a central computer. The advantages and disadvantages of these two methods are presented in item 6 below. Further details on the Delphi conference are given in Paragraph 5.6.

    In preparing a Delphi exercise or conference, there are three or four groups of people to be considered: the design and monitor team(s), which may be separate groups, or more usually, a single group; the respondent group; and the user group. The user group is the group with the questions, the sponsor of the endeavor. They, or some of them, may also be members of the respondent group, but Turoff says they should not act as monitors. However, he states the following as one of what he says are the only four positive statements that can be made about Delphi:

"The utility of the results depends upon the close cooperation between the design and the intended user body or at least a clear understanding by the design team of the goals or requirements of the user body."

2. It follows, from the latter part of item 1. above, that either the user body or the design team must formulate, as clearly as possible, the purpose of the exercise.

   Turoff lists the following possible objectives for a Delphi[5, 6]:

   a. To determine or develop a range of possible alternatives.

   b. To explore or expose underlying assumptions or information leading to differing judgments.

   c. To seek out information which may generate a consensus of judgment on the part of the respondent group.

   d. To correlate informed judgments on a topic spanning a wide range of disciplines.

   e. To educate the respondent group as to the diverse and interrelated aspects of the topic.

   f. Examining the significance of historical events.

   g. Gathering current and historical data.

   h. Putting together the structure of a model.

   i. Delineating the pros and cons associated with potential decision or policy options.

   j. Developing causal relationships in complex economic or social phenomena.

   k. Clarifying human interactions through role playing concepts.

   In addition to being influenced by the purpose of the exercise, the questions and format of the Delphi and the number and selection of respondents may

be influenced by whether or not the results are to be confidential or widely published, and whether the Delphi is intended as a supplement, precursor, or alternative to a conference or committee meeting. In Reference 5, Turoff states his view that the proper role of a Delphi dealing with policy matters is as a precursor for committee activity. At least in the factual field, however, it has been shown that following up a Delphi exercise with a face-to-face conference usually degrades, rather than improves, the accuracy of the results produced by the Delphi.[7] There is, therefore, some question as to whether it might not be better to use a Delphi as a replacement for a committee discussion, rather than as a precursor to it.

3. The number of respondents, and the criteria for their selection, is the next topic which must be considered. It has been shown that results improve with the size of the group, at least up to 25 or 30, although the difference between groups of 13 and 30 is not very large. One must allow for the chance that some of the respondents will drop out, for one reason or another, after the exercise begins. Furthermore, if one wants to base the results on the answers of self-rated experts, one needs a larger group to begin with, so that the group of people who rate themselves as expert on any particular question will generally not be too small.

Budgetary limitations restrict the maximum size of the respondent team which is practical, particularly if they have to be paid to participate. Even if they are not paid, the more respondents there are the more computer or clerical time will be required to process their answers, the more time will be required from the monitor team to secure their cooperation and answer their questions, etc.

The criteria for selection of the respondents is very important. A second of Turoff's four positive statements is: "Success of the Delphi is dependent upon the ingenuity of the design team and the background of the respondent

group." (His other two statements are: "No hard and fast rules exist to guide the design of a particular Delphi" and "The Delphi requires a degree of quantification to be imposed upon subjective judgmental factors and the definition of this quantification is a matter of principal concern to the design team.") The two major factors that must be included in the set of criteria for respondent selection are expertise and diversity. Obviously, it is desirable to select as respondents people who know something about the subject in question. It is also very important to get an interdisciplinary approach. In a Delphi on communication needs, for example, it would be desirable to have respondents who are in the business of providing communications, respondents who are users of these services, some who are on government regulatory bodies, and some with an academic background in the subject. Each of these, in turn, could include diversity within itself. For example, the users could include broadcasters, amateurs, the military, users of police and taxi bands, aircraft and marine users, radio astronomers, etc. Paragraph 4.1 gives further details on the selection of communications panel members.

After the number of respondents and the criteria for their selection have been decided upon, there are the tasks deciding who will nominate candidates for the panel, making the nominations, choosing among them, contacting them and persuading them to participate, making the financial arrangements if they are to be paid, etc. If the user group participates in the nominations or selection they may unconsciously bias the panel with a preponderance of people who see things the way the user group does.

4. The question of whether or not the respondents will be paid must be considered. If they will be paid, more questions can be asked, more types of information can be requested with each answer, and more rounds can be run without the respondents losing interest and dropping out. Although a Delphi exercise or conference takes less of the respondent's time than a conventional conference would, each round may still take an hour or more,

particularly if the respondent must fill out cross-impact matrices, or if he is asked to put next to each answer his rating of his own expertise on that question, his assessment of the importance of the question, and various other types of supplemental information which will be mentioned below. Furthermore, respondents will take the exercise more seriously if they are involved as part of their normal job function or if they are paid a normal consulting fee than if they are asked to volunteer their time.

5. The amount of anonymity must be decided by the design team. Should the participants know the names of the other participants, and their backgrounds? Their backgrounds but not their names? Neither? If a participant wants to identify himself by name when making a comment should he be permitted to do so? (The voting is always strictly anonymous, in a Delphi exercise, but strict anonymity may not be required for comments.)

Several authors have stressed that it is important that the panel of respondents know they are dealing with their peers. It may be desirable to let each participant know the names and backgrounds of the other participants. However, in a number of Delphi studies anonymity of respondents has been strictly preserved.

6. As has been mentioned, an important decision is whether to conduct the Delphi by mail, using questionnaires, or by telephone, using interactive terminals such as teletypes, possibly supplemented with mailed hard-copy summaries in the case of Delphi conferences which last many weeks. (Summaries could also be produced on high speed line printers, if the respondents have access to such facilities.)

The computerized Delphi conference has the following advantages over the Delphi exercise using mailed questionnaires:

a. It is usually faster than the mailed questionnaire procedure. Some Delphi conferences, however, go on for weeks or months.

b. It is usually less expensive to process responses by computer
    than to process them manually. The mailed questionnaires
    could be converted to punched cards and processed by machine,
    however.

c. If the Delphi conference is kept short (1 day to 3 days) relatively little
    "rethink" time will be required from the participants. With the mailed
    questionnaires, so much time can elapse between rounds that the par-
    ticipants may have to start thinking about each question all over again
    on each round.

d. Delphi conference computer programs can contain interactive features
    which are useful to the respondents. For example, the computer can
    help them eliminate inconsistencies in their probability estimates, can
    run Monte Carlo solutions of cross-impact matrices, etc.

e. As Turoff says in Reference 6, "A significant observable effect of a
    computerized conference system is the group pressure to restrict
    discussion to the meat of the issue. Verbose statements always tend
    to receive low acceptance votes and individuals quickly learn, because
    of this, to sharpen their position if they wish to make a point. "

The disadvantages of the computerized approach are:

a. There is some inconvenience, even though the computer programs,
    running such Delphi conferences are designed to be as convenient as
    possible. Teletypes are noisy and fairly slow in printing. The limited
    width of teletype paper makes it hard to display tables with many
    columns. Line errors, computer malfunctions, and other problems
    slow things down. Some of these problems can be alleviated somewhat
    if the respondent lets his secretary or data technician handle the
    terminal. Such a procedure, however, reduces the usefulness of the
    interactive features of some Delphi conference computer programs.

b. Some of the respondents may not have access to teletype terminals. Terminals which operate more quietly and at a higher speed than teletype are available, reducing the impact of disadvantage (a), but even fewer respondents are likely to have access to them. Of course, access to a terminal could be made one of the criteria in choosing respondents, but that might eliminate some respondents whose other qualifications were superior.

c. In order to use the computerized procedure, one needs access to a computer and a computer program. Several programs are available, as mentioned in Paragraph 5.6, but they run only on certain computers. This is not really a serious objection, since there are a multitude of time-sharing computer services that provide nationwide access to their computers, and some of these use Univac 1108 computers, which were used for Turoff's Delphi computer program. Furthermore, programs can be modified to fit other computers, but this does involve costs (possibly a few man-months of effort, depending on the computer and the program).

d. The overall cost of the Delphi conference will probably be a little higher than the cost of a Delphi exercise, because of the cost of computer and terminal time. Some of the respondents may also have long distance line charges, if they are not near a concentrator of the time-sharing service being used.

Among the advantages of both of the above types of Delphi over conventional conferences is the savings in travel time and expense. There is also a gain in convenience to the respondents, since they can answer when they can spare the time (within limits), rather than having to reserve a particular date for a conference. If the design team holds the respondents to a very narrow schedule, such as one round per day, this advantage is somewhat reduced, but at least the respondent can

answer at the time of the day he wants, which is especially handy if he is in a distant time zone.

7. Scheduling the overall project is the next problem. This schedule must include the time for the design team to complete the consideration of the topics below, contact the respondents, and get their consent; decision on the number of rounds to use and the time the respondents are given to answer each round; and, for the exercise conducted by mail, the time to allow for mail deliveries both ways plus processing and tabulation of the results of each round.

At least four rounds are generally used. On the first round, the respondents give their initial estimates. On the second round, those who find themselves in the bottom or top quartile, and who do not want to move into the interquartile range, are asked to give their reasons. These reasons are displayed to the other respondents in the third round, at which time other respondents may refute them. Based on these refutations, which are displayed in the fourth round, some respondents may change their votes. On the other hand, some new reasons or refutations may be presented, suggesting that it may be fruitful to go on to a fifth or sixth round. Such a situation is especially likely if policy questions are being considered. Turoff notes, in regard to policy Delphi studies, "On some issues where strong polarization existed in the respondent group, we discovered that each side on obtaining the summary of the first round did not really believe that the other held so completely different a view and felt that a few casual comments would shift the other group to their "logical" position. Upon getting the results of the second round this belief is usually shattered. When the positions were still far apart on the third round, some respondents in the past Delphi exercises have become disgusted and given up on the study, however, a good many began to work very hard at developing very careful arguments and comments. In essence, it was not until the third round that

the majority of the respondents reacted to the seriously polarized issues."[5]
In answering technical questions, on the other hand, two or three rounds
may be sufficient, if there are few reasons given and little changing of
votes.

The number of rounds is less distinct in a computerized Delphi than in one
run by mail. In the computerized version, a few people may interact with
each other online or at short intervals, having many rounds, while others
may be off-line for days at a time. One participant may thus give his fifth
round refutation before another gives his second round estimate.

As has been mentioned, allowing the participants a short time for each
round of questions reduces the rethink time required, and reduces the
overall time required for the Delphi, but also reduces the convenience,
since some participants may be busy with something else for a few days.

8. The next step is to decide on the format of the questions, the approximate
number of questions, the general subject of each question, and finally the
specific wording of each question. Paragraph 4.2 discusses the generation
of the questions in detail. Here it is sufficient to note that virtually every
Delphi exercise has used a different format for the questions and answers.
Some ask for dates, some ask for probabilities. Some ask for self-
assessments of expertise on a question as compared with the other partici-
pants, some ask for self-assessments on a particular question as compared
to the other questions, and some don't ask for self-assessment. Some ask
for cross-impact matrices, others do not. Those asking for cross-impact
matrices use many different approaches, as described in Paragraph 5.8 and
Appendix A.3. The respondents may be asked to rate comments or proposed
items for importance, validity, desirability, and/or feasibility or probability
of occurring, as applicable.

If a computerized Delphi conference is planned, and the desired format
doesn't agree with the format provided in available computer programs,

some time will have to be allowed for modifying the program. This should not be too difficult if the program is in a high level language such as FORTRAN, BASIC, XBASIC, or JOSS.

The design team must also decide how much freedom should be given to the respondent group to change the nature of the issues presented, and should set guidelines on the editing of comments generated by the respondents and fed back without editing. At the other extreme, the monitor group can consolidate and summarize generally similar comments from many participants; perhaps edit out emotional phrases and arguments, if they think that desirable (it may not be); and inject arguments and rebuttals of their own, if they think the participants are overlooking or misinterpreting something. If they inject comments of their own, they must decide whether to identify such comments as coming from them, rather than from the respondent group.

In view of all the above decisions which must be made, ample time must be allowed for the formulation of formats and questions, plus some time for trying them out on a pilot sample of people outside the design team, and revising them to increase clarity, based on the results of the pilot test. The pilot run should also test the clarity of the instructions to the respondents, discussed in 9 below.

9. Closely associated with the detailed formulation of the questions is the formulation of the instructions to the respondents. Decisions must be made on whether a neutral judgment will be considered the same as a no judgment or blank answer; how many permissible answers are allowed to each question, and whether a neutral judgment is a permissible answer. For example, in Reference 5 no neutral answer was permitted. The respondent had to feel that an item was either a little important or a little unimportant. A no judgment category was, however, allowed. The set of instructions presented in Reference 5 are particularly clear. They were designed for a policy Delphi, however, and would require some revision for other types.

Many other specific decisions must be made in formulating the instructions. In a computerized Delphi conference, a decision must be made as to how many responses must be received before the computer summarizes the votes, computes the new median and quartile values, and makes these figures available to respondents who subsequently log in. A decision must be made on exactly what information is fed back. For example, is the number of respondents who answered a question (not counting the "no judgments") displayed? Are the results of both the overall group and the self-rated experts displayed, or only one of these? What are the exact criteria for adding an item to the list to be considered, or dropping an item from the list? Can the author of a new item later modify its wording? Can someone else later restore the original wording? Should there be a limit on the number of active items? On the total number of active and inactive items? If so, what should these limits be? How does one feed back a summary of group response on non-numeric items which have no median (for example, the answers to questions like "In what ways will communications in the year 2000 differ from the year 1974?"). Most of these decisions must be made in running a Delphi exercise as well as in running a conference, but the decisions must be more explicit in the conference situation if they are to be programmed into a computer.

Turoff says "The design effort can take a month, and possibly two or three months if no member of the design group has a strong background in the subject. Outside consultants can be extremely useful in this phase."[5]

He also says that the design team should prepare a fact and data summary indicating whatever appropriate benefit or cost measures are available on a historical basis. This summary would be supplied to the respondents. His remark was in connection with a policy Delphi. For other types of Delphi, other historical information should also be supplied to the respondents. Such would probably include historical trend data on usage of various types of equipment and communication bands, in a communication

study. Other data might include graphs relating telephone traffic to per capita GNP and total GNP, data relating telegraph, telephone, and teletype traffic to various trade statistics, etc.

10. Finally, the plan must allow some time for the preparation of a final report summarizing the findings of the exercise or conference, the procedure used, etc.

2.2 SCHEDULE REPORTING AND CONTROL

The time allowed for the respondents to complete their answers to each round of questions, and the time the monitor team takes to process and tabulate their answers and issue the next questionnaire (in a manually processed Delphi exercise) are in the critical path of the exercise. Accordingly, if the results of the exercise are wanted in a relatively short time (as is usually the case), it is important to hold these times on each round to a minimum.

In Reference 5, Turoff describes a Delphi exercise in which the participants were requested to mail their answers to each questionnaire within 3 days of receiving it. He stated that the results of a round can be manually analyzed and summarized in 1 or 2 weeks with allowance for overtime when required. He adds, "The processing of the returns does not lend itself to a normal eight-hour day, five-day week schedule, and the peaks in professional and secretarial work load do not coincide. Because of the complexity of the issues, it is probably preferable for a professional on the monitor team to plan to work on a given well-defined section of the exercise in one sitting and to ensure that another professional will double check him before the summary and new questionnaire are prepared. "

In addition to the above times, one would have to allow several days each way for mail delivery, if the respondents are spread over a large geographic area.

The above figures were for a policy Delphi he conducted which started with 70 items. In this exercise 295 items were generated by the respondents and fed back for evaluation, and 74 additional items of interest were not fed back but were

summarized in an appendix to the report. Many of these comments were either emotional or fell in the sections from which he excluded feedback. On the last round, a free form question asking for respondent's final recommendations generated 46 items which were compiled separately but tended to duplicate much of the earlier material. In addition, approximately 100 items were purged completely as outright duplication or not meaningful (as judged by the monitors). Therefore, the original 70 items generated aboue 500 items on the part of the respondents, about a 7:1 ratio on the average. The more controversial items generated the most new items.

In a manual operation of this type the time required to process the returns can be expected to be proportional to the number of respondents and to the number of items, and inversely proportional to the size of the staff.

It is possible to shorten the duration of the Delphi dramatically by using the computerized approach discussed in Paragraphs 2.1 and 5.6. In such an approach the mail delivery time and the time required for analyzing and summarizing each round are eliminated. In Reference 8, Turoff describes a computerized Delphi conference which ran for 13 weeks. In that case the convenience of the respondents, rather than a sense of haste, was the factor considered most heavily in establishing the schedule. One round per day could be maintained, if time was urgent, the scope of the study not too extensive, and the list of questions not excessively long. At this pace, relatively little editing of the new items could be expected from the monitor team.

Reference 8 included a report on an experiment to determine the effects of time permitted to answer each question on the accuracy of the answers. The results showed that accuracy was best if the respondent spent only 30 seconds on each question. Fifteen seconds was too short a time for the respondents to take all factors into account, but times longer than 30 seconds were also not as good from an accuracy point of view. Although the test was on almanac-type questions, the respondents had to make fairly complicated judgments. For example, a question like, "What was the popular vote for Kennedy in the 1960 presidential election in the state of Texas?"

involves a number of factors: the population of Texas in 1960, the fact that Texas is a southern state, predominantly Democratic, but conservative, and predominantly Protestant, that Kennedy was a Catholic, and so on. As Dalkey says, "Apparently, there is a fairly sharp limit on the number of factors and the amount of 'processing' that can be dealt with profitably. At all events, we seem to have validated the advice frequently given in connection with objective examinations - 'Trust your first estimate'."

If the respondents are told to spend only 30 seconds on each answer, it should not take them very long to complete each round.

Regardless of whether the Delphi is conducted by mailed questionnaires or by computer, it is desirable to have a procedure to check on the timely receipt of answers from all respondents, and to flag respondents who are late in answering. The monitors should contact such respondents by telephone, to find out if they are having difficulty, and to try to alleviate whatever problem is causing the delay.

If the exercise is conducted by mail, it is possible to speed up the tabulation of the replies if they are punched into cards and processed by machine. Machine processing is also more accurate and cheaper than hand tabulation, once the program has been written or otherwise obtained.

2.3 TECHNICAL REVIEWS

It has been shown that the interquartile values Q_1 and Q_3 (defined in Appendix A.2) of the answers to each question generally move toward the median as the Delphi progresses through its rounds.[9] Such a movement indicates and defines a growing consensus among the respondents. Accordingly, the monitor team should maintain a close watch on the changes in the interquartile range from round to round for each question. If some questions show little change, or a divergence in the interquartile values as the Delphi progresses, something may be wrong. Perhaps the phraseology of the question is unclear, and different participants are interpreting the question in different ways. In such a case it would be worthwhile for the monitor team to look closely at the questions and comments responsible for such behavior, and perhaps to

talk to some of the people who have changed their votes away from the median, to find out what their interpretation of the question is and the reason for their change of vote.

If a computerized Delphi conference is being run, it would be desirable to check by telephone with some of the respondents, to get from them information on difficulties or undesirable system characteristics they have encountered, and ideas for improvements in the system. Alternatively, one of the items given to the respondents might be a request for their opinion of the system, a list of defects they found, and suggestions for improvements.

If the respondents are asked to construct a cross-impact matrix, the matrix which results from their consensus can be used as input to a Monte Carlo program after each round of the Delphi, and the results fed back to the participants, so they can change their probability and conditional probability estimates if they feel the results of the Monte Carlo are unrealistic. The Monte Carlo results of their individual cross-impact matrix should also be fed back to them. The computer can also check the cross-impact matrix and their probability estimates for consistency with equations of the form of equations (1) and (2) in Appendix A.3, and bring any inconsistencies to the attention of the monitors. If the monitors feel the inconsistencies are large enough to be worth passing on to the respondents, they should do so, and the respondents may then improve their estimates during the next round.

2.4 BUDGETING FOR PROGRAM EXECUTION

It is convenient to divide the costs associated with a Delphi exercise or conference into three parts: design, execution, and report.

As has been mentioned, Turoff recommended a team of two to five professionals, and the same number of secretarial/clerical people, for a manual Delphi exercise with 10 to 50 respondents and 70 initial items on the questionnaires.

The design effort can be expected to be approximately proportional to the number of items on the questionnaires. The design effort will also depend somewhat on the number of people in the respondent group, since they all have to be chosen,

contacted, given some instruction, etc. Furthermore, if a large respondent group is to be used, it is appropriate to put more effort into the design of the questions and instructions.

If a computerized Delphi conference is to be run, rather than a mailed questionnaire type of exercise, the design effort could be expected to be somewhat larger. All of the things which have to be done during a mailed exercise also have to be done with a computerized conference including the payment of consultant fees or other renumeration to respondents. In addition, one must decide which computer to use; which computer program to use; whether to modify the program, and, if so, how; make sure the respondents have access to terminals compatible with the computer and program, etc.

If the computerized conference approach is selected, there will probably be some cost associated with obtaining the necessary computer program. This cost may be rather nominal. For example, we understand that Turoff's program is available for $300. Other programs, of course, may be more or less expensive than this. Any program that is obtained will probably have to be modified to fit a particular conference format, unless the format was planned with the program in mind.

The difference in effort between the mailed questionnaire and the computerized approach may not be quite as large as the above paragraph would imply, because before a decision is made on which approach to use, the design team will probably want to review the formats and instructions associated with available computer programs, to see if they are suitable. The effort of obtaining and comparing this information would therefore be incurred whichever decision is finally made.

A computer program which compiles and tabulates the replies to a mailed questionnaire can be expected to be simpler and cheaper than one which is used to run an interactive, computerized Delphi conference. Nevertheless, such a program can be a fairly expensive item itself. In Reference 10 it is mentioned that the respondent's questionnaires were converted to 40, 000 IBM cards which were then manipulated by over 30 separate computer programs written primarily for that project and using a variety of separate computing systems.

That was an effort involving 210 respondents and 500 multiple-part and graphical questions.

During the execution phase, Turoff reports that each round of the exercise can be manually analyzed and summarized in 1 to 2 weeks with allowance for overtime hours when required. He states that the secretarial work load, which is comparatively massive, is not well distributed time-wise during the redesign period between rounds. This could be cut to some extent by the use of online text editing and composition systems now available on a number of time-shared computer systems. The peaks of the professional and secretarial work load do not coincide. These figures were for the aforementioned policy Delphi exercise he ran.

In a computerized Delphi conference the secretarial work load during the execution phase of the project would be virtually eliminated. The exercise can be designed so that relatively little editing by the monitors is required. For example, rather than the monitors deciding on which comments to consolidate, which to eliminate, and which to modify, all comments can be fed back unedited to the respondents, and can be dropped by the respondents if a certain fraction vote to do so. If that is done, the monitor team would have a much smaller work load during the execution phase. They would mainly answer questions, clarify instructions, and perhaps modify the computer program or instructions if the respondents so request. However, the editing task would add to the work load of the respondents.

In a computerized Delphi conference that Turoff ran, 20 respondents used 100 hours of terminal time over a period of 13 weeks.[8] Central processing time on a Univac 1108 was about 1 hour. Less than 100,000 characters of storage were used in this exercise, which was limited to 99 active plus rejected items. Initially, respondents were on the terminal for about a half hour per interaction. Once the novelty of the terminal and the exercise wore off, 10 minutes was a more common interaction time for the purpose of seeing new discussion items and adding or changing some votes. Respondents requested, and were given, three hard-copy summaries at 3 to 4 week intervals. By the time the conference was over, at least

10 of the respondents were using secretaries or junior staff to obtain the latest items and submit responses as directed. Turoff states, "The success of this alternative is extremely important in obtaining the participation of any busy individual. Being able to treat the system as one would treat the news wire service is probably beneficial to its potential application."

In this connection, it should be noted that it is important that the computer program used have an option available to permit the user to receive detailed instructions the first few times he interacts with the system, or to receive very abbreviated cues, once he is familiar with the system. Turoff's program had this feature. The junior staff, however, generally preferred to continue to use the long, slow, detailed option.

Turoff estimated that the conferees spent one additional hour thinking about the issues for every hour on the terminal. Thus, the average respondent spent 5 hours away from the terminal, and he or his assistant spent 5 hours at the terminal during this exercise.

In estimating the costs of an exercise of this kind, one must estimate the charges for terminal time, computer time, and computer storage. Different time-sharing services have different rates, and even a single service usually has a multi-plicity of alternative rate plans the customer can choose among, but the following rates are believed to be fairly typical:

Terminal time: $12.00 per hour during prime time (7 AM to 7 PM) for nation-wide access to the same computer. Regional access would be about $11.00 per hour.

Central processing unit time: 50¢ per second on a Univac 1108

Online storage on disc: 2.5¢ per day per page of 2,098 characters

If a respondent is not located in one of the cities that provide entry to the time-sharing system, he would have to include long distance line charges to the nearest entry point in addition to the terminal time costs.

The above charges do not include costs for the rental of the teletype or other terminal equipment, which are usually treated as overhead at most installations. Presumably they are available anyway, so there is no marginal cost. If the terminals at a particular location are heavily used, there may be some cost in the form of delay to others who wish to use the terminal for other work.

If the Delphi were run by mail and the results tallied by computer, computer costs would be much lower. The computer time would be considerably shorter if the tabulation were done in a batch mode rather than in an interactive mode, and the charges per hour would be much lower if the runs were made during off hours. At the lowest priority, the charge for CPU time drops to about 10¢ per second.

Running the exercise by mail and tabulating the votes by computer would require an allowance for some clerical time in converting the respondent's replies to punched cards. On the other hand, there would be a corresponding reduction, or perhaps a larger reduction, in the time required by the respondents to obtain instructions and data from the terminals and enter their answers.

About the only cost item which would be larger for mailed questionnaires than for a computerized Delphi conference in addition to the processing of responses is the rethink time required of the participants, if the exercise stretches over a long period of time than the conference.

In summary, the overall expense of the Delphi exercise using mailed questionnaires should be less than the expense of a computerized Delphi exercise. The difference may not amount to a great many dollars, however, and the advantages of the conference over the exercise may make it a better choice in spite of its somewhat higher cost.

Both the conference and the exercise would probably be cheaper than a face-to-face conference if some of the respondents would incur large travel charges in going to a conference site. The computer charges above come to about $3000. If 20 consultants had to travel to some city for a face-to-face conference, their travel and

lodging bills alone might total more than $3000 if they were not located close to the conference site, and they would have to spend many hours in travel in addition to the time required for the conference. The time required for the conference itself would be considerably more than the time required to fill out the Delphi questionnaires.

It is reasonable to believe that expenses during the execution phase of the Delphi are proportional to the number of respondents and to the number of items they are asked their opinions on.

At the end of the exercise, the monitor team will require some time to write up the results of the exercise or conference and publish a report. This effort will probably be approximately proportional to the number of items in the Delphi, and will be affected somewhat by the number of respondents, since the more respondents there are, the more comments and new items are likely.

SECTION 3 - DELPHI METHODOLOGY

3.1 DEFINITION OF DELPHI AND HISTORICAL DEVELOPMENT

Delphi methodology is essentially the repeated interrogation of a panel of experts to obtain a systematic consensus of informed opinions. As such, Delphi solicits informed judgments on what will happen and when in a stream of events it will happen. The members of the panel are queried separately in order to avoid bandwagon effects and authority biases. After the members of the panel submit their estimates, a median of the responses is computed with an interquartile range and outerquartile range (see Figure 3-1).
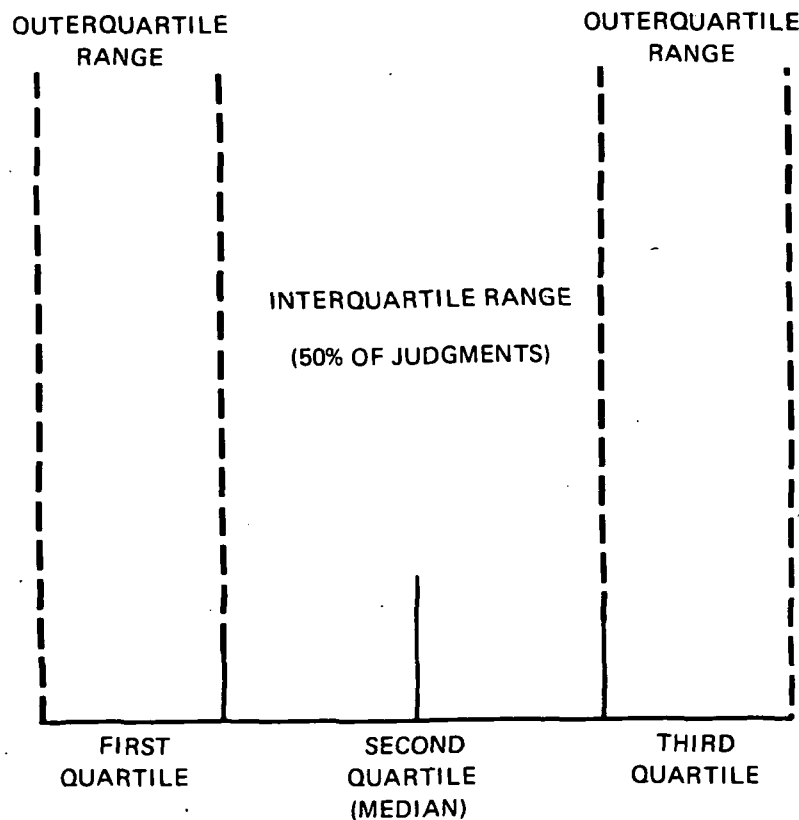
Figure 3-1. Range of Responses

Justification statements are requested from members of the panel whose judgments were in the outerquartile range. These statements and the statistical distribution of the responses are retransmitted to the members of the panel who may then alter

their judgments or repeat them. At least three rounds of questionnaires are usually required to obtain a "homing in" or convergence of a group of opinions.

The Delphi method evolved from a series of pioneering efforts at RAND Corporation under the direction of Dr. Norman Dalkey and Dr. Olaf Helmer. Their milestone paper "An Experimental Application of the Delphi Method to the Use of Experts"[1] described the philosophical basis of the Delphi system for combining expert opinion into a group consensus. This basis uses what can be called, "cybernetic arbitration;" cybernetic because the process of deliberation is steered through feedback, by a control group.

Delphi is the name of a Greek town and is famous, in Greek history, for the oracle who resided there. Ancient civilizations looked for signs to help them make important decisions, and consulting oracles was one of the decisionmaker's tools in those days. The name Delphi was proposed by the RAND group to suggest the practices of ancient Greeks who obtained the counsel of a deity concerning the future through questions submitted to the Delphic Oracle, who was the most renowned of all oracles. This particular oracle was chosen because the RAND group first envisioned that this method could be used for better political forecasts as the Delphic Oracle had so often been utilized by the ancient Greeks. Indeed, the oracle at Delphi was consulted before any important step was taken in affairs of state.

The Delphi procedure consists of seeking a consensus of opinions among experts about a particular subject and about conditions that will prevail in the future, thus explaining its increasing use in forecasting.

The main features of the Delphi method are:

1. No member of the panel of experts knows what another member of the panel says about a particular question. However, this does not mean that the identity of the other members is not known.

2. Questions are asked in two or more iterations. They may be the same on each round and thus force a reexamination of views from the members of the panel; or they may consist of new questions raised by earlier responses.

3. At each iteration, additional information is given to the participants, in the form of statistics on the earlier responses of the group as a whole, or the answers and comments themselves. This feedback mechanism might also include additional data obtained outside the group.

The Delphi method is thus an important attempt to bring rigor and logic to forecasting by obtaining the consensus of a number of experts in a climate that eliminates the influence of personalities. Strictly speaking the Delphi method is not a forecasting technique, but a means for obtaining a consensus.

After its initial impetus from Helmer, the Delphi method has been extensively used to determine long-range forecasts of expected technological and sociological developments.

The 1964 Report on a Long-Range Forecasting Study by T. J. Gordon and Olaf Helmer[2] shows the application of the Delphi method to scientific breakthroughs in physical and biological technologies, world population growth, innovations in automation, progress in space, new weapon systems, and the causes and the prevention of wars.

A forecast of computer developments and applications was performed by Parsons and Williams in 1968.[11] George B. Bernstein prepared a 15-year forecast of Information Processing Technology for the U. S. Navy in 1968.[12] A. Douglas Bender of Smith, Kline, and French Laboratories conducted a set of Delphi studies on various aspects of the future of medical care, in the late sixties (unpublished report).

TRW, Inc. adapted the Delphi method to their long-range planning and have conducted a series of long-range forecasts between 1966 and 1970 designed to show the adaptability of the Delphi method in an industrial environment[13] (see Paragraph 6.4).

The Delphi method has been applied in medicine, in 1971-1972, to the problem of extrapolating the results of animal experiments to human equivalents.[14]

A detailed survey exploring the views of American economicsts on economic, social, and political trends throughout the rest of the century has been conducted by the Delphi method, in 1972-1973.[15]

The Japanese Government has used the Delphi method to foresee socio-economic changes so as to formulate a science and technology policy. This forecast covered 30 years up to the year 2000 and was performed in 1970[16] (see Paragraph 6.1).

The applications of the Delphi method are therefore numerous and cover a large range of activities. In every case, the method has been tailored to each application and some innovation has been introduced to improve on past results. Examples of such innovations are: (1) having respondents rate themselves relative to their degree of expertise on the subject matter, and (2) establishing an elite group of experts from the population of respondents.

3.2 ILLUSTRATION OF DELPHI APPLICATION

A simplified example is included in this section in order to provide the reader with a quick overview of the essential steps in the Delphi method. This example was used in an audience participation workshop held at a Conference on Technological Forecasting and discussed in "The Delphi Method - An Illustration"[17] by Dr. O. Helmer and Mr. T. J. Gordon and is reprinted here by permission of Prentice-Hall Publishing Company. The questions encompass a wide spectrum of subjects. Summaries of results and group consensus charts are at the end of the article. It is strongly recommended that the reader should:

1. Answer each question.

2. Have a number of his associates respond to these same questions and then he should conduct a feedback as required in Delphi methodology.

This is the fastest way to familiarize oneself with the workings of Delphi: a learn-by-doing approach. It is essential for a Delphi study leader to acquire this familiarization with integration of group opinion in order to effectively perform such a study.

The Delphi Method—
An Illustration

One way to understand the concepts, potential, and limitations of a technological forecasting method is to try it. Dr. Olaf Helmer, assisted by Mr. T. J. Gordon, conducted an interesting audience participation session at the Conference on Technological Forecasting. Although limited by time and selection, this simple illustration quickly and effectively familiarized participants with the attributes and theory of the Delphi method.

The following example is presented as an illustration of the Delphi method. It describes a Delphi session which was conducted by Dr. Olaf Helmer and was evaluated by Dr. Helmer and Mr. T. J. Gordon at the First Annual Technology and Management Conference. The session was intended to give conference delegates an experience in the Delphi technique, and the participants were selected at random, not on the basis of their expertise in regard to the session's subject matter. Consequently, attention should be directed toward the methodology, not the results. Under ideal conditions, each of the participants would have been selected for his particular knowledge of the fields for which projections were being made.

STEP 1

Questionnaire 1 (see Exhibit 1) was distributed to over one hundred conference participants and each was asked to complete the form and return it to Dr. Helmer. In addition to giving his answers, each participant was asked to rank his expertise to deal with the particular questions. A "one"

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was to be placed in the box beside that question which the participant felt most competent to answer, and a "seven" alongside the question about which he believed himself to be least competent. Each of the remaining questions was to be ranked so that every number from 1 to 7 was used exactly once. Although questions were raised concerning biases in the wording of the questions, for purposes of the illustration participants were asked to accept the questions exactly as they were presented on the form.

EXHIBIT 1.

QUESTIONNAIRE #1

This is the first in a series of four questionnaires intended to demonstrate the use of the Delphi Technique in obtaining reasoned opinions from a group of respondents.

Each of the following six questions is concerned with developments in the United States within the next few decades.

In addition to giving your answer to each question, you are also being asked to rank the questions from 1 to 7. Here "1" means that in comparing your own ability to answer this question with what you expect the ability of the other participants to be, you feel that you have the relatively best chance of coming closer to the truth than most of the others, while a "7" means that you regard that chance as relatively least.

RANK	QUESTION	ANSWER *
☐	1. In your opinion, in what year will the median family income (in 1967 dollars) reach twice its present amount?	☐
☐	2. In what year will the percentage of electric among all automobiles in use reach 50 percent?	☐
☐	3. In what year will the percentage of households reach 50 percent that are equipped with computer consoles tied to a central computer and data bank?	☐
☐	4. By what year will the per-capita amount of personal cash transactions (in 1967 dollars) be reduced to one tenth of what it is now?	☐
☐	5. In what year will power generated by thermonuclear fusion become commercially competitive with hydroelectric power?	☐
☐	6. By what year will it be possible by commercial carriers to get from New York's Times Square to San Francisco's Union Square in half the time that is now required to make that trip?	☐
☐	7. In what year will a man for the first time travel to the Moon, stay for at least one month, and return to Earth?	☐

* "Never" is also an acceptable answer.

Please also answer the following question, and give your name (this for identification purposes during the exercise only; no opinions will be attributed to a particular person).

CHECK ONE:

☐ I would like

☐ I am willing but not anxious

☐ I would prefer not

to participate in the three remaining questionnaires

NAME (block letters please):

....

From among those participants who indicated on the returned questionnaires that they would like to participate in the remaining sessions, Dr. Helmer selected twenty-three. The selection attempted to achieve a uniform distribution of the number of "expert ratings" (i.e., those who ranked themselves "1" or "2," etc.) for each of the questions, but was otherwise random. Each of the twenty-three participants then received Questionnaire 2 (see Exhibit 2), containing a summary of the results of Questionnaire 1 (derived from the responses of the entire group of conference participants). Each participant's Questionnaire #2 also listed the estimates he gave on his Questionnaire #1.

The completed Questionnaires #2 were returned to Dr. Helmer and analyzed, and each participant then received a copy of Questionnaire #3 (see Exhibit 3). The participant's Questionnaire #2 was also returned to him.

The completed Questionnaires #3 were returned to Dr. Helmer. These were analyzed and each participant then received a copy of Questionnaire #4 (see Exhibit 4). The participant's Questionnaire #3 was also returned to him.

The series of questionnaires were analyzed by Dr. Helmer and Mr. T. J. Gordon, and the results were presented to the entire group of conference participants. The results are summarized in Exhibits 5–8.

Participants found the session to be extremely educational. It also raised a number of questions relating to the importance of proper question formulation, the selection and ranking of experts, and the tendency to move toward the interquartile range to avoid extra effort (i.e., the justification of one's position in writing). Such illustrations were believed to be very valuable for imparting knowledge of the technique, even though the results of the forecasts, in this case, were not expected to be particularly reliable.

EXHIBIT 2

QUESTIONNAIRE #2

This is the second in our series of four Delphi questionnaires.

The same seven questions that had been posed in the first questionnaire are repeated below, together with information on the median and the interquartile range (IQR) of the first-round responses. [The IQR is the interval containing the middle 50% of the responses.]

Please reconsider your previous estimate, and change it if you wish. Whenever your present answer is outside the IQR, briefly state your reason why you think the answer should be a year that much earlier (or later) than that given by the majority of respondents. (No such reason needs to be given when your answer is inside the IQR.)

Question	Median	IQR	Your Old Answer	Your New Answer	Reason Why Your Answer Is Below or Above the IQR
1. In your opinion, in what year will the median family income (in 1967 dollars) reach twice its present amount?	85	80–92	F		
2. In what year will the percentage of electric among all automobiles in use reach 50%.	90	85–2012	I L L		
3. In what year will the percentage of households reach 50% that are equipped with computer consoles tied to a central computer and data bank?	2000	90–2075	E D		
4. By what year will the per-capita amount of personal cash transactions (in 1967 dollars) be reduced to one tenth of what it is now?	90	82–2000	I N B Y		
5. In what year will power generated by ther-monuclear fusion become commercially competitive with hydroelectric. power?	90	79–2005	D R		
6. By what year will it be possible by commercial carriers to get from New York's Times Square to San Francisco's Union Square in half the time that is now required to make that trip?	80	75–85	H E L M E R		
7. In what year will a man for the first time travel to the Moon, stay for at least one month, and return to Earth?	77½	75–85			

NAME: ....

EXHIBIT 3

QUESTIONNAIRE #3

The same familiar seven questions are restated below, together with the medians and interquartile ranges (IQRs) or the 23 second-round responses. Also included are some brief arguments as to why the estimates should be either earlier or later than those within the IQR.

Please reconsider your previous estimates (which are attached), and revise them if you wish, giving the stated reasons for raising or lowering them what weight you think they deserve. (If there is no change in your previous response, please re-insert it under "Your new answer.")

If your present answer lies outside the indicated IQR, briefly state in the last column why you think the argument that had been given in favor of an estimate on the opposite side of the IQR from your own is unacceptable. (In other words, if your estimate is high, refute the argument for a low estimate; if your estimate is low, refute the argument for a high estimate.)

Question	Median	IQR	Argument in Favor of An Earlier Date	Argument in Favor of A Later Date	Your New Answer	Your Critique of Arguments Unacceptable to You
1. In your opinion, in what year will the median family income (in 1967 dollars) reach twice its present amount?	1985	1980–1990	There is a 10% annual inflation. Union demands will bring this about sooner, through amendments to the "guide posts." The number of workers per family will rise. Income will grow faster than GNP as wage earners take a greater share of productivity earnings due to new technology.	The GNP goes up only 4% per year. There will be a decrease in the number of hours worked per family. Increasing inflation will devaluate the dollar. A major business depression may be expected. Real family income rose only 50% in last 25 years. The productivity per family will not grow so fast because neither the size of family unit nor productivity per family will.		
2. In what year will the percentage of electrical among all automobiles in use reach 50%?	1995	1985–2020	The first use will be for local travel, which will rapidly exceed 50%, in view of urban development. Developments in nuclear-power cost/effectiveness and energy storage point to an earlier date.	Pollution will force improvements in the combustion engine. Batteries don't provide enough power or range. Battery recharging is too inconvenient. The oil industry will resist this.		

EXHIBIT 3

QUESTIONNAIRE #3—Continued

Question	Median	IQR	Argument in Favor of An Earlier Date	Argument in Favor of A Later Date	Your New Answer	Your Critique of Arguments Unacceptable to You
				Electric cars will be too expensive. Natural-gas fuelled turbines have a better chance. There are enormous problems in economic conversion to electric energy in small packages, hence delay until fossil fuels exhausted.		
3. In what year will the percentage of households reach 50% that are equipped with computer consoles tied to a central computer and data bank?	2010	1985–2100	The technology is here now. This will be combined with your telephone. Computers are getting cheaper fast. We need to reduce the volume of mail. Progress in computerization in commercial and social organization will require individual computers in homes; 15 years should do it (analogy: TV in 1945–60).	The social demand will not be great enough, considering the high cost. The main use would be for education and reference; we are several generations away from the intellectual level that can use such teachers and librarians. Cost-effectiveness of personal data banks and decentralized computers will rise, and they are preferable because of privacy. Who needs instant bank statements that badly?		
4. By what year will the per-capita amount of personal cash transactions (in 1967 dollars) be reduced to one tenth of what it is now?	1985	1985–1990	Everyone will soon be assigned a combination credit card and social security card. Studies by the banking industry are already underway to computerize monetary transactions. Connecticut already has a state-wide credit card.	We seem to be already approaching the minimum now, and therefore may never reach that low a level in the near future.		
5. In what year will power generated by thermonuclear	1985	1977–2025	Water shortage within 10 years will force this development.	Fission-generated power is not yet commercially competitive; fusion-gener-		

Question				
fusion become commercially competitive with hydro-electric power?			Power demands, especially in connection with desalination, will rapidly become so great that thermonuclear power production will be generally accepted. Decentralization of population centers and cost of distribution favor nuclear power. The next drought will be world-wide.	ated power still requires development of basic technology, with immense problems to overcome. There is little economic incentive since electric power is cheap. Tidal power is yet untapped. The cost of hydro-electric facilities is shared, there is no fuel cost, and maintenance is lower. Efficient containment of thermonuclear energy seems to be completely out of the question.
6. By what year will it be possible by commercial carriers to get from New York's Time Square to San Francisco's Union Square in half the time that is now required to make that trip?	1976	1975-1980	Rapid transit approaches to the airports will be set up. Baggage will be handled faster. The Concorde will appear on U.S. schedules by 1973, and a U.S. SST by 1975.	Supersonic flight is not possible over land barriers. Now it takes $15m + 4h\ 30m + 30m = 5h\ 15m$; with SST it would take $10m + 2h\ 15m + 20m = 2h\ 45m$, which is more than 50%. Increase in aircraft speed alone will not achieve this so soon; other developments (vertical take-off etc.) will be required, which will take somewhat longer.
7. In what year will a man for the first time travel to the Moon, stay for at least one month, and return to Earth?	1977	1975-1980	After a first successful landing, only about 3 years will be required to develop life-cycle equipment for an extended stay. The capability will exist in the early 70s, national prestige and curiosity will dictate the decision. Mission profiles compatible with Apollo/LEM hardware/payload capabilities will be available in the early 70s.	Regular Moon trips will not occur until 1980, and a Moon station not until after 1990. The rise in cost will force a slowdown in the Moon program, especially in view of alternative goals (e.g. oceanographic research).

EXHIBIT 4

QUESTIONNAIRE #4

This is the last in our series of four questionnaires. Together with each of the seven questions, restated once more below, you are given the third-round median and IQR of the 23 responses received, as well as a summary of statements critical of the reasons that had been given in response to the second questionnaire.

Please reconsider (and possibly revise) your previous estimates once more in the light of the arguments (see attached Questionnaire 3) and counter-arguments that had been advanced for and against raising or lowering them.

Question	Median	IQR	Counter-Arguments In Defense of An Earlier Date	Counter-Arguments In Defense of A Later Date	Your Final Answer
1. In your opinion, in what year will the median family income (in 1967 dollars) reach twice its present amount?	1985	1980–1990	The GNP rose 4.3% before the "guide posts" were removed; now it will go up faster. Advanced skills will sharply increase income. A major depression (as opposed to a healthy recession) is very unlikely under current and future federal safeguards. Family size is not of critical importance; husband and wife are the essential income producers.	Even if income grows faster than the 4% rate of GNP, it will not double in 20 or 30 years. Greater productivity of direct labor is largely offset by indirect labor due to maintenance etc. of more sophisticated equipment. The inflation argument is beside the point since the question is phrased in terms of 1967 dollars. The Union bargaining position has been weakened by strikes; federal intervention is more likely to be demanded in future. The number of workers per family will not rise, because as income increases, families tend to subdivide into new units.	
2. In what year will the percentage of electrical among all automobiles in use reach 50%?	1995	1985–2011	The later-date arguments overlook the political pressure. Battery and fuel cell improvements will, in the 1970s, provide sufficient power and range (cf. e.g., Ayres's envelope curves). Inconvenience will be minimized because recharging can be automatic upon garaging. Resistance of the oil industry can be countered by positive response of electric utilities. The later-date proponents seem to overlook the possibility of the car to tie into a power grid.	If it were not for pollution, this would occur even later than 2000. Energy storage would have to improve by 10 orders of magnitude. Consumers buy cars for long-distance high-speed driving.	
3. In what year will the percentage of households reach 50% that are	2010	1985–2075	Social demand can be generated artificially. A home computer will be sold as a great convenience and as insurance against los-	The computerization argument fails to establish why home computers are required. The TV analogy does not hold because that is entertainment.	

EXHIBIT 5

SUMMARY OF OUTCOME

	Inter Quartile Range	Median	"Expert" * Median
1. Family income doubled	1982–90	1985	1985
2. Electric autos 50%	1985–2000	1995	1997
3. Home computer consoles	1985–2075	2010	1985
4. Credit card economy	1985–90	1985	1987½
5. Economical fusion power	1985–2030	1990	1987½
6. N.Y. → S.F. in ½ time	1975–80	1976	1975
7. Man on moon one month	1975–80	1977	1975½

* Median of the 8 individuals who ranked themselves highest. The cutoff point was usually 2 or 3.

EXHIBIT 6

CONVERGENCE OF RANGE WITH SUCCESSIVE QUESTIONNAIRES

(Heavy Lines — Range, Dotted Lines = Final Median)
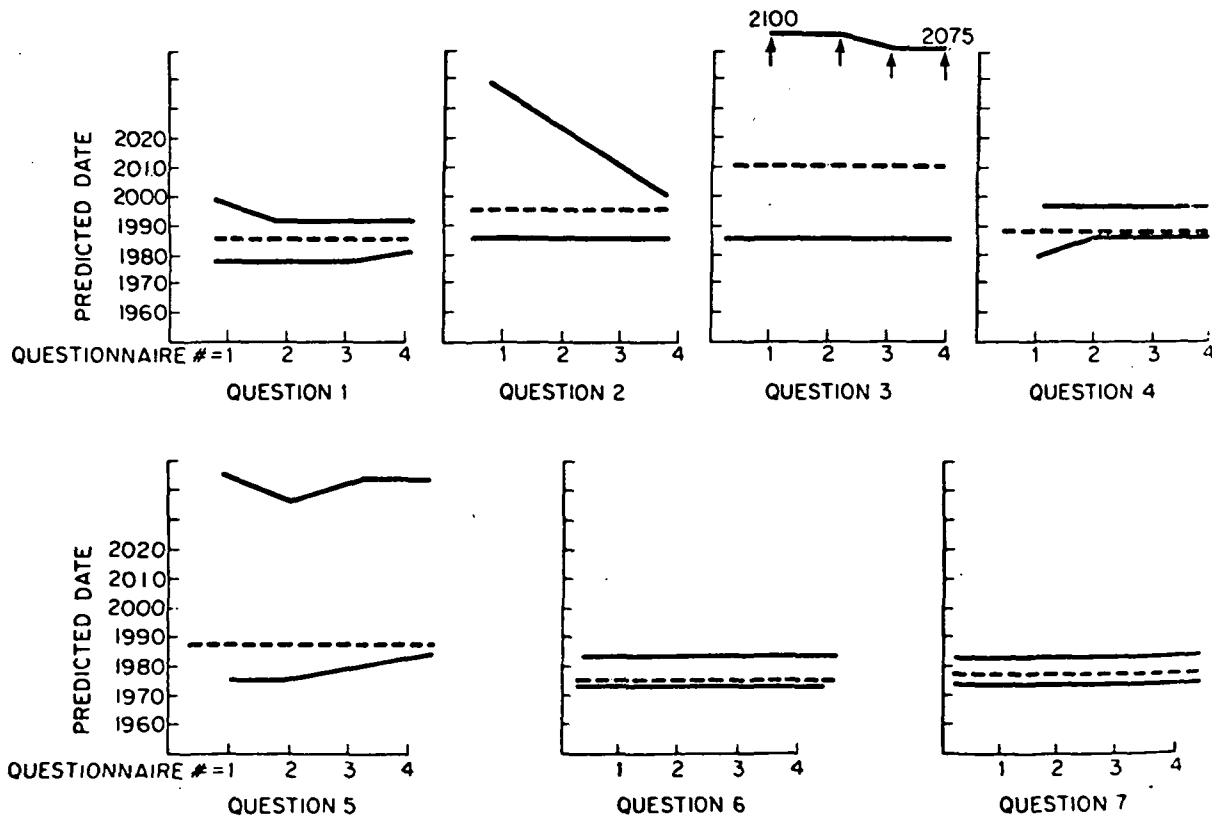
EXHIBIT 7

COMPARISON WITH OTHER STUDIES

(Medians)

	Present Conference Forecast	RAND * Pretest	1963 ** LRF Study	
1. Family income doubled	1985	1985	—	
2. Electric autos 50%	1997	1988	—'	
3. Home computer consoles	2010	2002	2005	Facsimile magazines in home
4. Credit card economy	1987	1995	1974	Credit link bank to stores
5. Economical fusion power	1988	1990	1986	Controlled fusion achieved
6. N.Y. → S.F. in ½ time	1975	1980	—	
7. Man on moon one month	1976	1980	1975	Two men on moon one month

* A 1966 Delphi pretest, using 23 RAND employees as participants.
** A 1963 RAND Long Range Forecasting Study. A report of this study appeared as an appendix to *Social Technology*, by O. Helmer (Basic Books, 1966).

EXHIBIT 8

FORECAST PRECISION

(Note: Numbers on Graph Refer to Questions Asked)
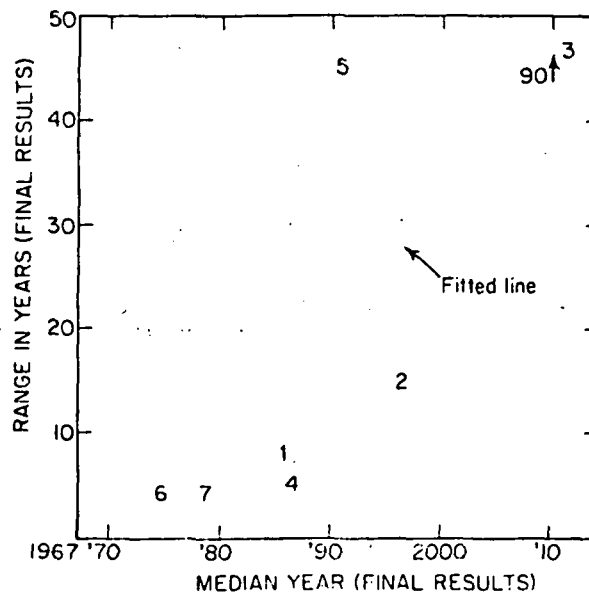
3.3 ADVANTAGES OF THE DELPHI METHOD

The Delphi method is probably the most progressive technique to be applied to technical or scientific forecasting.

The main advantage of this method is that it does away with the pressures which can occur at committee gatherings due to possible personality conflicts by a few or a majority of the members. In a Delphi exercise, anonymity prevails and each participant or respondee can freely state his own opinion.

Another advantage of the Delphi method is that it provides, through the use of multiple rounds, a feedback mechanism beneficial to both the respondents and the evaluators of the answers. To the former, because they must constantly submit their answers to their own reevaluation, and provide justification for answers that fall outside of the range of majority thinking. To the latter, because they may modify the scope and depth of the questions to be submitted during one round on the basis of the answers obtained during preceding rounds.

The results of a Delphi exercise may be precisely presented in terms of two simple statistics, the median and the interquartile range. Variations of these statistics from round-to-round offer the evaluators a valuable tool to determine if a consensus is being obtained.

The size of the panel need not be as large as would be required in a statistical sampling of a population of experts, since the Delphi method does not rely on a Gaussian distribution of the sampled population to give meaningful results. Moreover, it has been found that large groups do not necessarily improve the quality of the answers.

The Delphi method affords a convenient means to test itself and improve on itself by having panel members arrive at a consensus about a question whose answer is already known. This is also a good way to test the expertise of a panel on the subject on-hand. Such an experimental group opinion situation affords also the means to check on the accuracy of the method.

Even if a consensus among members is not obtained, the Delphi method serves to crystallize the reasoning process that might lead to one or several positions on an issue and thus helps to clarify that issue even in the absence of a group consensus.

3.4 LIMITATIONS IN RESULTS OF DELPHI METHOD

There is a body of thought prevailing that experts in any one particular field do not really hold the key to forecasting wisdom relative to that field and that collected errors in their forecast, although presented in a suitable mathematical fashion, are still errors. This argument may be countered to an extent by establishing a multi-disciplinary panel of experts. In attempting to arrive at a consensus, respondents are asked to answer the same questions over several iterations and to defend outlier opinions. This can produce pressures on some respondents to "give in" and "go along with the crowd, "thus moving their estimate closer to the median. Although this is possible and likely does occur, it may be minimized by careful selection of panel experts who will, when they feel they have a good argument for a deviant opinion, refine and develop their case.

The anonymity, which can be an advantage of the Delphi method, may tend to reduce communications and eliminate the often stimulating direct verbal interchange between persons in committee and brainstorming sessions. Anonymity combined with feedback tends to make the whole process of evaluation cumbersome and time-consuming. This is why the choice of the size of the panel is such a delicate operation, given the time available for the whole survey.

It is very difficult to eliminate bias completely from the Delphi method: there could be bias on the part of the administrator, and the pressure to conform mentioned above is also a kind of bias. Relative advantages of the committee and Delphi techniques are still being debated and proponents of both present valid arguments.

The Delphi method has also been criticized because it yields a set of "linearly independent" estimates of the future, with the probability or date of each item estimated independently of the others. The answer to this objection is to see the future as

a large tree network with a multitude of paths. In this model, the realization of certain events will make other alternatives more or less probable. See also cross-impact analysis described in Paragraph 5.8 and Appendix A.

Once again, the complications inherent in a model that allows for cross-correlations must be weighted against the need for obtaining answers from the panel within a reasonable amount of time.

Note that the role of the evaluators is much greater in a Delphi exercise than in committee work, where their task is practically completed once the committee has been selected and tasked. In a Delphi exercise, the evaluators' task just begins with the assembling of the panel. The foregoing limitations reveal some of the hesitancy in applying any new method. With practice and the accumulation of further data, more questions will be answered about the Delphi method, thus hopefully mitigating most of the objections to its use.

SECTION 4 - PROCEDURE FOR DELPHI APPLICATION TO LONG-TERM NATIONAL TELECOMMUNICATION NEEDS

4.1 SELECTION OF COMMUNICATION PANEL MEMBERS.

The selection of communication panel members is predicated upon the nature of national communications, covered in Appendices B and C. Such choice is highly dependent on the character and density of communications in relation to the distribution of population throughout the country. Finally, panel selection reflects both the predictive quality and the highly technical orientation associated with determination of telecommunications needs and priorities.

First, consider communication scientists as panel members who are familiar with the work being carried out at the frontiers of knowledge in their respective field: they will have to blend the quality of long-range vision with technical competence in order to predict the nature of communications in the 1990s.

Second, communications engineers, well versed in the technical aspects of their field, are required on the panel. It is preferred that they be familiar with technology forecasting, and have a "down-to-earth," practical approach broadened by experience in economic and social fields where possible.

Third, the panel should include communication policy experts who have decisively contributed to, or who have made major decisions affecting national communications (e.g., persons who have prepared dockets for the FCC).

The membership of the panel is not limited to communication specialists. Since economic, cultural, and societal factors determine the distribution of population, the panel should include representation from such fields as needed to form a composite picture of population trends and consequent communication needs in the 1990s.

Changes in values are certain to influence the development of technology in general and of communications in particular. All panel members and particularly the social scientists are expected to be aware of changing values such as the growing concern of society with the impact of technological growth.

Long-term forecasting has usually been thought of as belonging to the realm of the scientist. However, previous exposure to forecasting is desirable for all members of the panel because it is a discipline that is consistently called upon during an actual Delphi exercise looking to the future.

In choosing the members of the panel, attention should be paid to their forecasting "temperament" and a proper unit of extrapolators, goal setters, and cyberneticists should be appointed.[18]

The recommended mix of panel members include representatives drawn from universities, Government agencies, private companies, and nonprofit organizations. A suggested list of organizations is presented below which is not intended to be all inclusive. The procedures for selection, detailed in the following paragraphs, are based on a synthesis of national communications as shown in Appendix B, and on the considerations expressed above. A large number of experts should be selected in order to form a preliminary list extensive enough to permit sufficient choice of a multidisciplinary panel adequate for the study.

The experts comprising the preliminary list must be apprised of the purposes of the exercise, also obtain their views on study objectives. The members of the panel finally selected must subsequently receive more extensive and more detailed orientation to cover the objectives and procedures of the study.

Step 1 - To ensure that the composition of the panel presents the proper mix and is adequate for the prediction of trends in national communications, the following set of procedures for obtaining a preliminary list of panel members is recommended:

1. Contact the Dean of Engineering of the universities listed below and solicit the names of at least five communication engineers or scientists to be recommended as members of the panel. The universities suggested are:

   California Institute of Technology

   Columbia University

   Massachusetts Institute of Technology

Purdue University

Stanford University

State University of New York (Polytechnic Institute of New York)

University of California

University of Illinois

University of Michigan

2. Contact the Managing Director or President of the following organizations and also seek from them the names of at least five suitable candidates:

Air Transport Association (ATA)

Stanford Research Institute

The American Federation of Information Processing Societies

The Armed Forces Communications and Electronics Association (AFCEA)

The Association for Computing Machinery (ACM)

The Association of Federal Communication Consulting Engineers (AFCCE)

The Bell Telephone Laboratories

The Communications Systems Group of the Institute of Electrical and Electronic Engineers

The Defense Communications Agency (DCA)

The Department of Commerce's "Environmental Sciences Services Administration" (ESSA)

The Federal Aviation Administration (FAA)

The Federal Communications Commission (FCC)

The Institute of the Future

The Maritime Mobile Community

The Mitre Corporation

The National Aeronautical Science Administration (NASA)

The Office of Telecommunications Policy

The Rand Corporation

3. Contact the Director of Engineering of the following corporations and obtain at least five suggestions from them:

American Satellite Corporation

ARINC

COMSAT

DATRAN

General Electric

General Motors

General Telephone and Electronics

International Business Machines

International Telegraph and Telephone

MCI

Radio Corporation of America

The American Telegraph and Telephone Corporation

Western Union

Xerox

The advantage of the method just described is that it is capable of giving a total of at least 160 potential panel members. If the number obtained is less than expected it means that the name of some of the communications experts were furnished by more than one source, which may be considered as an additional endorsement. Admittedly, there are problems in selecting experts for any type of long-range forecasting. In "Problems of Selecting Experts for Delphi Exercises," Gordon Welty,[19] of the American University, mentions that it is difficult to distinguish among levels of expertise, and that the method of self-assessment has been found wanting. The need to use experts for the forecasting of technological breakthroughs is not in question here. As to the method of choosing a preliminary list, it is simply illustrated by the idea that "if a man is considered an expert by what amounts to be an extended peer group, then he must be one." As an analogy, a good technical reference is one that is consulted a lot.

When the previously enumerated sources of potential panel members are contacted, they should be apprised clearly of study objectives (i.e., forecasting national communication needs), and the types of expertise required (scientist - long range; engineer - technical; decisionmaker - legal, economic; social scientist - communications, behavior, ethics). The determination of the forecasting "temperament" of the candidate experts, who are nominated, should be left for the next round of selection.

It is possible that some of the people contacted will be at a loss to name an expert in the social sciences. Should this happen, it is suggested that such persons be requested to name someone else who may be able to furnish this information, e.g., the Dean of the Social Sciences Department of a university.

Step 2 - Next, determine the optimum size for the panel. The question is: "how many experts are needed to give a good answer to meet Delphi study objectives?" When the specific answers sought are of a quantitative nature, this question may be answered by considering how large an error in the estimate can be tolerated and how great a risk of exceeding that error should be taken. This approach cannot be used if the questions are not well defined and if at least some are not of a quantitative nature. The number of panelists can be determined somewhat arbitrarily but must be consistently chosen, taking into account the following factors:

1. The panel may be larger than that of a committee doing the same type of work.

2. It should not be so large as to render the whole Delphi process too lengthy.

3. The panel should be large enough to validate the statistics to be applied to the answers.

4. Given these considerations, a panel size of about 40 members is a reasonable objective. It is also a practical one since it represents an acceptance rate of about 1/4 of the maximum available number of

candidates. Out of the 40 members, at least five should be social scientists. If the scope of the study is sufficiently broad, the panel may be expanded to 50-60 members and may be broken down to as many as 10 subpanels, each assigned an area of specialization.

Step 3 - Having obtained a preliminary list of experts from universities, government, and industry, the next task is to select from them the members of the panel. The approximate 160 candidates obtained from the first contact should be given a description of the forecasting exercise and asked if they are willing to participate. Once their willingness to undergo the complete Delphi exercise has been obtained, they should be asked to answer some questions the purpose of which is to categorize them in any one of the following four forecasting attitudes as described in Reference 18.

Discounters: Interested only in near-term problems, disinterested in forecasts.

Extrapolators: Consider the future as an extension of the past, put emphasis on data, use extrapolation.

Goal Setters: Believe that the future can be created, put emphasis on values, use narrative analyses.

Cyberneticists: Combine the past and future creative approaches, are adaptive, use the interaction of exploratory and narrative forecasting.

The results of the questionnaire will help to eliminate the discounters from the panel and ensure the predominance of extrapolators, goal setters, and cyberneticists, the latter to counterbalance the opposite but necessary tendencies of the two other types.

This latter step takes into account the "forecasting temperament" of the candidates and the number of referrals given. Other factors to consider in final selections are a candidate's particular area of expertise and his degree of exposure to other areas of knowledge.

4.2 GENERATION OF SIGNIFICANT QUESTIONS

The construction of a questionnaire for a Delphi experiment poses several problems for the experiment designer. Each question must be so constructed that it reflects a valid possible future condition, yet at the same time it must avoid the pitfall of being so worded that it biases the participants' responses. Additionally, the questionnaire designer is ordinarily tasked with providing the back-up material for the participants' use (or not, depending upon their individual preferences) in formulating their responses. This increased responsibility provides further opportunity for inadvertent bias, which must be avoided to the greatest extent possible.

The general method for the creation of a Delphi questionnaire is for the experiment designer to seek the assistance of highly qualified individuals in formulating the questions to be asked and then to subject those questions to close scrutiny by psychologists or other social scientists experienced in questionnaire development. The role of the social scientist is to examine the structure of each question and of the questionnaire itself for comprehensibility, bias, and likelihood of producing a useful set of results. If the experiment designer is able to fill either of these roles himself, so much the better, but if he is in the slightest doubt concerning his expertise he should demand the professional assistance which will assure the success of his experiment.

In seeking the assistance of the most qualified experts in designing the questionnaire, one may eliminate such experts from consideration as panel members who may be the best source of Delphi data. While this is true, it is of no more consequence than the same objection raised to the appointment of the most skilled expert to occupy the objective chairmanship of a regular committee. His contribution in the objective, guiding, analytical role will always outweigh his potential contribution as a panel member.

4.2.1 Structured and Unstructured Questionnaires

Questionnaires fall into two general types: structured and unstructured. Where the purpose of the questionnaire is to develop statistically useful data, it is

necessary to use a closely structured approach, that is, each question must be such that it may be assigned a value. Yes-no, percentage estimate, probability, and other rating-scale questions are of this type. Very obviously, from the standpoint of the Delphi method, it is necessary that questions be carefully structured.

And yet, what assurance is there that in the construction of the questionnaire the experiment designer has addressed all or even the most significant of the issues impinging upon his area of investigation? That the answer to the question is a resounding "none" is very well illustrated in the author's own critique of his RAND long-range forecasting study. [2]

> "First of all, we would like to register our surprise at some of the ideas that have propounded. To other persons, of course, a different set of items might be the unexpected ones which we had failed to anticipate:
>
> The implication that the water-covered portions of the earth may become important enough to warrant national territorial claims.
>
> . . .
>
> The probability, in the relatively near future, of very widespread use of personality-control drugs.
>
> . . .
>
> The fact that control of gravity was not rejected outright. . . "

And so on, for a rather lengthy list, considering the qualifications of the individuals who prepared the experiment.

The fairly obvious conclusion is that unstructured, or open-end questions must also be included in any Delphi experiment, if for no other reason than to discover those areas which have not been properly addressed. There are other reasons why and when an unstructured question should be used, and these are addressed subsequently in this section. For the moment, let it suffice that both structured questions and unstructured questions which can lead to discovery are essential ingredients in the Delphi mix.

4.2.2 Order

It is axiomatic in the construction of any questionnaire that its order appear logical to the respondent. It is important to remember that even in a Delphi panel, composed of experts, perception of relationships is highly individual, so that the relationship the experiment designer wishes to explore may not be an obvious one to the respondent. For example, a respondent may see a definite relationship between message switching in the range of a microsecond and the development of extremely wide bandwidth laser carrier systems. To the researcher this may be an obvious relationship but one which is less important to him than (to stretch a point) that between fast message switching and the level of industrialization in Latin America. Even if it is possible to expand the question to include the reasons for grouping it with another, it is still wise to order the questionnaire in such a way that the obvious relationships are exposed. Not only does such a construction method aid the respondent to order his thinking, it reduces the bias and distortion that may result from over-emphasizing the experimenter's conception of the cross-impacts which may exist in his experiment.

4.2.3 Quantification

The general form of the Delphi investigation lends itself readily to quantification, which form might be stated, "What is the probability that event X will happen within time frame Y?" Once the time frame is chosen quantification becomes a matter of understanding what the respondents mean by the probabilities they choose.

This is often not as simple as it might appear. The experimenter has no way of looking into the minds of his respondents to ascertain that one man's 20 percent is not another man's 45 percent. Using verbal classifications is equally ambiguous: what, to a group of respondents, is the variation in meaning among likely, very likely, and extremely likely? In the latter example, all one needs to do is to provide a null (central) point between the likely side and the unlikely side of the question and he has reduced his data effectively to a simple three-value answer whereupon he might as well eliminate the rest.

There have been many ingenious attempts to derive some sort of confidence in the accuracy of the qualitative measures applied to Delphi questions, and in the absence of any real means for evaluating their adequacy, it might prove wise for the experiment designer to try all of them (as well as to apply what is known about human responses). Among the more interesting innovations are these:

- Instruction in the location of the 50 percent confidence point. Since Delphi is a voting system, the respondents are carefully instructed (on the question-naire) that a 50 percent probability is that point at which he would be as content to wager that an event would occur as that it would not, or that it would occur before a date as after. Examples are usually given in terms of the actual experiment.

- Pairing of numerical probabilities with corresponding verbal statements, such as "10 percent = could possibly happen, but so unlikely as to be insig-nificant" or "90 percent = Virtually certain, but by remote chance might not occur at this point."

- Paired choice. The respondent is required to choose the timeframe in which some event will absolutely occur and given a companion question in which he must choose the frame in which it will absolutely not occur. There is little ambiguity with this method, but it also limits the total amount of information which can be derived from the question.

Figure 4-1, from Reference 2, illustrates four rounds of Delphi questionnaires and several means of writing questions so that they may be quantified. In the first iteration, questionnaire 1, the authors stated the purpose of their investigation and requested that the respondents select, individually, those topics which they felt should be studied in the Delphi. While this form of question is totally free-form, it can result in a list which can be quantified through analysis of the submitted topics, clas-sifying those that seem to be the same or nearly so as identical. A choice can then be made of the most frequently occurring topics; these can then be used for the second iteration of the questionnaire. Alternatively, the first iteration could be a listing of

LONG-RANGE FORECASTING STUDY

Questionnaire 1

1.1. SCIENTIFIC BREAKTHROUGHS

One of the major problems of conducting a predictive study which poses its questions on the basis of extrapolations of current technology is the almost unavoidable exclusion of discontinuous state-of-the-art advances.

In this current study a period of 50 years is being considered. It is possible that inventions and discoveries not yet visualized could have a major impact on our society during this interval. It is easy to observe that the pace of scientific and technological innovation has been steadily increasing and that the time between origination and application has been decreasing. Therefore we believe that many generations of inventions can find application during the period under study.

Some insight even into discontinuous state-of-the-art advances might perhaps be gained by examining the world's need for such advances, in view of the old truism that necessity is the mother of invention. Therefore, you are asked to list below 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:

Do you know of the existence of any information, in the form of tabulations or analyses, that might be particularly valuable in reaching projections of the kind requested?

Questionnaire 2

1.2 SCIENTIFIC BREAKTHROUGHS

a. Listed below in Table 1.2a are most of the scientific breakthroughs suggested by the respondents as potentially possible during the next 50 years. Please indicate your judgment of the probability of implementation during each period. Note that the numbers inserted by you in each row should add up to 100. (In the case of items involving gradual development such as synthetic food production or automated education, "implementation" should be interpreted as referring to the time from which the effect on our society will no longer be negligible.)

b. Considering the breakthroughs suggested in Table 1.2a are there other potential breakthroughs which you would care to add? When do you believe they will occur? Please make your additions in Table 1.2b.

Table 1.2a

SUMMARY OF OPINIONS ON SCIENTIFIC BREAKTHROUGHS

Biological	1953-65	65-68	68-72	72-78	78-86	86-97	97-2013	Later	Not at any time
1. Chemical control over heredity - molecular biology									
2. Biochemical general immunization									
3. Biochemicals to stimulate growth of new organs and limbs									
4. Synthetic generation of protein for food									
5. Oral contraceptive									
6. Other means of fertility control									
7. New organs through transplanting or prosthesis									
8. Use of telepathy and ESP in communications									
9. Understanding of the physiology of mind-brain behavior									
10. Chemical control of the aging process, permitting extension of life span by 50 years									
11. Cancer cure									
12. Man-machine symbiosis, permitting man to extend his intelligence directly through the use of computing machines									
13. Creation of artificial life									

TABLE 1.2a	1953-65	65-68	68-72	72-78	78-86	86-97	97-2013	Later	Not at any time
Sociological									
1. Communication with animals									
2. Breeding of intelligent animals (apes, cetaceans, etc.) for low-grade labor									
3. Education by automation									
4. Education by other means, such as direct information-recording on the brain									
5. Education or conditioning to social behavior to reduce the likelihood of war									
6. Automatic language translators									
7. Efficient idea-coding to convey precise information independent of language									
8. Popular use of personality control drugs									
9. Long-duration coma to permit a form of time travel									
10. Solution to the problem of distribution of goods--computer identification of points of need									
11. Computing machines becoming the most significant source of intelligence on earth									
12. Discovery of life on Mars									
13. Communication with extra-terrestrials									
Physical									
1. Reformation of physical theory, eliminating confusion in quantum-relativity and simplifying particle theory									
2. Experimentation with anti-matter									
3. Control of gravity									
4. Controlled thermo-nuclear power									
5. Commercially efficient transmutation of elements									
6. Focused electromagnetic radiation for power transmission									
7. Relay of solar energy via satellite									
8. Efficient electric storage device									
9. Limited weather control									
10. Reliable weather forecasts									
11. Miniaturization of electronics carried to the molecular level									
12. Automated highways									
13. Measurement of curvature of the universe									
14. Ballistic transport - 2 hours to anywhere on earth									
15. Theory of the earth's crust permitting accurate earthquake prediction									
16. Development of new synthetic materials for ultra-light construction									
17. Operation of nuclear power systems providing electricity @ 3-4 mills/kw-hr 5-10 year refueling period									
18. Collection and concentration of solar energy, used for power or in man-made organic chemistry manufacturing processes									
19. Operation of a central data storage facility with wide access for general or specialized information retrieval									
Food and Raw Materials									
1. Rise in world agricultural gross yields by a factor of ten									
2. Economically useful desalination of sea water									
3. Economical working of low-grade metal ores									
4. Exploitation of the ocean bottom through farming and mining									

Figure 4-1. Question Qualification (Page 1 of 3)

1.3 SCIENTIFIC BREAKTHROUGHS

Of the list of potential scientific and technological breakthroughs submitted to you previously we are now proposing to drop a large fraction from further consideration. Some do not seem important enough to warrant further examination. On others some form of consensus has already emerged (see Part (a) below). Those resubmitted to you (as Items 1-17) in Part (c) below, therefore, are potential breakthroughs on which no satisfactory consensus has been obtained to date but which are important enough to justify looking for an explanation as to why opinions on their occurrence differ so widely.

a. The following summary represents a consensus of a large majority of respondents:

Table 1.3a

Item by	Description	Predicted time of occurrence
Biological 7	New organs through transplanting or prosthesis	Within 25 years
Sociological 6	Automatic language translators	
Physical 16	Development of new synthetic materials for ultra-light construction	
Physical 10	Reliable weather forecasts	Not within 5 but within 35 years
Physical 19	Operation of a central storage facility with wide access for general or specialized information retrieval	
Sociological 9	Long-duration coma to permit a form of time travel	Not within 25 years but eventually
Sociological 13	Communication with extra-terrestrials	
Biological 3	Biochemicals to stimulate growth of new organs and limbs	Not within 25 years if ever
Sociological 2	Breeding of intelligent animals (apes, cetaceans, etc.) for low-grade labor	Not within 35 years if ever
Biological 8	Use of telepathy and ESP in communication	Not within 50 years if ever
	Computing machines becoming the most significant source of intelligence on Earth	

1.3 p.2

Do you, by and large, agree with the opinion represented by the consensus tabulation given on the preceding page? If you disagree with any particular item, please indicate which, and briefly state your reason for your differing opinion:

b. It has been suggested that major breakthroughs are urgently needed in the organizational and operational methods of scientific investigation. The following table lists three examples of such. Please add others at the end of the table. Give us your opinion of the probability of occurrence and of the desirability of each item:

Table 1.3b

Breakthrough	Probability of occurring within 10 yrs	25 yrs	50 yrs	Benefit to society if occurring High	Mod	Low	None	Neg
1 A reform of present modes of scientific communication through the use of automated information retrieval systems								
2 Reorientation of scientific methodology toward greater interdisciplinary cooperation								
3 Widespread use of simulation for experimentation in the social sciences								

c. The following table gives a list of potential scientific and technological breakthroughs on which thus far no satisfactory consensus has been obtained. It consists mostly of items previously submitted to the panel and judged to be sufficiently important but deserve further exploration, plus a few afterthoughts suggested by panel members in response to Questionnaire 2. You are being asked to reestimate the time of occurrence of each item and in certain cases to state briefly your principal reason for this opinion.

Table 1.3c

#	Description of potential breakthrough	Consensus or dissensus to date	In your opinion, by what year does the probability of occurrence reach 50%	90%	If your 50% estimate falls within either the earlier or the later period indicated, briefly state your reason for this opinion
1	Possibility of chemical control over hereditary defects through molecular engineering	Consensus that it will occur; disagreement as to when			Why before 1987 or after 2013?
2	Biochemical general immunization against bacterial and viral diseases	Consensus that it will occur; disagreement as to when			Why before 1987 or after 2013?
3	Possibility of commercial generation of synthetic protein for food	Consensus that it will occur; disagreement as to when			Why before 1979 or after 2013?
4	Effective fertility control by oral contraceptive or other simple and inexpensive means	Majority opinion that it will be feasible within 25 years			Why before 1969 or after 1986?
5	Chemical control of the aging process, permitting extension of life span by 50 years	Virtual consensus that it will occur (though not within 10 years); disagreement as to when			Why before 1979 or after 2013?
6	Man-machine symbiosis, enabling man to extend his intelligence by direct electro-mechanical interaction between his brain and a computing machine	Widely divergent opinions, possibly due to differing interpretations of the original question			Why before 1977 or after 1997 (or never)?

Table 1.3c (continued)

#	Description	Consensus	50%-year	90%-year	Reason
7	Creation of a primitive form of artificial life	No consensus, but a majority opinion that it will occur, though not within 25 years			Why before 1978 or after 2013 (or never)?
8	Possibility of education by direct information recording on the brain	No consensus			Why before 1987 or never?
9	Substantial reduction in the likelihood of war through education or other conditioning in social behavior	No consensus			Why before 1979 or after 2013 (or never)?
10	Widespread socially accepted use of nonnarcotic personality control drugs producing specific psychological reactions	Divergent opinions, possibly due to differing interpretations of the original question			Why before 1987 or after 2013 (or never)?
11	Reformation of physical theory, eliminating confusion in quantum-relativity and simplifying particle theory	Consensus that it will occur; disagreement as to when			Why before 1975 or after 2013?
12	Control of gravity through some form of modification of the gravitational field	Majority opinion that it will probably never occur, and at any rate not within 50 years			Why before 2013 or never?
13	Controlled thermo-nuclear power	Consensus that it will occur; disagreement as to when			Why before 1979 or after 2013?
14	Commercially efficient manufacture of arbitrary chemical elements from sub-atomic building blocks	No consensus, possibly due to differing interpretations of original question			Why before 1998 or never?
15	Limited weather control, in the sense of being able to exert a substantial effect on regional weather at acceptable cost	Consensus that it will occur; disagreement as to when			Why before 1979 or after 2013?
16	Economically useful exploitation of sea water	Consensus that it will occur; disagreement as to when			Why before 1975 or after 2013?
17	Economically useful exploitation of the ocean bottom through farming and mining	No consensus			Why before 1987 or after 2013 (or never)?
18	Use of drugs to raise average intelligence level	Newly proposed item			Why before 1987 or after 2013 (or never)?
19	Direct cure for serious mental illness	Newly proposed item			Why before 1987 or after 2013 (or never)?
20	Stimulated emission ("lasers") in X and gamma ray region of the spectrum	Newly proposed item			Why before 1987 or after 2013 (or never)?
21	Implanted artificial organs made of plastic and electronic components	Newly proposed item			Why before 1987 or after 2013 (or never)?
22	Wide-spread use of ground-effect machines, providing travel above the ground on a cushion of air, for commercial transportation	Newly proposed item			Why before 1977 or after 1998 (or never)?

Figure 4-1. Question Qualification (Page 2 of 3)

Questionnaire 4

1.4 SCIENTIFIC BREAKTHROUGHS

This is the last questionnaire in our present inquiry into opinions on scientific breakthroughs.

Before giving you an account of what further consensus seems to have emerged in the preceding round and putting some further substantive questions before you, we would like to ask your preference as to whether or not a report on this study should mention your participation as a respondent. Under no circumstances will any direct quotations be attributed to you.

a. Check here if you have no objection to having your name mentioned as that of a respondent in this current study: ☐

b. Table 1.4b on the next page lists a number of potential developments in the organizational and operational methods of scientific investigation. Of these, the first three are repeats from Questionnaire 3; the others are additional items proposed by the respondents for consideration.

Thus far, there is no clear-cut consensus regarding either the probability of occurrence or the desirability of the first three items. All are considered rather likely and, on the average, of moderate benefit. Over the next 25 years, Item 3 is considered slightly more likely than Item 2, and Item 2 slightly more likely than Item 1. As for their potential benefits, the order is reversed: Item 1 is thought to be slightly more beneficial than Item 2, and Item 2 slightly more beneficial than Item 3.

In concluding the consideration of these potential developments in the organizational and operational methods of scientific investigation, we would like you to rank the eight items in Table 1.4b from 1 to 8 in two respects: The probable degree of their realization within the next 25 years, and the desirability of their realization.

Table 1.4b

#	Potential developments in the organizational and operational methods of scientific investigation	Rank* by expected degree of realization within 25 years	Rank* by desirability in terms of expected benefit to society
1	Reform of present modes of scientific communication through the use of automated information retrieval systems		
2	Reorientation of scientific methodology toward greater interdisciplinary cooperation		
3	*Widespread use of simulation for experimentation in the* social sciences		
4	Increased emphasis on basic research in government-supported R + D		
5	Widespread use in scientific research of more intelligent machines, with computers on the level of "colleagues" rather than of "servants"		
6	Synthetic stimulation of individual inventiveness (by chemical ingestion, cerebral manipulation, external rewards, etc.)		
7	Reformation of educational processes toward an increased interdisciplinary understanding of science		
8	Shift in approach to biomedical problems from predominant experimentation to more theoretical ground		

*Use Rank 1 for highest degree and greatest desirability, Rank 8 for lowest degree and least desirability.

Of the twenty-two specific potential breakthroughs put before the panel in the previous questionnaire, Items 9 (on reducing the probability of war through education) and 22 (on ground-effect machines) are being dropped from further consideration (9 because of inherent vagueness of the question, 22 because of comparative unimportance in the face of a considerable divergence of opinions).

On eleven other items a sufficient consensus has been established to warrant our bringing their consideration to a close, — unless you wish to take explicit exception to any one of them. They are listed below (Table 1.4c) together with the majority opinion on the expected time of their occurrence.

Table 1.4c

Items on which at least a moderate consensus seems to have been obtained

#	Description of breakthrough	Majority opinion	*
16	Economically useful exploitation of sea water	Already accomplished in certain areas (magnesium, desalination); considerable further progress likely within 10 years	
4	Feasibility of effective large-scale fertility control by oral or other simple and inexpensive means	During the 1970's	
20	Stimulated emission ("lasers") in the X and Gamma ray regions of the spectrum	About 20 to 25 years from now	
21	Implanted artificial organs made of plastic and electronic components	Plastic tubes, heart valves, electronic heart pacers already in use; whole organs within 20 to 25 years	
11	Reformation of physical theory, eliminating confusion in quantum-relativity and simplifying particle theory	Probably gradual development, by about 2000	
13	Controlled thermo-nuclear power	During the period from 1980 to 2000	
2	Biochemical general immunization against bacterial and viral disease	Extensive, though not necessarily universal, immunization during the period from about 20 to 40 years from now	
5	Chemical control of the aging process, *permitting an extension of* the average life span by 50 years	During the period from 1990 to 2050	

Table 1.4c (continued)

#	Description of breakthrough	Majority opinion	*
6	Feasibility of man-machine symbiosis, enabling man to extend his intelligence by direct electromechanical interaction between his brain and a computing machine	During the period from 1990 to 2050	
12	Control of gravity through some form of modification of the gravitational field	Not for 100 years, if ever	
8	Feasibility of education by direct information recording on the brain	Not for 200 years, if ever	

c. Please mark with a cross in the last column of the above table any items regarding which you find yourself in substantial disagreement with the stated majority opinion. For each such case, state below the nature of your disagreement and, very briefly, the reason for your differing opinion:

There are now nine residual items requiring further examination. They are listed in Table 1.4d below. The table also includes, as Items 23 to 25, three items about which a tentative consensus had already been announced in Table 1.3a of the previous questionnaire: their consideration is being resumed here because in each case several respondents explicitly voiced disagreement with the opinion stated.

d. Please reconsider the potential scientific and technological breakthroughs listed in the following table. They are the remaining items on which thus far no satisfactory consensus has been attained. In some cases, the description has been reworded in an effort, to eliminate vagueness (which may have been partly responsible for the apparent discrepancy of opinions).

In giving us once more your estimates of the years when the probability of occurrence reaches 50% and 90% respectively, please take such reformulations into account, as well as the merits of any statements of minority opinions:

Table 1.4d

#	Description of potential breakthrough	Majority consensus to date	Minority opinion	50%-year	90%-year
1	Feasibility (not necessarily acceptance) of chemical control over some hereditary defects by modification of genes through molecular engineering	By 2000	Will take longer or occur never, because it would *necessitate* intervention during embryonic development, when the foetus is inaccessible, hence would require prior development of techniques of gestation in vitro		
3	Economic feasibility of *commercial generation* of synthetic protein for food	By 1990	If in-vitro generation of proteins *with all essential amino acids is* intended, then such perfect control of polymer synthesis and grafting chemistry are required that more than 50 years are needed		
7	Creation of a primitive form of artificial life (at least in the form of self-replicating molecules)	Not for 10 years but by 2000			
10	Widespread and socially widely accepted use of nonnarcotic drugs (other than alcohol) for the purpose of producing specific changes in personality characteristics	By 2000	Will take 50 years or more, because research on psychopharmaceuticals has barely begun, and negative social reaction will cause delays		
14	Economic feasibility of commercial manufacture of many chemical elements from subatomic building blocks	Not within 25 but within 60 years	Never, despite technical feasibility, because other methods will be cheaper, such as processing of low-grade natural sources or reprocessing from waste		
15	Feasibility of limited weather control, in the sense of substantially affecting regional weather at acceptable cost	Within 25 years			
17a	Economically useful exploitation of the ocean through farming, with the effect of producing at least 20% of the world's food	Not within 50 years, if ever			
17b	Economically useful exploitation of the ocean bottom through mining (other than off-shore oil drilling)	Within 25 years	Not within 50 years, because costs will remain too high		
18	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)	Not within 25 but within 50 years	Never, because the use of molecular engineering to raise the IQ will *come first; also, the effect of drugs* is limited because they cannot affect the basic synaptic connectivity of the brain		
19	Increase by an order of magnitude in the relative number of psychotic cases amenable to physical or chemical therapy	Within 50 years	More than 50 years, because an entire science of biopsychiatry must be built		
23	Long-duration coma to permit a form of time travel (former "Sociological 9")	Not within 25 years but eventually	Never, because organisms are too delicate to be kept in long coma; also because the demand is questionable		
24	Two-way communication with extra-terrestrials (former "Sociological 13")	Not within 25 years but eventually	Never, because the elapsed time between message and response would be unmanageably long		
25	Biochemicals to stimulate growth of new organs and limbs (former "Biological 5")	Not within 25 years and possibly never	Definitely eventually, at least for artificial regeneration of limbs		

e. Do you wish to add any comments? In particular, is there anything further you wish to say in support of your views as expressed in your entries in the foregoing table?

Figure 4-1. Question Qualification (Page 3 of 3)

topics generated by the experiment designer and submitted to the panel for a consensus of those topics which merit further consideration. The latter is possibly the preferred method, but it should be accompanied by a free-form response in which the panel could suggest other topics.

In the second iteration, questionnaire 2, in Figure 4-1, the designer has chosen a time-line probability of occurrence approach. This is a very useful approach for most Delphi subjects, but it should be pointed out that only very careful instructions will provide any confidence that the probabilities expressed by the individual respondents have any relation to each other.

With sufficient instruction, the panel will probably respond in such a way that confidence can be placed in the extremes and the mean, so that derived partial values can also be useful.

The third iteration, questionnaire 3 of Figure 4-1, uses a forced choice two-valued answer but allows an unstructured response to a specific aspect of the questions. This technique might be called semi-structured and has much of the value of both approaches, allowing for quantification at the same time that additional insights are sought through the respondents' free choice answers. Note that asking the respondents to choose any year for their 50 and 90 percent choice points does not unduly compli-cate analysis, since the designer may group the years in any way he chooses. On the other hand, the respondents are not made to feel restrained by any arbitrary choice of time period.

In the fourth iteration, questionnaire 4 of Figure 4-1, the authors chose to ask for rank ordering by the panel of those items on which a reasonable consensus could be expected. The number of items to be ranked here is eight, which is very nearly the useful limit of ranking. Because Delphi is an averaging technique, longer rank lists may be used, but little confidence should be placed in the limited discrimination afforded by adjacent ranks. If a large number of ranks is used, quartile values would probably be more useful. In Table 1.4c, in Figure 4-1, the designer has sought two things: verification of the consensus he feels has been reached, and exploration of the

extremes of disagreement with the consensus. It is well to add this extra step, not so much to validate the statistical consensus as to illuminate the real degree of confidence which one may place in the final form of the question itself.

4.2.4 Phrasing the Question

Precision of question construction is probably the most important requirement placed upon the designer of any questionnaire, and certainly a Delphi experiment is not immune to this requirement.

The general rule in the construction of questions is to avoid descriptive words to the maximum extent possible. They are confusing, and they tend to bias the question. On the other hand, at every opportunity terms should be defined. A question should be precise yet retain the simplicity of a direct statement. Legalistic and jargon-filled questions should be avoided.

A general rule of question construction is that each should be unidimensional. A question should address one dominant thought or theme and permit only choices that are truly parallel and related. Although one of the more interesting aspects of Delphi is the opportunity to explore cross-impacts, it is wise not to do this exploration within the framework of a single question. Rank ordering may, obviously, involve nonrelated items, but where a choice must be made among question elements, they should always be truly related. (Don't ask which is more likely controlled, mass psychological conditioning or economic solar energy, because the respondent will be led to think that a relationship is perceived by the designer; on the other hand, including the two items in a rank ordering scheme may be permissable so long as direct relationships are not implied.)

4.2.5 Special Freedoms Allowed in Delphi

The Delphi questionnaire designer has freedoms not generally allowed the experimenter involved with other forms of questionnaires. For example, the questions need not appear easy, since the panel is made up of interested experts who do not require this form of sugar coating. It may one day be shown that the absence of a null

in a Delphi question is a drawback, but since the respondent always has the freedom of no choice, a better form of the null is available and the forced choice question may be used with impunity and no fear at all of distorting the results. It may well be that for any given Delphi the pros and cons are of much greater value than any consensus could be--so that a question may be provocative or open-ended as the designer chooses. Finally, in the Delphi, it is expected that questions will be reworded in successive iterations of the questionnaire, so that the designer is free to ask those questions he considers most meaningful in early iterations, rather than those which he considers most likely to produce reliable information. (Obviously, the questions on which the final conclusions are based must be those which are most reliable, but they may be arrived at by a circuituous route if desired.)

4.2.6 Deriving the Delphi Questions

As stated earlier, the most useful method of deriving Delphi questions is through the active efforts of highly qualified experts. On the other hand, as has been observed, the panel itself may generate some questions to be asked, once the general theme and the broad questions have been decided upon. The latter method has the disadvantage that one round of questions is not statistically productive, and further, it is difficult to provide the panel with appropriate source and backup material in the absence of definition of the questions themselves. It might be useful here to propose a method of construction of Delphi questions which has not been explored in any of the literature. That method is the assembling of hierarchies related to outcome statements. The experimenter may wish to know the total data transmission requirement over a distance of 2000 miles or more (or between selected points, or at a given transmission rate, or with some other useful qualification) at a given period in time. He might construct several hierarchical branches leading toward his main question: classes of data--business, financial, governmental, scientific; technological capacity to use the data, in the form of computational facilities and new equipment; technological capacity to transmit the data; costs of use and transmission; economic advantage enjoyed by data users over non-users; and so on. He might well then discover tangential relationships which would

seem to him to require investigation: dispersion versus concentration of industries; the effect of nationalization of industry or the growth of internationalization; the impact of industrialization of underdeveloped countries both upon their own use of data and upon the already industrialized countries; population growth and concentration; the "saturation limit" in cities which produces a theoretical chaos; changes in transportation cost and availability; and hundreds of other possible areas of investigation.

The construction of such hierarchies can illuminate the experiment for the designer in many valuable ways. Time-based relationships can be discovered where none were constructed; the availability not only of technology but of money which can reasonably be expected to be devoted to the particular event can be considered; a priori technological events can be properly related to each other; and sociological, governmental, and scientific events can be seen in preliminary relationship. Where weaknesses exist in the designers' own knowledge, those weaknesses can be highlighted and made the subject of early inquiry in the Delphi.

4.2.7 Bias and Ambiguity

Every method of construction of Delphi questions opens itself to possible bias. Where the panel is allowed to formulate the questions to be used, the sheer weight of numbers or the emphasis of conviction can lead to biased questions whose outcome is certain before the panel is even consulted. When an expert creates a question, he is almost certain to have an answer in mind or at least some feeling as to the answer and may bias the question to produce that answer. When hierarchies are constructed they constitute a pattern, and these patterns can produce bias.

The avoidance of bias becomes, in the final analysis, an exercise in honesty and vigilance on the part of the designer. The elimination of bias is easier-- because the panel, if encouraged to do so, will respond explicitly and in great detail in criticism of any biased question. Further, the iterative nature of the Delphi can provide insight into the success or failure of a question to develop real answers. This element is discussed in Paragraph 4.2.8.

4-17

Ambiguity in questions is often even less apparent to the framer of the question than is bias. The standard observations concerning any human communication apply: the briefer the question the more likely that it will be understood; all descriptive words and qualifiers lead to potential or partial understanding and should be reduced to a minimum; multidimensional questions will always cause trouble; definition of terms is almost always required; a forced choice should always be accompanied by a "no choice" option.

One of the more interesting methods of creating questions to avoid the particular form of ambiguity of estimates that results in trivial or useless answers is to make the question itself unsymmetrical. One may use an arbitrary group of percentages, such as 10, 50, 75, 90, 100 or one may divide time in unsymmetrical groups, such as 1976-1980, 1981-1990, 1991-2010, or some such arrangement. (The type of time division illustrated here also has the advantage of corresponding to the respondents' relative inability to make precise predictions of events in the distant future as compared with the precision of their near-term forecasts.) The effect of ambiguity of perception or estimate can be eliminated fairly well in this manner, provided that the choice of asymmetry is logical and reasonable.

4. 2. 8 Improving the Questions on Successive Iterations

As has been noted earlier, the experiment designer of a Delphi experiment has an invaluable tool in the successive iterations to improve the questions he is asking. The respondents are the best of all possible sources of new questions, improved (that is, more meaningful, more clear) questions, and of information concerning those questions that should simply be eliminated, for whatever reason. Therefore, it is imperative that the Delphi contain a method for communicating directly between the experimenter and the respondent. Comments should be sought actively and repeated opportunities for comment should be included in the questionnaire. Extreme positions should be noted for the respondents' benefit at the next iteration (not merely at the end of the study.) Even the sarcastic--and perhaps even the scatalogical-- comments may be included at the next iteration without harming the experiment in

the least, especially if the designers have responded by altering and improving the questions being commented upon. Each comment, and each improved question, will bring dividends in the form of further suggestions for improving the questions.

There are other, internal evidences which should be noted at each iteration of the questionnaire in an effort to arrive, finally, at the best, most meaningful set of questions. One phenomenon which should be investigated is very early convergence, or very early consensus. A question on which everyone agrees from the first is very likely to be trivial, at best, and if that is so there is no particular loss. On the other hand, the question may well have been answered uniformly by the panel from that mass of misinformation, "everyone knows." While it may not be true that what everyone knows, no one knows, a question that strays into this area can lead to much misleading data. (One would assume, for example, that in the 1920s "everyone" would have known that harnessmaking was a poor long-range business, since with the popularity and availability of the automobile there would be progressively fewer and fewer horses--yet today harnessmaking is a thriving business in the United States.) The convergence may be true and valid, but it should be analyzed.

Extreme divergence is another type of internal evidence which must be investigated. Usually if the question is at fault in this case it is because of ambiguity, although the area under investigation may simply be one in which there is no consensus possible. Polarization, particularly at the two extremes, is another signal to the designer that he has, at the very least, a very interesting question demanding further exploration. He may well have constructed a question which actually has two opposite meanings for two groups of respondents. If his analysis informs him that the question is not ambiguous, he should single it out for special attention at the next iteration and seek to discover the reasons for each respondent's choice of one or other of the polarized positions. He may find it necessary in the final iteration to investigate the area with a whole new set of questions.

4.3 STATISTICAL ANALYSIS OF ANSWERS TO FIRST ROUND OF QUESTIONNAIRES

The answers to the questions given in the first round may either be quantitative, or qualitative. Quantitative answers are, for instance, the year in which a given event will supposedly take place, or the percentage of circuits that might be needed in a given year to satisfy a given communication need. Qualitative answers can be rated according to their ascending degree of importance. For instance, the answer to "how will a given need be met?" can be "not at all" which is given a rating of 0, or "in an excellent manner," given a rating of 10. Answers that fit between these extremes can be rated accordingly. For instance, if the requirement is not well met, the rating may be 4; if the requirement is well met, the rating could be 6.

In any event the answers to the first round of questions may always be put on a quantitative basis and can thus always be subjected to statistical analysis. The statistical information desired is the median and the interquartile range (IQR) of the first-round questions. (See Appendix A.2.)

The median is the value such that half the observations are below and half above this value. The IQR is the range of values which were observed more than 25 percent of the time and less than 75 percent of the time.

Answers that lie in the IQR are chosen as representative of the disagreement within the group consensus because these answers lie on each side of the median and encompass half the answers given. It is a logical step in the Delphi exercise to choose the IQR as a measure of information since the objective is to arrive at an answer around which there is the least amount of disagreement.

Note that the use of the median and of the IQR are inherent in a procedure that seeks a majority decision.

In order to calculate both the median and the IQR a histogram of the values under consideration is plotted. A histogram is a graph whose abscissa are the values collected as answers to the questions and whose ordinate consists of the frequency of occurrence of these values. Once a histogram is obtained, the cumulative frequency

distribution of the answers can be plotted. Corresponding to a given ordinate we find an abscissa which gives the limit below which we have that fraction of the observations indicated by the ordinate. This abscissa is called the fractile corresponding to the given fraction. The 50 percent fractile is the median, and the 25 percent and 75 percent fractiles are called quartiles. Thus, the cumulative frequency polygon gives the values needed in this analysis.[20]

A question arises as to the necessity of weighting each answer according to the degree of expertise of each participant. If we choose not to weigh the answers the randomness of the answers is preserved, i.e., skewness is not introduced the way it might be if weighting were used. Moreover, this does not stop us from taking into account the degree of expertise of the participants at a later stage.

It has been established that the median and the IQR can be obtained in the first round of a Delphi exercise. The results may be looked at collectively and some conclusions derived from a comparison of actual results from expected results. For instance, it is expected, on the basis of past studies, that as the median date of a forecast event extends more and more into the future, the IQR about that date will increase, thus reflecting the increasing uncertainty of the panel. For answers that do not verify this, it is suggested that the next set of questions probe further around the question which produced the "deviant" answer. This is just one illustration of the importance of using the evaluation of the statistics obtained to produce a more meaningful set of following questions. This feedback mechanism is an important feature of the Delphi technique. (See Paragraph 4.8.)

Another statistic that will help in evaluating the answers obtained, is the standard deviation, defined as the positive value of the square root of the variance. The variance is the average of the square of the deviation of each answer from the mean (the mean or average of the observations is in turn defined as the sum of the observed values divided by their number). The standard deviation is useful in determining the proportion of the population that includes a given range about the mean, given that the distribution is Gaussian.[20] A comparison of the standard distribution and the IQR

will give the evaluator an idea of how close to the normal distribution is the one produced by a particular set of answers.

There will be answers that lie outside the IQR. These answers will not be dismissed since they constitute two important elements of the forecast. An answer which lies in the lower quartile will denote optimism or pessimism (depending on the nature of the question) with respect to answers lying in the IQR, i.e., closer to the median. Similarly, an answer that lies in the upper quartile denotes the opposite attitude from that in the lower quartile. Both types of extreme answers will have to be validated, in further rounds of questions. In this first round, they give the evaluator a measure of the extreme positions being taken within the panel and of the corresponding difficulty in arriving at a majority decision.

4.4 FEEDBACK OF RESULTS OF FIRST ROUND ANSWERS TO PANEL AND REQUEST TO FILL OUT SECOND ROUND QUESTIONNAIRES

One of the most important aspects of the Delphi technique is its feedback mechanism, whereby the respondents are asked to reevaluate their answers in the light of the results and comments obtained in previous rounds.

In its simplest form, the respondents are given the statistical results of the first round of questions (the mean and the IQR) and are asked to reconsider their previous answer. They may give the same answer or change it. If their new answer falls outside of the IQR (i.e., if it is an answer given by less than 25 percent or more than 75 percent of the respondents), they must state their reason for giving this answer.

Note that there is a veiled attempt, in this second round of questions, to bring the answer of each respondent within the IQR. However, this influence of the IQR on the respondent is much less than that of a forceful personality in the usual committee situation.

Note also that an answer in the upper quartile is not necessarily considered desirable, although it represents an upper limit to more than 75 percent of the respondents. This is true because it is also a lower limit to less than 25 percent

of the respondents. By means of the Delphi method we want to arrive at an answer that reflects as much as possible both a majority opinion and a "centrist" one (as reflected by the median). The onus is therefore on the "deviant" respondent to justify his answer. This has had the effect, in past studies, of causing those without strong convictions to move their estimates closer to the median, while those who felt they had a good argument for a "deviant" opinion tended to retain their original estimates and defend them.

Although the expertise of each panel member is not necessarily taken directly into account, it is helpful to know their ranking in expertise for each question being asked. Since the members of the panel may all be unknown to each other, the method the evaluator can use to ascertain the degree of expertise of the participants is to ask the latter to evaluate themselves according to a preestablished scale.

The rating scale may be based on the following evaluation:

DEGREE OF EXPERTISE	RATING
Excellent	10
Very Good	8
Good	6
Not Good	4
Bad	2
Nil	0

This type of evaluation will be useful if weighting of the answers according to expertise is needed at a later date.

The Delphi method is flexible enough to allow for a reevaluation of the questions being asked. Due to the nature of the subject matter, i.e., national communications needs, it might even be helpful to increase the scope and depth of each question at each round of questioning. This may be done after consultation among the evaluators and discussion with other communication experts about the results obtained so far (see Paragraph 4.8).

4.5 STATISTICAL ANALYSIS OF ANSWERS TO SECOND ROUND OF QUESTIONNAIRES

The results of the second round of questionnaires has the same statistical results as the first round (mean, IQR) plus some brief arguments as to why the estimates should be either earlier or later than those within the IQR. The selection and redaction of these arguments are done by the evaluators.

A comparison between the mean and IQR after the first round of questions and the mean and IQR after the second round of questions will show the evaluators whether or not a shift has occurred in the opinion of the group. The nature of this shift (positive or negative) may be used to plan the next round of questions. The questions may also be influenced by the nature of the arguments obtained to justify answers outside the IQR. The changes in response can also be analyzed by the following methods:

1. Calculation of the percentage change in the variance, the standard deviation, or the IQR

2. Calculation of the change in the median

3. Calculation of the deviation of the results from a known probability distribution function, such as the Gaussian one.

The main point is to consider the provision of questions at each round as a process that can be made dependent on the results obtained during the previous rounds (see Paragraph 4.8).

The task of the evaluator becomes more important in the second round of questions. He must sort out the arguments that were advanced for extreme positions and present them in an orderly and concise fashion so that they may be examined by the members of the panel during the next round.

He must evaluate the shift in opinions that is taking place in the panel and determine the extent to which the questions must be changed in the next round to accommodate this shift.

Some of the evaluators, assessing the results of the second round of questions, will either themselves be communication experts or have available the advice of communication experts who are themselves not members of the panel.

4.6 FEEDBACK OF RESULTS OF SECOND ROUND ANSWERS TO PANEL AND REQUEST TO FILL OUT THIRD ROUND QUESTIONNAIRES

The same familiar questions are restated again, together with the medians and the IQR. Also included are some brief arguments as to why the estimates should lie outside the range defined by the IQR.

The members of the panel are asked to reconsider their previous estimates (which are attached) and to revise them if they wish. If they revise their answers they are asked to give a weight to the stated reasons that apply to their latest decision. For instance, if they increase the value of their estimate, they must weigh each one of the reasons that are given for increasing the estimate. A respondent whose answer still remained outside the IQR is required to state why he was not persuaded by the opposing arguments.

If new questions or modifications of old ones are given to the respondents, they are asked to state the reasons for their answer. These reasons will be incorporated into the arguments that have already appeared as a result of round two.

4.7 STATISTICAL ANALYSIS AND PRESENTATION OF TOTAL RESULTS OF QUESTIONNAIRES

There is no set limit to the number of feedback cycles that occur before the final results are tabulated. The actual limit depends on the amount of time available to the evaluators and to the members of the panel to come up with the answers to the forecasting problem.

Following the third round of questions, a fourth one may be envisioned, where counterarguments are presented in defense of an earlier figure or of a later figure than those limiting the IQR. And again, a revision of the estimate is sought.

There will come a point, however, when some or all of the following effects will be noticeable:

1. The spread of opinions around the median will not shrink considerably from round to round.

2. All questions pertaining to a given topic will have been duly explored in scope and in depth as a result of the responses of the panel during preceding rounds.

3. The desirability, cost, and feasibility of all occurrences under investigation will have been duly explored.

4. The likelihood of all events under consideration will have been sufficiently explored, i.e., all possibilities from the "barely possible" to the "virtually certain" will have been considered.

Having all the data on hand, the evaluators enter into the period of data processing. Before organizing the data into meaningful results, it is good to remember the purpose of the Delphi exercise:

1. To reach decisions concerning the probable outcome of future events.

2. To reach those decisions by considering a consensus of the opinions of a body of experts.

3. To present the data obtained from the survey in a clear and concise form so as to facilitate the reaching of decisions.

4. To present enough data so as to give a multidimensional picture of the events which have been forecasted. This means that the importance, confidence, desirability, cost, feasibility, and likelihood of the event will have been touched upon, at least during one round of questioning.

The median and IQR will thus be clearly presented for each of the questions that were raised. Recall that all questions, whether of a quantitative or of a qualitative nature, may be rated quantitatively by using some relevant transformation (see Paragraph 4.3).

In presenting the data, it will be interesting to trace the evolution of opinions of the panel as a whole and this will be the most noticeable in the way the IQR varies from round to round.

This can be done by using the graphical method shown in Exhibit 6 of Reference 17, "The Delphi Method - An Illustration" included in Section 3.

To verify that the spread around the median increases when the median data of a an event is pushed further away in time, the format shown in Figure 4-2 from Reference 21 is suggested.
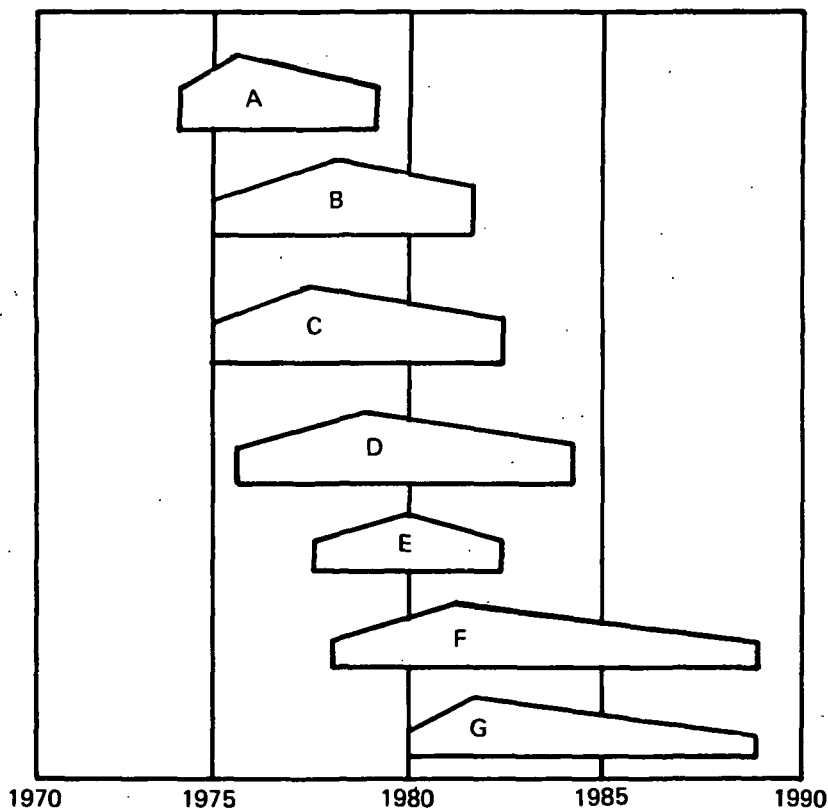
NOTE: A—Flexible internal storage; i.e., easily increased or decreased in size and at will with use of plug-in units.
B—Majority of software built into the hardware; i.e., small packages of integrated circuits to be attached to the computer.
C—Briefcase computers "advanced slide rules" with large memories).
D—Oral input to the computer.
E—Laser memory.
F—One-million-byte memory small enough to be included in an independent desk computer.
G—Pocket-size computers ("advanced slide rules" with large memories).

Figure 4-2. Some Results of a Delphi Forecast of Computer
Improvements and Applications

This format is also a clear way of presenting pertinent data.

Data presented in tabular form allow important questions to be brought out by phrasing them as headings of columns.[13]

Given that the precise questions relative to national communications needs and priorities are not yet formulated, an exact statement of how best to present final results cannot be made. It can be stated that the best way to present the final data is to attempt to maximize its utility to the decisionmaker. Most likely some of the techniques of presentation discussed above will prove useful.

It is at this final stage in organizing results that the ranking of panel members according to expertise may assist in evaluating the data. The results from "expert" subgroups may be obtained and in turn compared with the results from the group taken as a whole.

4.8 AN EXAMPLE OF THE EVOLUTION OF A QUESTION

The dynamic aspects of the questionnaire have been stressed and the manner in which the results of each round can be used to prepare the questions of the next. A simple example will illustrate this.

Round	Question	Results Median	IQR
1	(1) In what year do you expect widespread use of satellites in land mobile communications?	1984	1979-2004

Interpretation of results: There is a greater tendency to predict a far-distant date than one in the relatively near future. Besides repeating the question, the evaluator may ask additional exploratory questions, as follows:

Round	Questions	Results
2	(1) As above	
	(2) Do you expect that in 10 years land transportation will consist mainly of private vehicles or of mass transit?	Private vehicles: 30% of answers Mass transit: 70% of answers
	(3) What is the main technical difficulty that must be overcome in order for satellite communications to be applied to land mobile vehicles?	Limit in frequency spectrum: 18 answers Radio frequency terrestrial interference: 42 answers Lack of downlink power: 10 answers

Round	Questions	Results
3	(1) As above	Restricting use of vehicles: 10 answers
	(2) As above	
	(3) As above	Restricting use of communications on vehicles: 15 answers
	(4) How do you see the problem of radio frequency terrestrial interference being solved?	Reallocation of frequencies: 15 answers Improvements in design of antennas and receivers: 17 answers

Although not shown here, the answers would be given statistical meaning by means already described. Moreover, each round would continue to seek the types of explanatory comments typical of the Delphi method. What this example illustrates is that the evaluator is free to pursue any avenue of inquiry suggested to him by an interpretation of the answers obtained in previous rounds.

SECTION 5 - DEVELOPMENT OF DELPHI MODIFICATIONS

5.1 INTRODUCTION

Although the fundamental concept of the Delphi method is clear, almost every aspect of it is subject to considerable differences in technique. The literature on applications of the Delphi technique reveals that almost every study was made with different methods used by the panel participants to rate themselves, different uses of this self-rating information, different numbers of topics to be discussed, different numbers and types of questions about each topic, different numbers of people on the panel, different amounts of knowledge given to the panel members about the identities and backgrounds of the other panelists, etc. Sometimes cross-impact analysis is used, and sometimes it isn't. When it is used there have been many differences in format, and even more important differences in the mathematical treatment of the information collected. The physical arrangements for gathering the information vary widely, too, ranging from a variety of computerized Delphi conferences run by teletype to printed questionnaires processed with varying time delays. Each of these factors can have a significant impact on the validity of the results and on the time required from the participants. Studies have been made of the effects of some of these factors, such as the size of the panel or the self-rating of the panelists, on the accuracy of the results. Other factors, such as the various techniques of cross-impact analysis, are still being varied on a judgmental basis, with no clear agreement on which is the best approach. The paragraphs below explore some of these areas, pointing out what is known and what is not known about various improvements to the basic Delphi procedure and giving what is believed to be the best guidance possible with currently available knowledge. They also include some related topics such as cross-support analysis and risk analysis which are useful in connecting the results of a Delphi study to a decisionmaking situation.

5.2 SELF-EVALUATION MATRICES

Some participants in a Delphi conference will be more expert at answering any particular question than other participants are. Those who possess such expertise are

usually aware of it. Consequently, it is reasonable to expect that it would be useful to ask the participants in a Delphi conference to rate themselves on their expertise with respect to each question, and to pay particular attention to the views of those who rate themselves highly. Experiment has confirmed this expectation.[22]

There are several ways in which a person can be asked to rate his own expertise. One way is in comparison with the other participants at the conference. If each participant is given some knowledge about the backgrounds of the other participants, he can estimate whether he has a relatively large or small knowledge about any particular question, compared with the other participants. In such a rating approach, it would be possible (and might be accurate) for one participant to rate himself 1 on expertise on all questions, and for another to rate himself 5, if a scale from 1 to 5 is being used.

Another possibility is to ask each participant to note which question he feels most expert in, which he feels least expert in, and to arrange all the others in relative rank of expertise. In other words, if there are N questions, and a rank of 1 is considered least expert, each person would rank himself with a 1 on some question, a 2 on some other question, and so on up to N. Only the answers of people who rated themselves from, say N-2 to N might be considered in subsequent consideration of the problem. One objection to this method is that some individuals might be relatively familiar with most of the problems, whereas others might be familiar with only one or two questions. If such is the case, it would seem that the participant should be able to indicate it, and have the information used. Nevertheless, this system has been tested and found to be more accurate than using answers with no self-rating mechanism at all.

A third possibility is to use the system described in Reference 22. In that study, each participant was asked to put down a "5" next to the question he knew most about and a "1" next to the question he knew least about. He could then put numbers next to the other questions, indicating his relative degree of knowledge about them. He might have several 5's, or just one. This, too, has objections, since one participant may not know much about any of the questions, and another may know a lot about all of them. Even if they are aware of this, this mechanism does not permit them to reveal it, and

their answers would be weighted equally as a result. Nevertheless, this method, too, was found to give more accurate results than a Delphi conference without any self-rating. However, if the participants of the Delphi conference are chosen carefully, there should not be any who don't know much about any of the questions, and the principal objection to the last method would be removed.

Even within the third method there exists a range of interpretation on how to instruct the participants. A 5 could mean that the participant considers himself relatively expert in the field covered by the question, or it might mean that he has high confidence in his answer. Even a person who is an expert in a field will have much more confidence in his answers to some questions than to others in that field. It is probably better to tell the participants to use the interpretation of confidence level, rather than expertise. Studies have shown that if the average confidence rating of a group is 3 or better on a scale of 5 then the group answer is likely to be close to the true answer. If the group confidence level is low, the answer is usually quite different from the true answer.[14]

Not only are there substantial differences in the way self-rating information is defined and collected, there are also substantial differences in the way it is used. Some of the possibilities are listed below:

1. If numerical estimates are being collected, the estimate of each participant can be weighted according to his evaluation of his expertise, when computing an average answer. This procedure is apparently not common, especially since a median answer, rather than an average answer, is usually presented. A median is considered better than an average because responses are highly skewed. For example, if the question is, "In what year will picturephone service come into widespread use?", a single answer of "never" would cause the average answer to be "never," but would have only a small effect on the median.

2. In Delphi rounds after the first, the responses of all participants can be tabulated, and the interquartile range and median displayed, but participants can be instructed to answer the question only if they rated themselves in the

top two or three ranks of expertise. On subsequent rounds only the answers of such people would be tabulated and processed. However, participants who feel that some of the arguments raised by the experts are faulty would be permitted to submit counterarguments.

3. All participants can be invited to continue to participate in answering questions, and the results both for the group as a whole and for the subgroup considering themselves relatively expert can be displayed along with the interquartile ranges and medians. The number of people in the expert group should also be displayed. At the end of the exercise, the results for the group as a whole, and for the expert group, can both be published, thus leaving up to the decisionmakers the problem of which group's estimates to use.

The second method outlined above seems to be the one generally used. One important factor which must be considered in deciding whether to restrict participation only to experts is that such action will reduce the size of the group participating in the forecast. It has been shown that the accuracy of the results produced by a Delphi group depends rather strongly on the size of the group, particularly if the size of the group is less than 7. Figure 5-1, obtained from Reference 22, shows the effect of group size on accuracy observed in one study. Therefore, if it is noted that the group would become relatively small if only the experts participate, it might be better to let everyone participate, or at least to relax the definition of who is considered an expert. Much more experimentation needs to be done before more precise guidance can be given on the optimum procedure to maximize expected accuracy, considering the effects of both group size and self-assessed expertise. The results of such experiments would probably depend heavily upon how much the nonexperts know about a subject as compared with the experts. For some questions the guesses of nonexperts might be quite wild, whereas for others the nonexperts might do almost as well as the experts.

5.3 TECHNOLOGICAL ASSESSMENT

Technology assessment has been defined in various ways. According to Cetron and Connor,[23] "Technology assessment is an attempt to establish an early warning
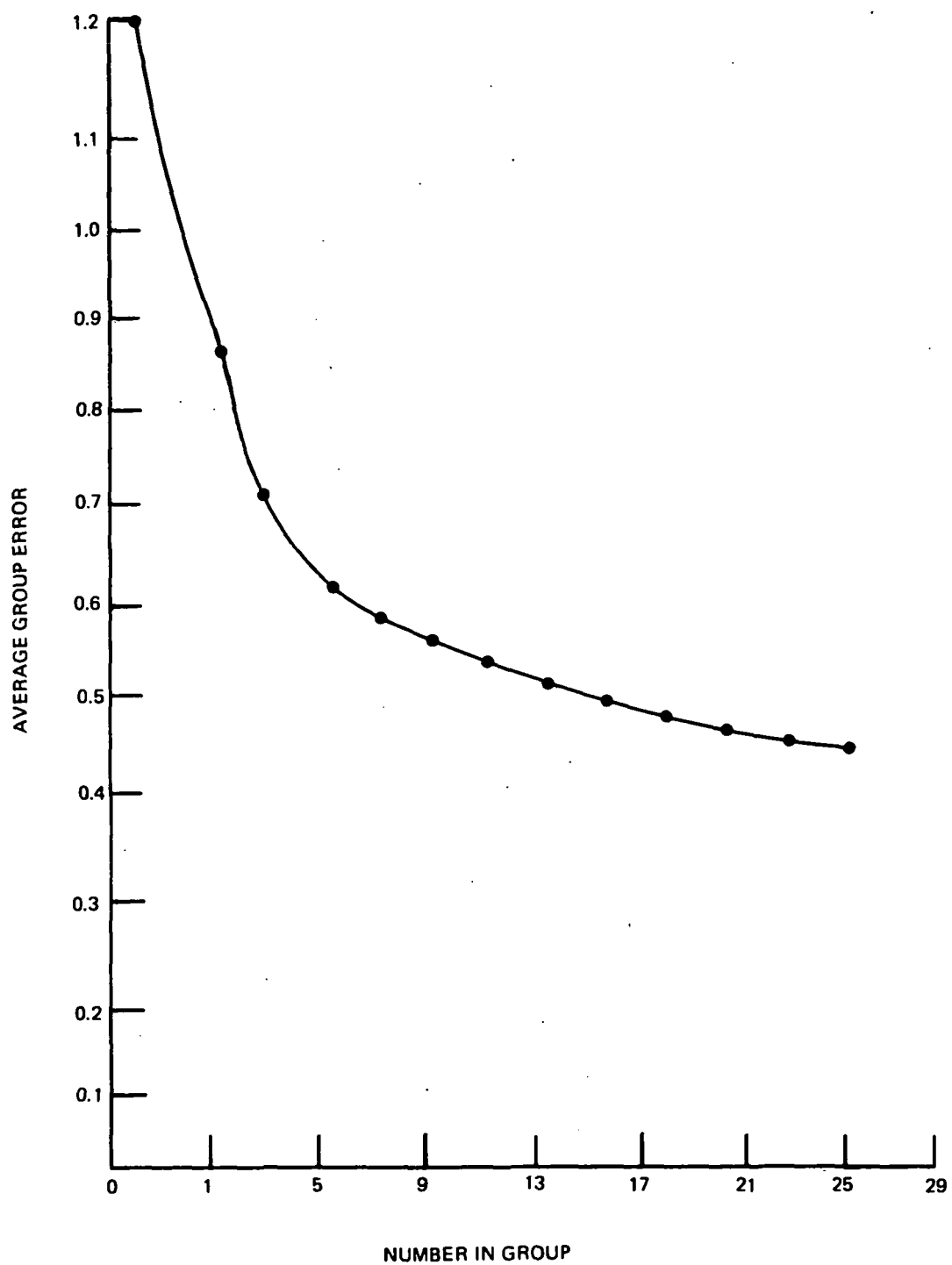
Figure 5-1. Effect of Group Size

system to detect, control, and direct technological changes and developments so as to maximize the public good while minimizing the public risks. It is a relatively new approach to allocating scientific resources, establishing technological priorities, and seeking relevant alternatives to current technology." Overly[24] says that "technology assessment programs are, for the most part, efforts to understand what significant impacts proposed and ongoing technological or applied science programs have upon the social, economic, and cultural systems." He goes on to list various societal indicators, and states, "Each of these societal indicators represents a specific set of interests - people, organizations, social and economic classes, and special interest groups - who, it is assumed either benefit or suffer from a new program. An estimate of what actually will happen is the purpose of the technology assessment process." Green[25] says "The basic problem in technology assessment is to assure an adequate articulation of potential costs and risks. It is axiomatic, I believe, that in any technology assessment the benefits are usually obvious and relatively immediate, and will always be more than adequately articulated and pressed by those with vested interests in the technology. Costs and risks are, on the other hand, typically much more remote and speculative and there rarely are authoritative interests which can be relied upon to articulate and press the costs and risks on the assessors and decisionmakers." Gordon and Becker[26] say "Technology assessment involves anticipating the likely impact of a technology on a variety of hard-to-quantify environmental, social, political, and value factors, as well as the effect of potential changes in these areas on the acceptability of the technology... At its root, the process of technology assessment is one of anticipating primary and secondary interactions. The most important of these interactions cross disciplinary lines and are therefore difficult to handle analytically." Finally, Cetron[27] quotes Gabor Strassers's definition: "Technology assessment is nothing more than a systematic planning and forecasting process, delineating options and costs, encompassing economic as well as environmental and social considerations, that are both external and internal, with special focus on technology-related 'bad' as well as 'good' effects."

Although all of these definitions differ somewhat, they all seem to be describing the same central idea. There is less agreement on exactly how technology assessment is done. Most workers in the field agree that it involves use of Delphi techniques, cross-support analysis, cross-impact analysis, relevance matrices, and trend extrapolation. Overly fits these techniques into a defineable approach as follows:

1. Establish organization goals and priorities. If a government agency is doing the analysis, these would be national goals and departmental goals. Cross-support analysis can be used to help establish priorities, since if it is found that one goal supports other goals, that goal should get a higher priority than if it does not affect them or hinders them.

2. Predict future developments. This involves trend extrapolation combined with subjective judgment of experts, preferably elicited via the Delphi technique. KSIM simulation studies and cross-impact studies (described subsequently in Paragraphs 5.6 and 5.8) are also helpful here.

3. Link organizational goals and priorities to predicted future developments.

4. Analyze organization resources. These resources include manpower, money, and information. By using these resources which the organization has, or can obtain in the future, the organization can influence the future course of events.

5. Develop resource allocation strategies.

Overly goes on to state that even if these five steps are performed, technology assessment may not achieve the objective of assuring that future technological advances will have wide-ranging benefits and few detrimental impacts. The major weakness, he points out, is that technology assessment, as practiced today, is primarily technology oriented, and does not make sufficient use of societal indicators. Adverse effects on the quality of life are not always recognized properly. He deals with what can be done, rather than with what should be done. Also, he states that future technological developments are often too sponsor-oriented.

Ralph[28] gives a detailed procedure for doing technology assessment, utilizing cross-impact and cross-support analysis.

In performing technology assessment, it is important to consider the higher-order effects of new technology, as well as the first-order effects. While the higher-order effects are admittedly difficult to predict, they are sometimes of great importance. For example, if every store had access to a packet-switched data network, an upgraded credit-card-like system in which sales were instantly debited to the buyer's account and credited to the store's account might become popular. This would cause large changes in the pattern of communications traffic, and might have major effects in other fields. For instance, law enforcement might be easier because almost everyone would probably have a sort of credit card with his photograph and fingerprints on it. This would facilitate identification if the police were given a copy. Forgery, which is the crime causing the largest financial loss each year in the U.S., might become harder (or easier). Mugging and robbery might decrease, because people wouldn't carry much money. (The ID cards would presumably be unusable by anyone but the owner.) The probability or expected extent of such high-order effects can be estimated by use of cross-impact analysis or techniques such as KSIM. Before the probability of these effects can be estimated, however, the idea that a particular effect is worthy of consideration must occur to someone. Use of Delphi conferences with fairly large numbers of participants who have good creative imaginations will increase the likelihood that the various side effects of an emerging technology will be imagined and added to the list of effects to consider.

One of the problems in technology assessment is that the social, cultural, and environmental effects of new technology is difficult to quantify on a common scale of value. Nevertheless, it is possible to do some quantification of these effects by ranking various alternatives. For example, a city with 7 TV stations is preferable to a city with only 3 TV stations because of the added variety of entertainment available to the residents. With some effort, even such choices can be put on a common dollars-and-cents value system, if necessary in the analysis. People can be polled and asked how

many cents per month they would pay for the addition of a new TV station to their city. With such numeric data one can obtain a numeric value for the desirability index of a new project or development, where desirability index is defined as utility multiplied by feasibility and divided by cost.

If the factors can only be ranked, rather than numerically evaluated, it may still be possible to eliminate some alternatives on the basis of a low desirability index. This can occur if one alternative is less desirable than another in at least one of the three variables (utility, feasibility, cost), and no more desirable on either of the other two.

5.4 RISK ANALYSIS

Risk analysis is an orderly procedure a decisionmaker can use in selecting one alternative among many possible courses of action, in a situation where he is making a decision under risk. A decision under risk is one in which the utility of the decision will be affected by some factors which are not under the decisionmaker's control, but whose probability of occurrence can be estimated.

The general situation is as illustrated in Figure 5-2. The decisionmaker must choose one alternative from the set a_1, a_2, ..., a_j, ... For example, the alternatives might be combinations of funding levels for various development programs. There are various mutually exclusive alternative possible states of the present and future world, s_1, s_2, ..., s_k, having probabilities p_1, p_2, ..., p_k, ... which affect the results of whatever action he takes. Examples of such states of the future world might be combinations of demand for various types of services, breakthroughs in related technology, etc. Examples of probabilistic features of the present world which may affect the results of his action are the values of certain natural parameters which are not known accurately in the geographic area he is interested in, the levels of man-made interference of various types, and various other economic, social, political and physical factors he may not have firm data on. For each combination of decision a_j and world state s_k, there will be some outcome Y_{jk} shown in the cell of the matrix. The outcome may have many attributes. For example, if a decision is made to fund

	s_1	s_2	s_3		s_k
	p_3	p_1	p_2		p_k
a_1	Y_{11}	Y_{12}	Y_{13}		Y_{1k}
a_2	Y_{21}	Y_{22}	Y_{23}		Y_{2k}
a_3	Y_{31}	Y_{32}	Y_{33}		Y_{3k}
a_i	Y_{i1}	Y_{i2}	Y_{i3}		Y_{ik}

a_i = AN ALTERNATIVE ACTION (A CANDIDATE SOLUTION TO THE RECOGNIZED PROBLEM)

s_k = A POSSIBLE STATE OF NATURE

p_k = PROBABILITY OF s_k, WHERE $\sum\limits_{k} p_k = 1$

Y_{ik} = THE OUTCOME ASSOCIATED WITH a_i IF s_k OCCURS

Figure 5-2. Decision Elements

development of a particular communication satellite system, there will be attributes in the form of channel capacity, S/N ratio, geographic coverage, mean time before failure, etc. Each of these attributes will usually not be known precisely in advance, but will itself have a probability distribution, even if the state of the world were known. (In this example, the state of the world might have to do with booster reliability, projected traffic, and so on.) In order to be able to make a rational decision, one must be able to combine into a single measure of utility the particular values of the attributes which may occur given that a particular alternative is selected and a particular state of the world is found to occur. This single measure of utility can be defined by weighting the relative importance of the various attributes, and for each attribute creating a normalized curve showing how the utility of that particular attribute varies with the magnitude of that attribute. For example, in a communication system the S/N ratio might be judged to contribute 15 percent toward the total utility, the remaining 85 percent being divided between attributes such as geographic coverage, long lifetime, large bandwidth, low doppler rates, etc. Within the 15 percent for S/N ratio, it might be judged that a S/N of 15 dB or less would have a value of zero, and that utility could be considered to increase linearly with S/N ratio (measured in dB) and independently of other attribute values, until a S/N ratio of 30 dB is reached, which might be the most that could be hoped for with the system being considered. A S/N ratio of 30 dB would then contribute 15 utility units toward a total possible utility of 100 units.

In each cell of the matrix, then, there is a probability distribution for the utility of that combination of decision and world state. The probability distribution can be obtained from the joint probability distribution of the various attributes in that cell, evaluated for utility at each combination of attribute values. The mechanics of obtaining the probability distribution of utility, and in particular its mean value, can probably be done most conveniently by Monte Carlo simulation, in cases where there are several attributes which affect each other's utility. Random numbers would be picked and plugged into the probability distributions of the individual attributes to find a random combination of attribute values, the utility of that combination would be calculated, and the process repeated several hundred or several thousand times to find an average

value of utility for that cell. If the utility associated with different values of each of the attributes is independent of the values of the other attributes, the process becomes much simpler. All that one has to do then is to find the mean utility associated with each attribute, and add up all of these means, since the expected value of a sum is equal to the sum of the expected values. However, it should be noted that the expected value of the utility of a given attribute cannot usually be obtained by simply taking the expected value of that attribute and computing its utility. The only time such a procedure works is if the utility of the attribute is linearly proportional to the magnitude of the attribute. If the relationship is not linear, the probability distribution of the attribute must first be transformed to the probability distribution of the utility of the attribute before the expected value is calculated.

The entries in each cell of the matrix shown in Figure 5-2 should be the expected utility, U_{jk}, corresponding to that cell. Since in decisionmaking under risk it is assumed that the probability p of each state of the world (each column) can be estimated, the expected value of each alternative course of action (row) can be calculated by simply summing the products of the probabilities in each column multiplied by the expected utility of the payoff in that row and column. The recommended decision is, of course, the one with the highest expected utility.

For the above procedure to work, the states of the world listed in the column headings should be mutually exclusive and exhaustive, so that their probabilities add up to one. If one wishes to allow for some unknown events, one can label one of the columns "other," and give it a probability.

Another way of visualizing the decisionmaking process and the risks and payoffs is a decision tree, such as the one shown in Figure 5-3. The decision tree can show the same information presented in Figure 5-2, and it can also handle multiple-stage decisions which are difficult to handle using the matrix approach.

The initial branches of the tree represent the set of alternatives a_i; they stem from the initial decision to be made by the decisionmaker from a decision fork. A decision fork is represented by a square.

5-12
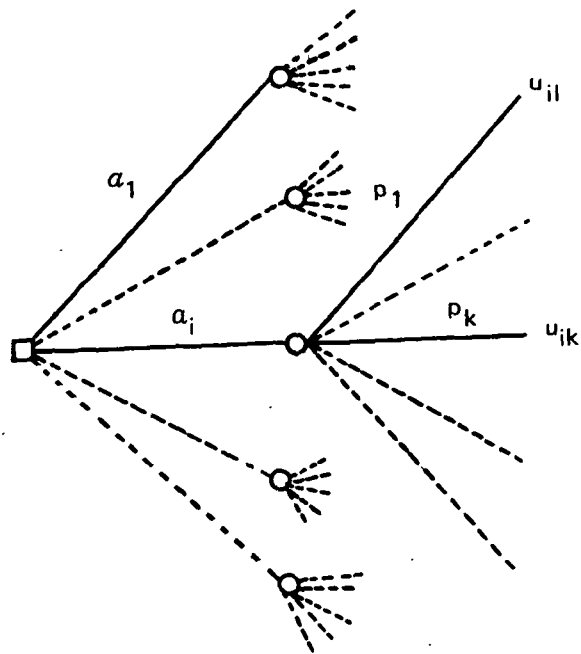
a_i = CANDIDATE ALTERNATIVE

p_k = PROBABILITY OF STATE OF NATURE

u_{ik} = $\sum_j u (y_j)_k \, f(y_j)_{ik} \, dy_j$

Figure 5-3. Decision Tree Representation of Decion Model

Each branch representing an alternative a_i terminates in a fork with branches representing the states of the world. The branch to be taken at this fork is determined by chance; a chance fork is represented by a circle. A probability p_k is associated with each of these branches. These branches can lead to outcomes or to other decision or probability forks.

Each path from initial decision fork through an outcome branch yields a payoff, an expected utility u_{jk}, which is obtained by combining utility functions with estimates of the probability distributions of various attributes as explained above. Multiplying u_{jk} by the probabilities of all the probability branches traversed in going from the initial decision branch to the final outcome gives the contribution of this outcome to the expected utility of the decision. This value should be entered adjacent to each outcome. Adding up these figures at all outcomes stemming from an initial decision branch gives the expected utility of that branch. The branch with the largest expected utility is the one recommended by this procedure.

5.5 SENSITIVITY ANALYSIS

In forecasting future events, one often finds that the probability of one event is dependent, to some extent, on the occurrence or nonoccurrence of another event. For example, the introduction of direct broadcasts from satellites to home TV receivers may be dependent, in part, on the development of high energy nuclear-fueled power supplies suitable for satellites. It is very useful to have a measure of such dependencies, for many reasons:

1. A particular expert may be qualified to give a good estimate of the likelihood of dependent event A if conditioning event B occurs, and a good estimate of the likelihood of event A if B does not occur, but not be qualified to estimate the likelihood of B occurring. Some other expert may be qualified to estimate the likelihood of B but not the effects on A of the probability of B occurring. The sensitivity figures obtained from the first expert can be combined with the data provided by the second expert to get a better estimate of the probability of event A than either of them could provide alone.

2. If it is found that a desired event is sensitive to the occurrence or non-occurrence of a prior, conditioning event, steps can be taken to increase the likelihood that the conditioning event will occur.

3. Through the use of sensitivity analysis it may be found that one event is dependent upon a second, which is dependent on a third, etc. By following chains of this sort, one may uncover connections between events that seem at first to be unrelated. If the first event on such a chain occurs, or does not occur, one can then estimate the effects on the probabilities of occurrence of the other events on the chain. For example, in recent years a change in the availability of anchovies off the coast of Chile reduced the availability of chicken feed (made from anchovies), which caused soy beans to be used for chicken feed, which reduced the availability of soy beans for cattle feed, forcing up the price of meat. If this chain of dependency had been known in advance, farmers could have been alerted to plant more soybeans in time to prevent the severe soybean shortages that developed.

4. If sensitivity analysis indicates that the probability of event A occurring does not depend much on whether event B occurs or does not occur, and if event A is the one the analyst is interested in, the analyst will know that he doesn't have to devote much effort to a careful estimate of the likelihood of B. On the other hand, if the probability of event A is strongly dependent on the occurrence of event B, the analyst may have to obtain a more accurate and complete estimate of the likelihood of B than he would otherwise have done.

Sensitivity analysis, in the context of Delphi forecasts, is very simple. Respondents are simply asked to indicate which events, if any, would change the probabilities of occurrence, or date of occurrence, of a given event (called A) if they happen (or do not happen) at some previous date. The respondents are then asked to estimate the probability that event A will occur by the given date if one of these other events occurs by a specified previous date, and the probability that event A will occur by the given

date if the conditioning event does not occur by the specified date. The difference between these two probabilities is the respondent's estimate of the sensitivity of event A to the conditioning event.

After several respondents have made estimates of the sensitivity of an event A to a given conditioning event B, the results are tabulated. The median is used as the group estimate. The interquartile range (difference between the first and third quartiles) is also usually computed (see Appendix A.2). A small interquartile range indicates that the respondents are in close agreement on the sensitivity; a large range indicates disagreement, and consequent uncertainty.

Several points in the above procedure are deserving of further comment:

1. The above procedure indicated that the respondents identify which events are sensitive to which other events. Sometimes the person creating the questionnaires, rather than the respondent, decides which events should be considered in this way, and formulates the questionnaire accordingly. It is also possible to ask respondents to evaluate the sensitivity of every event to every other event. Such a procedure is really a form of cross-impact analysis, which will be discussed in a subsequent section.

2. The procedure outlined above asks respondents to estimate the probability of event A occurring by year y if event B has occurred by year w. The choice of y, and particularly w, is difficult. If w is made too close to y there may not be much time for B to affect the occurrence of A, even though the two events are closely related. Moreover, if w is made too close to the present the probability of event B occurring may be small. The estimates of the probability of event B occurring by year w, the probability of event A occurring by year y if event B does occur by year w, and the probability of event A occurring by year y if event B does not occur by year w, will change as a function of w. Ideally, the changes in these three quantities should be related in such a way that the computed probability of event A occurring by year y will be the same for every value of w. In actuality, it is not likely that this

will occur. If the analyst and respondents have sufficient patience and time to estimate the probabilities and sensitivities for several different values of w, a useful check on the consistency of the estimates can be made. If the various computed values of the probability of event A occurring by year y come out about the same, the estimates are at least consistent. If the probabilities come out substantially different, depending upon the value of w, the estimates are inconsistent, and the reason for this inconsistency should be investigated.

The probabilities and sensitivity factors are related as follows:

$$P(A_y) = P(B_w) \cdot P(A_y/B_w) + P(\overline{B_w}) \cdot P(A_y/\overline{B_w})$$

where: $P(A_y)$ = the probability that event A will occur by year y

$P(B_w)$ = the probability that event B will occur by year w

$P(A_y/B_w)$ = the probability that event A will occur by year y given that event B occurs by year w

$P(\overline{B_w})$ = the probability that event B will not occur by year w

$P(A_y/\overline{B_w})$ = the probability that event A will occur by year y given that event B does not occur by year w.

Conditional probability is also discussed in Appendix A.3, Cross Impact and Contingency Analysis.

5.6 COMPUTER SIMULATION

A digital computer can be useful in Delphi studies in at least four ways:

1. Monte Carlo simulation can be done on a digital computer to perform a cross-impact analysis, as described below and in Paragraph 5.9.

2. A somewhat different form of cross-impact analysis can be performed, as described below, using a computer program called KSIM.

3. The computer can be used as the medium through which the Delphi conference itself takes place. Using teletype or similar remote access devices, participants can receive instructions, enter their data, and be informed of questions, comments, and the results of previous rounds by the computer. The computer can serve as a convenient storage device, keep a record of all entries, and do the various arithmetic calculations required. Accounts of two such computer programs are given in References 8 and 28, and are summarized below.

4. Computers are used in higher-level simulations. This approach is much more ambitious than is normally consistent with a typical Delphi exercise, but is potentially much more accurate.

5.6.1 Monte Carlo Simulation

As described in Paragraph 5.8, cross-impact analysis is a procedure in which the effects of the occurrence or nonoccurrence of certain events on the probabilities of other events are estimated. Starting from a set of initial estimates of the probabilities of various events and the impacts of these events on the probabilities of other events obtained from the Delphi participants, the object is to obtain a better estimate of the probabilities of the various events, allowing explicitly for the interactions. Or the object may be to see what effect changes in the probabilities of certain events would have on the probabilities of other events. The easiest way to obtain such a result is by Monte Carlo simulation.

In Monte Carlo simulation, as applied to this problem, the computer starts with an initial event on the list. If the events are ordered chronologically, the computer would start with the first event. If two or more events affect each other's probabilities and there is no clear indication as to which would come first, one is selected at random. A random number between zero and one is selected by the computer, and compared with the probability of the event occurring. If the random number is less than the probability, the event is considered to have occurred. The probabilities of all events affected by that event are then changed to the value they would have if the event

occurred, and another event is considered. This procedure is repeated until all events have been considered. Tallies are then made by the computer of which events occurred, completing the first Monte Carlo trial. The whole procedure is repeated N times (usually about 1,000), and the percentage of the N trials on which each event occurred is printed out by the computer. These updated percentages will be approximately the same as the original percentages if the cross-impacts of the various factors are weak or tend to cancel out or have been correctly included in the original probabilities, but may be quite different from the original percentages if the cross-impacts are strong and reinforcing in ways not fully considered in the original probability estimates.

The decisionmakers, the government, or the outside world may take actions that change the probabilities of some events. To see what effect such changes would have on the probabilities of other events, all that is necessary is to change the initial probabilities of these first events, hold them at the desired value, and rerun the simulation. Similarly, if an event is definitely known to have occurred (or if one wants to explore what would happen if it did occur), its probability would be set and held at one. The changes in the probabilities of other events can then be tabulated. These changes are often not at all intuitive, because the many interrelationships in the cross-impact matrix often cause the probabilities to affect each other in a very complicated way.

5.6.2 KSIM

KSIM is the name of a computer program, or set of programs, which make it very easy for people with no programming experience to see how a system of interrelated variables will change with time, given that they affect each other in certain ways.

The first, and most important, step is for the key people familiar with the system to be modeled to get together and decide what are the significant variables, and to give at least a rough indication of how they affect each other. They create a matrix which somewhat resembles a cross-impact matrix, except that instead of the row and column headings being events, they are variables representing levels of activity or

quantity of some sort. For example, one variable might be the number of intercontinental telephone calls per year. Another might be the average cost of an intercontinental call. Others might be per capita income, the number of telephones per capita, level of international trade, etc. The participants must first decide what the variables are, then indicate, for every pair of variables, whether the first variable in the pair has a positive, negative, or zero influence on the second. If there is an influence, they must then decide whether the influence is weak, fairly strong, or very strong. Finally, the initial levels of the variables must be estimated by the participants, on a scale from zero (representing the lowest reasonable level of the variable that might be encountered) to one (representing the highest possible level that might be encountered, within reason). The program takes this data and continually readjusts the computed level of each variable, allowing for the levels of the other variables and the cross-impact effect. It then plots out the results of this procedure as a function of time, showing the users the transient behavior and the general behavioral trends of the system. The simulation can then be rerun with different values for the initial levels or the cross-impact factors, to see how much effect such changes have.

One of the variables that can be included in such an analysis is government or other outside intervention. For example, if government intervenes to hold down prices, such a constraint can be introduced into the model, and the effects on the other variables observed.

It often turns out that the results are surprisingly insensitive to substantial errors or changes in most of the initial values of the variables and most of the cross-impact coefficients. The behavior of the model often doesn't change much in response to moderate efforts at governmental intervention, either. Certain factors are often found to dominate the behavior of the system, and even rather large changes in other factors shift the equilibrium only slightly. Results of this sort were discussed by J. Forrester in his book, "Urban Dynamics," in which he pointed out that his models showed that most government efforts to improve the quality of housing in the cities were counterproductive or ineffective, and this seemed to correspond to actuality. He stated

that interventions in complex systems often lead to results which are entirely at odds with the initial expectations. Any complex system defines an integrity of its own and strongly resists external changes, a fact well understood by ecologists. When complex systems change they seldom change continuously but rather flip suddenly into an entirely new configuration. Such results are of great interest, because they can keep large sums of money from being spent on programs that will be ineffective. This situation also can increase the confidence of the user in the results he obtains, since some error in one or several inputs is not likely to change the final state, or even the transient behavior, of the system very much. The factors which are critical, if any, can be identified by experiment, and an effort can be made to get better data on those.

The number of cross-impact cells that must be filled in by the participants is proportional to the square of the number of variables in the set being considered, so there is a strong incentive to keep the number of variables down. As a result, the model created will have to be highly aggregated, in most cases. Nevertheless, the program can produce some very useful and unexpected insights into the behavior of a system. After setting up and working with such a model, the participants will usually have a much better appreciation of what factors dominate the behavior of the system, and why, than they could obtain in any other way.

5.6.3 The Computer as a Medium

The Delphi exercise is an attempt to obtain the benefits of a conference without some of its disadvantages. One means by which a Delphi exercise can be implemented is to call the participants to a common meeting place, but to control the interaction between them by artificial means, so that individual participants do not control the participation of others through the force of their personalities. Such a methodology has the disadvantages of all conferences - the difficulty of finding a meeting time that is convenient for all participants, the travel costs (both time and money) for the participants who are distant from the meeting place, etc. The alternate method of procedure has usually been to conduct the proceedings by mailed questionnaires. This is much more convenient for the participants, but is slow. A Delphi conference could be run

by telephone, but such a procedure is rather slow and awkward, and there are time zone problems if the participants are spread out geographically. An interesting and useful alternative, therefore, is conducting the conference by computer. In Reference 29, Vallee described a computer program named FORUM that permits people to exchange ideas and information, make decisions, participate in making forecasts, etc. The users do not require training in the use of a particular computer language, and can go through an entire conference without learning a single command. They must, of course, use a computer terminal, such as a teletype, but no special or control characters are used. FORUM not only has the ability to administer hundreds of questionnaires simultaneously, but it also allows a completely open, unstructured conferencing style. It performs the routine functions of administering the inquiry, providing instructions to participants, leading them through the agenda, posing questions, storing and processing answers, presenting summaries of results, etc. In addition, it allows the participants to ask questions, make comments, permits deviations from the original agenda, and is quite flexible. One of the valuable by-products is a written record of the discussion and context in which decisions were reached, which is often not available with conventional conference techniques.

The FORUM program was written for a PDP 10 computer operating under the 10X operating system. It could, of course, be modified or rewritten for use on other computers.

In Reference 8, Turoff describes a somewhat similar program he wrote and debugged in about three man-months of effort. It is written in XBASIC for the Univac 1108. An improved version was later written in 3 months' time by a professional programmer. Turoff conducted a Delphi exercise on the usefulness of his original program, and asked ideas for ways it could be improved. The results of the exercise are given in the same reference.

One of the advantages of using a program written in a simple language such as XBASIC is that it can easily be modified by the Delphi conference monitor if he, or the participants in the Delphi conference, desire to do so.

5.6.4 Higher-Order Simulation Models

The KSIM simulation described previously is a simplified, relatively easy-to-use mechanism for estimating the effects of various variables on each other. Although the results it produces are often of considerable interest, the idea that the effect of one variable on another can be represented by a single number is a gross simplification, and, one may fear, in most cases an oversimplification. As Julius Kane says in his paper on KSIM,[30] "For greater realism we have begun consideration of cascaded models of the variety described. This permits the interactions themselves to be functions of the state of the system. Clearly A need not always be B's friend. A's attitude towards B can be conditional on the relative status of their difference A-B or perhaps depend upon the state of a third individual C. Perhaps much more important is the following refinement. Often we sense not a variable but rather changes in a variable. Our response to environment has much this character. Whether our locale is good or bad we quickly become acclimatized to it and then become sensitive only to gross changes. Such derivative interaction is very important and is the subject of other papers (Kane, Vertinsky, and Thompson)."

It may be added that there are also often time delays, of various magnitudes, that enter into the interactions between the variables.

Estimating the interactions between the variables in this more detailed but realistic way is a substantial effort, and thus it cannot really be considered that creating a higher-level simulation would be a way of using a computer to support a Delphi exercise. On the contrary, the Delphi exercise would probably be used to support such a higher-level simulation effort, identifying the variables to be simulated and the level of aggregation for each variable, and defining the cross-impact functions. J. Forrester has used such simulations (though without benefit of Delphi techniques, insofar as is known) in his work on Industrial Dynamics, Urban Dynamics, and World Dynamics. Even more elaborate simulations have been made in the economic field, in which the U.S. economy is divided into several dozen or several hundred sectors, and the differential equations linking each sector to each other sector are estimated

and modeled. The effort required is large but the results are correspondingly improved. Our society consists of many interacting multiloop feedback systems, some with positive feedback, some with negative. With time and effort we can make pretty fair estimates on how each little link of the whole apparatus works. Human beings, rather than computers, have to do that part of the job. When it comes to figuring out how all these feedbacks and time delays affect each other, however, only a computer can cope with the problem. Forrester first, and most successfully, demonstrated the utility of this approach when he showed why some firms were subject to violent oscillations in their level of business activity whereas others were relatively stable. He did this by the method outlined above, and described in his book "Industrial Dynamics."

The level of detail in the model need not be extremely great in order to produce useful results. In his book "World Dynamics," for example, he describes the results of his studies on a model containing only five variables (population, pollution, food supply, industrial development, and raw materials), all aggregated on a global basis. The whole computer program consists of only 127 lines of computer code.

The interactions simulated by Forrester are all of the types called "trend to trend" by Helmer in Reference 31. The same applies to KSIM. They are, however, more realistic than Helmer's trend to trend interactions. Helmer attempted to define the interactions in terms of a matrix which shows the effects on trend j if trend i departs from its initially predicted value. In reality, the interactions are much more complicated than this, as mentioned above in connection with KSIM. Helmer's approach has the advantage over Forrester's simulations and KSIM, however, in explicitly modeling interactions between events and events, events and trends, and trends and events, in addition to the interactions between trends and trends. Forrester did not model the effects of trends on events or events on events. He did model the effects of events on trends, in essence, by changing the values of certain coefficients in his simulation at particular future times, to represent changes in government policy, people's values, etc. In summary, these higher-order simulation models are the most realistic and accurate way we have, at present, of predicting the complicated interactions of our

society. They will almost certainly be used increasingly, and become increasingly accurate. For example, it is easy to enrich and extend KSIM or Forrester's detailed trend to trend simulations by including the effects of trends on events and events on events. Such higher-order simulations are, however, major efforts in their own right.

5.7 REITERATION OF PROBABILITY ESTIMATES

It has been shown that the consensus judgment of a group using the Delphi technique improves with feedback.[7] There are numerous variations in the way information can be gathered and fed back and successive rounds handled. Reference 32, for example, recommends a procedure which is rather inapt for estimating a probability density function using the Delphi technique. In that example, which had to do with estimating the probability distribution of the thrust of a jet engine, each of five experts, upon being questioned alone, gave five values of thrust which he could discriminate between on a probability basis. He was subsequently given a thrust value picked randomly from a list of 11 values (which he could presumably not discriminate between) and asked to estimate its probability. The longer list was a compilation of the thrust values mentioned by the five experts when questioned individually, and was apparently not revealed to the participants. In a situation like this, one person might respond with a low probability value, since he might figure that other, nearby values of thrust might be just as likely, whereas another might respond with a high number, since he might figure that the thrust he is being asked about is in the vicinity of the high probability region of performance. After three rounds on this one value of thrust, there were another three rounds on the next randomly selected value from the list, so that a total of 33 rounds was required to complete the analysis of this one question. If more care had been taken in the design of this procedure, the amount of time required of the participants could have been reduced substantially and much more information obtained.

A better procedure in a case like this would be to work with cumulative probability distributions, rather than with probability densities. It is easier for a person to think that an engine is 90 percent likely to have more than 31,000 pounds of thrust and 10 percent likely to have more than 37,000 pounds of thrust than to estimate the

probability of its having exactly 31,000 pounds of thrust, particularly when he does not know what the alternatives are he will be asked about. Furthermore, by asking each expert on the same round where he would put the 90 percent, 75 percent, 50 percent, 25 percent, and 10 percent cumulative probability values, the total number of rounds could be reduced to three or four, instead of 33. Once consensus has been reached on the cumulative probability distribution, it can be converted to a density function, if desired.

After the first round of answers have been collected, the participants are given the median and quartile results for each question, along with data on what the participant's own answer was to each question. If enough people rate themselves as relatively knowledgeable on a question so that they form a subgroup of adequate size (at least 7, with 12 or more desirable), feedback should be based on the answers only of this knowledgeable subgroup, and on such questions the participants in the less knowledgeable subgroups can be instructed to skip the question in subsequent rounds unless they have some comment they want to make. For example, they may know of some reason why the arguments supplied for or against a particular estimate are invalid, or they may have some reason for making a particular estimate that none of the people who rate themselves more highly has mentioned. Participants going on to subsequent rounds are asked to revise their estimates if they wish to and to supply reasons for their estimates if they fall outside the interquartile range. Starting on the third round, when such reasons are fed back to the participants, the participants are also asked to refute any reasoning they believe to be faulty.

There is some disagreement about the extent to which participants should be urged to answer all questions, particularly on the first round. For example, Reference 33 says "Panelists--particularly those with technical backgrounds--must be convinced that judgments often have to be made about issues before all facets of the problems have been researched and analyzed to the extent they would like. (For these situations they must be persuaded that their subjective judgments may be a decisionmaker's most valuable source of information.)" However, that same reference, on the

following page, says "If a multidisciplinary approach is desired, respondents should be encouraged to consider all items but to make estimates only on those scaled descriptive phrases with which he feels comfortable. For example, in these exercises it was helpful when respondents indicated their familiarity with a specialized area or the importance of an item even though they did not make probability estimates."

Four rounds are generally used in a Delphi exercise, in order to give participants a chance to respond to and refute arguments raised for particular estimates during the second and third rounds. If new arguments or refutations are advanced during the fourth round, or if participants are still changing their positions appreciably in this round, additional rounds can be added until no further substantial change appears likely.

The final output of the exercise is usually the median and quartile points for each question, based on the last round results for the subgroups consisting of self-rated experts. If the population of such subgroups is small, the results are based on the estimates of the whole group of participants. If the group seems to divide itself into two or more relatively large factions clustered closely about substantially different estimates, this should be noted. The arguments for and against the various estimates should also be preserved.

During the course of the exercise, some participants may ask that additional questions be added to the list being considered. The answers to such supplementary questions may be helpful in answering questions on the original list. Such questions can be submitted to the other members of the group for a vote on the usefulness of adding them to the list, or may be added to the list at the discretion of the team conducting the exercise.

Reference 33 recommends letting the panelists decide through their suggestions and evaluations what items should be considered. The criteria for retaining an item for further evaluation should be made clear at the outset of the exercise.

Some Delphi exercises have been conducted with different participants on each round. No comparative studies have been published on the benefits and disadvantages

of this procedure as compared with using the same participants for all rounds. It is much more customary to use the same participants on all rounds, except, as has been mentioned, that participants rating themselves low on expertise on certain questions are sometimes asked to refrain from answering those questions.

Other helpful hints mentioned in Reference 33 for use during reiteration of the probability estimates are noted below:

1. Interpersonal techniques, such as interviews and seminars, should be interspersed with the rounds of questionnaires and information feedback.

2. The source of a suggested item should be identified (for example, panel member number and basic biographical information), taking care not to compromise the anonymity of specific inputs.

3. Standardized scaled measures should be available to a respondent so that he can qualify his response to specific questions. Such measures are relative competence in a technical area, familiarity with a geographical region, or confidence in an estimate.

4. If the exercise is conducted by mail, a definite date on which the questionnaires are to be completed should be specified.

5. Personal comments and arguments submitted by respondents should be part of the information feedback.

5.8 CROSS-IMPACT ANALYSIS

Cross-impact analysis is a method of taking into account the interrelationships of a set of events in assessing the individual probabilities of those events. It is applied in two ways:

1. Cross-impact analysis is used in an attempt to improve the estimates of probabilities of future events, based on an initial set of estimated probabilities and a matrix of cross-impact effects.

2. It is also used to find out what happens to the probabilities of certain events if other events occur. This is useful in two ways:

    a. It may be possible to increase or decrease the probabilities of certain events. The cross-impact analysis shows what effect this would have on the probabilities of other events.

    b. With the passage of time, some of the events in the matrix will occur, or not occur. The results of the analysis can then be updated by simply changing the probabilities of those events to one or zero, as the case may be, and rerunning the cross-impact analysis. Such a procedure is much faster and cheaper (though probably not as accurate) as rerunning the whole study by obtaining new probability estimates from a panel of experts.

Several different procedures have been reported in the literature for obtaining the cross-impact matrix and performing the analysis. None of them can be completely justified mathematically, and the procedures which come closest to possessing mathematical consistency are the most awkward and tedious to apply. A discussion of the differences between the various procedures which have been suggested, and their shortcomings, is given in Appendix A. The procedure outlined below is intended to combine the better features of several approaches, plus some simplifications which appear obvious but have not been reported in the literature. The major reason for the mathematical problems is that although the cross-impact matrix contains considerably more information than a simple list of estimated probabilities does, it still does not contain enough information to uniquely specify all the joint probabilities. It does, however, contain enough information to be capable of being inconsistent with itself and with a list of estimated probabilities. Checking for, and removing, the inconsistencies poses difficulties, and may or may not improve the quality of the estimates produced. Therefore, the results of the cross-impact analysis should be used with caution.

The recommended procedure is as follows:

1. Obtain agreement on a list of events whose probabilities are to be estimated. In some situations the list may be prepared in advance and presented to the participants; in others the participants in the study will create the list. In any case, there will probably be revisions to the definitions of the events, and possibly events added or deleted from the list, on the basis of the comments by the participants.

   The list should not be too long, because the number of cells in the cross-impact matrix grows approximately as the square of the number of events considered.

2. The participants should estimate the probabilities of occurrence of each event.

If possible, the probabilities should be in the form of numbers, on a scale of 0 to 1 or 0 to 100 percent. If this is confusing to the participants, they can be given a copy of Table 5-1 which shows the equivalence between English phrases and probability values.[33]

Table 5-1. Probability Equivalents of Common Phrases

Phrase	Probability Value	Odds in Favor of Event
Very Unlikely	0.10	1 to 9
Rather Unlikely	0.25	1 to 3
Toss Up	0.50	1 to 1
Good Chance	0.75	3 to 1
Highly Probable	0.90	9 to 1

Table 5-2 gives an example of a list of events and their probability values. The list would usually be longer in a real Delphi exercise.

Table 5-2. Events and Their Estimated Probabilities

Event	Estimated Probability	Odds In Favor
E1. Development of 100 kW ERP satellites by 1980	.75	3:1
E2. Considerable commercial use of optical waveguides by 1980	.25	1:3
E3. Direct satellite-to-home TV becomes common between 1980 and 1990	.50	1:1
E4. Pocket-size portable telephones become widespread between 1980 and 1990	.50	1:1
E5. Picture phone service or equivalent, becomes widespread between 1980 and 1990	.25	1:3
E6. Most remote access computer terminals have graphic display capability by 1990	.30	3:7

3. The participants should then fill in two cross-impact matrices. The first matrix gives their estimate of effect on the probability of each event if some specified event is certain to occur, and the second matrix gives the effect on the probability if the specified event is not certain to occur. Figures 5-4 and 5-5 are examples of such matrices. If the occurrence or nonoccurrence of the specified event has no effect on the probability of occurrence of the other event, the cell in each of the two matrices at the row corresponding to the specified event and the column corresponding to the other event should be left blank or have a zero entered. If the occurrence of the specified influencing event increases the probability of the other event, a positive number greater than one should be entered in the first matrix. The magnitude of the number signifies how much the odds in favor of the event will be multiplied if the influencing event occurs. For example, if a four is entered, an event which had odds of 1:1 (probability 0.5) would be given odds of occurring of 4:1 (probability 0.8) if the influencing event occurs. If the odds were originally 4:1, the odds would be raised to 16:1 (probability 0.94) if the influencing

event occurs. If the odds were originally 1:20 (probability 0.0475) they would be raised to 4:20 or 1:5 (probability 0.167).

If the participant believes that the occurrence of the influencing event would reduce the probability of the other event, he should enter a negative number in the corresponding cells of the first matrix. The magnitude of the number will then indicate the factor by which the odds will be divided. For example, if a -4 is entered and the odds in favor of the event were originally 16:1, they would be reduced to 4:1 if the influencing event occurred. If the odds were originally 1:5, they would be reduced to 1:20.

The second matrix should be filled in similarly, except that here the numbers refer to the effects on the probability of an event if the influencing event definitely does not occur. The numbers entered in the two matrices will often be different in magnitude. For example, if optical waveguide comes into widespread use the likelihood of picture phone service becoming commonplace may be increased substantially, but if optical waveguide doesn't come into widespread use the likelihood of picture phone service becoming commonplace may not decrease much. Other fairly likely developments may make picture phone service practical even without optical waveguide.

4. The responses produced by the various participants are then collected, and the median and interquartile values for the probabilities and impact factors are tabulated. All three values are fed back to the participants for use in subsequent rounds. After the last round the median values are used for further processing.

5. The next steps can most conveniently be done by a computer, if one is available. If not, they can be done manually.

   a. Scan the two matrices of median impacts and find which events, if any, do not affect the probabilities of any other events and are not affected by the probabilities of any other events. Event E4 in Figures 5-4 and 5-5

If this event were to occur	Then this would be the factor used to adjust the odds of					
	E1	E2	E3	E4	E5	E6
E1	X	O	3	O	O	O
E2	O	X	O	O	3	2
E3	O	O	X	O	O	O
E4	O	O	O	X	O	O
E5	O	O	O	O	X	5
E6	O	O	O	O	O	X

Figure 5-4. Matrix Showing Impact of Occurrences

If this event does not occur	Then this would be the factor used to adjust the odds of					
	E1	E2	E3	E4	E5	E6
E1	X	O	-5	O	O	O
E2	O	X	O	O	-2	-1.5
E3	O	O	X	O	O	O
E4	O	O	O	X	O	O
E5	O	O	O	O	X	-2
E6	O	O	O	O	O	X

Figure 5-5. Matrix Showing Impact of Nonoccurrences

is such an event. All of the numbers in column E4 are zeroes in both matrices, showing that E4 is not affected by the occurrence or non-occurrence of any other event. All the numbers in row E4 in both matrices are zeroes, showing that E4 does not affect the probability of any other event. When events such as E4 are identified, they should be removed from the matrix and noted separately, since they are independent of the other events in the matrix.

b.   If the matrix consists of independent groups of events which interact within the group, but not between groups, the matrix should be broken up into submatrices corresponding to these groups. This greatly simplifies the processing, presentation, and interpretation of data about them. In the example given herein, events E1 and E3 are related, and events E2, E5, and E6 are related. These can be split apart as shown in Figures 5-6 and 5-7. A method for splitting the matrices in this manner is given in Appendix A.

Although it seems obvious that simplifying the matrices in this manner should clarify and simplify further work on them, this step has not been mentioned in previous descriptions of the cross-impact procedure.

c.   Within each submatrix, the events that are not affected by any other event should be listed first, then the events which are affected by only one other event, etc.

6.   The median, initial probabilities and cross-impact values are used as inputs to a Monte Carlo computer simulation which uses them to compute revised probabilities. The procedure is explained in Paragraph 5.6. During each Monte Carlo trial run, the events which are not influenced by any other event should be simulated first, then the events which are only influenced by one other event, etc. If several events influence each other's probabilities, their order of simulation should be random.

If this event were to occur	Then this would be the factor used to adjust the odds of		
	E1	E3	
E1	X	3	
E3	O	X	

If this event were to occur	Then this would be the factor used to adjust the odds of		
	E2	E5	E6
E2	X	3	2
E5	O	X	5
E6	O	O	X

Figure 5-6. Simplified Matrices Showing Impact of Occurrences

If this event does not occur	Then this would be the factor used to adjust the odds of	
	E1	E3
E1	X	-5
E3	O	X

If this event does not occur	Then this would be the factor used to adjust the odds of		
	E2	E5	E6
E2	X	-2	-1.5
E5	O	X	-2
E6	O	O	X

Figure 5-7. Simplified Matrices Showing Impact of Nonoccurrences

After the computer makes several hundred or several thousand Monte Carlo trial runs, the percentage of trials during which each event occurred will be printed out. These percentages are the revised estimates of the probabilities. If the participants properly allowed for all the interactions when making their initial estimates of the probabilities of the various events, the revised set should agree fairly closely with the initial set. If there is disagreement between the initial values and the revised values, the cause may be one or more of the following reasons:

a. The revised values may be better estimates than the initial probability values, because the cross-impact effects have been taken into account more fully. There is no experimental evidence at the present time that would support (or refute) this interpretation, however.

b. The cause may be inconsistencies within the cross-impact matrices and between the cross-impact matrices and the data. Even if there are inconsistencies, or perhaps especially if there are inconsistencies, the revised probability estimates may be better than the original estimates. However, it is possible they may be worse. As mentioned above, although the cross-impact method is used, it has never been validated. Validating it is difficult because it is usually used to estimate the probability of occurrence of unique events.

c. Statistical noise inherent in the Monte Carlo process causes some scatter in the results of Monte Carlo simulation. This noise is inversely proportional to the square root of the number of Monte Carlo trials made. Appendix A contains data on the expected magnitude of this effect as a function of the number of trials.

5.9 CROSS-SUPPORT ANALYSIS

The purpose of doing studies is to provide information which leads to decisions and action. One cannot know what decisions to make unless one knows what goals one

is trying to achieve, and the relative importance of different goals. Some goals may be of only moderate importance in themselves, but achievement of these goals may contribute significantly toward the achievement of other goals. Such goals should get more support than goals of equal importance which do not support other goals, or which interfere with the achievement of other goals. Cross-support analysis provides an orderly method of assessing the importance of various goals, considering both their inherent desirability and their interactive effects. The procedure outlined herein is based on Reference 23.

Step 1. The initial step is to list the major goals which are to be achieved. The list may be provided by the organization sponsoring the study, or it may be produced by the participants.

Next, the importance of the individual goals should be assessed based on their relative importance. This is based on the criticality of the goal and the degree of advancement which one hopes to make in the near future. The mechanism for assigning importance is to distribute a total of 100 points among the goals in proportion to their estimated importance. In a study bearing on communications, the goals of communication policy, and their relative importance, might be as shown in Table 5-3.

Table 5-3. Goals of Improved Communications

Improve educational services	15
Provide more employment	15
Increase exports	15
Reduce costs	10
Improve public access to news and information	10
Improve convenience	10
Improve safety, police and emergency services	10
Improve privacy	5
Improve security	5
Provide greater variety of entertainment	5
	100

The judgments on the relative weights of the various goals should be based on their relative desirability, not on factors such as technological costs, capital investments, amount of budget allocated to each goal in previous years, political factors, etc.

Continuing with the analysis, subtargets under each major goal are then identified and weighted in the same manner. The total of the weights of the subtargets under each major goal is constrained to the weight of the major goal, so that the total weights of all subtargets will equal 100 points. For example, the following subtargets might be identified and weighted under the major goal of convenience:

Major goals and subtargets	Major goal weight	Subtarget weights
CONVENIENCE	10	
Availability		3
Portability		2
Reliability		2
Usability by handicapped people		1
Ruggedness		1
Fidelity and clarity		1

Step 2. The major goals and their associated subtargets, together with their respective weights, are transcribed on the left-hand margin of a matrix. Figure 5-8 illustrates an abbreviated version of such a matrix, without any subtargets shown for any of the goals except convenience. The subtarget weights from step 1 are also to be listed under the column headed OW (Original Weight). To facilitate subsequent manipulation of the subtarget-to-subtarget matrix, it is suggested that these be called primary subtargets.

Step 3. The major goals and subtargets and their associated weights are also transcribed across the top of the matrix. It is suggested that these be called complementary subtargets to distinguish them from the primary subtargets in step 2. At the right end of the matrix also provide columns labeled TCS (Total Cross Support), APA

Figure 5-8. Example of Cross-Support Analysis Matrix

(Additional Points Added), OW (Original Weight), NW (New Weight), and NNW (New Normalized Weight).

Step 4. Having constructed the framework of the goal-to-goal cross-support matrix, the next step in the methodology is to determine the degree to which achievement of one subtarget (goal) contributes to the achievement of all others. This is done by considering the effect one subtarget has on each of the others, and then summing these separate contributions to obtain a total. The effect that one subtarget may have can either be beneficial (positive) or detrimental (negative). For example, reducing costs may tend to reduce employment but increase exports.

Each cell of the matrix should be divided by a diagonal line. Above the diagonal line the participant filling in the matrix should enter an H, M, or L, if he thinks the contribution of the primary subtarget to the complementary subtarget is positive and high, medium, or low, respectively. If he thinks the contribution is negligible, he should leave the cell blank. If he thinks the contribution is negative, he should enter -H, -M, or -L.

Numeric values will be associated with these letters as follows:

$$H = 4$$
$$M = 2$$
$$L = 1$$

Multiply the numeric equivalent of the letter in the upper part of the cell by the weight of the complementary subtarget and enter the product in the lower part of the cell. If the upper part of the cell is blank, the lower part should be, also.

Step 5. When the lower part of all applicable cells are complete, sum horizontally and place the total in the column headed Total Cross Support (TCS). Sum up all the entries in the TCS column and place the total at the bottom.

Step 6. Apportion 100 points to the Additional Points Added column, giving each row a number of additional points equal to its percentage of the total TCS score. Add up the APA column. The total should be, of course, 100 points.

The decision to award 100 additional points for cross-support effects, rather than 50 points or some other number, is quite arbitrary. No justification has appeared for it in the literature. It would probably be desirable to let the participants decide on what this number should be, rather than always using 100 points. For example, if only one of the subgoals supported any other, the subgoal doing the supporting would get a normalized new score larger than all other subgoals combined. Such a result would be highly unrealistic. This is admittedly an extreme example, but one which reveals that in situations where there is little cross-support the total points awarded for cross support should be less than 100.

Step 7. On each row, add the entry in the Additional Points Awarded column to the entry in the Original Weight column, and enter the total in the New Weight column. The New Weight column should add up to 200 points.

Step 8. Finally, normalize the weights by dividing each entry in the New Weight column by 2, and entering the result in the Normalized New Weight column. The entries in the NNW column are the revised weights of the various subgoals, allowing for cross-support effects. Add up the values for the subtargets under each goal to get the weight to attach to each goal.

Using the above procedure helps assure that all important goals and subgoals will be considered and their effects assessed. It also preserves a historical record establishing that various conflicting interests were considered and, insofar as possible, weighted according to their importance. Use of this sort of approach also increases the chances that decisions taken in different years will be more consistent than they would be in the absence of such a framework.

As can be seen from Figure 5-8, the new normalized weight produced by the cross-support matrix method can differ substantially from the original weights assigned to the goals. For example, the subgoal of fidelity and clarity was initially assigned a weight of 1 point but the new normalized weight for it was -5.1 points. This occurred because it was felt that any developments which increase fidelity and clarity are likely to have a high negative impact on costs and portability. It is also interesting to note

that the goals of privacy and security both nearly doubled weight from 5 to 8.8 because they strongly support each other.

Of course, the example presented herein is purely hypothetical, and no significance should be attached to the weights assigned or the results obtained. A great deal of judgment must be used in assigning the cross-support factors. For instance, in this example the effect of costs on employment was judged to be negative medium, and the effect of fidelity and clarity on employment was judged positive low. But stereo hi-fi equipment, which costs nearly twice as much as monaural and is less portable, has been selling well, boosting employment.

5.10 THE POTENTIAL AND EVOLVING STATUS OF DELPHI

The Delphi technique was originated relatively recently, in 1948, and did not come into general use until 1964.[34] As mentioned in Paragraph 5.1, it is still evolving in most of its detailed procedures. Nevertheless, it is possible to list its basic assumptions, outline the types of problems in which it is useful, and attempt to evaluate its growth potential.

The basic assumptions of the Delphi method are the following:

1. N heads are better than one. In other words, a group of people will have more ideas, think of a problem from more angles, and usually will do better at estimating partially known factual data, than a single individual of the group would do. There is a subassumption here that the single individual who would be asked the questions if the Delphi method were not used is not outstandingly more informed about the problem than the other members of the group are.

2. Conventional conference techniques for eliciting a group consensus are beset with the following problems:

    a. Many people don't like to abandon a position once they have proclaimed it in public, even if they are later shown evidence which would otherwise make them change their mind.

b. Conferences are often dominated by the views of one vociferous or prestigious individual.

c. Conference discussion often meanders and in some cases never does arrive at a consensus.

d. Committees often fail to make their assumptions and reasoning explicit, since their findings are obtained through bargaining.

e. A conventional conference requires considerable time from the participants, particularly if some of them have to travel a long way to attend.

On the other hand, conferences do provide a flexible mechanism for exchanging and stimulating thoughts and ideas. The Delphi procedure attempts to retain and encourage this, insofar as possible, by permitting participants to explain their reasons if they are not in the center 50 percent, by preserving anonymity with regard to who made which comment, and by feeding back to participants the median and interquartile range from the previous round. The format of the questions deters the participants from going off on tangents and permits them to supply their ideas relatively rapidly and at their own convenience. The Delphi technique also helps individuals in separate fields to establish meaningful constructive cooperation. If all the participants have convenient access to remote computer terminals which are netted together, a Delphi conference can be called on short notice, and can continue for as short or long a time as is appropriate. Furthermore, larger numbers of people can participate at such a Delphi conference than would be practical at a live conference.

Delphi techniques seem to be most useful for the following types of problems:

1. Making numeric estimates of unknown quantities, whether the quantity be the time until some new development is introduced, the probability of a particular project or medical treatment being successful, the probable performance of some new device, or the number of doctors in Baltimore in 1880. The emphasis on numeric estimates arises because the most feasible and effective feedback seems to be the median and interquartile range of the estimates

produced by members of the panel. If estimates are not numeric, or at least rankable, it is difficult or impossible to define the median and the interquartile range. For example, if a group of economists are asked what action the government should take in the economic field at the present time, and each gives an entirely different answer, ranging from price controls to raising taxes to raising interest rates, no median can be defined.

2. Problems of a brainstorming sort. In spite of the impossibility of feeding back median and interquartile information as noted above, a Delphi conference can produce many ideas for possible solutions to a problem. A regular brainstorming conference can do this also, but some types of people may be too inhibited to present their tentative and undeveloped ideas at a conventional conference. The anonymity of the Delphi conference is a help to such people.

3. Problems involving judgment, opinion and goal selection. If the participants are chosen properly, a Delphi exercise can increase the probability that no significant viewpoints or factors are overlooked.

Delphi exercises, when properly managed, have been found to be a highly motivating environment for the respondents. Quoting from Reference 7, "The feedback, if the group of experts involved is mutually self-respecting, can be novel and interesting to all. The use of systematic procedures lends an air of objectivity to the outcomes that may or may not be spurious, but which is at least reassuring... The experience of many practitioners has shown that the results of a Delphi exercise are subject to greater acceptance on the part of the group than are the consensuses arrived at by more direct forms of interaction. All of these features of a Delphi exercise are desirable, especially if the exercise is conducted in the context of policy formulation where group acceptance is an important consideration."

Reference 35 sums up the potential and evolving status of Delphi even better:

"Further experimental work is needed. This includes using the Delphi technique in conjunction with in-depth interviews, structured conferences, and operational gaming... But, imperfect as it is, the Delphi process or some further modification appears to be one of the most promising approaches under development for the investigation of problems with a high social and political content. Because it can be used to allocate resources rationally and to force explicit thinking about the measurement of benefits, it offers a hope of introducing cost-effectiveness thinking into these problems."

SECTION 6 - EXAMPLES OF DELPHI METHOD APPLICATIONS

This section presents four examples of application of the Delphi method. They have been selected to illustrate the flexibility of Delphi and types of results which may be achieved. The Japanese scientific and technological survey,[16] in particular, included a number of communication items, many of which are indicative of communications developments that also may be expected to occur in the United States. These communication items are included to provide additional basis for selection of subject areas of inquiry which may be undertaken in a NASA Delphi forecast of telecommunications developments. The example from Quade and Boucher[36] contrasts simple and more complex Delphi applications and serves to clarify the principles of the Delphi technique. The University of Michigan Sea Grant inquiry[33] critically evaluated Delphi techniques in an operational application to long-range research and planning efforts for water resources management. The Sea Grant Delphi is a progressive study with a number of innovative adaptations worthy of consideration in further Delphi applications. The TRW Probe II Delphi study[13] illustrates industry belief in and commitment to Delphi as an aid in R&D planning and long-range forecasting to help management improve its decisionmaking processes by providing immediate information on probable and significant future trends.

6.1 JAPAN TECHNO-ECONOMICS SOCIETY PUBLICATION

6.1.1 Introduction

In 1971 Japan's Science and Technology Agency made public the results of a forecast survey on scientific and technological developments in the 30 years up to 2000 A.D. This survey used Delphi techniques involving 4000 experts on 620 development subjects. The report of the survey, published by the Japan Techno-Economics Society, was entitled "Science and Technology Development up to 2000 A.D."

A basis for the study was the assumption that science and technology will lead the way in establishing the future society and economy of Japan. Prior to the actual survey, a general study group formulated subject areas, questioning methods, format

of results, etc., with the assistance of five sectional groups, covering the areas: social development, information, medical care and health, food and agriculture, industry and resources. The forecast sought to probe future social and economic needs, the technology to meet such needs, and attendant technological consequences. A number of guiding principles were adopted for the survey by recognition that:

1. Changes in social and economic needs (values) impact technological forecasting.

2. A comprehensive national view of all science and technology fields must be taken.

3. Both normative and exploratory approaches must be adopted.

4. Emphasis must be placed on identification of tasks of prime urgency, i.e., priorities must be established by evaluation of the relative importance of the various developments.

6.1.2 Planning the Survey

A 30-year period for the survey was selected as a balance between allowing a sufficient interval to take account of discontinuous technological changes or "breakthroughs" and yet not extending over so long a period that foreseeing changes in needs due to changes in people's concept of values would be of exceeding difficulty. Since the field of science and technology is so broad, adequate handling could be assured only by dividing the field into the five areas mentioned in the previous paragraph. In selecting a technique for forecasting, the projected scope of the effort in subject matter, the considerable period of 30 years, a primary desire to evaluate the urgency of individual tasks, and the wide range of persons in scientific and technical development - all led to a decision to use the Delphi method. To meet the purpose of the survey, conventional Delphi techniques were applied for forecasting the time of realization, i.e., the expected date of event occurrence. Modified Delphi techniques were used to evaluate the relative importance of individual subjects addressed.

6.1.3 Conduct of the Delphi Survey

6.1.3.1 Selection of Experts

The number and type of experts selected for participation in the survey were guided by the following factors:

1. Approximately 4,000 experts were estimated for coverage of the various fields taking into account the expected recovery rate, i.e., based on past experience a number of experts contacted would not respond for one reason or another.

2. Individuals with cultural as well as natural scientific background should be selected from the industrial, academic, government, and other sectors.

3. Future-oriented individuals should be chosen.

4. Some participants should be selected from persons having broad experience and outlook with the expectation that their judgments would reflect a broad viewpoint.

A preliminary inquiry was addressed to candidates, taking care to choose an appropriate number in the various fields. Candidates were selected from a group made up of individuals recommended by government agencies, academic societies and associations, those individuals publishing forecasts in recent literature, and various persons in private organizations and information institutes expected to have specialized knowledge. In selecting the all-around group, preference was given to those individuals frequently mentioned by academic societies or listed in magazines. Respondents to the preliminary inquiry, the well established Japanese scientific and technical community, were requested to nominate members of the younger generation who were qualified for technological forecasting; this latter group was included as questionnaire addressees.

6.1.3.2 Setting Up Development Subjects

The first questionnaire of the survey was a set of "hypotheses" to which the addressees were asked to respond by exploring subjects. The first questionnaire was sent to generalists and was intended as a step for identifying anticipated future socioeconomic needs and exploring subjects in respect to these needs. Anticipating that needs in the next 10 years would likely be distinct from those 10 to 30 years from now, the forecast period was divided accordingly. The 1500 addressees were asked to evaluate the relative importance of given hypotheses as well as to nominate additional development subjects, if possible, with respect thereto. Approximately 650 subjects were set up by the five sectional groups on the basis of the results of the general study group's formulation of socioeconomic needs. The second and third questionnaires were for investigating the relative importance and the time of realization of the subjects set up by the foregoing procedure. These questionnaires were sent out to the original 1500 plus about 2500 specialists including researchers and engineers. Responses to the first questionnaire were sent out with the second questionnaire as reference data. The second questionnaire had columns for degree of specialization, evaluation of relative importance, time of realization, reason for nonrealization, and a comment. Since it is unreasonable to assume that all addressees would be familiar with all subjects, the specialization column was provided to determine the degree of specialization by the following code:

1. Mark "h" (high) if you were formerly or are now engaged in research or job related to the subject.

2. Mark "m" (medium) if you read books or other material related to the subject and have specialized knowledge.

3. Mark "l" (low) if you only read about the matter in newspapers or general magazines or have heard about it but have not much specialized knowledge.

The columns for inquiring about the importance of realization of the subject was contingent upon social, economic factors, and other conditions, assigning one of the following marks:

1. "h" - very important

2. "m" - important

3. "l" - not important or unnecessary.

The columns for time of realization were five-year periods up to the year 2000 with two additional columns labelled "Unrealizable until 2000" and "Unpredictable."

The columns for reason for nonrealization offered four choices, namely, Technically Impossible, Social Restrictions, Economic Restrictions, and Other. In the third questionnaire these columns were replaced by a number of choices entitled "Government measure," since the subjects were chosen from the government's standpoint. These latter columns solicited opinion about government policy to realize the particular development subject.

The column labels were:

1. Financing researches

2. Training research personnel

3. Coordinating researches

4. Other.

The meanings of these government measures are explained in the next paragraph.

6.1.3.3 Responses to Questionnaires

About 74 percent of the 2414 addressees of the first questionnaire made valid responses. About 74 percent of the 4100 addressees of the second questionnaire made valid responses. About 78 percent of the 3108 addressees of the third questionnaire made valid responses. A tabular summary of responses to second and third

6-5

questionnaires is given in Table 6-1 for communication subjects, which were selected out of the total response in all areas. To the right of the subject column, the respective columns are explained as follows:

1. <u>Poll Number</u>. The data for the second questionnaire is shown on top, and that for the third questionnaire on the bottom.

2. <u>Respondents</u>. The total number of valid respondents for each subject is given.

3. <u>Importance</u>. The distribution in percentage of the importance ratings by the valid respondents is given.

4. <u>Realizable/Unrealizable</u>. The proportion (percent) of those forecasting realization by 2000 A.D. versus proportion (percent) of those forecasting nonrealization before 2000 A.D.

5. <u>Time of Realization</u>. Graphic representation of inner quartile range of respondents on second poll by outline figure and on third poll by hash-marked figure; the peak of the figure indicates the median time. The distribution with regard to individuals with "h" specialization mark on the third poll are indicated by a straight line with a tiny circle; the circle marks the median and the extremities of the line the interquartile range.

6. <u>Reason for Nonrealization (Second Poll)</u>. The proportion of reasons for nonrealization in percentages of all respondents excluding those giving no specific realization time. The reasons are coded as follows:

   A: Technically impossible (unrealizable before 2000 A.D., because of the many technical difficulties involved)

   B: Social restrictions (technically possible but unrealizable before 2000 A.D. because of ethical, moral, social, or institutional restrictions)

   C: Economic restrictions (technically possible but unrealizable before 2000 A.D. *because the product, process, etc., cannot economically*

Table 6-1. Communication Items in Japan's Science and Technology Survey

Subject	Poll No.	Respondents	Importance (%) h	m	l	Realizable (%)	Unrealizable (%)	Time of Realization	Reason for Nonrealization (%)				Govt. Measure (%)				
Establishment of an information transmission system from office to home and vice versa, following the development of TV telephone and telex, and establishment of enterprises permitting those personnel engaged in general electrical routine work to work at home.	2	138	18	45	37	69	31		A 0	B 21	C 4	D 7	A 23	B 2	C 29	D 9	E 40
	3	108	6	60	34	85	15										
Commercialization of an information transmitter system that makes it possible to purchase goods while staying at home, owing to the development of TV telephone and telex.	2	137	14	47	39	87	13		A 0	B 4	C 7	D 3	A 28	B 4	C 22	D 11	E 39
	3	107	7	59	35	97	3										
Commercialization of house sales by means of video signal apparatus such as TV telephone.	2	129	5	28	67	81	19		A 0	B 9	C 3	D 7	A 18	B 2	C 21	D 16	E 46
	3	103	1	13	86	98	2										
Development of a facsimile transmission machine for family use and its utilization by about 10% of households.	2	110	28	49	23	92	8		A 0	B 0	C 6	D 2	A 29	B 4	C 14	D 12	E 41
	3	92	12	70	19	99	1										
Development of an instruction simulator that enables one to learn within an hour the rules of a game one wants to play.	2	100	5	24	71	76	24		A 5	B 4	C 3	D 13	A 8	B 7	C 10	D 28	E 47
	3	88	3	17	80	91	9										
Spread of an information transmission system on highways by the inductive radio method.	2	99	52	42	6	98	2		A 0	B 1	C 0	D 0	A 37	B 6	C 25	D 1	E 34
	3	85	72	25	4	100	0										

Time of Realization scale: 1975 1980 1985 1990 1995 2000

Table 6-1. Communication Items in Japan's Science and Technology Survey (Continued)

Subject	Poll No.	Respondents	Importance (%) h	Importance (%) m	Importance (%) l	Realizable (%)	Unrealizable (%)	Time of Realization	Reason for Nonrealization (%) A	B	C	D	Govt. Measure (%) A	B	C	D	E
Development of pattern recognition techniques which can recognize artificial, complicated patterns (e.g., any kind of drawings) at a speed comparable to that of man.	2	423	63	34	3	85	15		12	0	1	2	35	19	22	3	28
	3	323	81	18	1	94	6										
Development of pattern recognition techniques which can recognize natural patterns (natural figures such as human faces) at a speed comparable to that of man.	2	420	51	46	3	87	13		11	0	1	1	30	20	19	3	32
	3	319	62	35	3	90	10										
Development of pattern recognition techniques which can identify individuals by means of voice patterns ("voice-prints").	2	414	39	52	9	92	8		7	0	0	1	34	16	16	3	33
	3	323	30	65	5	96	4										
Development of techniques for detecting smells and tastes (kinds, qualities, etc.).	2	386	21	44	35	73	27		23	0	0	4	16	21	16	10	39
	3	305	11	55	34	71	29										
Techniques for translating foreign documents (in English) into Japanese.	2	423	58	37	5	91	9		8	0	2	0	35	16	20	2	32
	3	319	80	18	2	96	4										
Development of automatic simultaneous-translation machines which can handle standard business conversations (Japanese-English).	2	413	51	42	7	67	33		27	0	2	4	27	19	21	4	33
	3	312	66	29	5	72	28										

Table 6-1. Communication Items in Japan's Science and Technology Survey (Continued)

Subject	Poll No.	Respondents	Importance (%) h	Importance (%) m	Importance (%) l	Realizable (%)	Unrealizable (%)	Time of Realization	Reason for Nonrealization (%)	Govt. Measure (%)
Commercialization of computers using bubble-domain elements for their memory units.	2	336	28	58	14	95	5		A 3	A 30
	3	284	15	76	9	99	1		B 0	B 15
									C 2	C 16
									D 1	D 3
										E 39
Development of computers capable of association processing.	2	385	46	45	9	89	11		A 8	A 23
	3	310	49	48	3	94	6		B 0	B 20
									C 1	C 17
									D 3	D 3
										E 36
Development of computers having a learning function.	2	400	53	39	8	92	8		A 6	A 29
	3	314	73	25	2	96	4		B 0	B 21
									C 0	C 18
									D 1	D 3
										E 32
Development of computers capable of adaptive processing.	2	374	48	44	8	92	8		A 7	A 27
	3	305	60	38	2	97	3		B 0	B 22
									C 0	C 16
									D 1	D 3
										E 35
Development of computers having self-repair capabilities.	2	387	49	42	9	87	13		A 9	A 27
	3	306	67	31	2	96	4		B 0	B 21
									C 1	C 18
									D 3	D 3
										E 35
Commercialization of modular computers in which internal memory units can be increased or decreased easily if users adopt any optional plug-in unit system.	2	386	35	51	14	97	3		A 1	A 35
	3	307	24	70	6	100	0		B 0	B 6
									C 1	C 13
									D 1	D 6
										E 43

Time of Realization scale: 1975 1980 1985 1990 1995 2000

Table 6-1. Communication Items in Japan's Science and Technology Survey (Continued)

Subject	Poll No.	Respondents	Importance (%) h	Importance (%) m	Importance (%) l	Realizable (%)	Unrealizable (%)	Time of Realization	Reason for Nonrealization (%)	Govt. Measure (%)
Realization of a system in which data banks of various statistics will be established at public organizations, and individuals will be allowed to retrieve information freely at any time.	2	384	35	55	10	91	9		A 0 / B 5 / C 3 / D 1	A 33 / B 6 / C 24 / D 6 / E 34
	3	312	23	72	5	98	2			
Practical use of information retrieval systems utilizing holography.	2	347	23	64	13	95	5		A 3 / B 0 / C 1 / D 1	A 32 / B 10 / C 19 / D 4 / E 37
	3	275	11	83	6	98	2			
Artificial arms having sensitivity and motive ability nearly equal to those of human limbs.	2	366	44	48	8	86	14		A 7 / B 6 / C 4 / D 4	A 33 / B 20 / C 16 / D 3 / E 33
	3	295	40	58	2	96	4			
An international TV network will be formed by coupling cable television to a broadcasting satellite.	2	–	–	–	–	–	–		A – / B – / C – / D –	A 31 / B 2 / C 29 / D 6 / E 36
	3	288	36	56	8	97	3			
All communication channels (transit trunks) will be digitized.	2	–	–	–	–	–	–		A – / B – / C – / D –	A 35 / B 4 / C 23 / D 7 / E 36
	3	272	35	55	10	90	10			
International data exchange will be carried out quickly as a result of direct access to overseas data banks.	2	–	–	–	–	–	–		A – / B – / C – / D –	A 21 / B 3 / C 33 / D 11 / E 35
	3	296	37	57	6	96	4			

Time of Realization scale: 1975 1980 1985 1990 1995 2000

Table 6-1. Communication Items in Japan's Science and Technology Survey (Continued)
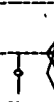
Subject	Poll No.	Respondents	Importance (%) h	Importance (%) m	Importance (%) l	Realizable (%)	Unrealizable (%)	Time of Realization	Reason for Nonrealization (%)	Govt. Measure (%)
Establishment of a nation-wide digital exchange network (integrated digital network).	2	366	61	34	5	95	5	(chart)	A 0, B 1, C 0, D 1	A 43, B 3, C 21, D 4, E 33
	3	303	81	16	3	99	1			
Commercialization of filters to be used for optical (laser) communication.	2	301	28	58	14	97	3	(chart)	A 1, B 0, C 1, D 0	A 35, B 11, C 14, D 5, E 35
	3	257	18	75	7	100	0			
Commercialization of equipment which can automatically produce summaries and excerpts of books and data (their outputs will be able to be given at any contraction ratios upon request).	2	389	38	51	11	69	33	(chart)	A 28, B 1, C 2, D 3	A 22, B 16, C 20, D 7, E 38
	3	304	26	67	7	74	26			
The storage and retrieval of and access to documents will be come as inexpensive and easy as the Xerox copying system. (Development of low-cost memory media and low-cost input/output equipment).	2	384	49	46	5	92	8	(chart)	A 3, B 0, C 4, D 1	A 40, B 8, C 15, D 4, E 37
	3	314	63	36	1	98	2			
Realization of unattended libraries. (The entire collection of books will be stored in video tape and in microfilm form. The visitor will be able to freely retrieve information using a personal peripheral device, and the information required by him will be displayed on the screen.)	2	396	32	53	15	86	14	(chart)	A 2, B 2, C 10, D 3	A 36, B 4, C 23, D 5, E 36
	3	312	23	70	7	96	4			
Establishment of patent data banks, which allow automatic (to a certain extent) retrieval of patent information with the help of a complete thesaurus.	2	367	41	52	7	97	3	(chart)	A 2, B 0, C 0, D 1	A 33, B 7, C 27, D 4, E 33
	3	285	34	63	3	98	2			

Time of Realization axis: 1975 1980 1985 1990 1995 2000

Subject	Poll No.	Respondents	Importance (%) h	Importance (%) m	Importance (%) l	Realizable (%)	Unrealizable (%)	Time of Realization (1975–2000)	Reason for Nonrealization (%)	Govt. Measure (%)
Development of techniques for direct-coupling of human brains with computers (for instance, a mutual input/output technique which will make it possible to feed the activities taking place inside the brain directly to a computer as input.	2	371	28	37	35	32	68	(graphic)	A 53, B 0, C 1, D 9	A 8, B 27, C 14, D 14, E 41
	3	304	15	45	40	24	76	(graphic)		
Development of computers having input functions similar to human sensory functions (excluding the senses of taste and smell).	2	369	29	43	28	48	52	(graphic)	A 39, B 2, C 2, D 9	A 9, B 24, C 13, D 14, E 42
	3	304	12	58	30	37	63	(graphic)		
Users will be able to give instructions to computers using a programming language (in characters) similar to a natural language in daily use.	2	406	55	39	6	85	15	(graphic)	A 9, B 1, C 2, D 3	A 25, B 20, C 20, D 2, E 37
	3	328	82	13	5	96	4	(graphic)		
The greater part of the software up to universal-use systems will be incorporated into the hardware—("Firmware")—.	2	399	57	37	6	93	7	(graphic)	A 2, B 0, C 2, D 3	A 40, B 12, C 12, D 3, E 35
	3	310	73	24	3	98	2	(graphic)		
Programming by voice input will facilitate computerization.	2	401	51	42	7	88	12	(graphic)	A 8, B 0, C 2, D 3	A 29, B 19, C 18, D 4, E 34
	3	323	64	31	5	95	5	(graphic)		
Programs will be fed directly to computers as input; e.g., flow charts will be fed directly to the computer without being encoded.	2	389	50	43	7	94	6	(graphic)	A 3, B 0, C 1, D 2	A 30, B 20, C 13, D 3, E 37
	3	314	74	24	2	99	1	(graphic)		

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Table 6-1. Communication Items in Japan's Science and Technology Survey (Continued)

Subject	Poll No.	Respondents	Importance h	m	l	Realizable (%)	Unrealizable (%)	Reason for Nonrealization (%)	Govt. Measure (%)
With simple feeding of the problem itself into a computer instead of preparation of software, the computer will be able to process data automatically.	2	384	50	41	9	72	28	A 22, B 0, C 2, D 5	A 18, B 25, C 14, D 5, E 39
	3	312	68	28	4	74	26		
Computers will be able to make algebraic calculations freely (formula calculations) as well as numerical value calculations.	2	370	39	51	10	95	5	A 3, B 0, C 1, D 2	A 24, B 19, C 14, D 6, E 38
	3	304	26	70	4	98	2		
Use of compilers for further compiling of compilers.	2	341	44	48	8	98	2	A 1, B 0, C 0, D 0	A 29, B 17, C 16, D 4, E 37
	3	281	33	66	1	100	0		
Display units showing three-dimensional images (the image can be seen in depth if it is looked at slightly sideways) will be put into actual use by means of the laser projection system.	2	380	22	62	16	95	5	A 2, B 0, C 2, D 1	A 34, B 10, C 14, D 5, E 38
	3	303	16	76	8	99	1		
Commercialization of display units of the plasma cell type, EL-element type and liquid-crystal cell type as display units for information systems.	2	344	30	58	12	98	2	A 1, B 0, C 0, D 1	A 39, B 8, C 15, D 5, E 36
	3	284	18	78	4	99	1		
Commercialization of portable TV-telephones which can transmit and receive images like those on the present television screen, by the radio system utilizing the bandwidth contraction technique.	2	371	20	55	25	88	12	A 4, B 1, C 5, D 2	A 34, B 7, C 13, D 10, E 37
	3	298	.10	74	16	97	3		

(Table includes a "Time of Realization" graphical column spanning 1975, 1980, 1985, 1990, 1995, 2000.)

Table 6-1. Communication Items in Japan's Science and Technology Survey (Continued)

Subject	Poll No.	Respondents	Importance (%) h	Importance (%) m	Importance (%) l	Realizable (%)	Unrealizable (%)	Time of Realization	Reason for Nonrealization (%)	Govt. Measure (%)
Japanese-made stationary satellites for domestic communication purposes will be launched into space.	2	390	40	44	16	94	6		A 0, B 1, C 4, D 1	A 40, B 2, C 23, D 4, E 35
	3	318	33	58	9	99	1			
Communication between man and animals (e.g. porpoises) will become possible.	2	355	11	26	63	57	43		A 34, B 2, C 1, D 6	A 6, B 23, C 10, D 19, E 44
	3	289	5	14	81	50	50			
Long-distance submarine communication with large capacity and at a high speed (higher than sonic or ultrasonic waves) similar to land communication using electromagnetic waves will become possible.	2	357	36	47	17	60	40		A 35, B 0, C 2, D 3	A 18, B 15, C 24, D 9, E 38
	3	288	25	65	10	65	35			
Development of active communication channels (having the same functions as the nerve functions of man)--where information will not be attenuated and satisfactory signal-noise ratio will be maintained.	2	358	39	47	14	72	28		A 20, B 0, C 4, D 6	A 14, B 25, C 19, D 7, E 39
	3	286	27	66	7	83	17			
Commercialization of the space-division laser multiplex communication system.	2	342	37	53	10	95	5		A 2, B 1, C 2, D 0	A 43, B 3, C 19, D 4, E 33
	3	271	24	71	5	100	0			
Practical use of communication methods utilizing gravitational waves.	2	295	18	35	47	38	62		A 49, B 0, C 6, D 8	A 6, B 20, C 12, D 16, E 47
	3	249	8	29	63	33	67			

Table 6-1. Communication Items in Japan's Science and Technology Survey (Continued)

Subject	Poll No.	Respondents	Importance (%) h	Importance (%) m	Importance (%) l	Realizable (%)	Unrealizable (%)	Time of Realization	Reason for Nonrealization (%)	Govt. Measure (%)
Establishment of systems for reflecting the will of the people regarding State administration by making it possible to collect from wide areas (e.g., by using push-buttons), and to analyze, arrange and utilize the opinions of the inhabitants as the data for State administration.	2	466	45	41	14	68	32		A 3, B 21, C 3, D 6	A 15, B 7, C 27, D 13, E 40
	3	402	31	50	19	78	22			
Standardization and computerization of most judgment work such as granting approvals and licenses.	2	481	28	56	16	90	10		A 2, B 7, C 0, D 2	A 26, B 7, C 28, D 9, E 33
	3	403	19	71	10	98	2			
Creation of data banks for technology (to be operated by the State) for the benefit of specialists. (These banks will store systematic and easily retrievable information on technical details and drawings.)	2	490	54	41	5	94	6		A 1, B 2, C 2, D 1	A 41, B 8, C 26, D 3, E 29
	3	405	70	27	3	99	1			
The majority of homes throughout the world will use home mini-computers and home data-processing peripheral devices using telephone lines, for performing domestic work (including burglary prevention).	2	465	8	42	50	71	29		A 1, B 5, C 18, D 6	A 24, B 4, C 15, D 15, E 44
	3	407	4	40	56	84	16			
Use of TV-telephone and Telefax on a wide scale will make it possible to do office work at home.	2	479	15	49	36	85	15		A 2, B 9, C 4, D 3	A 21, B 5, C 16, D 15, E 44
	3	403	6	61	33	95	5			
The "CAI" technique using a computer will progress and the "CAI" service equipped with a program enabling students to master simple English conversation will be widely employed.	2	490	32	54	14	98	2		A 1, B 0, C 0, D 0	A 33, B 12, C 15, D 8, E 6
	3	408	19	72	9	99	1			

Table 6-1. Communication Items in Japan's Science and Technology Survey (Continued)

Subject	Poll No.	Respondents	Importance (%) h	Importance (%) m	Importance (%) l	Realizable (%)	Unrealizable (%)	Time of Realization	Reason for Nonrealization (%)	Cont. Measure (%)
Commercialization of a fully automatic control system for speed and starting, stopping and emergency adjustment of rail vehicles following the adoption of an automatic closing system.	2	138	47	44	9	95	5		A 0 / B 1 / C 3 / D 1	A 44 / B 6 / C 17 / D 5 / E 28
	3	126	57	41	2	99	1			
Realization of full automation of landing and take-off of regular planes in any weather.	2	139	63	33	4	95	5		A 3 / B 1 / C 0 / D 0	A 37 / B 6 / C 30 / D 3 / E 31
	3	127	80	20	1	99	1			
Realization of a traffic control system with collective arrangement of area control, control by traffic lights, etc., which covers all the districts of a large city with about 1,000,000 inhabitants.	2	144	63	32	6	90	10		A 1 / B 0 / C 7 / D 2	A 29 / B 9 / C 38 / D 3 / E 29
	3	132	77	21	2	99	1			
As information transmission systems employing TV telephone, telex, etc., develop, the ratio between home study and study at school in college education will become 1 to 1.	2	121	22	47	31	64	36		A 4 / B 13 / C 8 / D 14	A 20 / B 6 / C 32 / D 8 / E 39
	3	109	13	66	21	86	14			
Offering of information through a television service network will spread and about one half of expenditure on cultural matters in each household will be used for this purpose.	2	115	18	48	34	76	24		A 1 / B 2 / C 7 / D 14	A 15 / B 6 / C 27 / D 9 / E 44
	3	106	4	62	34	89	11			
Reservation systems for transportation facilities and hotels (hotels located in major cities and main recreation resorts) will be connected on a world-wide basis; and a world-wide real time system for hotel and transportation reservations will be established.	2	499	14	59	27	95	5		A 0 / B 2 / C 2 / D 1	A 18 / B 5 / C 21 / D 17 / E 43
	3	402	6	69	25	99	1			

Table 6-1. Communication Items in Japan's Science and Technology Survey (Continued)

Subject	Poll No.	Respondents	Importance (%) h	Importance (%) m	Importance (%) l	Realizable (%)	Unrealizable (%)	Time of Realization (1975–2000)	Reason for Noncentralization (%) A	B	C	D	Govt. Measure (%) A	B	C	D	E
Wide-scale automation of diagnosis, including clinical investigation, case-history control and automatic questionnaire diagnosis, will be adopted with the introduction of computers.	2	483	55	41	4	99	1	(graph)	0	0	0	1	40	11	20	4	33
	3	403	77	22	1	99	1	(graph)	1	9	3	3	31	6	30	6	33
Establishment of medical data-banks for centralized control of case-history cards kept by all hospitals and doctors in respective regions (e.g., prefectures).	2	470	46	44	10	85	15	(graph)	13	1	1	3	19	18	24	5	38
	3	401	56	41	3	98	2	(graph)									
Development of automatic information-sorting techniques to sort out needed items from a flood of information by automatic comparing, weighing and selecting of information, and by judging according to the purpose of utilization of the possessor of the information.	2	468	52	41	7	82	18	(graph)	2	1	4	1	38	11	35	2	25
	3	400	76	21	3	96	4	(graph)									
A synchronous astronomical satellite will be launched and thereby astronomical observation from space will become possible.	2	192	37	50	13	94	6	(graph)	2	1	4	1	48	8	21	1	27
	3	159	23	70	6	98	2	(graph)									
Realization of broadcasting by a direct broadcasting satellite.	2	183	68	33	9	98	2	(graph)	0	0	2	0	49	11	17	1	28
	3	159	77	17	6	99	1	(graph)									
Development of a laser for space communications.	2	190	56	37	7	99	1	(graph)	1	0	1	0					
	3	156	73	24	3	100	0	(graph)									

Table 6-1. Communication Items in Japan's Science and Technology Survey (Continued)

Subject	Poll No.	Respondents	Importance h (%)	Importance m (%)	Importance l (%)	Realizable (%)	Unrealizable (%)	Reason for Nonrealization (%) A/B/C/D	Govt. Measure (%) A/B/C/D/E
Development of techniques for high-density data storage at the molecular level (functioning like DNA and RNA).	2	365	52	38	10	71	29	24 / 0 / 6 / 5	20 / 25 / 20 / 6 / 33
	3	283	70	27	3	68	32		
Development of highly-durable memory elements which can withstand magnetic interference, electrical trouble and fire and are not subject to accidental erasure of information.	2	390	52	35	13	72	28	21 / 0 / 6 / 2	25 / 14 / 21 / 6 / 36
	3	296	76	19	5	80	20		
Commercialization of highly-sensitive (sensitivity equal or superior to that of films) optical memory elements which are freely erasable and re-usable.	2	406	51	45	4	94	6	5 / 0 / 1 / 0	25 / 14 / 17 / 2 / 35
	3	290	66	30	4	98	2		
Commercialization of large-capacity and cheap (similar to magnetic tapes and discs) data films requiring no mechanical access and allowing access at a higher speed than those requiring mechanical access.	2	399	67	30	3	96	4	4 / 0 / 0 / 0	43 / 11 / 17 / 1 / 32
	3	318	88	11	1	99	1		
Commercialization of light memory utilizing laser holography to greatly increase the memory capacity required for information retrieval.	2	386	49	46	5	97	3	2 / 0 / 1 / 0	41 / 9 / 15 / 1 / 35
	3	303	59	38	3	99	1		
Commercialization of a large-capacity random-access memory which could store, for example, the entire collection of books in the National Diet Library.	2	386	51	41	8	84	16	7 / 1 / 7 / 1	43 / 7 / 15 / 2 / 35
	3	320	66	31	3	96	4		

Time of Realization scale: 1975, 1980, 1985, 1990, 1995, 2000

Table 6-1. Communication Items in Japan's Science and Technology Survey (Continued)

Subject	Poll No.	Respondents	Importance (%) h	m	l	Realizable (%)	Unrealizable (%)	Time of Realization	Reason for Nonrealization (%)	Govt. Measure (%)
Commercialization of a pocket signalling bell by means of a movable communications satellite.	2	160	11	37	52	79	21		A 4 / B 3 / C 10 / D 6	A 25 / B 9 / C 17 / D 15 / E 38
	3	138	3	24	73	95	5			
Agricultural, marine and mineral resources observations will be made by means of artificial satellites.	2	178	49	40	1	94	6		A 3 / B 0 / C 1 / D 1	A 38 / B 12 / C 30 / D 1 / E 26
	3	157	63	31	6	99	1			
Realization of a worldwide meteorological observation system by means of an artificial satellite.	2	195	82	17	1	100	0		A 0 / B 0 / C 0 / D 0	A 42 / B 11 / C 30 / D 1 / E 25
	3	162	93	7	0	100	0			
Realization of a worldwide aviation control system by means of an artificial satellite.	2	187	71	24	5	100	0		A 0 / B 0 / C 0 / D 0	A 36 / B 9 / C 37 / D 1 / E 26
	3	159	90	9	1	100	0			
Commercialization of letter readers which can read clearly hand-written manu-scripts containing Chinese hieroglyphic characters and the two Japanese alphabets. (These machines will have a reading error ratio of less than 1% and will be able to read "educational" Chinese characters which are of the standard lettering style and have about 15 strokes per character.)	2	431	60	35	5	91	9		A 5 / B 2 / C 2 / D 2	A 38 / B 16 / C 20 / D 2 / E 28
	3	329	82	16	2	97	3			
Commercialization of voice input equipment which can accommodate input data containing not only numerals but also several hundred Japanese words. (These machines will be put into use only with specially trained persons who speak with clear and correct pronunciation.)	2	426	56	28	6	93	7		A 6 / B 0 / C 1 / D 1	A 39 / B 17 / C 17 / D 2 / E 30
	3	328	76	20	4	99	1			

Time of Realization axis: 1975 1980 1985 1990 1995 2000

compete with other similar processes, etc., or because little market potential is seen)

D: Other (unrealizable before 2000 A.D. for some other reason).

7. <u>Government Measures (Third Poll).</u> The proportion of the most urgent government measures on science and technology in percentages of the total of valid respondents to a particular subject. The measures are coded as follows:

A: Financing researches (sufficient funds including special tax concessions are needed to carry forward research and development in order to realize the development)

B: Training research personnel (to realize the development, more research and development manpower must be supplied by training programs)

C: Coordinating researches (to realize the development, there must be organic collaboration among research institutes and researchers and also, the organization for research and development should be improved)

D: Other (some other measure is required)

E No entry or "unnecessary" (those responses indicating the "Other" column and a comment to the effect that no government measure is necessary at all).

6.2 TWO EXAMPLES CLARIFYING DELPHI TECHNIQUE

In Systems Analysis and Policy Planning: Applications in Defense by E. S. Quade and W. I. Boucher, two examples of Delphi procedure are presented. The first example illustrates a simple application followed in seeking an answer to a narrow question, e.g., estimating a noncomplex quantity. The second example describes the procedure when a much broader question is asked, e.g., selecting a policy. The two examples serve to clarify the principles of the Delphi technique. They are quoted in the following two paragraphs.

6.2.1 Example 1. Choosing a Number by Delphi

Consider the common situation of having to arrive at an answer to the question of how large a particular number N should be. (For example, N might be the estimated cost of a measure, or a value representing its overall benefit.) We would then proceed as follows: First, we would ask each expert independently to give an estimate of N, and then arrange the responses in order of magnitude, and determine the quartiles, Q_1, M, Q_3, so that the four intervals formed on the N-line by these three points each contained one quarter of the estimates. If we had 11 participants, the N-line might look like this:

$$N_1 \quad N_2 \quad N_3 \quad N_4 \quad N_5 \quad N_6 \quad N_7 \quad N_8 \quad N_9 \quad N_{10} \quad N_{11}$$
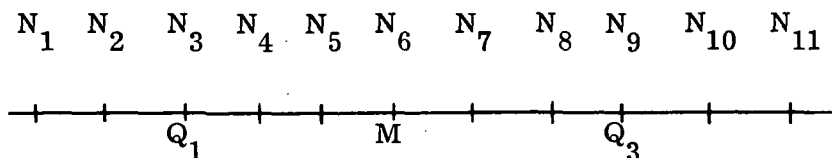
$$\overline{++\underset{Q_1}{+}++\underset{M}{+}++\underset{Q_3}{+}++}$$

Second, we would communicate the values of Q_1, M, Q_3 to each respondent, ask him to reconsider his previous estimate, and, if his estimate (old or revised) lies outside the interquartile range (Q_1, Q_3), to state briefly the reason why, in his opinion, the answer should be lower (or higher) than the 75 percent majority opinion expressed in the first round. Third, we would communicate the results of this second round (which as a rule will be less dispersed than the first) to the respondents in summary form, including the new quartiles and median. In addition, we would document the reasons that the experts gave in Round 2 for raising or lowering the values. (As collated and edited, these reasons would, of course, preserve the anonymity

of the respondents.) We would then ask the experts to consider the new estimates and the arguments offered for them, giving them the weight they think they deserve, and in light of this new information, to revise their previous estimates. Again, if the revised estimate fell outside the second round's interquartile range, we would ask the respondent to state briefly why he found unconvincing the argument that might have drawn his estimate toward the median. Finally, in a fourth round, we would submit both the quartiles of the third distribution of responses and the counterarguments elicited in Round 3 to the respondents, and encourage them to make one last revision of their estimates. The median of these Round 4 responses could then be taken as representing the group position as to what N should be.

6.2.2 Example 2. Policy Advice from Delphi

The Delphi technique can also be applied to broad policy problems. For example, let us consider how it might be used to uncover and evaluate measures that might help to speed recovery of a nation after a thermonuclear war.

There are a number of reasons why an approach to this problem via the development of a mathematical model or a computer simulation might not be the most desirable way to proceed. ·If we had in mind six or eight fairly well defined and promising alternative postwar measures, we might consider adding a 'recovery' model to one of the many models that have been constructed to compute the damage caused by a nuclear attack. Assuming this could be done, the alternatives could then be compared in the traditional way used for comparing alternative force structures, employing a range of different war initiation scenarios and undertaking sensitivity analyses of the uncertain parameters.

But the concept of 'recovery' is not very well defined. Very few of the many measures that might aid the survival of a nation or an area after a thermonuclear attack have been studied extensively. The emphasis so far has fallen primarily on measures such as shelters and active defense, which seek to reduce the immediate effects of the attack, rather than on measures to speed recovery after the initial effects of an attack have been experienced. Almost everyone has ideas about recovery

measures of this type that might be helpful, but seldom any well developed notion of their relative effectiveness and cost. Thus, there is a need to survey these ideas—to create an atmosphere in which they may be brought forth, subjected to critical review, modified and ordered according to various criteria with respect to their possible effectiveness, acceptability, and costs, including social costs. The Delphi technique is well suited to this task.

In addition to the presence of so many ill-defined alternatives, and the difficulties with the notion of recovery, there are a number of other reasons why an approach to the problem that puts emphasis on informed judgment is desirable. The decision-makers who would use the study would clearly be in the best position to judge the acceptability of measures that might either require radical changes in the prewar way of life or imply such changes for the postwar period—for example, how far to violate the rights of privacy or favor one sector of the economy or country over another if nuclear war were to come. But, their decisions would necessarily be based on many lowly but important relationships that require the intuition and judgment of specialists. Determining objectives—what we want to accomplish in the way of recovery and how we might distinguish one type of postwar world from another—must also be the responsibility of the decisionmaker. But how to attain these objectives would require contributions from many disciplines.

The alternative provided by the Delphi technique is to give up for the moment any attempt to compute the state of the postwar environment at various times after hostilities have ceased and instead to try simply to rank alternative prewar policies on the basis of the qualities that promise, in the judgment of specialists, to contribute the most to postwar recovery. This procedure cannot demonstrate beyond all reasonable doubt that a particular course of action is best. At most, it can assess some of the implications of choosing certain alternatives over others. But the systematic searching out and partial ordering of promising steps could be extremely valuable.

We should be under no illusion that for this problem a Delphi procedure would be the easiest thing in the world to carry out. In order to persuade the proper people to

authorize or to participate in such a study, the following points would have to be brought to their attention. One, the effort would not be intended as a substitute for other research. Two, if nothing else, it would highlight areas needing detailed study and in general, stimulate further work. Three, ideas provided in the course of the study--because of their possible half-baked character--would be kept anonymous unless attribution was specifically authorized. And four, the entire effort, in terms of man-power, could be kept quite minor, even though as much as 10 months might be needed to complete the study, since getting responses to questionnaires is just slow business.*

Since the kind of survey being proposed is not a statistical survey of the Gallup type, but an attempt to generate ideas and to use the respondents to trace out the relationships among these ideas and the consequences of their adoption, it is im-material whether the respondents form a representative sample of the initially known points of view. What matters is that the viewpoints of persons with all major relevant backgrounds have a chance of being voiced.

Assuming that our study would involve a range of experts both within and out-side the organization conducting it, the respondents might be organized into several "units," so that the administrative task of running the experiment could be kept sim-ple. Each unit might consist of a central committee of three plus a panel of 6 to 12 respondents. The committee chairman would be the person responsible for organiz-ing his unit's activity, for maintaining liaison with the project director, and for trans-mitting the responses of his unit. One or more units might be located within the organization carrying out the study and the other units at some of the various places

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*Incidentally, there exists an Act of Congress (5 U.S.C. Sec. 139, c-e [1942]) that forbids a government agency to conduct or to sponsor a study in which identically worded questionnaires are circulated to more than nine respondents without prior permission of the Bureau of the Budget. Since the intent of the Act is to keep businessmen from being bothered with a continuous stream of government forms-- not to hamper scientific investigation--users of the Delphi technique whose support comes from government funds should not have difficulty obtaining such permission. Of course, one could confine the respondents (except for at most nine outsiders) to the research organization (this includes consultants) or the sponsoring agency.

where there is a concentration of respondents. Alternatively, the respondents might be dealt with directly or split into functional groups or disciplines such as ecology, economic growth, and so on.

The inquiry itself could be broken down into four to six successive rounds, each based on a suitably formulated questionnaire. Only round one would necessarily involve all respondents.

The first questionnaire would contain, in addition to the questions themselves, a brief background statement explaining the purpose of the study. It would include a statement that responses will be handled anonymously, except that approval for the use of names may eventually be asked in case certain suggestions are deemed worthy of being recommended for further action. Only the members of the steering committee would initially be cognizant of the authorship of ideas. In the statement, suggestions would be included about keeping the proposals in practical operational terms and avoiding generalities. The respondents would be urged to include all suggestions that they think should be examined, even though they might be dubious about advocating them.

The following sample questionnaire incorporates a number of these suggestions. Since it is addressed more to the readers of this book than to potential respondents, considerable reworking would be required before it could actually be used.

<center>Questionnaire 1</center>

This questionnaire is being submitted to you in an effort to elicit fresh ideas on what steps should be taken to reduce the problem of postattack recovery after a thermonuclear exchange. We are not looking for measures that reduce the manner of weapons impacting (ABM, for example) or measures that reduce their efficiency (such as shelters). Primarily we are looking for ways to help restore agriculture and manufacturing and the structure of society and government. An earlier study has suggested that the measures we are seeking to identify and weigh fall into three classes: preventive, which would aim at reducing the damage to our resources, such

<center>6-25</center>

as food stocks and water and power sources; emergency, which would attempt to deal with the distribution and management of supplies to sustain the population after the war; and long run, which would deal with recovery proper. Regardless of your feelings about the probability of nuclear war and the futility of such actions--in themselves or in contrast to the results we might obtain if we contributed equal resources to deterrence--ask yourself what measures should be considered.

This effort is being conducted very much in the spirit of a brainstorming session, except that it sets out to collect ideas in written form rather than through the give-and-take of open debate. At this stage, therefore, it would be entirely in order for you to submit ideas even if you yourself consider them half-baked, or if you merely regard them as worthy of further exploration without wishing to endorse them, or if they would only gain full meaning within an adequately elaborated context. Remember that this survey is in no way intended as a substitute for other research; indeed, its chief virtue might be to highlight areas needing detailed study and, in general, to stimulate further work.

Question A. If you were a close advisor to the President, what actions would you advise him to consider taking (including recommendation of legislation to Congress) that might speed recovery after a thermonuclear attack?

The following considerations--the list is by no means complete--seem relevant to this question. You may wish to delete or modify some items or add others. They are offered only to spark thought, and are listed randomly to avoid prejudging the order of importance or the feasibility of any measures.

    1. Since the control of infectious diseases could be a serious problem in the disrupted postattack environment, should current public health policies be reviewed for possible changes that would improve their effectiveness in a postattack situation? What policies? What changes?

2. A number of studies indicate that fires, both urban and wildland, as well as their sequelae of floods, erosion, and additional fire hazards, could be serious long-term problems in the postattack environment. Is there a need to review current fire prevention and control practices for possible changes and innovations that could improve our postattack capabilities to cope with these problems? What changes might be made? It has been suggested, for example, that we might undertake controlled burning prewar and also create appropriate firebreaks to prevent wildland fires from encroaching on contiguous urban areas or to keep urban fires from spreading to the countryside. We might also consider some steps to provide for reseeding burned areas post-attack to reduce erosion and flooding.

3. How serious a problem would it be to find feasible alternatives for post-attack land uses that would be keyed to postattack requirements for food and other agricultural products? For example, what other crops could be grown on land too heavily contaminated with fallout to grow food, or what food crops could be grown on land not heavily con-taminated but now used to grow non-food products?

4. What priorities should be observed in restoration of facilities post-attack?

5. Should differential protection be provided for different segments of the population?

6. Is organizational damage likely to be a serious problem in the post-attack environment?

Question B. What research should be undertaken by the scientific and technical community that might either lead to or accelerate the discovery of measures that would help speed postwar recovery?

Again, here are a few possibilities that you may wish to consider in your response.

1. Develop models. It might, for example, be important to build a flexible modular fallout model, or a model of the ignition and spread of urban fire and its impact on population in the fire area, including the protection afforded by available shelters against heat and carbon monoxide poisoning. A model of wildland fire that would relate ignition and spread to plant cover, season of year, weather, geographical region, and the nature of the nuclear attack might also be useful, as would models of a disrupted economy, since current models all seem to assume an organized society.

2. Perform further research. Research in atmospheric physics, for example, might give us a way to estimate the effects of nuclear exchanges on weather and climate. Similarly, research might be undertaken on ecological disturbance or on the long-term genetic effects of radiation on man. (Both of these problems have already been studied in some detail, but much ignorance remains.)

3. Develop technologies for food storage and synthesis.

4. Develop contingency plans for priorities in resource allocation by age, sector of the economy, or some other standard.

Once the responses to this first questionnaire are received, the next, and hardest, step would be for the steering committee to sort and collate them, clarifying their meaning through checks with the respondents if necessary, eliminating obviously nonoperational suggestions, doing some minor editing and, hopefully, generating useful additions to the list.

The list of proposals thus produced might then be submitted either directly to the original respondents or, as an intermediate step to obtain further refinement, to the "unit" committees. The result of this review might be the elimination of, say,

two-thirds of the proposals as being less promising. The remainder would then be

annotated by the steering committee with brief arguments pro and con; they might also

be ranked by merit according to some consensus formula.

Because the wording of every questionnaire except the first depends on the outcome

of preceding rounds, we can at best indicate only the form the remaining question-

naires might take. The second might look something like this:

Questionnaire 2

The tabulation given below contains a list of tentative proposals to speed post-

war recovery. We would like you to give us your judgment of each item in terms of

its desirability, feasibility, and potential importance (assuming feasibility).

For each item, check one box under Columns A, B, and C. In making this

evaluation, consider the intrinsic rather than relative merits of the proposal.

	A DESIRABILITY					B FEASIBILITY					C IMPORTANCE			
NO PROPOSAL	DESIRABLE	MILDLY DESIRABLE	DOUBTFUL	MILDLY UNDESIRABLE	UNDESIRABLE	DEFINITELY FEASIBLE	POSSIBLY FEASIBLE	DOUBTFUL	POSSIBLY INFEASIBLE	DEFINITELY INFEASIBLE	VERY IMPORTANT	IMPORTANT	SLIGHTLY IMPORTANT	UNIMPORTANT
1 ESTABLISH CONTINGENCY PLANS FOR PRIORITIES IN ALLOCATING RESOURCES														
2. MODIFY CURRENT PUBLIC HEALTH POLICIES TO IN- CREASE THE POSSIBILITY OF CONTROLLING INFEC- TIOUS DISEASES AFTER NUCLEAR ATTACK														

This questionnaire would, of course, be accompanied by written arguments, pro and con, for each proposal listed.

If the results of this appraisal indicate that an item ranks no higher than 'doubtful' in any category, it would be eliminated from further consideration.

For the remaining items, some of which would obviously be controversial in one or more aspects, more exacting standards of acceptability would need to be set. The next questionnaire would explore the reasons for any divergence of opinions; it might take this form:

Questionnaire 3

The following items out of the list previously submitted to you have been eliminated for the reasons checked:

Item	Description	Reason for Elimination Undesirable	Infeasible	Unimportant
1	.. .. ..	X		
3	.. .. ..		X	
4	.. .. ..	X		X
–				
–				
–				

The following items have been accepted as being desirable, feasible, and important.

Item	Description
11	.. .. ..
17	.. .. ..
—	
—	
—	

The remaining items are controversial in one or more respects. In those cases where a check mark is circled, your previously expressed opinion was at variance with the opinions of several of the other respondents. For each, please indicate very briefly why you hold this particular opinion. (For example, if, in Item 6, a check mark in the Desirability column is circled, please explain why you gave Item 6 the desirability rating you did in response to Questionnaire 2.) Alternatively, if on reconsideration you do not feel strongly enough about your previously expressed opinion to defend it, please indicate this by stating a revised rating.

| Item | Description | Controversial as to | | | Reason Previous Rating or Revised Rating |
		Desirability	Feasibility	Importance	
2	.. .. ..				
5	.. .. ..				
6	.. .. ..				
-					
-					
-					

If the replies to this questionnaire continue to move toward a consensus on some of the proposals, or if for some reason the apparently irreconcilable differences of opinion seem inadequately documented, one or more additional questionnaires may be worthwhile. In form, these would resemble Questionnaire 3.

What might the final result tell us that we did not already know or could not obtain from less unconventional types of analysis? The answer can be very brief. Many aspects of the postattack recovery problem cannot be handled by standard cost effectiveness techniques. For example, how can one assess the effect on the arms race of a prewar measure such as the storage of materials for the recovery period? Our example suggests that the Delphi technique offers, at the very least, a way to approach such questions.

6.3 UNIVERSITY OF MICHIGAN SEA GRANT INQUIRY

6.3.1 Introduction

The Sea Grant Program provided an excellent opportunity for critical evaluation of Delphi Techniques in an operational environment. The principal challenge was representing a wide range of opinion systematically in putting together the vital parts of long-range research and planning effort for water resource management. The associated Delphi exercises were designed to support Sea Grant goals of encouraging the involvement of university people in a concern for comprehensive management of the water resources of the Great Lakes, the integration of their informed judgments, and the communication of these judgments to citizens who are faced with decisions that will affect their region's social and economic development for many years to come.

For the Sea Grant exercises, informed judgments were solicited in lieu of expert opinion. Consequently, a rationale existed for inclusion of politicians and concerned citizens on the panels and making the most of passing along pertinent information during the questioning process. Further, the concept of consensus was shifted from an emphasis on unanimity and a meeting of the minds to a measure of collective judgment.

6.3.2 Overall Plan of Delphi Effort

Three groups of panel members were formed for the Delphi exercise in the Sea Grant Program. The first group was technicians knowledgeable in water resource management. The second group was behaviorists, who in academic background and interests were oriented toward the social sciences. The third group was decision-makers, who were persons from the Grand Traverse Bay area believed to be influential in that political process through which decisions on regional planning are made. The function of the three groups was considered to be reasonably consistent with the actual roles anticipated for such groups in deliberations and actions associated with planning for future regional development.

A progressive type of Delphi was planned, building from specific issues toward final group recommendations and research priorities. Previous Delphi exercises had been characterized by listing of technical events and requesting judgments thereon. Here, the Delphi effort was designed to identify potential technical, social, and political developments or to accomplish specific objectives. Special attention was given to the communication aspect of the method so that information could be most effectively transmitted to the decisionmakers.

Broader-based panels were formed among the three groups to assure interchange of information useful in regional planning.

In the phase dealing with potential technical, social, and political developments, each of three panels were planned to have four rounds of questionnaires. The first round asked panel members for suggestions and estimates regarding future events affecting marine resources in the Grand Traverse Bay area in the next 20 years; also, they were to evaluate several items according to statements on an evaluation matrix in order to familiarize themselves with numerical estimates that would be requested on subsequent rounds. On round two the discrete items identified in round one plus some additions were to be considered. Self-evaluation estimates were to be requested. For each item estimates were made of relative importance, economic and technical feasibility, and probability and timing associated with developments with which panelists had some familiarity. Further, on this round, panel members were to suggest related developments and requisite technology. On the third round items were screened and those that were unimportant, that lacked panel member insight thereon, or that had ambiguous specification were to be dropped from further consideration. Progressive feedback of information, including statistical summaries were to be provided from previous rounds. In the final round the technicians were to make additional probability estimates for pairs of events that panel members had suggested were closely related, considering whether or not occurrence or nonoccurrence of one event would affect the outcome of a following event.

In order to provide a point of reference in making other subjective judgments panel members were to project trend curves of statistical values that ordinarily are used to measure socioeconomic growth of a region. The technical panel would be requested to produce supporting studies on pollution sources and recommendations regarding waste water treatment and disposal systems for use by broader-based panels.

6.3.3 Methodological Modifications

In carrying out the Sea Grant Delphi exercise, certain significant modifications and refinements in methodology were developed. In particular, panelists indicated that emphasis should be given to:

- Safeguards against a manipulated consensus
- Scaling of words and phrases
- Aids to personal probability assessments
- Relationships among forecasted developments.

Safeguards were taken by coding each suggestion by panel member number and associating basic biographical information, by retaining all pertinent comments with minimum editing, by carrying over estimates from a previous round if respondent missed a round, by full information feedback, and by specific request of supporting arguments from those respondents whose estimates for the previous round were outside of the consensus range. (To the extent that other panelists were influenced by these arguments, the consensus would tend to broaden rather than narrow.) Unfortunately, the biographical data compromised the anonymity of some panel members. On the other hand biographical data gave weight to suggestions and comments and assured panelists that they were in a peer group.

The scaling of words and phrases were considered critical in the Delphi method for obtaining and communicating subjective judgments. It was found that panelists had wide variance in their viewpoints of verbal phrases corresponding to commonly used numerical probabilities. In the opening round of the Sea Grant Delphi, the

participants were asked to make such associations. The substantive results were that many words are inappropriate for use with the Delphi method and that excessively refined probability estimates cannot be achieved due to inconsistencies of meaning among panelists. Among all the words or phrases considered, those corresponding closely to the commonly used probabilities of 10, 25, 50, 75, and 90 percent are shown in Table 6-2. A Delphi procedure was used to determine whether feedback and reassessment would result in greater agreement on numerical probabilities associated with several expressions. It was found that the dispersion of estimates narrowed while only slightly changing the measures of central tendency.

A guide for making personal estimates of probability was sent to all members of the broad panels. It was believed that many panelists had little experience with assessment and interpretation of personal probabilities; it was believed they would have problems in making consistent assessments. The results of the research on scaling words and phrases gave strong empirical evidence that there are specific words and phrases denoting the likelihood of a future event which multidisciplinary groups associate with numerical values closely corresponding to the probabilities of 10, 25, 50, 75, and 90 percent. A remarkable degree of agreement was obtained between Sea Grant researchers and decisionmakers.

In investigating the relationships among forecasted developments, the Sea Grant administrator used the expertise of the panel members and inherent Delphi techniques in lieu of cross-impact analysis. Several procedures were employed to encourage respondents to assess intuitively the relationships among future developments under considerations:

- Correlation of different points of view of multidisciplinary groups.

- Preview by technical experts of issues particularly vulnerable to technological advances.

- Identification by panelists of closely related developments.

- Concurrent assessment of related issues and developments.

Table 6-2. Words or Phrases Corresponding Closely to
Commonly Used Numerical Probabilities

Commonly Used Numerical Probability (Percentage)	Word or Phrase	Mean	Median	Standard Deviation
10	Very unlikely	.129	.100	.086
	Improbable	.135	.100	.088
25	Rather unlikely	.241	.250	.085
	1-to-3 odds	.258	.250	.051
50	Toss up	.500	.500	.000
75	Good chance	.712	.750	.099
	3-to-1 odds	.735	.750	.065
	Quite likely	.767	.750	.102
90	Highly probable	.833	.900	.065

- Request for conditional probability estimates by panelist of "paired" developments.

Most panelists altered their final estimates on those developments subjected to conditional probability assessments, indicating that relationships had not previously been fully considered. With the strong emphasis on relationship among events throughout the Delphi exercise, any movement in the final estimates as a result of the consideration of specific conditioning effects was believed to be significant. One of these groups of developments and the evaluation matrix is shown in Figure 6-1. The events for this particular series of interrogations will be referred to either as dependent events or as conditioning events. Any single event may be placed in either category as the interactions among pairs of events are sequentially considered.

A sample of an individual response is shown in Table 6-3. The summary includes the respondent's evaluation of his competence to judge the development--using a scale ranging from 1 (unfamiliar) to 5 (expert or researcher in the area), his initial estimate of the probability of the development occurring in 1971-80, his third round estimate, his final estimate, and his conditional estimates. The technique of systematically obtaining and analyzing conditional probability estimates proved particularly valuable for:

- Encouraging respondents to reexamine their estimates in view of related developments.

- Assessing extent of panelists' intuitive relationship of anticipated developments.

- Identifying the influence of conditioning events and the uncertainty associated with their effect.

- Assessing the impact of alternative strategies that will most effectively influence the outcome of important developments.

- Providing a mechanism, in combination with self-evaluation and confidence-indexes, for weighing individual estimates.

Round 4
Panel Member 12

Developments and Events that Respondents Have Suggested Are Interrelated	Probability 1971-80	50% Probability Date	Panel T-1
D-32 Requirement by the state, calling for tertiary treatment of municipal sewage for Traverse City			
Your Previous Estimates	80	1977	
Panel Estimates, Round 3	75 (50-85)*	1977 (1975-80)	
Those Who Rated Competence ≥ 3	83 (62-95)	1978 (1975-80)	
Your Next Estimates for D-32			
D-39 Full-scale operation somewhere in the U.S. of physiochemical system for waste water treatment applied directly to primary waste, which is economically competitive with 1970-designed facilities using activated sludge secondary treatments--with chemical precipitation for phosphate removal			
Your Previous Estimates	50	1975	
Panel Estimates, Round 3	55 (30-85)	1979 (1975-80)	
Those Who Rated Competence ≥ 3	75 (20-90)	1979 (1979-80)	
Your Next Estimates for D-39			
D-31 Construction of a spray irrigation system for waste water disposal in the Grand Traverse Bay region			
Your Previous Estimates	50	1980	
Panel Estimates, Round 3	50 (50-50)	1980 (1980-90)	
Those Who Rated Competence ≥ 3	50 (15-50)	1980 (1978-80)	
Your Next Estimates for D-31			
If you were certain that D-32 would occur before 1980, your estimates for D-31 would be			
If you were certain that D-32 would not occur in 1971-80, your estimates for D-31 would be			
If you were certain that D-39 would occur before 1980, your estimates for D-31 would be			
If you were certain that D-39 would not occur in 1971-80, your estimates for D-31 would be			

*Interquartile Range

Figure 6-1. Interrelated Developments, Group 3

Table 6-3. Conditional Probability Estimates of Individual Respondent

Devel. No.	Self-Evalua-tion	Initial Estimate	3rd Round Estimate	Final Estimate						
					P (38|80)	P (38|$\overline{80}$)	P (45|38)	P (45|$\overline{38}$)	Comp P (33)*	Comp P (45)
80	3	20	20	25	100	80	10	0	85	8
38	4	60	60	80						
45	3	10	10	10						
					P (84|20)	P (84|$\overline{00}$)	P (7|84)	P (7|$\overline{84}$)	Comp P (84)	Comp P (7)
20	3	25	25	35	75	75	100	75	75	94
84	4	75	75	75						
7	3	50	50	50						
					P (31|32)	P (31|$\overline{32}$)	P (31|39)	P (31|$\overline{39}$)	Comp P1 (31)	Comp P2 (31)
32	3	80	80	75	100	100	50	100	100	63
39	3	50	50	75						
31	3	50	50	100						

*Computed probability of the dependent event using the formula $P(A) = P(B)P(A/B) + P(\overline{B})P(A/\overline{B})$.

- Determining some of the respondents' assumptions regarding overall social, political, and technical environments when making specific judgments.

6.3.4 Evaluation of the Sea Grant Delphi Exercise

The conduct of this exercise went closely according to plan. The panelists were interested in improving Delphi techniques to integrate the judgments of a multi-disciplinary research team and to convey informed insights to society. In the second round of questionnaires the panelists were asked to provide estimates on 75 discrete items identified in round one. The several estimates on each item compounded the work effort of the panelists to the point where they complained that estimates took too much time and became tedious. In the third round a special questionnaire form was sent to technicians soliciting their views on the positive and negative aspects of Delphi and appropriate areas for further application. In fact, this was a Delphi procedure. The results indicated that the Sea Grant Delphi exercise corresponded rather closely to the panelists concept of an ideal treatment.

Additional evaluations showed that among the participants the techniques were more highly regarded by groups formed on the basis of broad ranges in training and experience than by technicians--the group most administrators of the Delphi technique have focused on. Evaluation results also supported tailoring the method to groups on the basis of their background, training, and experience.

6.4 TRW PROBE II DELPHI STUDY

Modified versions of the Delphi techniques, called Probe I and Probe II, were developed by Harper A. North and Donald L. Pyke for internal use by the Thompson-Ramo-Wooldridge Corporation (TRW). This proprietary program has been discussed in various aspects in at least three different articles and Bright and Agers books on technological forecasting - all of which are cited in the bibliography. TRW has applied these Delphi approaches to collect, from its large and diverse staff, new ideas for products and product areas. The Delphi procedure has proved useful as a means of communication among division technologists, division executives, and corporate managers; it has served to integrate corporate goals and objectives with technologically

feasible capabilities. The Delphi supplemented trend extrapolation in TRW's technological forecasting to aid R&D planning. Such a technically based company must examine the face of the existing technological explosion and estimate the pace with which their industry must cope during the years ahead. For TRW purposes long-range forecasting was defined as the prediction of likely inventions, specific scientific refinements, or discoveries in technology, including new applications, or products which may become possible. Scope of forecasts were limited to events likely to have a more or less direct impact on the company. TRW approaches technological forecasts, because all these forecasts serve the same final purpose - namely, to help management improve its decisionmaking processes by providing immediate information on probable and significant future trends.

6.4.1 Probe I

TRW's first Delphi study, called Probe I, was completed in June 1966. The basic approach taken was patterned after Helmer and Gordon's, "Report on a Long-Range Forecasting Study."[2] Generally, this initial effort was a test of the feasibility of using a Delphi method in an industrial environment. Twenty-seven senior technical experts from different divisions and departments were polled directly, individually and anonymously. They were asked to anticipate major technical "events" occurring in the period 1966 to 1985 that would have major potential impact on TRW. A list of 401 events, sorted into 15 categories were compiled. These items were more the extrapolation of the current technology rather than speculative long-range events. A review of R&D activities during the latter half of 1966 revealed that Probe I had been a useful checklist and a vision-extending exercise for the panelists and others, but that no real evidence existed that it had been used directly in R&D planning. The principal benefit the company received was a great deal of publicity concerning its foresight. However, the results of Probe I were sufficiently provocative to indicate both significant threats to one part of TRW's business as well as major opportunities to other groups. It was decided, therefore, to undertake a major in-house study of these areas, adding a rather elaborate second stage to the original survey.

6.4.2 Probe II

Probe II was launched late in 1967 and completed by December 1970. The 15 categories of events determined in Probe I were refined to focus more closely on the current interests. Probe II followed a revised procedure taking advantages of lessons learned in Probe I.

1. The second version assumed a socioeconomic environment, essentially TRW's 1975 long-range corporate business plan, whereas, in Probe I panelists made own assumptions.

2. Subject matter was restricted to 15 specific areas.

3. The number of participants was expanded. Each operating division was represented if possible by an expert in each of 15 categories in which the division held an interest. This led to the selection of 140 experts. Figure 6-2 lists the categories and indicates the applicable divisions interest as well as presence of expert opinion in those divisions.

4. More penetrating questions concerning events were sought in lieu of the limited inquiry in Probe I asking for only the most probable date of occurrence.

In round one of the questioning each panel member was asked to list probable technical events by category and make three separable evaluations as follows:

● Desirability (needed desparately; desirable; undesirable but possible).

● Feasibility (highly feasible; likely; unlikely but possible).

● Timing (year by which probability of occurrence exceeds 10 percent; 50 percent; 90 percent).

Desirability was to be considered from the viewpoint of the customer, i.e., as reflecting an estimate of demand.

Feasibility was to be considered from the viewpoint of the producer, reflecting both technical possibility and difficulty in development.

	Automotive								Electronics						Equipment							Systems					
Probe II Categories	Michigan Division	Marlin-Rockwell Division	Ross Gear Division	Valve Division	Replacement Division	Thompson Products, Ltd.	Staff	Ramsey Corporation	Electronic Components Division	Semiconductors Inc.	Capacitor Division	United Transformer Company Division	Electro Insulation	Globe Industries Division	Equipment Laboratories	Accessories Division	Jet & Ordnance Division	Metals Division	Magna Corporation	Mark 46 Program Office	Staff	Electronic Systems Division	Power Systems Division	Space Vehicles Division	Systems Engineering & Integrating Division	Systems Laboratories	Instruments Division
Technologies																											
Electronics & electro-optics							X		X	X	X	X			X	X		X				X		X		X	X
Materials (including coatings, fuels & lubricants)		X		X				X	X	X	X	X	X	X	X	X	X	X	X	X			X			X	
Mechanics & hydraulics	X	X	X		X	X	X	X	X						X	X							X	X		X	X
Power sources, conversion & conditioning		X		X		X	X		X	X		X		X	X	X				X		X	X	X			X
Information processing							X		X												X	X		X		X	
Instrumentation & control		X							X						X	X	X		X	X		X	X			X	X
Manufacturing processes	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Systems & Subsystems																											
Plant automation — production & business	X	X	X	X	X	X	X	X	X	X	X	X		X							X	X				X	
Transportation	X	X	X	X	X	X	X	X	X	X					X	X					X	X	X		X	X	
Defense & weapons (exclude missiles)		X	X				X		X	X					X	X	X	X			X	X	X	X	X	X	X
Aerospace (include missiles)		X				X			X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X
Oceans									X	X					X			X	X	X		X	X	X		X	X
Personal & medical									X	X				X							X	X				X	X
Urban & international									X		X										X	X				X	X
Environmental control	X	X					X		X					X	X							X	X	X		X	X

Key "X" indicates the presence of expert opinion in a division for each category.

Figure 6-2. Probe II Categories and Divisions' Interests

<u>Timing</u> was to reflect an estimate of the date by which there is reasonable chance that the event may have occurred (p = .1), the date by which the event is almost certain to have occurred (p = .9), and the estimated date by which there is a 50/50 chance that the event will have occurred (p = .5).

Round one produced 2100 predictions. Four critical editings, to eliminate duplicate and trivial or irrelevant items, reduced the list to 1438. In the course of editing, statements were modified to improve clarity and avoid distortions of intent and meaning.

In the second round each panel member received a composite list of the edited predictions contributed by his panel plus those from other panels related to his category. The panelists were asked to evaluate all events with respect to the same three factors considered in round one. Estimates made by the originator of an item were not included; each panelist was on his own. Each expert was specifically asked to make sure that his evaluations and estimates were consistent with each other, especially with regard to expected date of occurrence. Printing of round two questionnaires and processing of the responses was accomplished by computer. The computer was an essential tool because the 1438 events considered by varying numbers of the 140 panelists involved 22,000 judgments, each containing seven bits of information. Moreover, the subsequent sampling of data by individuals seeking specific information would be exceedingly difficult without computerization. Figure 6-3 shows a sample question from a round two questionnaire with hand-written responses. Note that each panel member is assigned a code number (here, 304) by which he may be identified, if necessary.

The number 201030 references the event statement to a particular source document. The numbers 01, 02, 04, and 09 indicate that this event was evaluated by the panels on Electronics, Materials, Power-conditioning, and Transportation. The responses indicate that the evaluator considers that:

- He is a specialist in a number of relevant technologies
- The occurrence of the event will be demanded by a significant segment of the public

PROBE CATEGORY: +9   TRANSPORTATION   PANEL MEMBER 304

EVENT NUMBER	EVENT DESCRIPTION	PANELS EVALUATING	FAMILIARITY	DESIRABILITY	FEASIBILITY	PROBABILITY OF EVENT	DATES
201030	ELECTRIC AUTOMOBILES USING FUEL CELL POWER OR FUEL CELL/BATTERY COMBINATION WILL BE MARKETED COMMERCIALLY.	01.02.04.09	1. FAIR 2. GOOD 3. EXCELLENT	1. NEEDED 2. DESIRABLE 3. UNDESIRABLE	1. SIMPLE 2. POSSIBLE 3. UNLIKELY	0.7	1. '79 2. '85 3. '90

Figure 6-3. Sample of a Round Two Questionnaire

● Substantial technical effort will be required

● The probability is .7 that the event will occur

● Assuming that the event will occur, he expects it to occur during the period between 1979 (.1 date) and 1990 (.9 date), with the most probable date (.5 date) being 1985.

In the informal third round TRW resolved any wide differences of opinion concerning events with estimated dates of occurrences falling outside of the median range (.1-.9) by discussing the predictions individually with the panelist involved. At the end of this round each event, on a statistical average, was evaluated by approximately 40 experts representing three or more different panels. Figure 6-4 shows how the event of Figure 6-3 may appear in its final published form (with a fictitious evaluation).

EVENT DESCRIPTION	DESIR-ABILITY $\bar{D}$	FEASI-BILITY $\bar{F}$	PROB-ABILITY $\bar{P}$	PROBABILITY DATES 1970	1975	1980	1985	1990	1995	2000 AND BEYOND .1	.5	.9
ELECTRIC AUTOMOBILES USING FUEL CELL POWER OR FUEL CELL/BATTERY COMBINATION WILL BE MARKETED COMMERCIALLY	+.7	+.4	.8									

Figure 6-4. Sample of Event in Final Published Form

The composite evaluation by all panelists questioned on the electric automobile indicate that:

1. On a scale ranging from +1. 0 (desirable) to -1. 0 (undesirable), the numerical average of evaluation of desirability is +0. 7.

2. On a scale ranging from +1. 0 (simple) to -1. 0 (unlikely), the numerical average of the evaluations of feasibility is +0. 4.

3. The numerical average of estimates of the probability that the event will occur sometime is 0. 8.

4. If the event does occur, the most likely date for it to happen is 1984 (the median 0. 5 date); the period of expectancy range from 1977 (the median 0. 1 date) to 1987 (the median 0. 9 date).

Hindsight suggests still other improvements to Probe II. TRW assumed, and with good reason, that engineers can forecast markets for radically new products. This assumption was based on the belief (still held) that the vendor's engineers and the customer's engineers make a better working team for speculating about the need for radically new products than do the vendor's salesmen and the customer's buyers. TRW plans in future Probes to include perceptive market managers and even sociologists to introduce more market-oriented factors and thus provide a better overview of the environment of the future. Another possible variation, which has been considered, is the submission of questions from operating managers to the Probe computerized data bank and, in addition, to the current panelists via the existing computer program.

SECTION 7 - UTILIZATION OF DELPHI-OBTAINED DATA

Harold A. Linstone[18] states that forecasting is only one of the first steps in planning; what one does with a forecast is important, and planning is what one does with it. After outlining major weaknesses of present-day forecasts, Linstone provides a checklist of what constitutes a good forecast, as follows:

- Does it provide useful planning insights?

- Does it combine extrapolative and goal-oriented methods in a feedback mode?

- Does it deal specifically with uncertainty?

- Does it deal with the total system? (In lieu of parameters.)

- How holistic an image does it present? (i. e., an image presented so well that a manager can place himself in the situation and find it meaningful in a way that can never be achieved with numbers and curves alone.)

- Can the forecast be replicated by other means? (i. e., can the forecast be reproduced using different techniques and personnel?)

- To what extent can the forecast be validated?

- How suitable is the forecasting team? (i. e., as diverse a group of thinkers as possible.)

Identification of telecommunications needs and priorities alone is not enough; the likelihood of occurrence of these developments as a function of time must also be determined (customary in Delphi studies). It must be recognized that the likelihood of occurrence of any one event typically depends upon the occurrence or nonoccurrence of other future events which precede the event in question (see Paragraph 5. 8 and Appendix A on cross-impact and contingency analyses). A determination of needs is a normative approach to forecasting rather than exploratory. The normative approach focuses on future goals and values (needs). One must then move from the future to the

present and ask how do we get there. This latter question is exploratory. Hence, for a forecast to be meaningful, it is vital that the normative and exploratory approaches be linked.

A Delphi statement of long-term communications needs and priorities is not an absolute, definitive assertion of what the future will be, but rather a probabilistic statement about the future with expressed confidence level. This may be useful to NASA in setting realistic and correct organizational goals. Also, such a forecast serves NASA management by stimulating awareness of what the future may hold in store sufficiently early for appropriate action to be initiated. Of course, to a very marked degree, the future will be what we (the present generation) make it. One cannot describe all the possible futures. It must be borne in mind that whatever statement of communications needs and priorities is made does not constitute that exhaustive enumeration of possible "states of the world" which is called for by decision theory. A decision theory model, although neat and intellectually elegant, may be a useful first approximation, but may be misleading in that the chances are very great that the "state of the world" that does materialize will be one which was not perceived in advance. Further, both the optimal strategy and the strategy finally chosen are likely to be different from those which were arrayed in the payoff matrix.

It is presumed that a NASA R and D manager will face a decision on the Delphi statement of needs and be held accountable for end results (i. e. , his guidance and definition of a path of progress toward fixed goals). In the chain of decisionmaking, experts must appear somewhere, distinct from the Delphi expert inputs on communications needs and priorities; there is no substitute for expert knowledge of the subject matter. Before initiating a NASA Delphi study of telecommunications needs and priorities, it would be well to anticipate the decision process at the end and include questions leading to some quantifiable measures of decision criteria (scientific values) by some subpanel of qualified experts or a separate panel of policy-making experts as used in the Sea Grant Delphi Study (see Paragraph 6. 3). It is not necessary nor recommended that the decision itself be delegated to outsiders, whose

professional interests may be partially involved and therefore susceptible to bias. If Delphi study results are simply circulated without specific advance measures for incorporation in the planning cycle, it may turn out that the Delphi report is viewed with idle curiosity or as a checklist, very much like what happened after TRW's Probe I Study (see Paragraph 6.4).

The data obtained from Delphi methods may be insufficient to make a rational decision concerning future events. Most decisions are made with some model in mind but are usually combinations of qualitative and quantitative judgments. A hybrid decisionmaking system attack on problems is considered superior to others since it brings into play intuitive and analytical approaches which support each other. Such a system is shown below in Figure 7-1. [37]
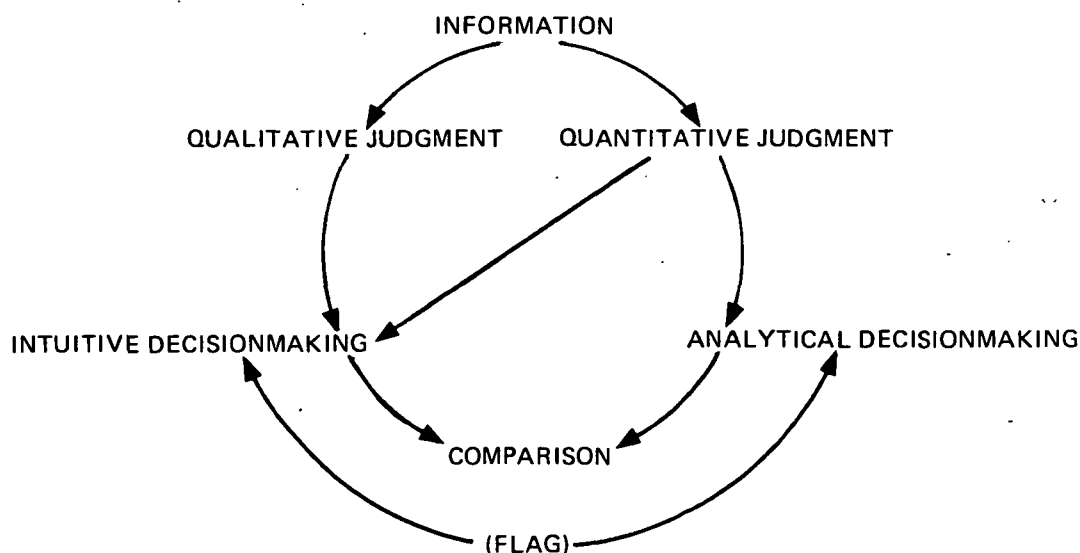
Figure 7-1. Hybrid Decisionmaking

The flag shown occurs when the two approaches disagree. By careful reexamination of intuition and analytical methodology, better forecasting can be accomplished for effective decisionmaking.

Since an unlimited amount of money is not available to develop all telecommunications systems, we can conceive in the real world decisionmaking process attempts to evolve optimum cost-effective mixes of communications systems with limited resources of future dollars. Therefore, the Delphi questions (see Paragraph 4.2)

should be formulated not only to obtain meaningful responses on telecommunication needs and priorities but also to provide: (1) probability of events occurring, or weighing of importance of a criterion; (2) criteria for decisions; and (3) utility values for different communications systems. These will enable the decisionmaker to make objective decisions on allocation of funds to mixes of communication systems.

If classical decision theory is to be used, the final answers obtained from the Delphi study must be appropriately formulated to fit such process. A short dissertation on classical decisionmaking follows. Again, it is emphasized that this technique provides only a first step in a decision process dealing with forecasts.

7.1 DECISION MATRICES AND CRITERIA

With a variety of questions and iterated consensus of opinions, the Delphi analyst should produce an output which compares various communication systems. This must be presented as a table or matrix showing the criteria associated with each system. These criteria might include:

Grade of service	National prestige
Reliability	Demographic migration projections
Travel	Economy of reaching remote locations
Avoidance	
Information retrieval	Flexibility for military and industrial reorganizations
Life cycle costs	State-of-the-art track records of performance

In general, the techniques should not frame the decision but should rather aid in making a decision. From here, results are given to the decisionmaker, who combines the inputs from other system analysts (who may be concerned with quite independent and/or exclusive problems) in order to select the "best" communication system mix.

The art of choosing and applying appropriate criteria is very difficult. The decisionmaker must review the criteria to be applied to the systems inherent or

implied in the statement of long-term communications need and priorities presented by the Delphi analyst and actively review each system development vis-a-vis the criteria. This is not necessarily a simple serial process. To the contrary, the decisionmaker may determine that additional information from the planning analysts is required and may define the bounds of the investigations required for sufficient definition of further communications needs. Upon completion of the study, the output is presented to the decisionmaker. This process may require several iterations.

It must not be presumed that, with the establishment of "good" criteria, the decisionmaker simply selects the communication system development that most closely satisfies the criteria and implements his decision. The process of decisionmaking is shown below:

1. A set of alternative actions on communication systems the decisionmaker might select.

2. A set of conditions which reflect the possible environment or criteria desired in which the decision is to be made, often called states-of-nature of states-of-the-world. Some criteria have been mentioned above.

3. A set of outcomes which may result depending upon which action is chosen and which of the environmental conditions exist at the time the action is taken.

4. A value or utility to the decisionmaker resulting from the outcome.

5. Some assessment of the likelihood or probability of each of the states of nature being the true one when the action is taken. When we evaluate communication systems, weighting factors may be used in place of probabilities.

Professor Ward Edwards of the University of Michigan, a noted decision-theorist, aptly described the above as follows:

"All decisions can be analyzed by means of a rather small set of concepts. They are:

1. The acts. These are different things the decisionmaker can do, defined so as to be mutually exclusive.

2. The states. The outcome of an act depends not only on its identity but also on factors not under the direct control of the decisionmaker. Such factors are called states, short for states-of-the-world, and are defined so as to be mutually exclusive and exhaustive. A probability is always associated with each possible state; sets of states vary in the precision with which the probability distributions over them can be ascertained. (A probability is your orderly opinion about how likely an event is, and so describes you more than it does the event. "Orderly" simply means that the sum of the probabilities of any exhaustive set of mutually exclusive events must be 1.0 – a very demanding requirement. Most people do not have such orderly opinions, a fact with serious consequences for decisionmaking.)

3. The outcomes. Each combination of an act and a state is called an outcome. Associated with each outcome is a payoff. Whether or not the payoff is defined numerically, it is convenient to assume that it has a subjective value or utility to the decisionmaker. Such utilities may sometimes be calculated, must more often be judged."

7.2 EXAMPLE OF DECISIONMAKING DISCIPLINE AND UTILITY VALUE

A hypothetical illustration of how classical decisionmaking could be used for deciding the proper allocation of funds to new telecommunications systems is presented in Figure 7-2.

The alternatives chosen were feasible telecommunication means. The criteria are the columns or parameters against which each of the telecommunication systems is evaluated. The numbers in the matrix are obtained by using a Delphi consensus and a utility scale such as that illustrated. The weights or importance of each criterion may also be obtained by Delphi methodology using a scale of 0 to 100 as mentioned.

	Communications Objectives	Volume and Loading Require.	Quality and Grade of Service	Operating Requirements	Growth Potential	Cost	Ease of Reaching Remote Loca- tions
Satellites	7	10	8	9	8	6	10
High Frequency Radio	3	2	4	9	2	10	9
Microwave	9	8	9	7	9	5	6
Tropospheric Scatter	5	5	6	8	3	7	8
Cable	9	9	8	8	7	5	7
Weight or Importance (0-100)	100	100	90	70	100	100	80

Figure 7-2. Decision Matrix Hypothetical Telecommunication System

A general decision model is discussed in Paragraph 5.4 and a general matrix shown in Figure 5-2.

7.2.1 Utility-Value

As has been shown, the utility or value is extremely important in providing objective decisions. For example, how do we go about putting in a utility or value on some measurement scale which exhibits the goodness or benefit of using a satellite to communicate news, educational materials, etc., to remote regions (e.g., Appalachia) as compared to a single telephone at the local country store?

Without going into the historical background of utility theory, well covered in texts by Edwards, Fishburn, Savage, and Stigler, a discussion of the types and application of utility in decision models may be useful.

7.2.2 Types of Utility

The concept of utility may be viewed as a measure of a pleasure-pain continuum. Pleasure is represented by positive utility and pain by negative utility. The decision or course of action yielding the most pleasure or utility is the obvious choice of the decisionmaker. Utility can be, and often is, measured in terms of dollars. Regardless of the units in which it is measured, there are two fundamental types of utility:

1. Ordinal utility

2. Cardinal utility.

7.2.2.1 Ordinal Utility

Ordinal utility involves the ranking of alternatives in order of the pleasure or utility associated with them without specifically assigning magnitudes. This might be accomplished by assigning utilities such as excellent, good, fair, and poor.

The only necessity is to establish a relative ranking. If utilities are assigned to alternatives A, B, C,..., n, a choice can be made as long as the ordinal scale of utility establishes that, for example, the utility of A is greater than B, B greater than C, etc.

$$u_A > u_B > u_C > \quad \cdots \quad u_n$$

where: u_A = utility of alternative A

u_B = utility of alternative B

u_C = utility of alternative C

u_n = utility of the nth alternative

Ordinalists contend that measurement of subjective utility on an absolute scale cannot be done meaningfully. However, it is believed that a preference between states in terms of relative utility can be established.

The use of indifference maps to assist the decisionmaker is a basic tool in applying the ordinal theory of utility. A typical indifference map is shown in Figure 7-3.
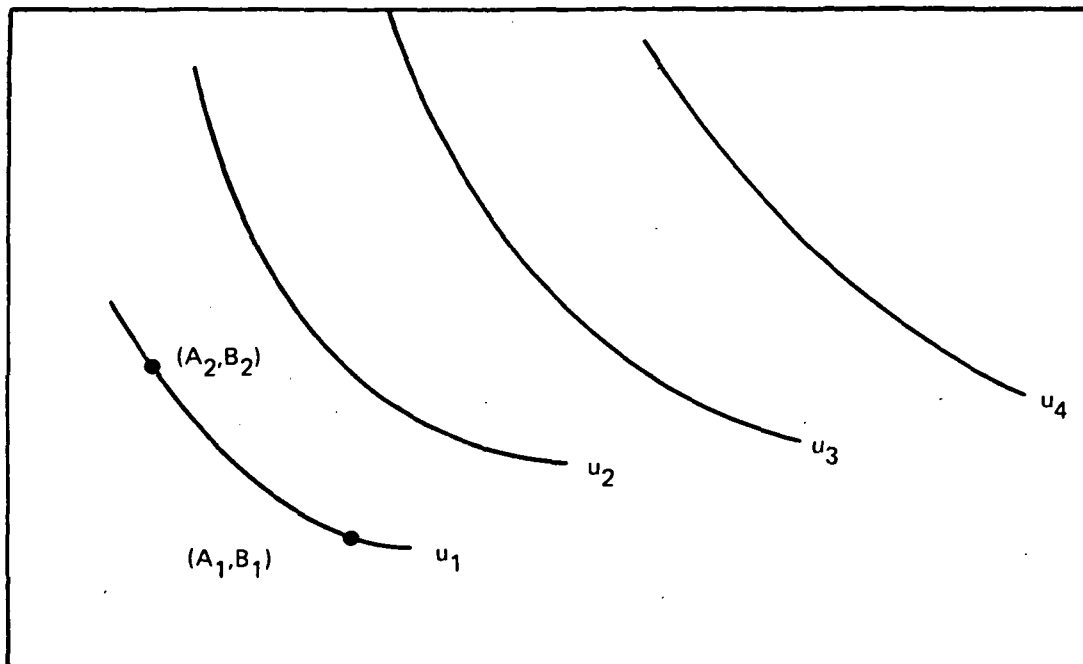
Figure 7-3. Typical Indifference Map

The quantities of two different states-of-affairs or commodities A and B are plotted. The preference for particular quantities of A and B are considered in terms of the ordinal utilities corresponding to various combinations of A and B. No preference exists between the combinations of A and B that fall on a given curve. For example, there is no preference between the points A_1, B_1, and A_2, B_2 on curve u_1. Curve u_2 represents a higher ranking utility curve, u_3 still higher, etc. It is significant, however, that curves on an indifference map need not always be in order of increasing utility.

7.2.2.2 Cardinal Utility

In constructing cardinal utility tables, it is usual to determine as a starting point a state-of-no-pleasure-or-pain and assign to it the value of zero utility. A

given state-of-affairs or a unit of a commodity relevant to the previous starting point is assigned a value of one "util." The unit of utility measurement is frequently the util. A comparison of alternative states of affairs or commodities within the framework of the two reference points defined is then made and appropriate values of utility assigned. Cardinal utility maps can be constructed by using the above approach.

Quite often the concept of marginal utility must be considered. If one unit of a commodity has a value of one util, it is unlikely that two units of the same commodity will have a combined value of two utils. The second unit may have a marginal utility of only 0.9 utils while still a third might have a value of only 0.8, etc. Therefore, utility can be considered as a function of the quantities of several commodities $C_i (i = 1, 2, 3, \ldots, n)$ and may be represented by a utility function

$$U = f(C_1, C_2, \ldots, C_n).$$

The marginal utility for an increase in ith state would be the partial derivative of U with respect to C_i. The decisionmaker should choose from several alternatives that one which yields the highest increment in utility.

The probability of a particular outcome or future state occurring given that a certain alternative or course of action is chosen must also be considered. The value of utility assigned a particular outcome must be modified by the probability that the outcome will occur. Utility multiplied by the chance of accomplishment should be the basis for effective decisionmaking.

7.2.2.3 Dollars as a Measure of Utility

For a given decision problem, all outcomes must be measured on one scale of utility so we can compare them. The value of an outcome, or the measure of its utility, is the result of a subjective evaluation by the decisionmaker. An obvious scale for value is dollars, but this is often an inappropriate measure. Consider, for example, the value of lives lost.

These values can be measured on a scale related to dollars: cost-effectiveness. It is often said that utility is maximized when the ratio of cost ($) to effectiveness (lives

saved or targets damaged) is minimized. Here again, there are cases where effectiveness is a subjective measure, such as pleasure for the cost of entertainment, or the peace-of-mind from insurance, or excitement from a lottery ticket.

The reason dollars cannot be generally used for utility is that the subjective value of money is not linearly related to dollars. For example, consider a game where the chances of "win" or "lose" are equally likely, and the payoffs are thus:

	$ Win (P = 1/2)	$ Lose (P = 1/2)
a.	1.50	1.00
b.	15.00	10.00
c.	150.00	100.00
d.	1,500.00	1,000.00
e.	15,000.00	10,000.00
f.	etc.	etc.

At what point on this scale would the bet no longer look attractive? Many people would say at level b. or c., or perhaps d. Yet the ratio of win to lose remains constant and favorable. This type of reaction can be generalized as shown in Figure 7-4.
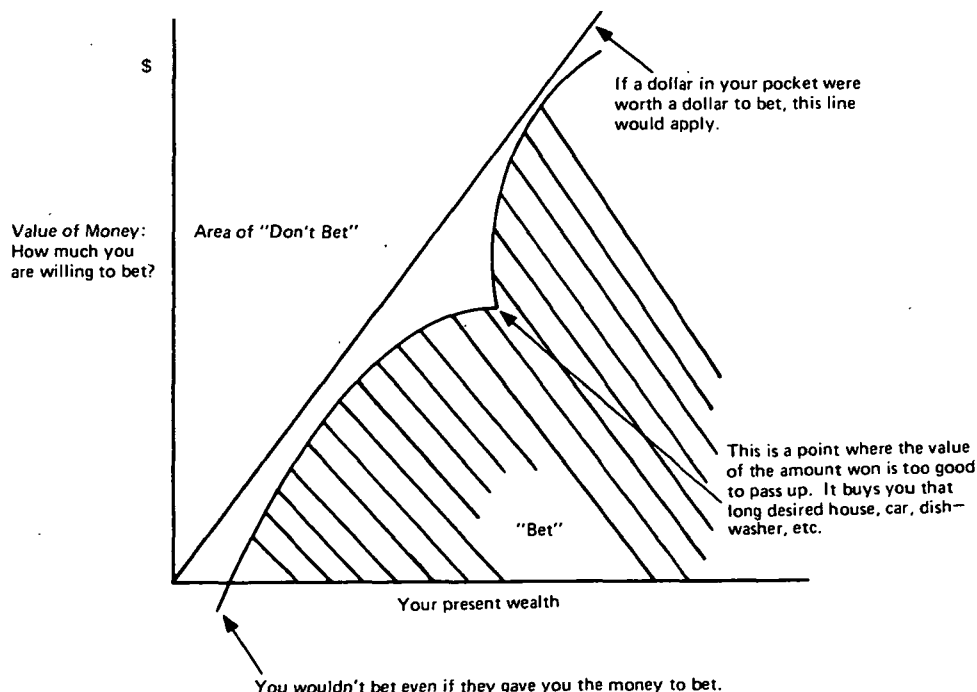
Figure 7-4. Relative Attractiveness of a Bet

7.3 MATHEMATICAL BASIS FOR DECISION PROCESSES

7.3.1 Decision Rules

At this point, one may ask "Given the matrix of utility values and weights of Figure 7-2, how do I pick a unique telecommunication system or combination of them to yield an optimum return for my money?" A decision rule is used to state how we will make our choice. Some of the more common decision rules are now shown.

7.3.2 The Minimax (Maximin) Rule

This rule is borrowed from game theory in which nature as a nonmalevolent opponent is the other player in a two-person zero-sum game. It is sometimes called the "pessimist's rule" or the rule of the conservative person who wants to protect himself against a high loss or one who is willing to settle for a minimum gain. It is normally called the minimax rule because many decision problems are structured in terms of loss tables.

The rule states that, if our table represents losses, we should find the largest loss for each action and then choose that action with the minimum of the maximums (thus the name, minimax). Thus we are assured of losing the least in the worst case, and we might do better. Hence, it is a "worst-case" or conservative rule. This may be expressed mathematically as

$$\underset{i}{\text{Min}} \quad \underset{j}{\text{Max}} \quad u_{ij}$$

which may be interpreted as for each action a_i, select the largest utility u_{ij}, then choose that action a_i which has the smallest of the selected utilities.

In the case of the example in Figure 7-2, we want to select maximin or

$$\underset{i}{\text{Max}} \quad \underset{j}{\text{Min}} \quad u_{ij}$$

Looking at the values in the matrix, we would have the following minimum values:

<u>Maximin</u>

a_1	6
a_2	2
a_3	5
a_4	3
a_5	5

and would therefore select action a_1 (satellite) which has the maximum of the minimum values. This assures us of never getting less than 6 utils.

7.3.3 The Maximax Rule

Corresponding to the pessimist or conservative person, there is always the optimist or gambler. This rule says choose:

$$\underset{i}{\text{Max}} \quad \underset{u}{\text{Max}} \quad u_{ij}$$

or simply find the largest utility in the matrix (assuming gains) and choose the corresponding action.

7.3.4 The Hurwicz Pessimism-Optimism Index

This rule is attributed to Prof. Leonid Hurwicz, a noted statistician and decision-theorist. Prof. Hurwicz reasoned that most people were neither ultraconservative nor gamblers but rather were some place in between. Combining the minimax and maximax criteria, he developed the following rule:

Choose that action which gives

$$\underset{i}{\text{Max}} \left(\alpha \underset{j}{\text{Max}} \, u_{ij} + (1-\alpha) \underset{j}{\text{Min}} \, u_{ij} \right)$$

where α is called the pessimism-optimism index of the decisionmaker. It can be seen that this reduces to the minimax rule when $\alpha = 1$.

7.3.5 The La Place Criterion

The La Place Criterion is a bridge between the above nonstochastic decision rules and the use of probabilities. It is based on the "principle of insufficient reason," first formulated by Jacob Bernoulli, who stated that if there is no evidence that one event (state-of-nature) is more likely to occur than another, then the events should be judged equally likely.

La Place stated that we should take the arithmetic average of the utilities which is equivalent to Bernoulli's principle.

Thus our decision rule in this case is to choose that action a_i which gives

$$\text{Max}_i \ 1/n \ \sum_{j=1}^{n} u_{ij}$$

This, in effect says that each state-of-nature has a probability $1/n$.

Applying the La Place Criterion to the stated problem in Figure 7-2 we have

<u>La Place</u>

a_1	8
a_2	6
a_3	8
a_4	6
a_5	8

7.4 SUMMARY OF USAGE OF DELPHI-OBTAINED DATA

The Delphi procedure is one of the most efficient known for uncovering the implicit models that lie behind opinions in the "soft" areas. An industrial or governmental Delphi effort is sponsored to collect opinions of individual experts and combine them into judgments that have operational utility to policy-makers. What to do with such judgments, particularly when dealing with the future, involves the planning cycle and decisionmaking. Planning and decisions assume a model of the situation, recognized or not, intuitive or well-defined. All our decisions imply some assumptions about the future; if assumptions are not made explicit, we do not criticize them. The Delphi method may be used to identify the elements involved, whether technological, societal, economic, values, assumptions, or decision criteria. The administrative plan for future-oriented Delphi application must anticipate the form of results and plan its utilization for any degree of effectiveness of the forecast.

The references and bibliography are sources of much additional information about Delphi methods, technological forecasting, decisionmaking, and the telecommunications future (see also Appendices B and C) which may be perused for amplification of information presented in this handbook.

APPENDIX A - MATHEMATICS OF DELPHI METHODS

A.1 INTRODUCTION

One of the advantages of the Delphi method over conventional conferences is that not only is a consensus opinion produced, but also numerical data is produced on the spread of opinion among the participants after they have considered all the arguments that have been raised. In situations where Delphi panel estimates could be checked, it has been found that a small spread among the panelists was associated with median estimates that were only slightly in error from the true facts which the panelists were guessing at. When the panel members had a relatively large difference of opinion after several rounds of the exercise, their median estimates were, in general, less accurate.[7] The measure which is usually used in Delphi exercises to express the spread of opinion within the group is the interquartile range. It and the median are defined in Paragraph A.2.

A conventional conference places the participants under considerable pressure to arrive at a consensus. Sometimes there are two or more groups of participants who have quite different views on a question. In such situations, if the participants remain divided after hearing all the arguments, the matter is usually settled by a majority vote. Sometimes, if the minority feels strongly enough about the matter, they may write a minority report, but such action is infrequent. In a Delphi exercise, on the other hand, the existence of such blocks of opinion can be made known to the people using the results of the exercise. Such information may alert them to possible political or other opposition to the majority position, and will at least cause them to examine the situation with more care than they might use if the panel had been more nearly unanimous. To provide this information to the people using the results of the exercise, the actual distribution of the panel results, or an approximation thereto, must be part of the output information, in addition to the median and interquartile estimates. Such a distribution is easiest to comprehend if presented graphically.

Cross-impact analysis is a technique which can be used to check whether the probability estimates generated by the participants in the exercise are consistent with their estimates of conditional probabilities. If not, the inconsistencies can be brought to their attention, which will produce deeper, and presumably sharper, thinking. The basic cross-impact analysis procedure is given in Paragraph 5.9. Background information on the advantages of various methods of doing the cross-impact analysis is given in Paragraph A.3.

It is frequently of interest to know how sensitive the probability or date of occurrence of one event is to the occurrence or nonoccurrence of another event. Paragraph A.4 briefly discusses the procedure for dealing with this problem.

A.2 MEDIAN, INTERQUARTILE RANGE

The median of a distribution is that value of the variable such that half the members of the distribution are larger, and half are smaller. Of course, in those cases where there are ties, there may be no member such that half the observations are larger and half are smaller. Also, there may be a whole range of values such that half the observations are larger and half are smaller. The procedure below can be used to obtain an unambiguous value for the median in every case.

When there is an odd number of observations, the median is the middle observation in this list. (The observations must be listed in order of increasing magnitude.) When the number of observations is even, the median is midway between the two central items.

Just as there is one median which, in effect, divides the distribution into two halves, there are three quartiles or points, which divide the distribution into four quarters. These three quartiles are usually designated by the following set of symbols.

Q_1 = First quartile

Q_2 = Second quartile = median

Q_3 = Third quartile

If there are N observations, and if N/4 is an integer, the first quartile has the value halfway between the N/4th observation and the next observation. The third quartile has the value halfway between the 3N/4th observation and the next observation. For example, if N = 8, the first quartile is halfway between the second and third observation, and the third quartile is halfway between the sixth and seventh observation.

If N/4 is not an integer, the first quartile has the value of the observation whose position corresponds to the next higher integer above N/4, and the third quartile has the value of the observation whose position corresponds to the next integer above 3N/4. For example, if N = 9, Q_1 = 9, Q_1 = the value of the third observation, Q_3 = the value of the seventh observation.

The interquartile range is the range of values of the center half of the population, namely, $Q_3 - Q_1$.

A.3 CROSS-IMPACT AND CONTINGENCY ANALYSIS

It might be thought that a good procedure for obtaining estimates of the probabilities of various events is one which produces a consistent set of probabilities and requires a minimum input of information from the participants in the exercise. Such is not the case, however. If it were, cross-impact analysis would have no role, since the participants could simply stop after estimating the probabilities of the individual events they are asked about. In the absence of further information which the participants could have supplied, this list would be consistent, and it would be much simpler to obtain than the data required for cross-impact analysis.

Further thought reveals that people may be able to make better estimates of conditional probabilities than of overall probabilities, at least for some items. For example, one individual may not have a good estimate for the likelihood of event A occurring, but he may have a good feel for the likelihood of event B. Another may have a good estimate for the likelihood of event A if B occurs, and the likelihood if B does not occur, but not have a good feel for the likelihood of event B. By putting these two estimates together via equation (1), it may be possible to obtain a better

estimate of the probability of the occurrence of event A than either of them could have produced alone.

$$P(A) = P(B)P(A/B) + P(\overline{B})P(A/\overline{B}) \qquad (1)$$

where   P(A)   =   the probability that event A occurs

P(B)   =   the probability that event B occurs

P(A/B)   =   the probability that event A occurs, given that event B occurs

$P(\overline{B})$ =   the probability that event B does not occur.
$P(\overline{B}) = 1 - P(B)$.

$P(A/\overline{B})$ =   the probability that event A occurs, given that B does not occur.

Even if the conditional probabilities cannot be estimated more accurately than the overall probabilities, use of equations like equation (1) can reveal inconsistencies that can promote further thought and clear up mistakes. If someone estimates individually the five numbers involved in equation (1), and finds the equation does not balance when he plugs them in, he can detect and correct errors in his thinking he would not otherwise be aware of. Cross-impact analysis is a procedure for doing this with a large number of interacting events. It checks whether the overall probability estimates are consistent with estimates of conditional probabilities. If they are not, it attempts to modify the probabilities to make them consistent with the conditional probabilities.

Not only does P(A) have to satisfy equation (1), but it also has to satisfy equation (2), where C is some other event whose occurrence affects the probability of A occurring:

$$P(A) = P(C)P(A/C) + P(\overline{C})P(A/\overline{C}) \qquad (2)$$

If there are N events whose probabilities are to be estimated, each of the N probabilities must satisfy N-1 equations like equations (1) and (2). Changing the

probability of any one event to balance one of these equations will affect the balance of N-2 other equations. Consequently, even if the conditional probabilities are correct it is not simple to obtain a consistent set of probabilities for the various events. Furthermore, as Dalkey shows in Reference 38, the conditional probabilities may themselves be inconsistent with each other. Dalkey points out that there is no "correct" method of resolving the inconsistencies. As he says, there are several directions that can be taken, depending on the interest of the study manager, on the availability of respondents for reestimation, and the like. "Assuming no restrictions on reestimation, it appears desirable to present the information concerning inconsistencies to the respondents, and obtain reestimates from them." He gives a method for averaging out the inconsistencies in the conditional probabilities, and then uses these to generate a consistent set of event probabilities that will be as close as possible to the original probability estimates. The main disadvantage of his method, however, is that it requires conditional probability estimates for all pairs of events including pairs that we are not accustomed to thinking of as dependent. For example, if event A is the development of a 100 kW satellite power supply by 1980, and event B is the initiation of direct satellite-to-home TV broadcasts by 1990, it is easy to think about the probability of event B given that event A occurred, but it is jarring to think about the probability of event A given that event B occurred, and the probability of event A given that event B did not occur. Dalkey's method requires such estimates. We are not used to estimating the probability of a prior event if a subsequent event occurs. Therefore, such estimates are likely to be much more erratic than the ones we are used to making, and this will almost certainly impair the results of a procedure using such estimates.

A procedure that seems reasonable is to use a reiterative Monte Carlo simulation, in which the initial estimates of probabilities of the various events are used to obtain an improved set of estimates, these are used as the starting point for a further improvement, and so forth, until the estimates stop changing substantially. At this point, if such a point is reached, the probability estimates would be consistent with the conditional probabilities. The Monte Carlo procedure does not require conditional

probabilities of earlier events given that later events occur, so the objection raised above to Dalkey's method does not apply to the Monte Carlo approach. Oddly enough, this procedure does not seem to have been used by any of the researchers who have written on the cross-impact method. Instead, most of them go through only the first iteration of this procedure, taking an original set of probability estimates and producing an improved set, but not going on until the process converges to a stable set of estimates. This occurs because they start from the same initial probabilities on every round of the Monte Carlo simulation, rather than starting from an updated set.

A further difficulty which is encountered in the Monte Carlo procedure as it has been described in several of the papers, although not generally pointed out as such, is that if at some point in the simulation events B, C, and D have occurred, and E has not occurred, and the occurrence or nonoccurrence of event A is about to be determined by picking a random number, there is a question as to what to do with the random number. We could elect to employ equation (1), and compare the random number with $P(A/B)$, since we know that in this round $P(B) = 1$ and $P(\overline{B}) = 0$. Or we could compare it with $P(A/C)$, using equation (2). Similarly, we could compare it with $P(A/D)$ or $P(A/\overline{E})$. There is really no reason for picking one or another of these equations, since none of them are strictly correct. The probability of event A in general does not depend just on the occurrence of B or C or D or E, but on all of them. The cross-impact matrix does not contain enough information to show these simultaneous interactions. Several authors use a random procedure to pick one predecessor event and the associated conditional probability. Others let all of the precedent events which have happened or not happened affect the probability of A, by multiplying the odds of A by appropriate factors that depend on the occurrence or nonoccurrence of all prior events which affect A.

For example, suppose that events B, C, D, and E always occur (or fail to occur) prior to the occurrence of event A being decided. Before we know whether B, C, D, or E will occur we estimate that the odds for event A occurring are 1:1 (probability 0.5). We also estimate that if event B occurs it will double the odds for event

A, but if event B does not occur it will reduce the odds for A by only 10%. We also make similar estimates for the effects of the occurrence or nonoccurrence of events C, D, and E. During the Monte Carlo round being used as an example herein, the odds for A would be multiplied by the factors corresponding to the occurrence of events B, C, and D, and reduced by the factor corresponding to the nonoccurrence of event E. If these factors happened to be, for example, 2, 3, 1.5, and 0.2, the odds for event A would be 1.8:1, corresponding to a probability of 0.643. A random number between zero and one would be selected and compared with 0.643. If the random number were smaller than 0.643, event A would be considered to have occurred, and the simulation would proceed on that basis. If the number were larger than 0.643, the simulation would continue on the basis of event A not occurring in that round.

Probability of occurring can be computed from odds for occuring as follows:

$$\text{Probability} = \frac{\text{Odds}}{1 + \text{Odds}}$$

Similarly, odds can be computed from probability as follows:

$$\text{Odds} = \frac{\text{Probability}}{1 - \text{Probability}}$$

The above method of allowing for the effects of several precedent events on a subsequent event is believed to be better than the approach of only considering one randomly selected precedent event, but it, too, has its problems. In particular, one must be cautious not to double count cross-impact effects. For example, suppose event A, when it occurs, greatly increases the probability of events B and C occurring. It, of course, does not follow that the occurrence of event B has a positive impact on C, but there may be a temptation to think so. If one did enter data showing cross impacts on C from both A and B, when in fact there was an impact only from A, the impact of A would have been counted twice.

Several authors have attempted to use rather complicated quadratic equations to compute the effect of one event on the probability of another, allowing for the time

between them and the strength of the cross-impact effect.[39,40,41] By multiplying the probability of an event by some factor which depends on the occurrence or nonoccurrence of another event, the strength of the coupling, and the time between them, one can avoid the criticism made above that only a single predecessor event affects the probability of a successor event in a single Monte Carlo round. The probability of the successor event may have been multiplied by many factors by the time the trial is made to determine whether it occurs in a particular round.

A description of the procedure is given below:[39]

Given that development i has 'occurred', the revised probability of occurrence for development j is

$$
P_j' = \begin{cases} s_{ij}\left(\dfrac{t - t_i}{t}\right) P_j^2 + \left(1 - s_{ij}\left(\dfrac{t - t_i}{t}\right)\right) P_j, & \text{for } t > t_i \\ P_j, & \text{for } t \le t_i \end{cases} \tag{3}
$$

where P_j = the probability of occurrence of development j by time t, prior to the occurrence of development i,

P_j' = the revised probability for development j,

s_{ij} = the element on the cross impact matrix indicating type and strength of the impact of i on j,

t_i = the original estimate of the time for occurrence for development i with 50% probability, and

t = the specified year in the future for which the modified probabilities are sought. Both the t and t_i are measured on a time scale with the origin at the present date.

The actual computation of the revised probabilities for each of the developments proceeds along the following lines: One of the N developments is selected at random, and by drawing a random number and comparing it with the chosen development's initial probability of occurrence it is determined whether or not the development 'occurred'. If the chosen development did occur, the probabilities of all of the

remaining developments are revised according to the previous formula, and the occurrence is recorded. If the chosen development did not occur this is also noted, and the probabilities of the remaining developments are left unchanged. Now one of the N-1 remaining developments is randomly selected and it is tested for occurrence, and if it does occur the probabilities of all remaining developments not yet tested for occurrence are again revised. Now one of the remaining N-2 not yet tested developments is randomly tested for occurrence, and the appropriate probabilities are again revised. This process continues until all N developments have been tested for occurrence. This process of one complete evaluation of the N developments will be referred to as being a trial. By running a large number of trials, and keeping track of the cumulative number of 'occurrences' for each development, the proportion of occurrences out of the total number of trials results in the modified probabilities for each development.

In the preceding description of the computation process it was assumed that during a trial any of the previously unselected developments had an equal probability of being chosen to be tested for occurrence. In many applications some of the developments may be necessary predecessors of others, and hence random selection is incorrect. In such a situation the procedures for selection of developments for testing can be modified to reflect precedence constraints.

There are several objections to this approach, however. First of all, the probability of event j is changed if event i occurs, but is not changed if event i does not occur. This produces a biased effect, since the original probability estimates of events presumably allowed for the possibility of other events occurring or not occurring. It would therefore be more reasonable to change the probability of event j in one direction if event i has occurred, and to change it in the opposite direction if event i has not occurred. Secondly, to keep P_j' in the range of zero to one, it is necessary to limit s_{ij} to the range of -1 to 1. If this is done, however, the maximum

impact one event can have on another whose probability is 0.5 is to change its probability to 0.25 or 0.75, depending on whether the first event occurs or not. If the probability of the second event is near zero or one, the occurrence or nonoccurrence of the first event has even less effect on it. The method therefore lacks the flexibility necessary to model situations in which the occurrence of one event can change the probability of a second event from a low number to a large number. Finally, the inclusion of a term proportional to time implies that the method will be used with time varying in some way, with a computer evaluating the probabilities at various points in simulated time. This, in turn, implies that the probability of event j occurring at that time should be calculated. But, the computer cannot evaluate equation (3) at any time other than the time associated with event j in the heading of the cross-impact matrix, because P_j is defined as the probability of occurrence of development j by time t, and the only value of t for which value of P_j is defined is the one in the heading defining event j. Therefore, the inclusion of a term proportional to t in the equation is a spurious refinement. In the Monte Carlo simulation development i can occur only in year t_i, and development j can occur only in year t_j. Since these years are given in the headings of the matrix, the effect of time can simply be included in s_{ij}, making equation (3) considerably less impressive looking.

It should also be noted that if the intent of this procedure is to permit Monte Carlo simulation in which events i or j could occur at several different possible dates, even graver problems would be encountered. In such a case it would be necessary to calculate the probability of event j occurring at a specific time (such as in a specific year). Equation (3) gives the probability that event j will have occurred by a specific time, which is a very different thing.

There is a way of simulating the probabilities of events having a possibility of occurring in a range of years. This procedure is explained in Reference 30. In that reference Helmer describes a game based on this approach, with a matrix showing the effects of individual events on individual events, individual events on each of a set of trends, trends on events, and trends on trends. In Helmer's notation an event is something which can happen only once, such as a particular scientific breakthrough.

A trend is a gradual development having a magnitude at any moment, such as GNP, population, etc. Part of the input to Helmer's game is a set of probabilities, P_{ij}, for each event E_i, giving the probability that event E_i will occur during time slot j, provided it has not already occurred sooner. There are corresponding projections for the trends. These additions make it possible to do a more realistic simulation than the previous approach permits. Helmer's procedure seems to be the most realistic approach available at present, and is recommended if time and resources permit its use. Although Helmer seems to have used manual and graphical methods in his gaming, it would be easy to computerize the procedure, making it faster and more convenient.

As Helmer himself points out, his approach is still highly simplified as compared with what a realistic simulation would include. For example, the effect of one event (E_1) on another (E_2) is considered to be characterized simply by a time delay before the effect is felt, (always assumed to be at least one time unit) and the factor by which the odds for occurrence E_2 are multiplied from then on. If E_1 fails to occur, the (delayed) effect on the probability of E_2 is in the opposite direction, with the same magnitude. A more realistic simulation would permit changing effects with time, and differences in magnitude for occurrence and nonoccurrence. These refinements could be added to the simulation fairly easily.

The effects of trends on each other in Helmer's approach are actually rather similar to the KSIM simulation, discussed elsewhere in this report. Helmer's games are more realistic, in that the trend variables are quantified in realistic units appropriate to the variable, such as dollars, channels, telephones, etc. Furthermore, Helmer includes time delays. In KSIM all the variables are arbitrarily scaled from zero to one, or from zero to 100. On the other hand, the KSIM simulation is easier to set up. A synthesis of these two approaches could be useful.

Prior to aggregating the probability estimates of the participants and performing a Monte Carlo simulation, it might be useful to give each participant a printout of his

probability and conditional probability estimates and their implications in terms of equations like (1) and (2), after which he would have one or more opportunities to make his estimates more consistent. While a more consistent set of probabilities and conditional probabilities is not necessarily a more accurate set, one is sure that something must be wrong in an inconsistent set, whereas a consistent set at least has the possibility of being correct. Some participants, particularly those not familiar with probabilities, may get bogged down in such a procedure, so it should be made strictly voluntary. This procedure does not seem to have been employed in any of the cross-impact studies reported in the literature.

A.3.1 Simplification of Matrix

As mentioned in Paragraph 5.8, the cross-impact matrix can be made less formidable to think about and work with if it is separated into submatrices that do not affect each other, if there are such submatrices. The procedure for doing this separation is quite simple. Suppose the events defining the row and column headings are called E_1, E_2, ... E_n. Starting with E_1, write down the subscripts of all the events that E_1 affects or that affect E_1. These can be found by inspection of the original matrix. If there are no events that E_1 affects or that affect E_1, E_1 is an isolated event and can be segregated. If there are some events, list them, and for each of them write down the subscripts of the events which they affect, or which affect them, if they have not already been listed. Continue this until no new events are added to the list. The events on the list form a connected group, and can be formed into their own matrix. If there are some events left, repeat the procedure, starting a new list with any one of them, to get the next group of interrelated events which form their own matrix. Repeat until no events are left. You may now have several small submatrices and several isolated events, rather than one large matrix to work with. In some cases, of course, it will be found that all of the events in the original matrix are connected.

A.3.2 How Many Monte Carlo Trials Should Be Used?

In performing a Monte Carlo simulation, one has to decide on the number of Monte Carlo trials to use. Increasing the number of trials reduces the statistical noise in the answer, but the noise is inversely proportional to the square root of the number of trials, so once an adequate level of accuracy is reached, additional accuracy rapidly becomes more expensive in terms of computer time.

If an event has a probability p of occurring in a Monte Carlo trial, and a probability q of not occurring, where q = 1-p, and if N trials are made, the standard deviation in the fraction of time the event will occur during the N trials is $\sqrt{pq/N}$. The number of occurrences actually has a binomial distribution, but for most purposes this can be approximated by a normal distribution. In a normal distribution, one is 68 percent sure of the result being within one standard deviation of the expected value, 95 percent sure of being within two standard deviations, and 99.7 percent sure of being within three standard deviations. For example, if p = 0.5 and N = 1000, the standard deviation = 0.0158. If the expected value is 0.5, therefore, 1000 Monte Carlo trials will give a 95 percent probability that the computed result will lie between 0.468 and 0.532. One would have a 99.7 percent probability that the results will lie between 0.453 and 0.547. This is sufficient accuracy for the purposes discussed herein, since the input data is highly unlikely to be more accurate than this.

If the true probability were any number other than 0.5, the standard deviation would be even smaller. For example, if p = 0.1 and N = 1000, the standard deviation would be 0.0095. The simulation results would then have a 95 percent probability of being between 0.081 and 0.119.

On modern computers, 1000 Monte Carlo trials should take no more than a few seconds of time, and so 1000 trials are recommended as a reasonable run from the standpoint of accuracy and cost.

If p is extremely small, so that Np would be less than 5 with N = 1000, either the number of trials should be increased until Np = 5 or the Poisson approximation to

the binomial distribution, rather than the normal approximation, should be used. The Poisson distribution states that the probability of getting exactly r occurrences out of N trials is

$$P(r) = \frac{e^{-Np}(Np)^r}{r!}$$

As has been mentioned, if the original estimates of the probabilities of the various events were consistent with the estimates of the cross-impact effects, the results of the Monte Carlo simulation should agree closely (within the statistical noise) with the initial probability estimates. If one or more of the probabilities differs by more than two or three standard deviations from the original probabilities, there was probably an inconsistency. There is no reason to believe that the results of the simulation are necessarily consistent with the cross-impact effects, though they should be closer than the original estimates were. The Monte Carlo run should be repeated, using the new set of probabilities as a starting estimate, to see if further substantial changes occur. Presumably the process will eventually converge to a consistent set of probabilities. The necessity for performing such iteration seems to have been overlooked by all previous practitioners, so it is advanced with some diffidence. If the process does not converge, the rationale for using cross-impact analysis would be weakened or destroyed. Even if convergence does occur, there is no mathematical proof at present that the solution will be unique. In spite of these caveats, cross-impact analysis is believed to be a useful and worthwhile procedure.

A.4 SENSITIVITY ANALYSIS

It is frequently of interest to know how sensitive the probability of occurrence of one event is to the occurrence or nonoccurrence of another event. Reference 31 defines the sensitivity of dependent event A to conditioning event B as the absolute value of $[P(A/B) - P(A/\bar{B})]$. In the Delphi exercise reported on in Reference 31 these conditional probabilities were estimated by the panelists. The value of each sensitivity factor of interest was computed from the above expression, and the median and quartile values of sensitivity were computed and published as part of the results of the exercise.

However, sensitivity can be given a slightly different, and perhaps more useful definition. It is possible that the occurrence of event C could affect the probability of occurrence of event A. The probability of occurrence of event A would be sensitive to event C in such a case, but this might not be revealed by the definition given previously, since the participants in the exercise might think in terms of first order effects when estimating conditional probabilities. It would therefore be preferable to find the sensitivities by running the Monte Carlo simulation of the cross-impact matrix twice for each event; once with the event given a probability of one, the other time with a probability of zero. The same random number seed should be used each time, guaranteeing that any differences in the results are caused by the sensitivity effects, rather than by differences in the statistical noise. For example, if event B is given a probability of one in the first run and a probability of zero in the second run, the sensitivity of each other event to event B can be found by subtracting the probabilities produced in the second run from those produced in the first run. Furthermore, it is a good idea not to take the absolute value, since the sign of the sensitivity is also of interest.

If one wishes nevertheless to use the approach given in the first paragraph rather than the procedure recommended in the second paragraph, it will be necessary to have the conditional probabilities. The procedure recommended in Section 5 of this report did not use conditional probabilities in the cross impact matrix. Instead, it used the factors by which the odds for the occurrence of one event would be multiplied if another event occurred. These factors can be converted to conditional probabilities by using the overall probabilities and the procedure given in A.2. For example, if the probability of A is 0.75, and the occurrence of B multiplies the odds for A by a factor of 2, one would convert the probability of 0.75 to odds of 3:1, multiply by two getting 6:1, and convert this back to a probability, getting 0.857. The value of P(A/B) would thus be 0.857.

APPENDIX B - SUMMARY OF THE TELECOMMUNICATIONS FUTURE

Both the selection of panel members and the delineation of significant questions for them to consider depend primarily on the present status of national communications, and on those individuals and entities responsible for continuing telecommunications development.

First, consider some of the major areas that are embraced. These areas are not mutually exclusive. The questions to be initially generated for the panel of specialists should be distributed among the identified areas of telecommunication needs in such a way as to assure sufficient coverage.

The forecast of national communications needs, like all forecasts, must evolve from a knowledge of potential needs and of present trends in technology. To examine in detail all the possible avenues of progress is beyond the scope of this appendix. What can be done, however, is to crystallize some of the thoughts on the subject and give the reader a structure, a frame of reference, which he can use to better formulate the answers to Delphi questions. Hopefully, this appendix will help in phrasing pertinent questions, and help the panelist focus on ideas related to the Delphi inquiry in order to add dimension and weight to his answers.

Communications is inherent in the nation, society, and business world activities-- almost like the air we breathe. If it is of good quality and plentiful, we accept it as a given blessing. Our nation is so dependent on fully functioning communication networks that we can hardly imagine being deprived of any existing system. A first reaction answer to, "what are this country's telecommunications needs?" might very well be, "more!" When asking experts or informed persons what are the national communication needs about the year 1990, we are, in effect saying, "please look at a fabric of national life that is feasible and desirable in your view, and give your opinion of the communications goals and values that our country should have at that time."

Focusing on the future and then moving from the future to the present to examine how one may obtain that future is the normative approach to forecasting. However,

this is but a single path into the future. For a forecast to be meaningful, it is vital that an exploratory as well as normative approach be taken and that the two be linked in a cybernetic feedback fashion. This means that, while the past is recognized as important in establishing the future (exploratory), new futures are considered as a basis for changing the trend (normative). In the remainder of this appendix, the normative approach to communications needs is first discussed followed by the exploratory approach.

There is communication when there is a transfer of information from user A to user B and conversely although not necessarily so, from user B to user A. This transfer of information has for a long time been assumed to take place between human beings. This assumption is no longer correct and we must take into account nowadays three types of communication: man-man, man-machine, and machine-machine.

The technology that provides existing means of transfer of information is the backbone upon which future technology solutions will evolve.* Future technological solutions will be thought of in terms of goals that are desirable, such as a lowering of cost (decrease of cost of earth satellite stations), an increase in the quantity of people that benefit directly or indirectly from the development (number of voice circuits per link) or other criteria directly linked to efficacy, efficiency, time, and the scarcity of resources.

The exploratory examination of all possible avenues and trends brought forth by existing or projected technological means will be monitored by considerations of an ethical or social nature. This is made necessary by the all encompassing nature of technological developments in our times. These ethical and social considerations will thus include behavioral, moral, religious, ecological, and energy considerations, as perceived by each panel member. The questionnaire should reflect this preoccupation with values by seeking information about the desirability of technological issues.

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*It is conceivable that some unknown technological development will be translated into means to transfer information. However, we are concerned here with known or intuitively possible means to achieve that transfer.

The foregoing reflects a first level, or conceptual level, of the problem at hand. At this point it is worthwhile to examine how all topics to be covered in the forecast will evolve from issues relative to information, processing, storage and retrieval of information, transmission of information, sources and sinks of information, control of information and, to an increasing degree, privacy of information.

The need for information has constantly been increasing because of the increasing complexity of modern life. This has also had the effect of reducing the required reaction time associated with day-to-day events. The payoff and risk of decision at government, corporate or private levels has become greater, thus justifying the gathering of information for statistical purposes.

Information in its raw form is but the beginning of the information process that leads to decisions. The information that is being gathered manually and automatically must be suitably processed and stored. It is at this stage that the computer comes to the rescue with implications that loom large in our forecast exercise: technological advances which affect the performance of computers will also affect our capacity to handle information.

So far we have evoked a static picture of information being needed, gathered, processed, stored and retrieved. Next we view possible developments in the transmission of information, which are highly important to a meaningful outlook of the future. Here, we are dealing with purely technical problems and solutions, like the availability of spectrum, the various uses of the medium (satellites, microwave, cable, laser), the availability of two-way communication (interaction) as opposed to one-way (broadcast), the transformation of information (analog vs digital), and the routing of information (range and capacity of the network, switching).

The developments in the satellite field are particularly challenging for the forecaster of communications needs. Larger available power on the downlinks means that ground terminals can be made smaller and therefore less costly. The proliferation of ground terminals, the availability of frequencies through extension of the

spectrum or super-position on existing bands, increased sensitivity in band selection and beam directivity, will enable satellites to reach more remote locations and play a useful role in the education and entertainment of users located far from urban areas. The use of satellites in mobile communications needs also to be explored (another consequence of the emergence of smaller, tactical-like, earth terminals).

Transmission of information between users located at remote locations can be exercised to perform control functions. If the users are permanently located we open up the whole field of automatic process control. If one of the users is in motion we deal with traffic control as applied to various forms of transportation (by air, by land, by sea).

The availability of mobile users and of frequencies allocated to this application raise questions of a technical and social nature, e.g., Will the day come when each person carries his own portable telephone?

Where the impact of information and communication technology will be felt the most is at the level of the user, man and machine.

The machine user is the computer and the whole field of computer technology with its own forecast can be addressed. The trend in the computer field has been the parallel development of very large, centralized computers, acting as the brain of a network, and of mini-computers at user locations in the network. Mini-computers will increasingly assume more and more functions previously assigned to large computers, and will perform them in less space and at a cheaper cost.

Man as a user has available to him a whole array of broadband terminals. One of the major questions to be resolved, predominantly a social and economic one, is the extent to which terminals will be allowed to be converted from a one-way or broadcast type of operation to a two-way or participative type of operation. It is at this level that we encounter the most challenging ideas for the future: homes with computer terminals, home videophone terminals, consumer information retrieval systems, electronic education and voting, etc. The advent of interreactive terminals raises the

question of how far can communication replace transportation, particularly as it affects work trips and shopping trips.

The increasing use of electronic means in the gathering and transmission of information raises the question of privacy. There are two aspects of privacy that should bear consideration. The first one is that of the individual or group subject to censors for a variety of purposes. The second aspect of privacy is that of the information itself as it travels from user-to-user. Privacy is but one of the nontechnical issues raised by an information hungry society. It is quite possible that new laws might have to be drawn up in answer to new problems created by future uses of communications.

We have given the reader an overview of the type of issues that he will face in a communications oriented forecast, be he an evaluator or a panel member. These thoughts are put in a schematic form in Figure B-1.

Let us turn now to what may be considered the practical level of communications developments. The services to be offered to customers are expected to expand in scope and complexity as efforts to speed up the delivery of information increase. The basic two-way random access telephone network will most likely expand to accommodate random access between man and machines and between machines. New telecommunication services are needed to fill the time gap that exists now between the delivery of mail and the completion of a telephone call. The telegraph could be replaced by one-way voice and one-way record services; MAILGRAM is already one step in that direction.

MAILGRAM is a service whereby a teletyped message is transmitted to a post office near the addressee and is delivered the following morning by the mailman.[42] The American Telephone and Telegraph Company allows a customer, through its TWX service, to send and receive messages over a teletypewriter circuit, through the switched network. The Western Union Telegraph Company provides a similar service to its customers, called TELEX which is international in scope.[43]
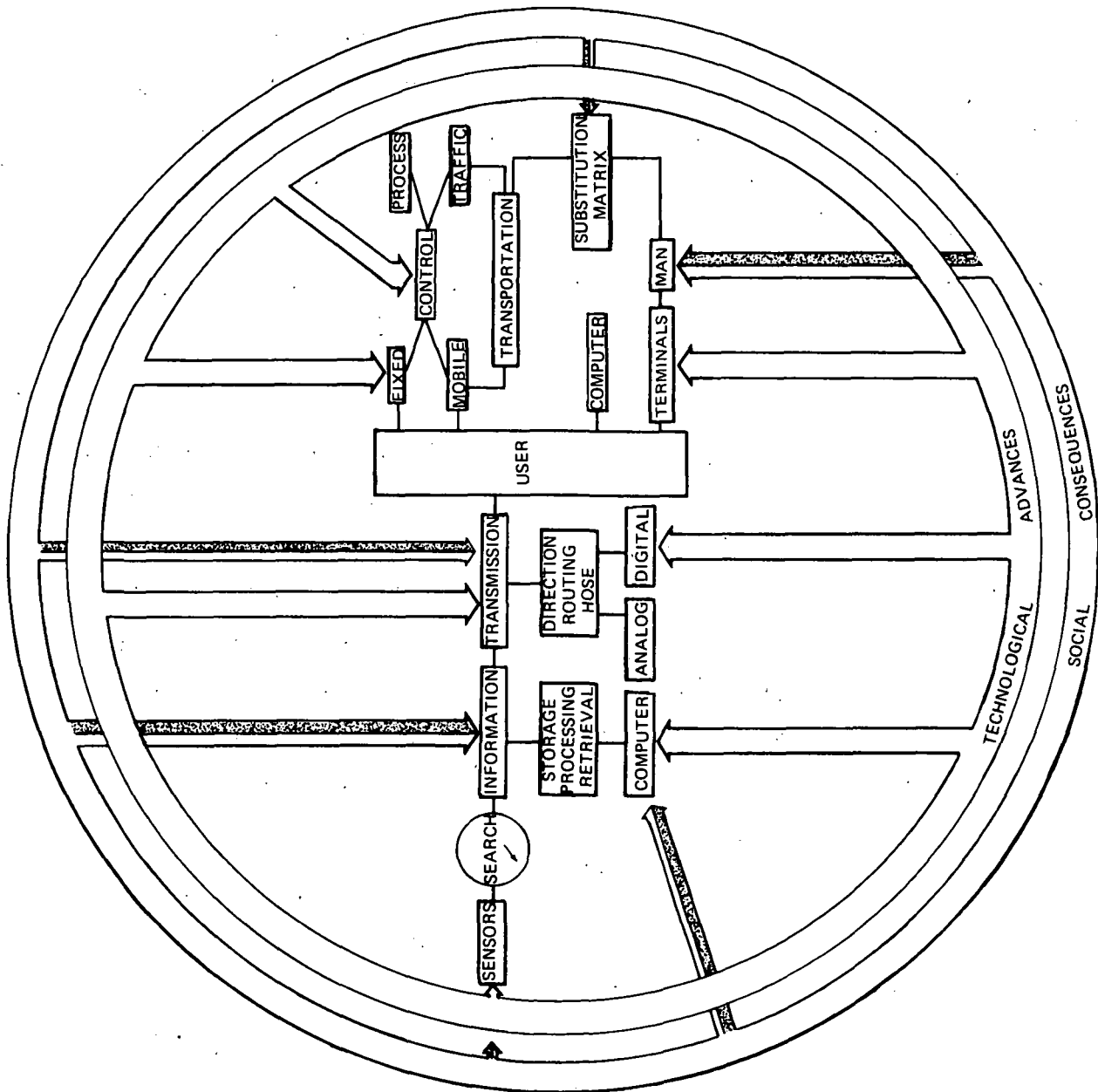
Figure B-1. Forecast of Communications Needs

The advantages of TELEX, TWX, private line teletype, and private line facsimile could be made available to each household. It is not too far-fetched to visualize a family of services that will combine mail delivery and the use of the telephone network. Added motivation for this surge in efficiency of communications is the need to save energy and to try to replace transportation by communications whenever this is possible.

Technically, increasing demands for communication circuits are pushing the boundaries of the frequency spectrum toward the frequency light. Moreover, the need for low cost broadband transmission facilities is giving strong motivation to the application of fiber optics technology to broadband circuits within a city. This development is complementary to the use of pulse code modulation (PCM) digital voice channels in U.S. metropolitan areas.

The PCM technique is combined with the time division multiplexing (TDM) technique to provide short-haul (10 to 25 miles) transmission of 24 voice-frequency signals (T1 carrier system).[44] As a concept of data transmission, the T1 line can carry a bit stream of 1.544 Mbps consisting of either message channels or wideband data.[44,45]

From a telephone plant point of view, the increased use of PCM in cities signals a change in the classical structure of the loop configuration (between the central office and the customer). We are seeing and will continue to see an increasing use of common equipment, common trunk groups, multiplexer systems, and concentrators between the central office and the customer. These developments illustrate the expansion of data communications and the development of facilities specially geared to cope with digital systems. Whereas, during the early years of the data communications business, service was mainly provided by modems on analog voice channels (sometimes specially conditioned), there is a continuing push to develop a truly digital data system, with switching centers capable of handling data.

The need for higher interoffice trunk capacity that is foreseen for the metropolitan areas in the 1980s is a consequence of increased urbanization and of new types of services that customers will expect from telecommunications companies.

The services to be provided will satisfy person-to-person, person-to-machine, and machine-to-machine communications. They will include one-way audio-visual communication from an information center to a user (alphanumerical information retrieval, distribution of television channels, etc.), the ability to store and forward messages in a format, code, and language compatible with the receiving terminal, abbreviated addressing, conference calling, controlled access and privacy during conversation, etc.

A restructuring of the existing telephone plant is needed to accommodate this increasing number of functions without impairing the nature of the network.

Digital transmission is an attractive solution to this problem because it provides a relatively economic way to carry simultaneously voice, picture, and data signals and it matches time-division switching.

A new digital long-haul coaxial cable transmission system will be introduced in 1975 in Canada. This system, known as the LD-4, combines PCM signals on a TDM basis to provide 4000 voice circuits. This system could very well set the pace in the extension of the digital hierarchy for North America.

Any examination of the national communications needs will therefore address itself to the growth of digital systems and to the successful integration of modems to the analog plant.

In 1968, in what is referred to as the Carterfone decision, the FCC ruled that the telephone company could no longer prohibit without cause the use of customer-owned modulation/demodulation devices and the interconnection of private systems for interstate communications.[46]

This official encouragement of competition has stimulated the emergence of specialized common carriers and satellite carriers offering their services to data

communication users. Thus, specialized carriers like MCI Communications Corporation offer nonswitched point-to-point circuits for intra-company communications for both data and voice. The Datran Corporation offers a switched all-digital network for data only, enabling any of its subscribers to communicate with any other Datran subscriber. Datran also has a contract from the International Brotherhood of Teamsters to integrate and support a nationwide communications network. American Satellite Corporation is implementing a specialized data network for the Air Force with the earth terminals located on the user's premises.

Western Union, Western Tele-Communications, Inc. and Space Communications Corporation are also in the domestic satellite field. Space Communications Corporation provides bulk channels for users with communications requirements large enough to operate their own ground stations. Alternatively, it provides turnkey service to allow a user to transmit data to a carrier's regional ground station and have the system carry the data from there.

Similarly, the data communication utility industry is utilizing the latest advances of computer technology to offer computer communication networks adaptable to user's needs. Time-sharing networks have helped users meet their requirements without having to design and implement data systems of their own. Companies offering comprehensive network services are planning to use existing carrier facilities to provide computer communication services based on the packet-switching concept developed for the Advanced Research Projects Agency Network (ARPANET).

These developments in turn spurred action from the established common carriers. Consequently, the Bell System is now offering a digital data system for short-haul and long-haul transmission. As far as the latter is concerned, the 1.5 Mbps Data Under Voice system efficiently utilizes the bandwidth available under the message channels on existing microwave routes. The 6.3 Mbps T2 digital line uses paired cable facilities.[44]

The ripples caused by the interconnection decision are by no means settled, hence, the configuration of telecommunication and computer networks is in a state of

flux. Many of the services to be offered in the future will depend on economic, legal and tariff matters. However, regardless of whether specialized common carriers, or utility networks dominate the communication scene, the progress of technology and demands of users will accelerate the use of data in such applications as banking, process control, transportation, health care, retailing, etc.

Part of the communication needs will originate from the military. We are already seeing some "fallout" from military technology into the commercial world (message switching). Plans are underway to convert the hybrid Defense Communication System (DCS) into an all-digital one. Therefore, for the initial purpose of setting up a base from which to study national communication needs, all three areas (commercial, military, government) will have to be represented on the panel although not necessarily in equal measure.

The projection of communication needs into the future is not solely determined by technological possibilities. Considerations of a social nature also spur the development of new methods of communications or applications of existing ones. The increasing use of broadband circuits within a city has already been mentioned. Also within a city, the various educational, instructional and cultural needs of local communities will be translated in a variety of special-purpose television programs, each beamed to a selective audience. The same idea may be carried over in remote areas along the lines provided by ATS-6, the direct-broadcast satellite recently launched. Although it is not clear at this stage what mix of Cable-TV, UHF TV and satellite communications will satisfy these needs, this is an example where social needs will spur the development of the technological applications necessary to their fulfillment.

We have seen that the forecast of national communications needs is very much influenced by the present and future capabilities of the communications and computer fields. We have also seen that the social aspects of this forecast cannot be neglected. This is because our society has become sensitive to the tremendous influence of technology on our lives and to the scarcity of our resources. A social presence

during this Delphi exercise is therefore highly desirable to point out possible advantages and disadvantages of certain technical developments. This social awareness may be obtained by having social scientists represented among the experts and the evaluators. Another way is to seek answers from the panel on the social desirability of a given technical event.

APPENDIX C – LITERATURE SURVEY OF FUTURE TELECOMMUNICATIONS TECHNOLOGY

The selected experts, who may participate in a Delphi exercise dealing with long-term national telecommunications needs, are presumed to be highly knowledgeable in specialized areas of communications and generally knowledgeable in many others. However, the present pervasiveness of communications in American society and its potential are so immense that a survey of recent literature may be helpful in providing additional perspective and "previews" of future telecommunications developments.

This literature survey includes a review of the President's Task Force on Communications Policy – Staff Papers 1 through 8 (13 volumes), dated June 1969. Staff Paper 1, entitled "A Survey of Telecommunications Technology," provides an overview of national telecommunications addressing the following nine specific subject areas:

1. Introduction

2. Common-Carrier Network

3. Transmission

4. Switching

5. Local Loops (Distribution)

6. Trade-offs Among Transmission Switching and Local Loops

7. Terminals

8. Mobile Radio

9. Television Distribution.

Paragraphs C.1 through C.9 summarize, under the titles listed above, the substance of Staff Paper 1 as it relates to future telecommunications developments. In addition, briefs of related subject matter were selected from other publications to supplement the paragraphs devoted to each subject area. In each instance the source of the brief is identified and listed in the bibliography.

C.1 INTRODUCTION

A wide range of opportunities exist for expanded and new services in tele-communications in the U.S. Video services can be expanded by adding TV communications capacity to about 20 channels per community; picture phones are technically available for point-to-point, small-screen, video communications; and so-called "switched broadband" systems offer pictures comparable to commercial TV in size and quality for point-to-point communications, shopping, or entertainment services of unlimited diversity. Automated data processing is emerging as an important customer of communications services. The number of computer-related terminals attached to the common-carrier network is growing rapidly, which may include such services as information retrieval, teaching, banking and shopping. Spectrum conservation made possible by low power transmission and multichannel receivers may foster extensive customer usage of portable and vehicle-installed mobile radios.

Cost reductions are essential in exploiting new and expanded communications services. Every home could have a data terminal, a facsimile terminal, a video telephone, and access to a switched broadband network if such capabilities are made less costly so that they can be available on a wide scale. Not considering technology for the moment, one can say that quite stable relationships exist between present communications services and population and national-income factors, i.e., such variables as GNP, personal consumption expenditures, government expenditures, and population. It is important to note that communications is not the only category of consumer expenditure in which new products or services will be introduced. In future trends it is not expected that new communications services will capture a greater share of consumer expenditures than at present; some new services may simply be new ways of doing old things. Although communications needs may be projected in many respects by relation to an economic model, the future course in communications is highly dependent on the future of technology - relatively much more speculative; however, technology which leads to reduction of costs in providing old services can be fairly well foreseen.

While costs of sending large amounts of information long distances are sharply decreasing, the outlook is much less favorable for dramatic cost reductions elsewhere. Costs of long-haul transmission systems may be substantially reduced by increased capacity provided by satellites, terrestrial microwave, and coaxial cables. The relative costs of switching, terminals, and local loops appear highly intractable to cost reduction. It is considered that the computer services business employing common-carrier networks will find that reductions in communications costs are unlikely to equal the rate at which the cost of computer processing and storage capacity is falling (i.e., by 50 percent every 2 years). Because cables used to distribute TV signals locally share some characteristics of long-haul coaxial cables, their costs are likely to fall.

Since the present communications system is not ideally suited to teleprocessing, a dedicated network for data processing may offer cheaper communications and greater flexibility. A major drawback to establishing an independent digital system has been the loss of economics of scale from sharing transmission facilities with voice traffic. In the near future it may be practical to establish a separate digital network for data customers within a shared system. On the same local distribution loops used by telephone customers, data signals could travel to local digital switches. From there, they could enter directly dedicated channels on the system's transmission lines, or a separate long-haul digital network, perhaps provided via satellite, by-passing the expensive multiplexing and routing facilities of the basic telephone network. It is probable that, while data terminals remain costly, the touchtone telephone instrument will offer occasional users direct access to computers.

The whole evolution of telecommunications in this nation has great implications for policy. The widely varying requirements of teleprocessors require a wide choice of services and freedom to establish subnetworks as necessary. Common carriers can provide these needs to a limited degree by offering a larger selection of band-widths, but customization for data communications is likely to exceed the diversity that franchised common carriers can provide. Progressive policy by regulatory

entities would be necessary for implementation. The policy regarding the depreciation method for investment in new technology affects the price that will be charged for new services, which, in turn, bears upon the expected level of estimated demand. Accelerated, economic-life depreciation, which projects a larger share of equipment costs in the system's early years, is the preferable method in a period of technological change. Another implication for policy relates to the fact that cost reductions are most needed in local loops and terminals. These two elements represent a growing share of network costs; significant overall cost reductions will depend on progress in these areas.

BRIEFS OF RECENTLY PUBLISHED RELATED SUBJECT MATTER

Hammer, Carl, "Telecommunications," Data Management, Vol 12, No. 4, April 1974, pp. 12-17.

The developing relationship between computer and telecommunication technology is possibly the most important event of our times. Computers will control the immense communication switching centers and assist in managing the enormous capacity of the new linkages into usable channels. Telecommunications in return, will make available the power of computers and the information in data banks to millions of users in remote locations.

It appears certain that future circuits will be designed to transmit very high-speed pulse trains into which voice, television, facsimile, and other data will be coded and sent in a uniform manner.

It is anticipated that the greatest impact of teleprocessing applications will be within the Federal Government. Likely the number of ADP systems will continue to increase rapidly during the coming years and most of the newly acquired systems will be communications-oriented. Thus the combined cost of computer and long-haul telecommunication services for the Federal Government of the United States is expected to reach levels approaching $10 billion by 1980.

This accelerating pace of teleprocessing developments will severely strain many segments of our national economy. The common carrier communication industry may be hard pressed to find the funds needed for the required plant expansion; other entities may insist upon the right to share in the growing market.

We may even see the beginning of fragmentation of what heretofore has been an integrated, nationwide teleprocessing communication network; significant security implications may not be adquately addressed; and even the question of negative socio-cultural impacts may not be adequately taken into account.

Such considerations point initially to the need for a higher degree of control, coordination and policy determination at the Federal level. In part, this need arises from the very nature of teleprocessing itself in that it is a new and qualitatively different medium for information processing.

We have already noted that teleprocessing is not just computers plus communications but instead has a unique dimension of its own much in the way that hydrogen and oxygen combined produce a wholly new property--water. It is the synergistic fact that teleprocessing is greater than, and, different from the sum of its parts that presents us with a need to manage this emerging resource, also on the international scene.

On the one hand, teleprocessing systems provide a powerful new mechanism for controlling, directing and managing complex organizations through the application of cybernetic concepts. Decisionmaking institutions, whether business or Government, can be viewed essentially as dynamic man-machine systems; and teleprocessing systems facilitate the management of such organizations within the context of a systems concept. The organization is thus viewed as an integrated whole wherein each system, subsystem, and supporting subsystems are associated with the total operation.

At the same time, however, the rapidly evolving teleprocessing technology challenges the capability of management to effectively integrate and manage the new resource itself to meet the needs of the organization.

Bagdikian, Ben, The Information Machines: Their Impact on Men and Media.
New York: Harper & Row. 1971.

A distinguished journalist, Bagdikian spent 2 years at the RAND Corporation where he directed a study of the impact of future technology on the gathering and dissemination of news. Part of his RAND research included a Delphi poll on the future of communications.

In forecasting the future technology of newspapers, Bagdikian is well aware that the present experts in newspaper technology--the manufacturers of typesetting machines and printing presses--may know very little about the coming technology, which will arise from computers and electronics. At the same time, today's commercial broadcasters, committed to preserving present techniques, also may not be the best sources of information on the news media of the future.

But from his research and questioning of people in many fields related to communications, Bagdikian believes that "the main lines of the future seem to be clear, or as clear as a look can ever be a whole generation ahead."

"Somehow computers will be involved in the storage, delivery and switching of popular communications. Somehow there will be additional capacity for the consumer in his home to receive a greater variety of information than he does now. He may be able to control the timing, content, and form of this information flow in ways not now available to him."

The Delphi panelists were virtually unanimous that every major step in the news process will be substantially changed by 1980, and after 1980 more radical innovations in whole systems will begin to take effect.

"A major innovation in home communications will be a reactive system, with the individual consumer having the power to order specific content and receive it immediately. There is already an elementary reactive system: it is possible to order items by telephone and get a reply by telephone. One can ask for other telephone numbers, or the right time, or airline schedules, or taped weather forecasts, and the answer comes immediately through the return electronic link of the same telephone

line. A more advanced system would permit the consumer to signal out for what he wants and get an immediate televised response.

"The panel believed that such a reactive system would be in normal use by 1990 (the specialists thought 1987), when the consumer would be able to get what he asked for either on his TV screen, by voice, or in a document produced in his home electronically.

"The consumer will order this information, at first, by Touch-Tone telephone, the pushbutton signaling system the telephone company is introducing throughout the country."

As home communications devices evolve, Bagdikian forecasts, they will serve not only entertainment, home education, and live public events, but information from all kinds of organizations.

Bagdikian, Ben, "How Much More Communications Can We Stand," The Futurist, Vol. V, No. 5, October 1971, pp. 180-183.

An immense volume of communication is technically feasible by means of a new world of electronic gadgetry. But the flow of information provided by this mechanical ingenuity must ultimately lead to a human being. For all the millions of words and images that our cables and computers can deliver, the final recipient is a human being who can process about 250 words a minute, at most about 1000.

There may be a physical and psychological limit to living with an exclusively abstract intake. Although communications are becoming increasingly efficient from a technological standpoint, their content is becoming ever more meaningless. Advertising and propaganda are debasing our symbols so that there is a breakdown in real communications between different generations and different political groups. The solution may lie in the increase of noncommercial media that are not committed to playing the game of collecting mass audiences for sale.

The basic American ethics of tolerance of dissent no matter how hateful is in danger of dying at precisely the moment when the authorities are about to inherit more powerful systems of mass communications. There is no point in having new

communications systems unless they are open and unauthoritarian. As usual, we don't have much doubt that we can produce and operate the technology. And as usual, we are not so sure that we can put the technology to work for humane and creative purposes.

The disparity between the capacity of machines and the capacity of the human nervous system is not a small matter in the future of communications. It has individual and social consequences that are already causing us problems, and will cause even more in the future. The human being of the near future probably will need as much sleep as he does today. He will spend more time absorbing abstract information than he does today, continuing the trend of past generations. But there is a limit that is important in a number of ways.

Haddad, Jerrier A., "Computer Systems Technology," published in Technology Forecast for 1980 by Weber, E., Teal, G. K., and Schillinger, G.A., Van Nostrand Reinhold Co., 1971, pp. 189-198.

Mr. Haddad is an IBM vice president, and director of its SDD Poughkeepsie Laboratory.

If now we are to look at what we expect our progress to be for the next decade, of necessity we must project the possibilities in a number of critical areas. Certainly we must look to improvements in hardware, in programming, in digital data communication, and in application ingenuity. These aspects are relatively easy to discuss.

Additionally, however, we must consider that as computers pervade the everyday life of more and more organizations and individuals they will affect societal relationships as well as legal and economic relationships. Clearly we cannot forecast to 1980 without these latter considerations--and clearly these societal, legal, and economic considerations are more complex and deeper in effect than those items which can be resolved in a laboratory. This is not brought up merely as a disclaimer to a technical forecast. Rather it is mentioned as a strong motivational element which can and will sway the intensity and direction of technical progress in the next decade.

A summary of assumptions regarding computers in the 1980 period are:

- We will continue to see a roughly three to five times improvement in the best performance every five years.

- We will continue to see a roughly three to five times improvement in the cost to the user of a given performance every five years.

- We will see continued increase in the capacity of on-line storage and in its performance.

- We will continue to see programming systems increase in functions and performance most probably by breaking the problem down into subsystems.

- We will continue to see batch fabricated electronics allow less and less expensive data entry and terminal products.

- We will see digital data communication improve in cost and reliability almost independently of distance.

The whole purpose of applying a computer system is to make people more effective. As the new generation, trained in the capabilities of computers and accustomed to their usage, finds its way to leadership in the professions, government, and business, the role of computer systems in our lives will become more pervasive and more meaningful.

The objective of a data processing system is to have the needed information at the right place at the right time in the right form. And that type of definition implicitly assumes communication as part of that system.

Now, if you step from that spot over and say: But there is a requirement for nondigital data--communication--nonaccounting, nonnumerical, if you will--and now what's the role of a digital computer in that? Then I think you'll find that what these people say is absolutely true; that the digital computer of one form or another will play a very strong role in the management of and in the operational aspects of communications systems of the future. Whether or not, by the way, pulse code modulation or the equivalent is used.

C.2 THE COMMON-CARRIER NETWORK

For convenience analysts look at the common-carrier network as consisting of four functional elements:

1. Transmission facilities

2. Switching facilities

3. Local loops

4. Terminals.

Most domestic communications traffic travels over the common-carrier telecommunications network; different users share a common set of facilities. Some services do not use all four elements. Mobile radio and TV distribution lie wholly or partly outside the network. Radar, navigation, and meteorology rely heavily on the same kinds of technology as the more traditional communications services and are likely to benefit from and contribute to technological cross-fertilization.

System planners for common-carrier networks are charged to minimize cost of each of the four functions. Planners may substitute one function for another or change costs by changing the way a function is performed. Presently, it is recognized that some tradeoffs may be made between switching and transmission; between terminals and local distribution lines. In seeking to decrease cost of transferring information, planners deal with three principal technical variables: channel bandwidth, S/N ratio and coding efficiency. New technologies, which may achieve a least-cost, reliable way of transferring information, rarely affect only one variable. Usually there is improvement in one variable and degradation in others. The rate at which innovation may be introduced is heavily limited by the need to adapt new systems to installed equipment. Long useful lives and a high ratio of fixed-to-operating costs are characteristic of transmission, switching, and local distribution facilities. It is easy to see that past investment decisions inhibit future evolution in the common-carrier network. Any new equipment must be compatible or installed

by taking adaptive or insulating measures. The upshot of technological changes are that, although they may technically be feasible, the cost consequences are often prohibitive.

Each of the four basic elements of the common-carrier networks is discussed in Paragraphs C.3 through C.7.

C.3 TRANSMISSION

After World War II the common carriers began to substitute coaxial cables for paired wires, which offered much more usable bandwidth with less signal degradation over long distances. At the same time, line-of-sight and wideband radio transmission links were introduced, using the microwave portion of the electromagnetic spectrum. Twisted pairs of wire have been virtually replaced for long-haul transmissions, but are still the primary medium between local exchanges and telephone terminals. In the near future, satellites are expected to be strong competitors for long-haul transmission, particularly for distribution services and variable-capacity routes. In the more distant future, newer facilities such as millimeter-wave guides and laser systems may come into use where routes with densities of 100,000 circuits are required.

Coaxial cables are essentially free from spectrum limitations and promise large economics of scale and low unit costs. They have certain advantages over radio for fixed point-to-point services such as operation over a wide frequency bandwidth and shielding from external radiation; however, signals over cables are subject to power loss and cannot pass extremely high frequencies. On the other hand, millimeter-wave guides are planned in the future to provide transmission in the range above 10 GHz for routes of 200,000 voice circuits and CATV systems.

Ocean cables show the same trends toward economics of scale.

Microwaves (1-10 GHz), like wire transmission methods, are characterized by high fixed costs and large economics of scale. Capacity increases for this line-of-sight medium have been significant, yet costs well exceed those projected for the highest capacity cable systems. Start-up and maintenance costs have been difficult to

reduce. Building of roads to relay sites and regular deliveries of fuel are costly factors not likely to benefit from other technological developments in the communications field. Largely because of multiplex terminal costs and spectrum crowding, microwaves have not been used for short-haul transmission of telephone or television signals.

Communication satellites provide another line-of-sight transmission medium; the cost of satellite circuits are expected to drop sharply in the near future. The communication satellite is a single-node configuration characterized by:

1. Circuit costs within a single satellite system are essentially independent of terrestrial distance within the coverage area.

2. Dense routes have some advantage because earth terminal costs can be spread over a larger volume of traffic.

3. Capacity among the routes a satellite system serves can be reallocated, whereas, terrestrial routes are fixed.

4. The entire capacity of a satellite repeater constitutes a single trunk group.

5. Satellites are particularly suitable for distributing a single, wideband (e.g., television) signal simultaneously to many points.

Synchronous satellites having improved equivalent isotropically radiated power (EIRP) and more directive antennas appear to be the most-cost-effective road for this transmission media.

In the competition among long distance transmission modes, high-frequency (3-30 MHz) radio has suffered from quality and reliability problems, even on the long, thin routes where it is most competitive from the standpoint of cost. At present no one seems to foresee a great future for HF systems.

As an alternative to present analog signal forms, digital transmission techniques offer superior signal quality and interference protection, particularly on long routes and for radio systems. Digital signals are relatively easy to amplify as compared to analog. Repeaters in a digital system ignore the noise and generate a clean signal

at each relay point. In an analog system there is no way to separate the original signal from noise picked up along the way. The inherent disadvantage of a digital system is the large amount of bandwidth required to reproduce analog signals. The bandwidth requirements for some analog signals (e.g., video, picture phone) may be reduced by redundancy-removal equipment. Digital systems are presently able to overcome the disadvantage of large bandwidth requirements only where:

1. The transmission medium is not bandwidth limited due to spectrum availability (e.g., cable, wire).

2. New transmission facilities are prohibitively expensive.

3. Conventional analog methods of expanding circuit capacity or the built-in signaling capability of digital channels can be exploited.

The dominant characteristic of transmission technology is the advantage of large trunk groups, which provide strong economics of scale. As the length and circuit density of trunk groups change, so do the relative costs of different transmission media. Sometimes the trade-off is between length and channel density. For U.S. domestic services, paired-wire cable dominates for fixed capacity routes of fewer than 500 circuits; microwave between 500 and 15,000; coaxial cables between 15,000 and 80,000; and wave guides above 80,000 circuits. Expected growth in volume of long-distance communications will allow the telephone companies to make greater use of economical, high-density transmission methods. It is anticipated that voice traffic will triple by 1980 and that information sent as "data" may exceed that transmitted by voice. By that time Bell anticipates that 90 percent of its long-haul circuitry will be in coaxial circuitry. Two technological breakthroughs in the 1970s promise expanded use of digital systems; in the meantime, digital and analog system developments will be in parallel. The two breakthroughs anticipated are redundancy removal techniques and full realization of large-scale integrated circuitry.

On intercontinental transoceanic transmission routes, communications satellites are likely to become the dominant mode by 1980. The alternative modes are HF radio and ocean cables. For normal international telephony and data services, HF radio is

unlikely to suffice except for the smallest, most isolated nations. Cables, however, provide technical benefits which are not easily quantifiable, such as reliability, no use of radio spectrum, and better quality for some services.

BRIEFS OF RECENTLY PUBLISHED RELATED SUBJECT MATTER

"Communications: Optical, m-m Waves Offer Promise," Electronics, Vol. 47, No. 9, May 2, 1977 pp. 36-37.

The wideband systems that will be transmitting large volumes of data at high speeds in the 1980s will combine optical and millimeter-wave links. That's the prediction of a study recently completed for the Air Force's Rome Air Development Center by Martin Marietta Aerospace, Orlando, Florida.

The Air Force commissioned the study as an aid to planning future intrabase communications between rapidly deployed command posts and a central headquarters unit. But the authors say much of the report applies equally well to commercial intracity links.

The major conclusion is that optical links are superior to m-m wave links only for distances of 1 kilometer or less, according to Terry Duffield, Martin Marietta staff engineer. In a paper being presented this week at IEEE Southeastcon in Orlando, Duffield says that the cost and performance studies performed by RADC show that the two types of systems are about equal between 1 and 3 km, but that millimeter waves take over at longer distances. In a related paper, Martin Marietta's H. B. Muench adds that today's optical systems are ready for serious consideration as short links.

Duffield's study, which projected cost and performance figures through the late 1970s and into the 1980s, centered on systems with information bandwidths greater than 500 megahertz and all-weather reliability of 99.9%. The millimeter wave systems were solid-state systems using bulk-effect devices for sources. The optical systems used light-emitting diodes for the short links, gallium-arsenide lasers for links in the 2- to 3-km range, and carbon-dioxide and neodymium-doped ytrrium-aluminum-garnet lasers for the longer links.

The recent price reductions for gallium-arsenide lasers is the basis for Muench's conclusion that they could be used in communications today. Lasers that were selling for more than $100 six months ago, he says, now are available for less than $20. In his paper, he quotes a recent Army (Fort Monmouth, N.J.) estimate of a $1,000 cost per terminal for a gallium-arsenide system operating at 10 megabits per second. Muench says that this cost may be achieved by early next year.

With such a system operating at 1.5 megabits per second, Muench points out that it could be useful for setting up short links in a telephone system to avoid the need to lay cables for a T1-type link, the Bell System designation for equipment that multiplexes 24 voice conversations on one wire pair. Muench says that such a system could be useful in, say, new housing developments to bring voice signals to a central switching office, or for setting up emergency communications.

Feldman, Nathaniel E. and Kelly, Charles M. "The Communications Satellite - A Perspective for the 1970s," Santa Monica, California, RAND Corporation, Report No. P-4658, September 1971.

Satellites will not play a major role in world electronic communications in the 1970s without major new R&D investment and new international arrangements to support developments. What must be done to make communications satellites compete more effectively with other forms of electronic communications?

We would characterize the status of communications satellites as follows:

- International long-haul and defense point-to-point systems are growing rapidly utilizing low-output-power satellites.

- Domestic systems are stalemated by regulatory authorities in the United States and by high development costs elsewhere except in the Soviet Union.

- Over-all research and development (R&D) effort is minimal for advanced point-to-point systems.

- Only minor R&D effort is being applied to the development of high-powered satellites and small ground terminals. Canada is sponsoring a 200-watt-

per-channel 12-GHz communications technology satellite, and there is some development of small mobile ground stations for operation with defense satellites.

● Frequency assignments for high-power satellites are being considered by the International Radio Consultative Committee (CCIR).

It is commonplace for the less developed countries to feel that their communications problems are unique and that these problems are neglected by the highly developed countries. It suggests that a type of satellite needed by advanced countries that spread over large land masses can serve the less developed countries as well.

Under Congressional direction to de-emphasize point-to-point communications satellite activity when Comsat was established, NASA essentially abandoned the development of high-power satellites and then proceeded to de-emphasize all satellite communications as well. By limiting the funds for all such activities, NASA opted for slow and modest progress. At today's funding levels, decades will be required to achieve the technical advance called for by a 1967 National Academy of Sciences study. R&D supported by the United States created most of the technological base for Intelsat. With exceedingly modest further support since the early 1960s, progress has been commensurate. Western Europe's communications-satellite programs, moreover, have demonstrated negligible operational results.

For satellites to play a major role in future world communications, the United States must press R&D leading to the more versatile high-power systems. In particular, the U.S. Congress must be persuaded to support a major international cooperative program to make progress possible. No national or international commitment to such an R&D effort exists. A new international consortium appears necessary to support the development of high-power satellites, since such a program appears beyond the means or charter of any communications organization.

Organizing an international cooperative program will be difficult and will take time. If NASA were to go forward with the necessary technical developments while the potential users organize, the major goal--to implement a high-powered reliable communication

satellite--would be advanced. Since bilateral national agreements on satellite communications have consistently proved easier to negotiate and more effective than multinational agreements, strong U.S. leadership in negotiating a series of bilateral agreements may lay the groundwork for an international program.

The primary motivations for the development of communications satellites in most countries have been to enhance national prestige, to support the aerospace industry, and to secure the manifold benefits of technology for the nation at large. Over the past decade, this order has become inverted and social benefit has been added to the list. So we see a grave danger that frequency allocations, power-flux densities at the ground, and orbital-slot assignments may be allocated by international agreements that inhibit high-power satellite development. Broad frequency bands and some very high flux densities need to be made available while delaying restrictions for many years to permit extensive experimentation with operational systems. Means must be found to deal with the pre-emption problem. Canadian and U.S. domestic communications-satellite operations and the U.S.-Canadian agreements which evolve might provide a firm experimental basis for international regulations.

In summary, we expect international and domestic point-to-point communications satellite systems to multiply throughout the decade. In developed regions, they will remain auxiliary to the over-all ground communication complex, even though very significant in dollar volume. In many undeveloped regions, however, point-to-point systems could become the primary means of communication. If potential users of high-power satellites make the necessary arrangements for frequency assignments, user agreements, financing, regulation, and legislation (both national and international) and establish appropriate interfaces with other communication entities and systems, then many new applications with large growth potential can be developed for populated as well as undeveloped regions.

Without support on the order of $200 million per year to the development of the space segment, however, no dramatic new services or improvements in communications via satellite will occur in this decade. Yet, among space activities, only

communication-satellite R&D offers the potential of generating a multibillion-dollar industry that can both make a profit and support world understanding.

Hult, J. L. Broadcast Opportunities with Satellites and CATV, and their Control in the Public Interest, Santa Monica, RAND Corporation, Report No. P-3333, March 1970.

Satellites do not provide a communications capability that could not be achieved by other means. However, they can drastically change the economics of communications both in magnitude and form and in so doing can serve as a catalyst for an enormous increase in volume and change in style of communications in general. It is the revolution in use of communications that can have the most far-reaching impact on every institution and aspect of society. It is for this revolution that we should prepare society, if we are to avoid serious convulsive reactions to the profound changes that seem inevitable.

The term "communication" as used here is meant to include any transfer or exchange of information. It may involve primarily natural transfer processes, for example, listening to or looking at the information directly in a personal visit; it may involve electronic transfer of information, for example, by telephone, telegraph, picture phone, radio, TV, facsimile, or data links; and it may involve recorded information such as mail, newspapers, magazines, books, records, tapes, or photographs. Communication in this most general use of the term is the fabric of society. It links places, times, institutions, and individuals to form societies. It is the means on which we must depend if we are to learn about and adapt to the on-rushing change in all aspects of technology. And, yet the technology of communications itself is one of the most active and volatile of all the components of our society. Thus, we may find it very difficult to ensure the appropriate communications development that will foster an evolutionary, rather than a revolutionary, transformation of society.

The pace of change is so dramatic that we need to focus attention both on the design of our material environment and on our philosophy of living, so that all elements of society can adapt gracefully to the changes. For example, we should design our communication equipment and its related facilities and economics for replacement or

obsolescence in 10 years or less, rather than freezing systems to obsolete configurations for most of their lives. Similarly, we need to review and reexamine basic values, concepts and traditions, such as various "freedoms" and "rights," privacy, individualism, the family, education, monopolies, and the regulation of international resources to determine if what has become conventional will be suitable to the changing environment.

Hult, J. L., <u>Satellites and Future Communications, Including Broadcast,</u> Santa Monica, California, RAND Corporation, Report No. P-3477, April 1967.

The important factors of public interest and support, government regulations and policy, and special interest are likely to determine the rate at which the potential of communication satellites is exploited. Technology will neither set the pace nor seriously constrain the possible beneficial applications. Among regulatory and policy matters related to the rate of satellite communications development one may make arguments for eliminating monopoly extensions to terminal ownership, the importance of domestic satellite growth, and the economic control of spectrum usage.

The large, versatile, high-gain antennas that can be boosted to, and erected in, the compellingly attractive environment of synchronous orbits are technologically feasible. The accurate, long-life control of these antennas in both attitude and orbit will enable us to increase satellite relaying capacity by tens of millions of times and multiply the effective available spectrum by hundreds to thousands of times. This could support an unprecedented increase in the application of electronic communications. It could provide a relaying cost-rate competitive with the shortest microwave relay, a much more beneficial usage of the spectrum, and a variety of capabilities not otherwise available. It becomes economically attractive only when large capacities are used, in which case it may have a serious impact on current systems and investments. The technology should also make possible satellite TV broadcast directly to homes at UHF frequencies with better quality signals at less broadcast cost than with conventional transmitters. However, transmission of broadcast programs with a general multipurpose broadband access to the home through central exchanges may prove to be the most appropriate means of distributing the bulk of future broadcast-like programs.

C. 4 SWITCHING

Fundamentally, switching is a way of conserving communication lines. A network configuration has evolved where a group of terminals share a local switching center, which, in turn, is connected via a multi-channel trunk route to a wider-area switching center, and so on through, at present, a hierarchy of five levels of switches.

The two basic switches are circuit and store-and-forward. There are three types of circuit switches: space-division, time-division, and frequency-division; each type provides an apparent continuous connection between communicating points. Store-and-forward switching at the simplest level is exemplified by a telephone answering service. Another example is the Western Union torn-tape system, which concentrates messages at a central location where they are stored on punched tape and relayed in batches. But, today, the high-speed computer is usually thought of for performing store-and-forward switching functions. Most rapid growth of such computer switching is anticipated as an ancillary service to data processing.

Progress in circuit switching has brought direct distance and automatic dialing and has increased switching speed. The key to switching economy in telephony has been the elimination of operator assistance. When relay computers were installed in large numbers, the logical operations necessary for alternate routing, long-distance switching were feasible; Bell was able to introduce direct distance dialing. Electronic switching systems (ESS) will allow switching centers to do jobs previously performed in other parts of the telecommunications system, such as:

1. Assist in automatic dialing by maintaining a file of frequently called numbers for a subscriber.

2. Route a call automatically to another terminal if the primary number is busy.

3. Set up conference calls.

The ESS has brought with it a steady reduction in the time a switch requires to make a connection.

A digital network, using time-division switches, may reduce modulation, switching and multiplexing costs for data communications. Three principal sources of cost savings for data users employing a digital communications system are:

1. Elimination of conversion equipment presently required on their terminals to adapt digital signals for transmission over an analog network.

2. Both local and toll switching would be 1/3 to 1/2 as costly if time-division technology were used.

3. Assuming reasonable ranges of demand, time-division multiplexing is expected to be between 1/10 and 1/3 as expensive as frequency-division multiplexing, required in an analog network.

The principal obstacle to a digital, multi-purpose network, serving inherently analog (voice, TV, etc.) as well as inherently digital (data) customers, is the cost of converting analog signals into digital form for transmission over the network. Nevertheless, it may be possible to provide data users with a digital system, without either requiring analog users to adapt to a digital network or foregoing entirely the economics of joint usage between analog and digital communicators. The distribution lines of data customers could by-pass the local exchanges, which must receive signals in analog form, and enter separate digital, time-division switch. Signals on this digital subnetwork could enter long-haul transmission facilities directly, whether these were dedicated channels on transmission facilities shared with the analog network, or a special digital long-haul network such as might be provided by a multiple-access satellite system.

Computerized store-and-forward switching is more costly than circuit switching. It is usually economic for activities requiring store-and-forward services to establish hybrid switching facilities, where a message is stored, if it requires processing or if the receiving terminal is occupied. Otherwise, a direct circuit-switched connection is established between the two terminals, and the message is relayed immediately. In most existing systems, a majority of messages can be

circuit-switched. The fewer the messages that must be stored, the less costly the the system will be.

Just as the time-sharing systems are most costly when they must accommodate a broad community of users, so do the costs of a message-switching installation grow in response to diversity, i.e., different data-speed, response-timing, and storage requirements. Moreover, when customers with incompatible terminal equipment share a single switching system and seek to communicate with one another, a larger share of their messages must be stored and forwarded, thereby generating cost increases.

BRIEFS OF RECENTLY PUBLISHED RELATED SUBJECT MATTER

Reese, Frank D., "Switching Trends Lead Independents into Digital Systems, Electronic COs," Telephone Engineer and Management, Vol. 78, No. 2, January 15, 1974, pp. 82-85.

The growth of the toll networks and the acquisition of toll plants within the Independent Telephone Company's operating area, plus a consolidation of several smaller toll centers into larger ones, has in recent years had the effect of greatly increasing the toll switching machine size requirements. The anticipated trends are that those larger machines whose switching requirements in 1975 will be between 5000 and 100,000 CCS, serving from about 300 to 6000 toll trunks, will by 1990 be expected to handle between 18,000 to nearly 1,000,000 CCS, serving between 1000 and 55,000 trunks.

The next changing trend observed in the past few years is in the very rapid growth in the use of PCM type carrier equipment, often referred to as the "T" type. The number of channels is increasing at the rate of something on the order of 400,000 to 500,000 channels or greater, per year.

Probably the most comprehensive and recent view of the technological evolution taking place, and its impact on the telecommunications field, has been gained from

observations made at The International Switching Symposium held in Cambridge, Massachusetts on June 6-9, 1972. The following observations were noted.

1. Stored Program Control. There existed an almost universal swing to stored program control. It was observed that the trend had shifted from a mild acceptance of stored program control some 3-5 years ago, to an almost complete acceptance not only by the development laboratories, but very importantly, by the telephone administrations. It was also observed that programming for switching machines is vastly different from programming for computers.

2. Telco Acceptance. It was observed that national telecommunication organizations were now talking about the more rapid introduction of electronic switching systems into their operations. This acceleration appeared to be more rapid than indicated in the past.

3. Device Acceptance. There was also less speculation given on the device operation (i.e., did it really work? because the "state of the art" had reached the point where the devices could be counted on to perform their allocated tasks in a reliable fashion. However, one notable exception to this was in the field of memories where much interest and notoriety was given to the use of semiconductor memories, and in some cases, improved ferrite core memories (improved in operating characteristics and, very importantly, in the costs of the device).

4. Programming Language. A move toward utilization of higher level programming languages was noted, and this is prompted by the fact that programming manpower can be saved, as compared to the use of assembly language programs. However, it was also seen that with the use of higher level "MACRO" languages, more real-time of the machine would be utilized and more memory space would be required-- and this increased the cost of the product. The caution, then, was to consider a judicious use of higher level programs, but at the same

time strive for greater programming efficiencies in those cost-bearing areas.

5. PCM Switching. Another trend observed at the symposium was the almost universal move toward PCM switching, especially in the "transit switch" area where the savings are so noticeable. With the move toward integrated PCM switching/transmission in the tandem switching portion of the switching hierarchy, it was apparent that the technological fallout would next be applied to the Class 5 environment. However, it was also thought that the local plant would probably be space-divided, at least that portion facing the telephone sets, for the next several years.

6. Compatibility. Switching systems planned for the future must communicate with existing plant; the new systems cannot exist in a vacuum. This is because of the tremendous amount of investment in plant which cannot be ignored and must be integrated within any new switching plans.

7. Maintenance and Administration. A final trend noted was the centralization and maintenance of administrative functions. Technical Assistance Centers (TAC), as implemented by AT&T or their equivalent, were prevalent simply because this was the only economical way to cope with the very difficult maintenance problem facing not only the Bell System administrators, but all electronic equipment users in future.

With the increasing usage of T-type digital carrier facilities, plus the fact that digital switching concepts are now economically possible and very definitely practical, we see a "digital thread" woven through the fabric of switching development. This will permit the creation of a "family of systems" having intimate compatibility, and permit common maintenance and training methods to be employed by the telcos in a manner never before thought possible.

C.5 LOCAL LOOPS (DISTRIBUTION)

Local loops perform the function of carrying signals between user terminals and the local exchanges. Despite the predominance of transmission costs in local loop expenses, technical progress has been slower in this area than in the telecommunications network as a whole. Moreover, many cities require the telephone company to lay its local distribution cables underground--a procedure for which current technology offers few prospects of significant cost reductions.

Broadband cable systems are substantially limited today to television distribution, but they may be an economic, attractive media for some point-to-point services as well. As a distribution loop. broadband cable represents a substitution of transmission for switching, carrying every signal to every terminal on the loop rather than switching signals only to the terminal for which they are intended. The cable system uses frequency-division switching, where a customer simply tunes in the frequency channel he wants to receive.

When installing cable for television distribution, it is relatively inexpensive to provide additional transmission capacity for other services through increased cable bandwidth, including point-to-point voice traffic. Present TV cables lack a signaling capability which must be provided for point-to-point service; in the near term, such service would be too expensive for individual subscribers, but perhaps, attractive to a few communicators who distribute a large amount of information among a wide local audience.

A broadband loop, equipped to carry digital rather than analog signals, may be substituted for the present local loop configuration. This configuration would have no centralized switching or multiplexing. All signals would be carried on a broadband loop which would have a dropline at each user's terminal. There, a time-synchronized gate would open during the customer's assigned time slot and pass a signal between the terminal and the loop. This system would have the full signaling capabilities of the present telephone network. Some costs may be saved over the present local loop facilities; considerable speculation is involved because this kind

of system depends so heavily on future trends in the cost of LSI circuits. At present, it appears that digital loop distribution systems will be installed subsequent to 1980.

BRIEFS OF RECENTLY PUBLISHED RELATED SUBJECT MATTER

Powers, Robert S. (ed.), The Digital Loop: One Approach to the Wired City, Appendix G, Staff Paper 1 - Part 2, President's Task Force on Communications Policy, PB 184 413, NTIS.

This appendix includes a list of some of the services which might be offered on a general purpose telecommunications system, particularly nonradiating systems in urban areas. It is recognized that a transition will be required from the present paired-wire system or present CATV systems to the general system, which is characterized by coaxial cables carrying multiple digital signals and time division multiplex (TDM).

Not all, but a substantial number of, homes and offices in the nation could be reached by a digital multipurpose system by 1980. The discussion of this subject is based on a number of explicit assumptions as follows:

1. A list of assumed needs for telecommunications service, which are categorized according to the information rate required and whether the service must be one-way or two-way.

2. There is no major technology which will be used on a large scale in public telecommunications systems by 1980 which is not already under development or at least being explored at this date.

3. Solid-state technology will be able to provide large scale integrated circuits (LSIs) of high quality at low cost and in large numbers. This is probably the key assumption in this list and the one least subject to control or precise forecasting.

4. Government regulation and legislation will encourage, or at least permit, the incorporation of new technology into the public telecommunications system.

5. Both the U.S. population and the per capita demand for telecommunications services will expand significantly in the next few decades. (It is predicted that the building plant in the U.S. will double by the year 2000. The doubling time for the telephone network has been about 10 years for several decades.)

The nation's telecommunications system has a vital role to play in the solution to many of our present major problems including education, transportation, air pollution, race relations, probing of public opinion, etc. For example, telecommunications facilities which allow a better approximation of face-to-face contact between individuals and groups of individuals would greatly reduce the need for physically transporting these individuals. If the telecommunication system is to have an optimum impact on these problems, it will have to be very much more versatile than our present telephone-telegraph-radio-TV systems.

A list of needs which might be met by future telecommunications systems follows in Table C-1. These items are categorized by certain required characteristics of the telecommunications systems which will meet the need. One characteristic of highest interest is information rate (bandwidth or bit rate), which assuming no compression (or redundancy removal), corresponds to the categories/bit rates: (l) low (voice), 50 kbps; (m) medium (videophone), 7 Mbps; (h) high (television), 50 Mbps. A second characteristic of highest interest is whether the communication is inherently one-way (entertainment broadcasting), or two-way (telephone conversation).

C.6 TRADE-OFFS AMONG TRANSMISSION SWITCHING AND LOCAL LOOPS

Because transmission costs are falling faster than switching costs, some intermediate switching will be avoided by creating more direct routes. Why route communications from point A to point C through an intermediate switching center (point B), if it becomes relatively more expensive to operate the switching center than to provide transmission routes directly from A to C ? When A-to-C volume becomes large enough, it justifies a direct high-density transmission line between the two points,

Table C-1. Needs for Telecommunications Systems

Needs (service)	Characteristics	
	Rate	Way
Telephone	l	2
TV (commercial or private)	h	1
Stored TV	l or m	1
Radio Broadcast	l	1
Videophone	m	2
Record communications	l	2
Facsimile	m	1 or 2
Shopping	l or m	1 or 2
Advertising	l, m or h	1
Teaching devices	l	2
Voting by the public	l	2
Meter reading (utilities)	l	1
Alarms (fire, burgular, system failure, etc.)	l	1
Emergency communications	l	1 or 2
Banking	l	2
Access to time-share computers	l	2
Communications between computers	l, m or h	2
Mobile communications	l	2
Vehicle traffic control	{ l	2
	m or h	1

exploiting economies of scale. Such economies in transmission and switching will lead to the construction of larger switching centers. This has been shown by complicated calculations involving the relative costs of high- and low-density transmission lines and large and small switching centers. There is a pronounced trend toward consolidating switching centers. Bell is considering dropping one of the upper levels in the switching hierarchy, so that trunk lines which previously came together only after passing through intermediate switching centers will now come together directly.

The advent of domestic communication satellites will significantly alter the trade-off between transmission and switching for some services. The best prospects for these satellites are where they can replace both the transmission and switching functions of the terrestrial network, rather than as a direct substitute only for terrestrial transmission facilities. Satellites are likely to find greater application in the provision of specialized long-haul networks for users with unique requirements, particularly where either the information rate or traffic loading on a given route is subject to wide variations over time.

C.7 TERMINALS

Terminals convert outgoing signals for transmission over the network; for incoming signals the process is reversed. Technical progress has given the telephone handset new capabilities and (through the introduction of the touch-tone phone) the ability to generate a data signal; however, the cost of the terminal function has remained essentially constant. Today, station sets account for more than a fifth of total network costs; as other elements of the network become cheaper while demands on terminals for new services come about, this fraction of costs is likely to rise. Labor expenses are a major portion of terminal costs. The charges for connects and disconnects under current procedures may be reduced by lessening the involvement of service personnel when customers move. Terminals may be simplified by having other parts of the system perform traditional terminal functions; e.g., the ESS may store a list of frequently called numbers and thereby remove from the terminal the burden of providing automatic dialing. The terminal in the home is foreseen

as interactive, providing many new communications services for the family. It is anticipated that cable TV networks will make such a service practical. A breakthrough in terminal design and cost is required.

BRIEFS OF RECENTLY PUBLISHED RELATED SUBJECT MATTER

Baran, Paul, "Potential Market Demand for Two-Way Information Services to the Home, 1970-1990," Report R-26, Menlo Park, Ca., Institute for the Future, December 1971.

A new industry, information services to the home, is expected by some to reach revenues of $20 billion per year by 1990, yet, it is an industry that does not in fact exist and is not even widely recognized. The Delphi inquiry by which market forecasts for possible future have information services were obtained took place in 1970. In the first round questionnaire, respondents were given a list of 30 potential new home information services, as shown in Table C-2. The 30 items were designed to be suggestive of the major types of services currently foreseeable. For each of the items, panelists were asked to give estimates for the following eight service characteristics:

1. Average dollar value of one conversation (low, median, and high estimates)

2. Duration of one entire transaction from completion of dialing to disconnect

3. Percentage of actual transmission of data or message

4. Average number of transactions per month, per home

5. Percentage of service home subscribers could be expected to pay

6. Most likely year of mass introduction in the United States (earliest, median, and latest estimates)

7. Percentage penetration of households 5 years later

8. The most likely entrepreneur to offer this service.

Table C-2. Brief Descriptions of Potential Home Information Services

1. CASHLESS-SOCIETY TRANSACTIONS. Recording of any financial transactions with a hard copy output to buyer and seller, a permanent record and up-dating of balance in computer memory.

2. DEDICATED NEWSPAPER. A set of pages with printed and graphic information, possibly including photographs, the organization of which has been predetermined by the user to suit his preferences.

3. COMPUTER-AIDED SCHOOL INSTRUCTION. At the very minimum, the computer determines the day's assignment for each pupil and, at the end of the day, reviews the day's progress report. At its most complex, such a service would use a real-time, interactive video color display with voice input and output and an appropriate program suited to each pupil's progress and temperament.

4. SHOPPING TRANSACTIONS (STORE CATALOGS). Interactive programs, perhaps video-assisted, which describe or show goods, at request of the buyer, advise him of the price, location, delivery time, etc.

5. PERSON-TO-PERSON (PAID WORK AT HOME). Switched video and facsimile service substituting for normal day's contacts of a middle-class managerial personnel where daily contacts are of mostly routine nature. May also apply to contacts with the public of the receptionist, doctor, or his assistant.

6. PLAYS AND MOVIES FROM A VIDEO LIBRARY. Selection of all plays and movies. Color and good sound are required.

7. COMPUTER TUTOR. From a library of self-help programs available, a computer, in an interactive mode, will coach the pupil (typically adult) in the chosen subject.

8. MESSAGE RECORDING. Probably of currently available type but may include video memory (a patient showing doctor the rash he has developed).

9. SECRETARIAL ASSISTANCE. Written or dictated letters can be typed by a remotely situated secretary.

10. HOUSEHOLD MAIL AND MESSAGES. Letters and notes transmitted directly to or from the house by means of home facsimile machines.

11. MASS MAIL AND DIRECT ADVERTISING MAIL. Higher output, larger-sized pages, color output may be necessary to attract the attention of the recipient--otherwise similar to item 10 above.

12. ANSWERING SERVICES. Stored incoming messages or notes whom to call--possibly computer logic recognizing emergency situation and diverting the call.

13. GROCERY PRICE LIST, INFORMATION, AND ORDERING. Grocery price list is used as an example of up-to-the-minute, updated information about perishable foodstuffs. Video color display may be needed to examine selected merchandise. Ordering follows.

14. ACCESS TO COMPANY FILES. Information in files is coded for security; regularly updated files are available with cross-references indicating the code where more detailed information is stored. Synthesis also may be available.

15. FARES AND TICKET RESERVATION. As provided by travel agencies now but more comprehensive and faster. Cheapest rates, information regarding the differences between carriers with respect to service, menus, etc. may be available.

16. PAST AND FORTHCOMING EVENTS. Events, dates of events, and their brief description; short previews of future theater plays; and recordings of past events.

17. CORRESPONDENCE SCHOOL. Taped or live high school, university, and vocational courses available on request with an option to either audit or graduate. Course or TV, paper support on facsimile.

18. DAILY CALENDAR AND REMINDER ABOUT APPOINTMENTS. Prerecorded special appointments and regularly occurring appointments stored as a program reminder.

19. COMPUTER-ASSISTED MEETINGS. The computer participates as a partner in a meeting, answering questions of fact, deriving correlations, and extrapolating trends.

20. NEWSPAPER, ELECTRONIC, GENERAL. Daily newspaper, possibly printed during the night, available in time for breakfast. Special editions following major news breaks.

21. ADULT EVENING COURSES ON TV. Noninteractive, broadcast mode, live courses on TV--wider choice of subjects than at present.

22. BANKING SERVICES. Money orders, transfers, advice.

23. LEGAL INFORMATION. Directory of lawyers, computerized legal counseling giving precedents, rulings in similar cases, describing jurisdiction of various courts and changes of successful suits in a particular area of litigation.

24. SPECIAL SALES INFORMATION. Any sales within the distance specified by the user and for items specified by him will be "flashed" onto the home display unit.

25. CONSUMERS' ADVISORY SERVICE. Equivalent of Consumer Reports, giving best buy, products rated "acceptable", etc.

26. WEATHER BUREAU. Country-wide, regional forecasts or special forecasts (farmers, fishermen), hurricane and tornado warnings similar to current special forecast services.

27. BUS, TRAIN, AND AIR SCHEDULING. Centrally available information with one number to call.

28. RESTAURANTS. Following a query for a type of restaurant (Japanese, for instance), reservations, menu, prices are shown. Displays of dishes, location of tables, may be included.

29. LIBRARY ACCESS. After an interactive "browsing" with a "librarian computer" and a quotation for the cost of hard copy facsimile or a slow-scan video transmission, a book or a magazine is transmitted to the home.

30. INDEX, ALL SERVICES SERVED BY THE HOME TERMINAL. Includes prices or charges of the above, or available communications services.

In the second round, respondents were given the results of the first round questionnaire and were asked to reestimate all numerical forecasts in light of the other panelists' responses. Table C-3 contains the medians of the panel's responses for each service, as well as additional computed results.

The results are subject to a number of qualifications. The definitions of the 30 items as provided to the panel were brief and in some cases ambiguous; different respondents may have interpreted a given question inconsistently. Therefore, the forecasts should be taken as broad-brush indications rather than precise projections of the new industry's general character. There is overlap between some of the services; the expansion of one service may diminish another. Aggregate market estimates for each category of services probably contain a certain amount of "double accounting." However, the list of 30 is deficient through inadequate foresight, omitting such major services as home security systems and utility meter reading. The principal direction of the report was to possible uses of broadband cable systems; however, the services presented were originally considered in a context where there were no constraints as to the communications medium used. Some parts of the questionnaires did consider new communications networks and techniques for the 1985 time period that could be used for the 30 services and other purposes. Thus, the technological constraints on the hypothesized systems, although not explicit, were to some extent considered by the respondents.

Finally, it should be understood that the data represents only the potential market and not the actual market that costs or technology will permit. The estimates assume that the services can in fact be provided at costs people are willing to pay: these forecasts represent the demand function and not the supply function. More precise estimation of future sales for each service must await a clearer picture of how these services might be provided.

Jones, Martin V., "How Cable Television May Change Our Lives." The Futurist, Vol. VII, No. 5, October 1973, pp. 196-201.

Mr. Jones states that cable television (CATV) makes possible a vast range of two-way information services, such as computerized teaching, thousands of plays

Table C-3. Summary of Median Forecasts

Service	Average $ Value of One Conversation			Duration of Single Trans-action (min.)	Data Trans-mission Connect Time (%)	Avg. No. of Trans-actions/ Mo./Home
	Low	Middle	High			
1. Cashless society transactions	$0.10	$0.16	$ 0.40	0.75	20%	40
2. Dedicated newspaper	0.10	0.20	0.50	10.00	95	30
3. Computer-aided school instruction	0.50	1.50	3.50	30.00	20	20
4. Shopping transactions (store catalogs)	0.20	0.50	1.00	6.00	40	10
5. Person-to-person (paid work at home)	0.50	1.50	5.00	20.00	50	60
6. Plays and movies from video library	0.60	2.00	5.00	90.00	100	10
7. Computor tutor	1.00	2.00	5.00	30.00	20	10
8. Message recording	0.20	0.35	1.00	3.00	75	7
9. Secretarial assistance	0.35	1.00	3.00	10.00	60	10
10. Household mail and messages	0.10	0.20	0.50	2.00	90	25
11. Mass mail and direct advertising mail	0.10	0.17	0.50	3.00	90	25
12. Answering services	0.10	0.20	0.50	2.00	80	20
13. Grocery price list, information, and ordering	0.20	0.35	0.50	5.00	80	15
14. Access to company files	0.30	0.60	2.00	5.00	65	10
15. Fares and ticket reservation	0.20	0.35	0.75	5.00	50	5
16. Past and forthcoming events	0.10	0.20	0.50	4.00	80	10
17. Correspondence school	1.00	2.00	5.00	40.00	85	10
18. Daily calendar and reminder of appointments	0.10	0.20	0.50	1.00	80	25
19. Computer-assisted meetings	1.00	2.00	5.00	30.00	40	5
20. Newspaper, electronic, general	0.20	0.50	0.75	10.00	95	30
21. Adult evening courses on television	0.60	1.00	5.00	50.00	95	10
22. Banking services	0.10	0.25	0.50	2.00	60	20
23. Legal information	1.00	5.00	15.00	10.00	75	5
24. Special sales information	0.20	0.50	1.00	4.00	70	10
25. Consumers' advisory service	0.25	0.50	1.00	5.00	70	10
26. Weather bureau	0.10	0.20	0.50	1.00	90	20
27. Bus, train, and air scheduling	0.10	0.20	0.50	1.25	80	5
28. Restaurants	0.10	0.20	0.50	3.00	80	5
29. Library access	0.50	1.00	2.00	10.00	90	5
30. Index, all services	0.10	0.20	0.50	3.00	80	10

Table C-3. Summary of Median Forecasts (Cont'd)

% of Service Home Subscriber Expected to Pay	Most Likely Year of Introduction Early	Middle	Late	% Penetration of All U.S. Households	Median Transmit Time (min.)	Average Value of Service, $/Subscribing Household/Mo. Median	High	Value of Service After 5 Years, $/Average U.S. Household/Mo. (At Penetration Rates Shown)
25%	1975	1980	1990	20%	0.19	$ 6.4	$ 12.50	$ 1.00
75	1980	1983	1990	10	9.00	6.0	15.00	0.54
50	1975	1982	1987	10	10.00	40.0	100.00	3.75
25	1977	1985	1990	10	2.50	3.0	5.00	0.38
5	1980	1985	1990	5	6.50	75.0	250.00	3.20
80	1975	1980	1985	10	90.00	20.0	50.00	2.00
80	1975	1980	1990	5	6.00	20.0	50.00	1.50
90	1975	1980	1985	10	2.50	2.5	6.25	0.20
100	1975	1980	1985	5	6.00	10.0	25.00	0.25
75	1980	1985	1990	10	1.80	5.0	12.00	0.60
0	1980	1990	1995	10	2.55	4.0	15.00	0.50
100	1975	1980	1985	10	1.60	5.0	11.25	0.30
50	1975	1980	1990	10	4.25	5.0	7.50	0.26
1	1980	1985	1990	2	3.50	15.0	50.00	0.30
40	1975	1980	1985	5	2.50	1.0	2.50	0.05
50	1975	1982	1990	5	2.70	2.0	5.00	0.11
75	1978	1984	1990	5	30.00	20.0	50.00	0.75
100	1980	1983	1985	5	0.95	4.0	10.00	0.20
40	1975	1980	1985	5	6.00	15.0	91.00	0.75
75	1980	1985	1990	5	9.00	15.0	22.50	0.75
80	1975	1980	1985	10	45.00	10.0	25.00	0.88
60	1975	1980	1985	10	0.85	4.0	10.00	0.38
100	1980	1985	1990	3	7.50	6.0	25.00	0.25
80	1975	1982	1990	5	2.70	5.0	10.00	0.25
100	1975	1980	1985	5	3.50	7.5	10.00	0.40
100	1975	1980	1980	5	0.90	2.0	5.00	0.12
80	1975	1977	1980	5	1.00	0.5	1.00	0.06
60	1975	1980	1985	5	2.50	1.0	2.50	0.05
100	1980	1985	1990	5	9.00	5.0	10.00	0.25
50	1975	1980	1985	5	2.50	3.0	5.00	0.10
								$20.12

and movies available whenever one wishes, and electronically delivered newspapers edited specially for the individual reader. Many communications experts believe that CATV will drastically change human life in a wide variety of ways. Table C-4 summarizes the impact of interactive television on life as projected by Mr. Jones.

Further consequences beyond the first-level effects are categorized in the following six headings.

1. General

   - Greater sense of community awareness in small, geographically isolated communities.

   - Increased volume of societal communications: within business and government, within communities, among people at all levels.

   - Reduced sense of national cohesiveness resulting from a fractionalization of TV audiences.

   - Increased national vulnerability potential from action by dissident internal groups or from enemy sabotage.

   - More equitable availability of societal resources: educational opportunities cultural facilities; opportunities to run for public office; etc.

   - Decentralized siting for education.

   - Reduced dependence of suburbanites on the inner city.

   - Increased potential for invasion of privacy.

2. Economic-Industrial-Occupational

   - Stimulated GNP, plant investment, business revenues, and employment.

   - Major industry realignments--over the air TV, movies, etc.

   - Reduced volume of business travel.

Table C-4. The Impact of Interactive Television on Life

Applications	Art-Level Effects
Business-Work at Home	
Computer-Assisted Meetings	Quicker, more efficient management communications
Electronic Mail	Better interface between different business firms
Business-Commerce	
"Cashless Society" Transactions	More convenient shopping
"Dedicated" Newspaper	Better informed business and professional personnel
Political	
Nationwide Voting Surveys and Voting	More responsive public officials
Free Political Channels for Candidates	More candidates in local elections
Government	
Index of government services	More equitable dissemination of authorized public services
Vocational Counseling	Less unemployment due to skill deficiencies
Health	
Remote Diagnosis	More widespread distribution of scarce, expert medical knowledge
Emergency Medical Information	Fewer accidental deaths
Household	
Consumer Advisory Services	Less consumer victimization
Water, Electric, and Gas Meter Reading	Slightly reduced utility rates
Education	
Adult Evening Courses	Better trained workforce
Library Access	Better informed citizenry

- Greater availability of electromagnetic spectrum for non-TV uses such as "land-mobile users" (e.g., police and fire departments, taxis, etc.).

- Increased demand on the local level for TV programming personnel, cameramen, control board technicians, etc.

- Shift in local advertising from newspaper to TV.

- Reduced role of postal service in servicing the nation's transactions and correspondence needs.

- Greater pressure on over-the-air TV to rectify its shortcomings-- e.g., limited consumer choice, poor quality reception, etc.

3. Political

- Heightened political "infighting" at all levels concerning who is to regulate cable TV--federal, state, or local governments and executives vs. legislative bodies.

- Increased lobbying for local cable TV franchises.

- Easier, more equitable access to voters by all political candidates regardless of financial backing.

- Greater trend toward "participatory" government at the expense of "representative" government.

4. Government: Administration

- Need for new quasi-public institutions:

  a. To promote the use of public-access channels

  b. To monitor access to the channels

  c. To represent public in rate formulation

  d. To furnish "seed" money.

- Reduced costs of providing basic community services--fire, police, postal services, etc.

- Reduced problems in administering the "fairness," "right-of-reply," and "equal time" doctrines.

- Increased problems in controlling defamation, fraud, and obscenity.

- A large retraining need for government personnel on how to use the cable effectively in their work.

- New financial problems, e.g., how the poor of the nation will pay for their communications if cable TV replaces or degrades over-the-air TV.

5. Legal

- Pressure for a review of many major legal concepts such as "common carrier" concept, "unfair competition," etc.

- Complicated anti-monopoly problems such as cross-media ownerships.

- Increased copyright litigation and mounting pressure for a major overhaul of the nation's copyright laws.

6. Recreation-Cultural

- More diverse TV programming and enhanced consumer choice.

- Greater trend toward sedentary recreational activity.

- Enhanced opportunities to upgrade skill levels for those who prefer active sports.

- Greater patronage and community support for such activities as operas, concert music, plays, etc.

- Decreased use of books, magazines, and other printed matters.

- Possibilities of electronic equivalent of junk mail.

C.8 MOBILE RADIO

The growth of mobile land radio has been limited by two factors: the shortage of available spectrum, particularly in urban areas where use is heaviest, and the cost

and size of portable receiver/transmitters. A trade-off may be made between spectrum use and cost. The less stringent the constraints on bandwidth, frequency stability, antenna directivity, modulation, and other measure of spectrum use, the less costly the radio equipment can be. A system of mobile radios with multichannel capabilities (more costly) uses less spectrum in achieving a given service level than a system of single channel sets.

The direction of technological advancement is to provide spectrum-saving features at a cost comparable to available sets. By 1980, receiver-transmitters that operate with narrower bandwidths and tighter frequency control are likely to be on the market, and 10-channel sets should cost little more than single-channel sets.

A principal constraint on portable, multichannel mobile radio has been battery weight. The development of solid-state components and integrated circuitry should have made low-power sets practical.

BRIEFS OF RECENTLY PUBLISHED RELATED SUBJECT MATTER

Communications: "Waves of the Future," Newsweek, May 20, 1974, pp. 88-90.

Of the 115 MHz made available, an FCC ruling this month allotted 40 MHz to AT&T and the independent phone companies and 30 MHz to other companies for use in the land-mobile radio industry; the remaining block of the new spectrum is held in reserve to accommodate any new developments or inventions. While no one was completely happy, the ruling almost doubled the spectrum available to the companies. In 5 years, the $500 million market for mobile-radio equipment is expected to top the $1 billion mark. FCC Chairman Richard Wiley called the decision "one of the most significant ever made by the FCC. It offers the communications industry an unparalleled opportunity to virtually revolutionize the land-mobile field."

Bell plans to hook vehicles into a nationwide system allowing them to contact dispatch officers anywhere in the U.S. And, using a "cellular" concept, the giant company will vastly increase the number of subscribers it can serve in a city from

300 to 200,000. To do this, AT&T will use the same frequency in adjoining areas but at very low power so that broadcasts will not interfere with one another.

The other companies may expand dispatch systems for police, firemen, and other users. It will also persuade equipment manufacturers to turn prototypes into commercial products.

"It's a horse race now," says Walter Sutters of the Federal Office of Tele-communications Policy. Motorola hopes to market its 3-pound portable telephone that fits in a briefcase. GE's plans are indefinite, except to supply mobile-telephone equipment and convert its two-way radio to the new frequencies. With room to experiment, according to some experts, it won't be long before investors come up with a practical version of Dick Tracy's two-way wrist radio.

C.9 TELEVISION DISTRIBUTION

The least costly means of distributing TV signals is the existing method: high-power transmitters and tall antenna towers. Little change is foreseen in local broadcasting technology by 1980; it does not appear possible to provide large numbers of TV channels (12 or more) to most viewers through normal over-the-air broadcasting means with existing industry structure and lack of available spectrum.

In considering alternative distribution methods that might increase the number of TV channels, the most interesting technological developments are occurring coaxial cable, in millimeter-wave radio, and in satellites.

Cable television is attractive in densely populated areas where cables need not be laid underground and where there are few natural barriers. Current CATV cables have the capacity to transmit 12 to 25 simultaneous TV signals, depending on distance and repeater spacing. Cable is excessively expensive for reaching isolated viewers, to install in major cities where streets must be dug up, or to cross natural barriers such as rivers and mountains. Millimeter-wave radio or satellites may be used in conjunction with cable to reduce the overall system cost of providing multichannel capability to each viewer.

Millimeter-wave (in the 18 GHz frequency range) radio techniques may provide economical multichannel primary distribution. Using such a system the entire VHF television spectrum (12 channels) can be simultaneously transmitted over distances up to 6 miles, using a 100 MHz bandwidth. Its most attractive prospect is serving as an alternative to coaxial cable:

1. In an urban environment with one transmitter using a fan beam transmitting to many receivers

2. For reaching outlying suburban areas

3. In by-passing natural barriers.

At present the higher cost of such systems limit their potential use to interconnecting localized (block or neighborhood) cable distribution nets to a central distribution point. It is problematical whether or not receiver costs could be reduced sufficiently to make direct broadcast to individual users feasible.

The direct broadcast satellite is cost-competitive only for reaching a very high percentage of television households from a single organization point; it is technically feasible now. The per household costs of the space segment are substantial until the number of houses sharing the cost is large. In addition, if all TV program distribution were by satellite, the viewer would be required to make an additional investment in a receiving antenna, which is estimated to range in cost from $50 to $300 per location.

GLOSSARY

Batch mode

A technique by which items to be processed must be coded and collected into groups prior to processing.

Central processing unit (CPU)

The central processor of the computer system. It contains the main storage, arithmetic unit, and special register groups.

Cross-impact matrix

A technique for examining potential relationships between forecasted events. If there is a cross-impact, the probability of individual items will vary with the occurrence or nonoccurrence of other items.

Cross-support analysis

A matrix display to determine the support effect of each item of a field on all other items. It is used to clarify complex relationships.

Cybernetic

Descriptive of a control system that links human brain and nervous system with mechanical-electrical communication systems, such as computing machines.

Decision tree

A structured study of outcomes represented by branches with assigned probabilities and costs. As the various possibilities are considered at branch nodes, deterministic or probabilistic judgments are made. Evaluation is made by finding "best" route down the tree, i.e., working backward through the developed tree.

Delphi conference

A Delphi procedure where conferees are linked by computer which provides essentially real-time discussion feedback, yet preserves panelists anonymity.

Exploratory

An approach to forecasting that is sequential from data of the past.

Gaussian distribution

The most important frequency distribution in statistics. A symmetrical bell-shaped curve also called the normal distribution.

Gross National Product (GNP)   The sum of all goods and services produced and paid for by a nation - including services supplied by Government.

Interactive mode   Usually a real-time, on-line computer operation where there is a high degree of man-machine interaction.

KSIM   A simulation language developed by Julius Kane for logical expression of cross-impact concepts and capable of stating in a realistic and graphic fashion the interaction of competing variables.

Monte Carlo trial   An iteration of the same forecasting model, each of which changes the inputs of the model in accordance with random values drawn from the probability distributions of the inputs.

Normative   An approach to forecasting that is "needs oriented." Having stated goals or objectives, the forecast works backward to the present to see what capabilities now exist or could be extrapolated to meet future needs.

Ontological   Investigating the nature, essential properties and relations of being, interpreted as self-generating or "inner-directed."

Outliers   Those values in a set of individual values that appear to differ considerably from the others (statistical).

Packet-switched data   Digital transmission of messages by packets consisting of a fixed number of bits. Packets are transmitted when ready and assembled at destination.

Policy Delphi   A Delphi study or exercise devoted to examining policy issues.

Quartile   The three points of a frequency distribution that divide the distribution into four parts.

Signal/Noise (S/N) ratio

The relative strength of a wanted signal to that of the noise interference present, the ratio being normally expressed in decibels.

Teleological

The fact or the character of being directed toward an end or shaped by a purpose.

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