REPORT ON A LONG-RANGE FORECASTING STUDY

T. J. Gordon
Olaf Helmer

September 1964

P-2982

REPORT ON A LONG-RANGE FORECASTING STUDY

T. J. Gordon

Consultant to The RAND Corporation, Santa Monica, California

Olaf Helmer

The RAND Corporation, Santa Monica, California

September 1964

SUMMARY

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

This report describes an experimental trend-predicting exercise covering a period extending as far as fifty years into the future. The experiment used a sequence of questionnaires to elicit predictions from individual experts in six broad areas: scientific breakthroughs, population growth, automation, space progress, probability and prevention of war, and future weapon systems. A summary of responses from each round of questionnaires was fed back to the respondents before they replied to each succeeding round of questionnaires.

Results of the experiment illuminate a number of points: the contents of the predictions themselves, the bases on which respondents claimed their predictions were made, the spread of expert views, the convergence of views

following data feedback, the experts' critiques of each other's views, and not least of all, the weaknesses of the method and the possible means for improving it.

The report also discusses potential objections that may be leveled at this approach: its inherently insufficient reliability; its tendency to produce self—fulfilling or self—defeating prophecies which would make it both undesirable and unreliable; the sensitivity of results to ambiguity of questions; the difficulty of assessing and utilizing the degree of expertise; and the impossibility of taking into account the unexpected. One must judge the merits or promise of an approach such as this in terms of the alternatives available. These same objections generally apply with even greater force to less systematic means of using any intuitive judgment. Moreover, it does appear that some of the observed or suspected defects in the method can be eliminated on the basis of what has been learned from this experiment.

No claims are made, or can be made, for the reliability of the predictions obtained here. However, inasmuch as they reflect explicit, reasoned, self—aware opinions, expressed in light of the opinions of associate experts, such predictions should lessen the chance of surprise and provide a sounder basis for long—range decision-making than do purely implicit, unarticulated, intuitive judgments.

A few thought—provoking examples of the predictions that were elicited are the following:

> The implication that the water—covered portions of the earth may become important enough to warrant national territorial claims.
>
> The values assigned for the probability of another major war. (E.g., medians: 10% in 10 years; 25% in 25 years. Most likely cause: escalation.)

The absence, on the one hand, of significantly new ideas for the prevention of war, and the confidence, on the other, that the application of what may be called traditional proposals could reduce the probability of war significantly.

The possibility that continued developments in automation will result in serious social upheavals; the almost complete acceptance of the necessity of regulative legislation.

The strong likelihood of the emergence of weapons of a nonkilling, nonproperty-destroying nature, covert perhaps, attacking on the psychological or biological level.

The eventual abundance of resources of energy, food, and raw materials, but also the possibility that a continuing inequitable world distribution of these assets to the increasing world population may furnish a persisting stimulant to warfare.

ACKNOWLEDGMENTS

Among the many persons who contributed to this study, the greatest share of the credit must go to our questionnaire respondents, both within and outside of RAND, for their wisdom, patience, and constructive criticism. Numerous colleagues and RAND consultants offered helpful advice; among them we would like to mention especially Norman Dalkey, James DeHaven, Oskar Morgenstern, Ed Quade, and Milton Weiner. Two of our overseas respondents, whom one of the authors had the pleasure of contacting personally, were particularly helpful and encouraging—namely, Professor Dennis Gabor and Monsieur Bertrand de Jouvenel. To Arthur L. Shef we express our thanks for helping us pre-test the first set of questionnaires. Much of the burden of recording and analyzing the responses was carried by Bernice Brown, to whom we would like to express our very special gratitude. Jan Kurtz and Margaret Ryan contributed help by abstracting material and preparing graphical displays. Ann Rierson deserves our particular thanks for handling with admirable patience and reliability the inordinate volume of correspondence in connection with this project.

CONTENTS

REPORT ON A LONG-RANGE FORECASTING STUDY

1. INTENT

This is a report on an experiment in forecasting which has been conducted during the past twelve months. ("Forecasting" is used here in the sense of mapping out possible futures, as distinguished from "predicting" a single future.) The intended purpose of this undertaking was both substantive and methodological.

Substantively, our interests lay in assessing the direction of long-range trends, with special emphasis on science and technology, and their probable effects on our society and our world. Here, by "long-range" we had in mind something of the order of ten to fifty years. Our natural curiosity in this regard was enhanced by an awareness of the fact that our work at RAND is in many instances closely related to plans and policies affecting the rather distant future, and that consequently the direction of our studies and the substance of whatever recommendations may result from them are inevitably influenced by our concept of the shape of things to come.

Methodologically, we found ourselves confronted by a near-vacuum as far as tested techniques of long-range forecasting are concerned. Here our hope was to sharpen the few systematic methods that are available and, through practical experience, to gain some insight into specific needs for further methodological research.

Depending on one's point of view, a project such as this may be considered predestined to failure because of its over-ambitious scope, or predestined to success because even very little progress in so important and neglected an area is bound to be of value in the design of long-range plans. Actually, the outcome of this experiment has in no way been spectacular. Yet we hope that the reader of this report will agree with us that our undertaking has indeed been mildly successful, in the sense that our findings

represent a beginning in the process of sifting the likely from the unlikely among the contingencies of the future, and that we have obtained some hints as to how such efforts can be conducted more effectively hereafter.

Future events can be considered as roughly belonging to one of two sets: the expected and the unexpected. A study such as this cannot hope to uncover the unexpected, spectacular, unanticipated breakthroughs, but must concentrate on narrowing down the dates and circumstances of occurrences which can be extrapolated from the present. We recognize this as a shortcoming of our present study. Nevertheless, some of the substantive predictive material was, to the experimenters at least, unexpected. In that sense, the future may now hold fewer surprises for some of us.

2. SUBJECT MATTER

Among the many features of the world of the future that are competing for exploration, we had, for the sake of sheer manageability, to select only a few. Our choice, while somewhat arbitrary, was guided by the desire to have a collection of areas which in combination would provide broad (though not exhaustive) coverage of the most important determinants of the society of the future. We finally decided upon the following six topics:

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

In seeking out the future trends in these areas, we were of course well aware that we would not through some miracle be able to remove the veil of uncertainty

from the future. This did not seem to us to imply, though, that it is altogether impossible to make meaningful assertions of substantive content about the future.

The reliability with which the future can be predicted is a matter of degree. In planning our daily lives, we are accustomed to predicting the immediate 24-hour future with a reasonable degree of certainty. Plans as far as a year ahead—say, concerning the budget of a family, or of a firm, or of the federal government—although afflicted with a noticeable degree of uncertainty, still are recognized and accepted as a highly reliable means of regulating our lives. Even if the planning horizon is five to ten years away, as it is with many major governmental decisions, standard trend projections, obtained by extrapolation from the recent past and from knowledge of current activities, usually provide fairly reliable results. Nevertheless, in employing past and present trends as indicators of the future, we begin to be strongly aware of the need for judicious intuitive assessment.

For the more distant future, as the uncertainties grow, increased reliance on intuitive (as opposed to theory-supported) contingency forecasts becomes inevitable. Yet this does not deter us from planning ten to fifty years ahead, as evidenced by our public policies regarding such matters as educational institutions, urban renewal, aid to developing countries, procurement of military weapon systems, space exploration, and so on.

In view of such common practice of long-range planning, which both affects the ten- to fifty-year future and is itself influenced by our expectations regarding the world

at that time, it seems reasonable to adopt a pragmatic attitude: Since the use of intuitive forecasting as a basis for long-range planning is unavoidable, we should at least make an effort to obtain this intuitive judgment as systematically as possible from persons who are recognized experts in the area of concern. Until a satisfactory predictive theory of the phenomena in question becomes available, it would seem that any improvement in reliability, however slight, that could be achieved by replacing casual guess with the controlled use of intuitive expertise would be desirable because of the benefits that long-range public policies might derive from it.

These potential benefits are likely to grow with each decade; for, because of the ever more explosive rapidity with which new technological developments are apt to take hold, it becomes increasingly important to foresee the advent of such impacts in order to prepare for their social consequences and to avert possible calamities.

It is this potentially large payoff from even minor advances in the reliability of trend forecasting—not to mention man's natural fascination with the idea of exploring the future regardless of any tangible returns (just like exploring the Moon)—which we offer as justification for the present effort.

Our procedure, if we are fortunate, might even succeed incidentally in crystallizing the nucleus of a predictive theory of the subject matter under inquiry, by goading the experts from whom we solicit opinions

into formulating some of their perhaps hitherto unarticulated reasons for these opinions. Thus we hope that an effort such as ours may go beyond merely filling a temporary gap and set into motion analytical thought processes which eventually might lead to the formulation of a scientific theory regarding the phenomena in question.

3. METHOD

The method which we have employed for the systematic solicitation of expert opinions is the so—called Delphi Technique.* Instead of using the traditional approach toward achieving a consensus through open discussion, this technique "eliminates committee activity altogether, thus ... reducing the influence of certain psychological factors, such as specious persuasion, the unwillingness to abandon publicly expressed opinions, and the bandwagon effect of majority opinion. This technique replaces direct debate by a carefully designed program of sequential individual interrogations (best conducted by questionnaires) interspersed with information and opinion feedback derived by computed consensus from the earlier parts of the program. Some of the questions directed to the respondents may, for instance, inquire into the 'reasons' for previously expressed opinions, and a collection of such reasons may then be presented to each respondent in the group, together with an invitation to reconsider and possibly revise his earlier estimates. Both the inquiry into the reasons and subsequent feedback of the reasons adduced by others may serve to stimulate the experts into

*N. Dalkey and O. Helmer, "An Experimental Application of the Delphi Method to the Use of Experts," Management Science 9, 1963.

taking into due account considerations they might through inadvertence have neglected, and to give due weight to factors they were inclined to dismiss as unimportant on first thought."*

In line with this program, we selected 6 groups of experts, one each for the 6 areas to be surveyed (see Section 2 above). Of the approximately 150 persons approached, 82 responded to one or more questionnaires. Of these, 35 were members of RAND, 7 others were RAND consultants, and the remaining 40 were not connected with RAND; 6 of these 40 were European respondents. Some of the participants responded voluntarily also to questionnaires submitted to other panels. (It was our practice, in order to keep the participants informed of all phases of the experiment, to send copies of the questionnaires for all 6 panels to each respondent, distinguishing that addressed to his own panel by a special color of paper.)

Each panel of experts answered 4 sequential questionnaires, spaced approximately 2 months apart. The average number of filled-in questionnaires received from each panel per round was 14.5 (making a total of $6 \times 4 \times 14.5$, or 348).

Details about the respondents and reproductions of the relevant parts of the 24 questionnaires are given in the appendix to this paper.

4. ILLUSTRATION OF PROCEDURE

To illustrate our procedure, we will give the details of a small segment of the inquiry conducted with the help of Panel 1 on Scientific Breakthroughs.

---

*See "On the Epistemology of the Inexact Sciences," by O. Helmer and N. Rescher, Management Science 6 (1959), p. 47.

In the opening round we addressed the following question to the panel:

> Questionnaire 1.1.
>
> 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.

Collation and paring of the responses led to a list of 49 items, which were presented to the panel in the next round (Questionnaire 1.2) with a request to indicate, for each item, the probability of actual implementation in each of the following time intervals:

1963–65	1972–78	1997–2013
1965–68	1978–86	Later than 2013
1968–72	1986–97	Never

Three examples of the 49 items were these:

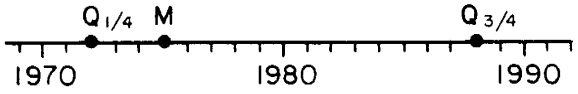
B1. Chemical control over heredity – molecular biology.
S8. Popular use of personality control drugs.
P10. Reliable weather forecasts.

For each item, each respondent's probability distribution over time obtained from Questionnaire 1.2 was used to determine approximately the year by which the item, in his opinion, had a probability of 50% of being implemented.

For the three illustrative items, these "50%-years" had the following medians and quartiles:

	Median	Quartiles
B1	1993	1982-2033
S8	2050	1984-2050
P10	1975	1972-1988

In the case of P10, for instance, this means that one quarter of the respondents thought that the date by which P10 had an even chance of occurring would be prior to 1972



(the lower quartile), and similarly that one half thought it would be prior to 1975 (the median), and one quarter that it would be later than 1988 (the upper quartile).

On the basis of findings such as these, it was judged that for 10 of the 49 items (Item P10 among them) there existed a reasonable consensus among the respondents. This consensus was announced to the respondents in Questionnaire 1.3, together with an invitation to take exception if they differed strongly from this majority consensus:

> P10 (Reliable weather forecasts): Not within 5 but within 35 years.
>
> Do you, by and large, agree with the opinion represented by the consensus...? If you disagree ..., briefly state your reason for your differing opinion.

As for the remaining 39 items, on which an insufficient consensus had been observed, the experimenters at this point used their discretion in singling out a subset of 17 items which they thought to be deserving of further exploration. These were presented once more to the panel, together with an indication of the consensus status to date and a request for a statement of reasons for opinions differing from those of the majority. In some cases the item was reworded, because it was felt that the ambiguity of the original phrasing, rather than any factual disagreement among the participants, might have been partly responsible for the

observed divergence of responses. (This contention was supported, in various instances, by explicit comments to this effect from the respondents.) In the case of our examples, B1 and S8, Questionnaire 1.3 followed up thus:

	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.
B1	Feasibility of chemical control over hereditary defects through molecular engineering	Consensus that it will occur; disagreement as to when			Why before 1987 or after 2013?
S8	Widespread socially accepted use of non-narcotic 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)?

The responses now had the following medians and quartile ranges:

	Median	Quartiles
B1	2000	1989–2015
S8	2000	1980–2033

We notice that in both cases the quartile range narrowed, while the median shifted to a somewhat later year for B1 and to a considerably earlier year for S8. Our sample was too small and unstable to permit us to trace such changes to specific causes. (The instability of the sample had two causes: the long interval between questionnaires, and changes in the composition of the panel.) We may merely conjecture that the sharpening in wording of the questions contributed to the narrowing of the quartile ranges; whether this also produced the shift in medians is even more uncertain.

The procedure for composing the last questionnaire in the series, 1.4, was similar to that used in the preceding cycle: Elimination of a few additional items, announcement

of a satisfactory consensus on some, and restatement (possibly again involving actual rewording) of the remainder. Both of our illustrative items were judged to need such reconsideration. In this case, the information given to the panel comprised both a statement of the majority opinion and an indication of the reasons for a deviating opinion on the part of a minority. As far as B1 and S8 were concerned, the questionnaire appeared as follows:

	Description of potential breakthrough	Majority consensus to date	Minority opinion	50%-year	90%-year
B1	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		
S8	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		

This time the outcome was as follows:

	Median	Quartiles
B1	2000	1990–2010
S8	1983	1980–2000

Thus, for B1 the median remained unchanged and the quartile range shrank a little further; in the case of S8, the median was now even earlier than before and the quartile range shrank considerably. In both cases we now had what may be considered a reasonably narrow consensus.

5. THE SUBSTANTIVE OUTCOME: INTRODUCTORY REMARKS

Having illustrated our procedure through the cases of these three representative items, we now present the prima-facie predictions by our panels, and then return later

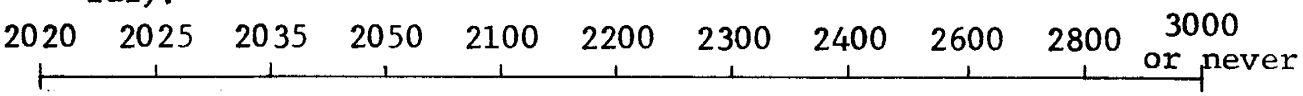
to a discussion and critique of the method. The reader is cautioned, however, to regard the data about to be listed with some reservation. It consists of summaries of considered opinions about the future by a small group of people, each an expert on some, but not necessarily all, of the subjects under inquiry. There is no question but that more reliable predictions could have been obtained with a greater effort and a wiser group of experimenters. We shall try to indicate later, through retrospective wisdom, how we believe that an effort such as this can be improved to the point where it might become a more reliable and valuable planning tool.

6. PREDICTED SCIENTIFIC BREAKTHROUGHS

Panel 1's predictions of scientific breakthroughs are summarized in graphical form on the following page. This is done here and throughout in terms of the "break-even" date, that is, the date for which there is an equal expectation that the event in question will materialize before or after it.

Each bar on the graph extends from the lower to the upper quartile of responses, the peak indicating the position of the median. The events are ordered according to the median date.

The time scale beyond 2020 has been foreshortened. The reader may wish to interpret the interval to the right of 2020, as we have done, as follows (although precise dates that far in the future are clearly not very meaningful):



In addition to specific substantive breakthroughs, the panel was interrogated regarding potential developments in the organizational and operational methods of scientific investigation. There was a strong consensus that the

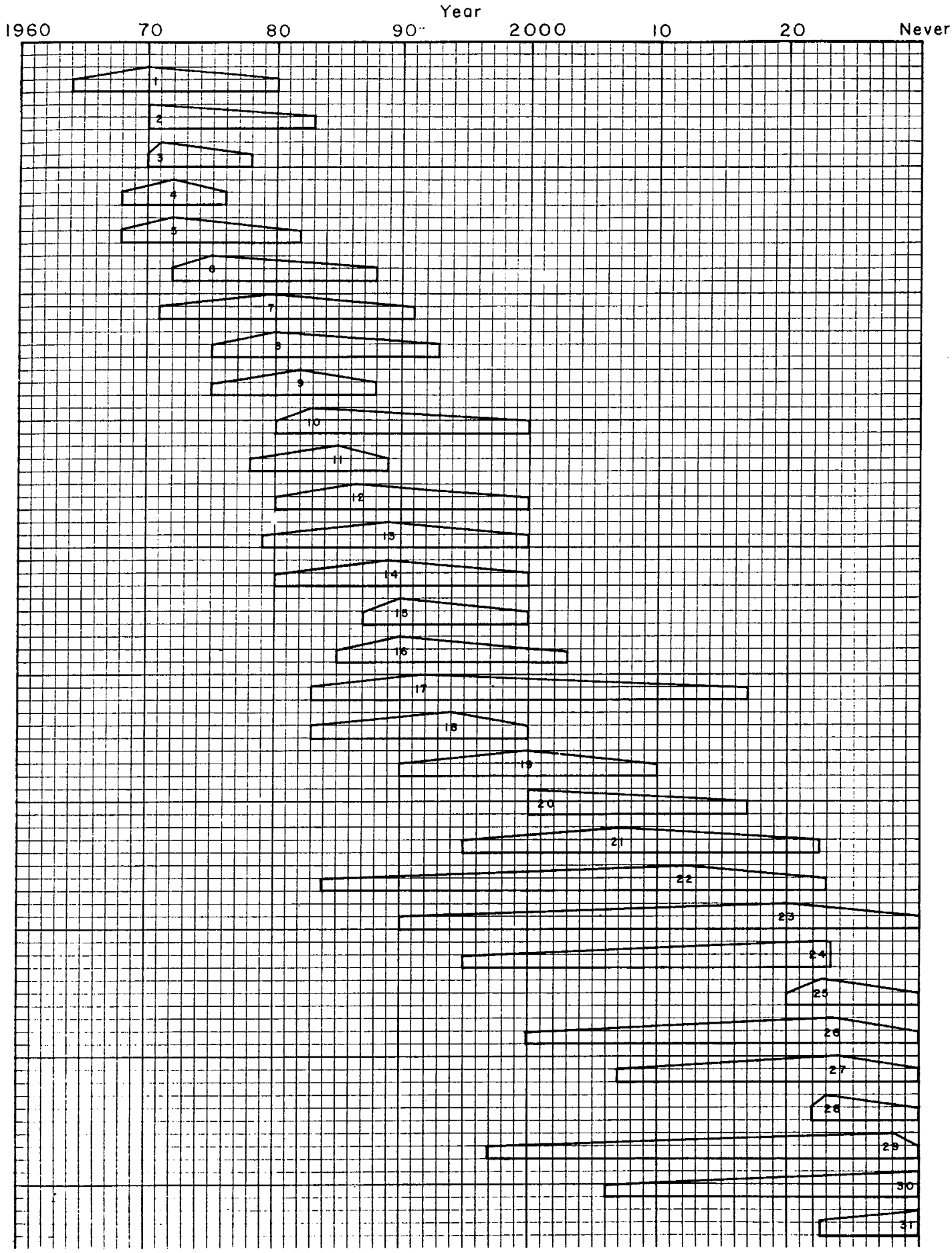


Fig. 6.1 – Consensus of Panel 1 on scientific breakthroughs (medians and quartiles)

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

following four, among eight taken into consideration, represent desirable trends which are likely to occur:

Reform of present modes of scientific communication through the use of automated information retrieval systems.

Reorientation of scientific methodology toward greater interdisciplinary cooperation.

Increased emphasis on basic research in government-supported R and D.

Reformation of educational processes toward an increased interdisciplinary understanding of science.

7. PREDICTED POPULATION TRENDS

The questions addressed to Panel 2, on Population Control, were concerned with world population growth between now and the year 2050. The following four graphs (Figs. 7.1–7.4) exhibit the median and quartile curves derived from the panel's predictions for the birth rate, the death rate, the net-growth rate (= birth rate minus death rate), and the population size.

The population curves in Fig. 7.4 were derived as follows: From the responses of each individual we determined approximately what, according to him, the population would be as a function of time; for each year t between the present and 2050, we then selected the median and quartiles of these predictions.

An obvious alternative method is to use the three net-growth rate curves shown in Fig. 7.3 and to compute the corresponding population curves; the result is shown in Fig. 7.5, and is seen not to differ significantly from that in Fig. 7.4.

We note that the population trend forecast by our panel is considerably more conservative than estimates obtained by straightforward extrapolation from past population growth, as shown by Fig. 7.6, where the shaded area, lying entirely below the projected curve, represents the quartile range of the panel's forecast over the next 87 years.

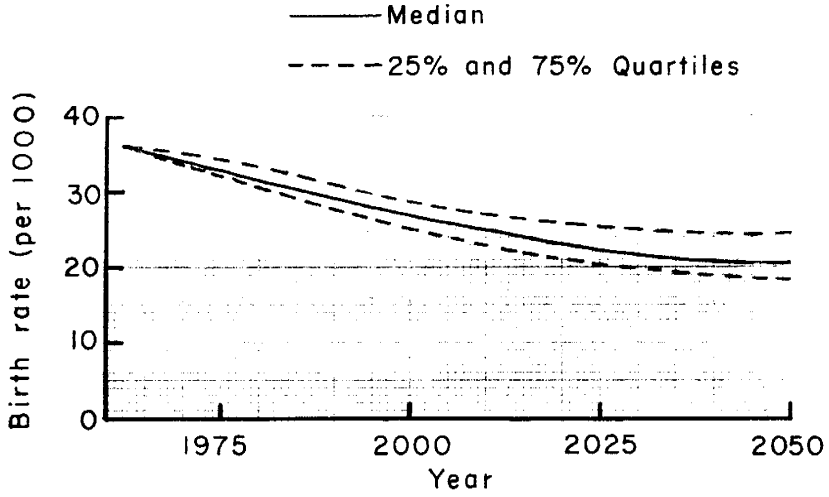


Fig. 7.1 — Birth rate per thousand

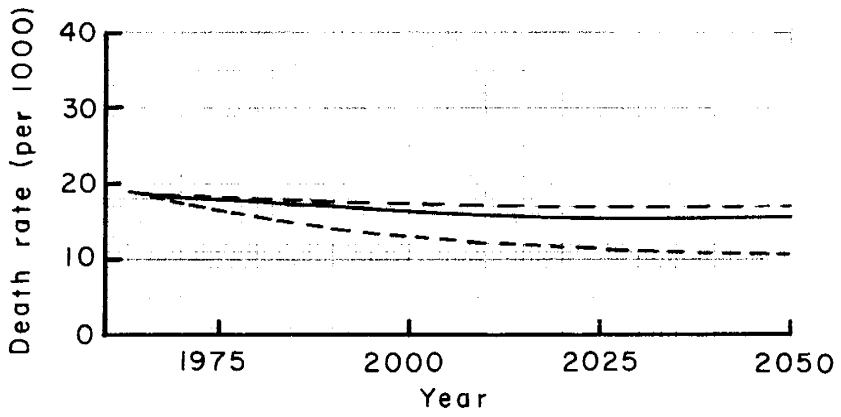


Fig. 7.2 — Death rate per thousand

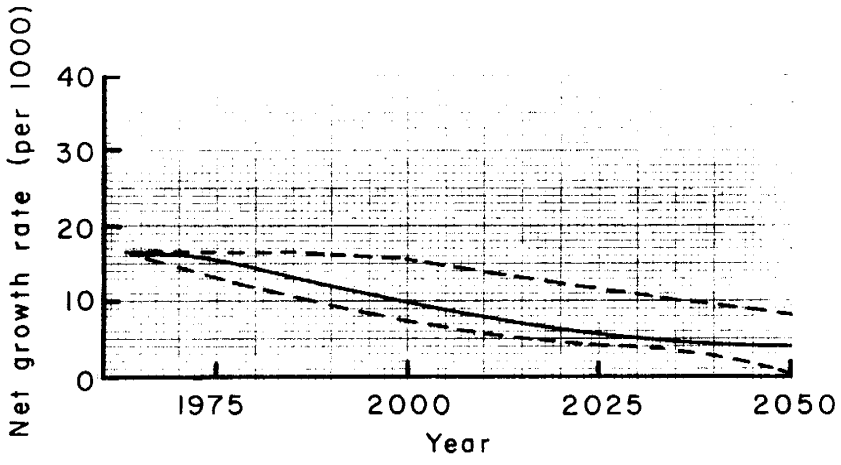


Fig. 7.3 — Net growth rate per thousand

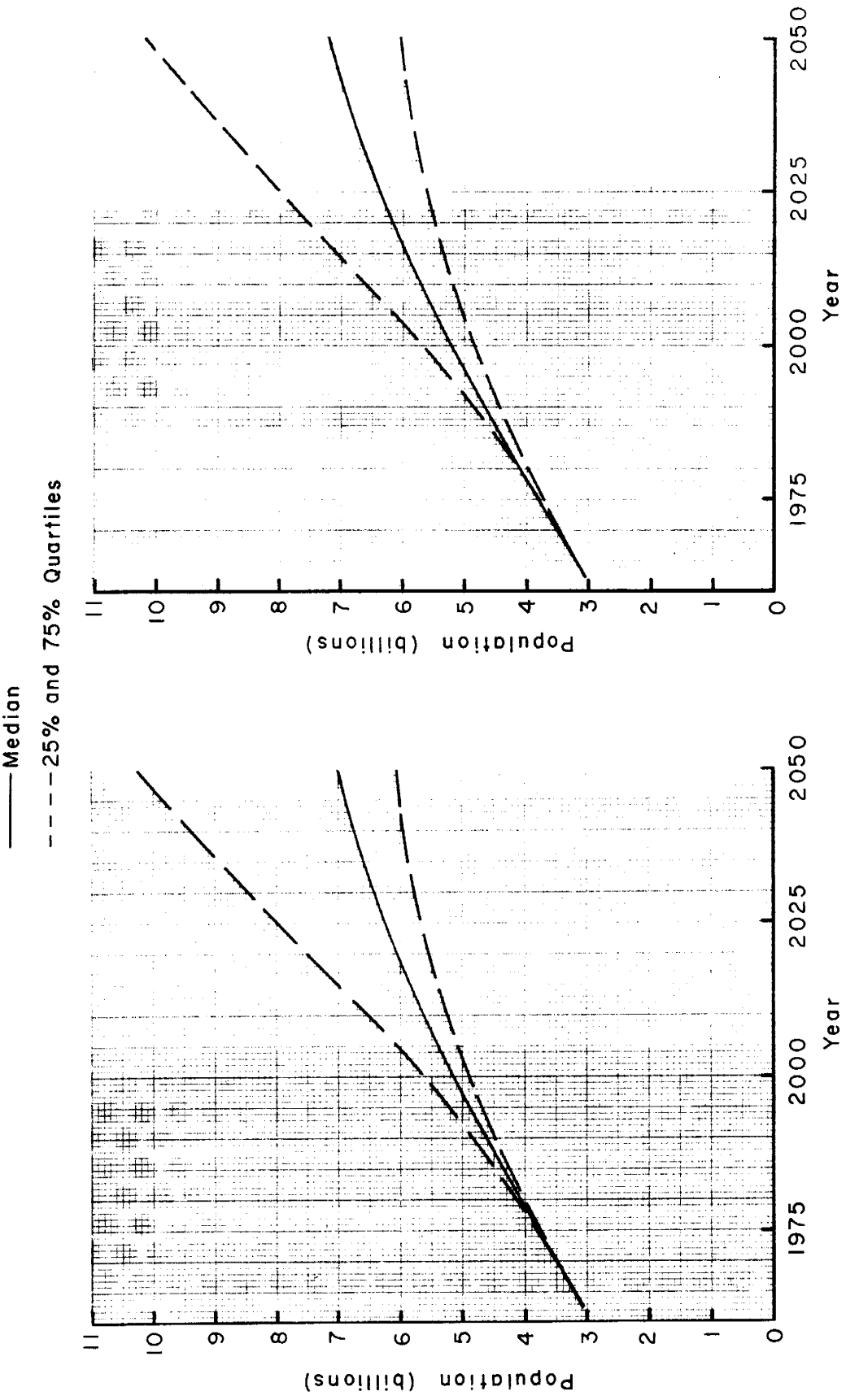


Fig. 7.4 — Population estimate (first method)

Fig. 7.5 — Population estimate (second method)

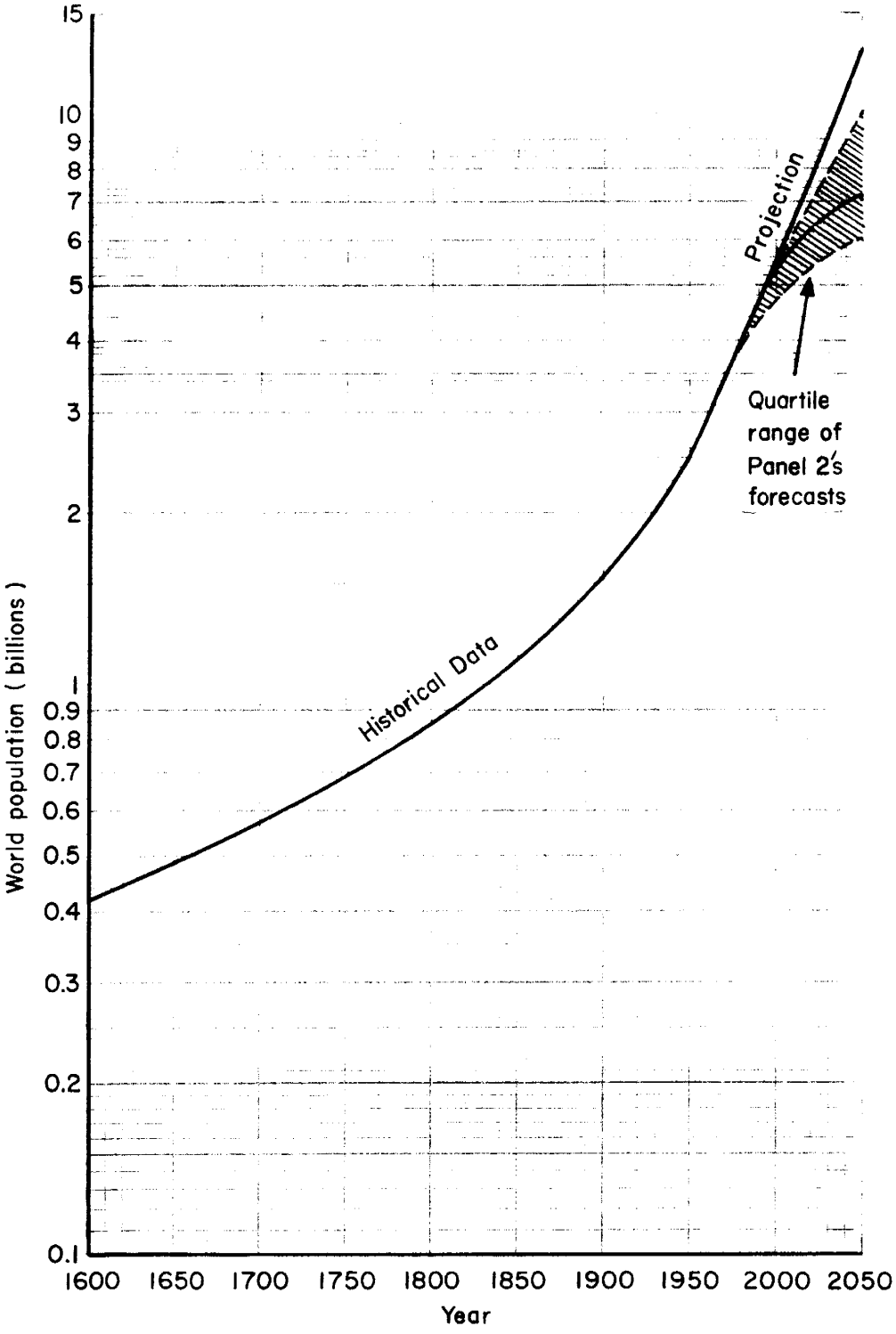


Fig. 7.6 — World population from 1600 A. D.

We did inquire into the reasons for the opinions reflected in these relatively low population estimates.

Not surprisingly, the following three factors emerged as the principal ones affecting birth and death rates, and consequently population:

(i) the degree of acceptance of birth control measures;

(ii) the rate of further medical progress;

(iii) advances in the production and distribution of food.

Of these, judging by the variance of responses, the first seems to be the least predictable. There was much more of a consensus regarding predictions of the availability (as opposed to the acceptance) of birth-control measures. This, incidentally, was confirmed by the Science panel (Panel 1), which predicted the general availability prior to 1980 of simple and inexpensive means of fertility control.

Further medical advances (Item (ii) above) were seemingly generally accepted as a matter of course. The consequent drop in the death rate will be attenuated, in the opinion of most respondents, by insufficient advances in the production and distribution of food (Item (iii)). A minority even predicted famine conditions and a consequent eventual sharp rise in the death rate.

These misgivings regarding food production and distribution should perhaps be examined in the light of relevant forecasts made by the Science and Automation panels (1 and 3). According to Panel 1, commercially efficient production of synthetic food may be expected within 40 years, to be augmented in the early part of the next century by large-scale ocean farming. In spite of this forecast of food abundance for even a much enlarged world population, there may still be an ominous gap between potential and effective availability of food for all, because, according to the view expressed by Panel 3, an effective world-wide system of food distribution may not be implemented until later in the twenty-first century.

In view of such facts as the uncertainty regarding large-scale acceptance of birth control measures, the comparative certainty of further medical progress, and the doubts about equitable food distribution, one cannot help but wonder whether the panel's forecasts (which in the median suggest a nonfamine-induced levelling off of the population curve) would have remained quite so optimistic, had the Delphi process of examining the reasons for proffered opinions been carried through another round or two.

8. AUTOMATION PREDICTIONS

The predictions by Panel 3 regarding major developments in the field of automation are summarized on the following page, in the same graphical form we used for Panel 1. Each bar again extends from the lower to the upper quartile of the responses and peaks at the median. The foreshortened scale beyond 2020 was explained in Section 6.

In addition to technological progress in automation, the panel was asked to give some thought to the problem of unemployment resulting from automation. Almost all respondents agreed that the problem is a very serious one. While one third of the panel felt that social upheavals will accompany automation, the majority opinion indicated that suitable counter-measures, taken either preventively or at least therapeutically, will forestall severe social disruptions.

Ten counter-measures, proposed by the panel members themselves, were appraised by the panel with regard to: (1) potential effectiveness in reducing unemployment, (2) overall desirability, and (3) the probability of actual implementation. The averages of the appraisals concerning these three aspects turned out to be highly correlated, as shown by the following tabulation of results, in which the measures at the top of the list are considered effective, desirable, and probable, while those at the bottom are

1. Increase by a factor of 10 in capital investment in computers used for automated process control
2. Air traffic control—positive and predictive track on all aircraft
3. Direct link from stores to banks to check credit and to record transactions
4. Widespread use of simple teaching machines
5. Automation of office work and services, leading to displacement of 25% of current work force
6. Education becoming a respectable leisure pastime
7. Widespread use of sophisticated teaching machines
8. Automatic libraries, looking up and reproducing copy
9. Automated looking up of legal information
10. Automatic language translator—correct grammar
11. Automated rapid transit
12. Widespread use of automatic decision-making at management level for industrial and national planning
13. Electronic prosthesis (radar for the blind, servomechanical limbs, etc)
14. Automated interpretation of medical symptoms
15. Construction on a production line of computers with motivation by "education"
16. Widespread use of robot services, for refuse collection, as household slaves, as sewer inspectors, etc.
17. Widespread use of computers in tax collection, with access to all business records—automatic single tax deductions
18. Availability of a machine which comprehends standard IQ tests and scores above 150 (where "comprehend" is to be interpreted behavioristically as the ability to respond to questions printed in English and possibly accompanied by diagrams)
19. Evolution of a universal language from automated communication
20. Automated voting. in the sense of legislating through automated plebiscite
21. Automated highways and adaptive automobile autopilots
22. Remote facsimile newspapers and magazines, printed in home
23. Man-machine symbiosis, enabling man to extend his intelligence by direct electromechanical interaction between his brain and a computing machine
24. International agreements which guarantee certain economic minima to the world's population as a result of high production from automation
25. Centralized (possibly random) wire tapping

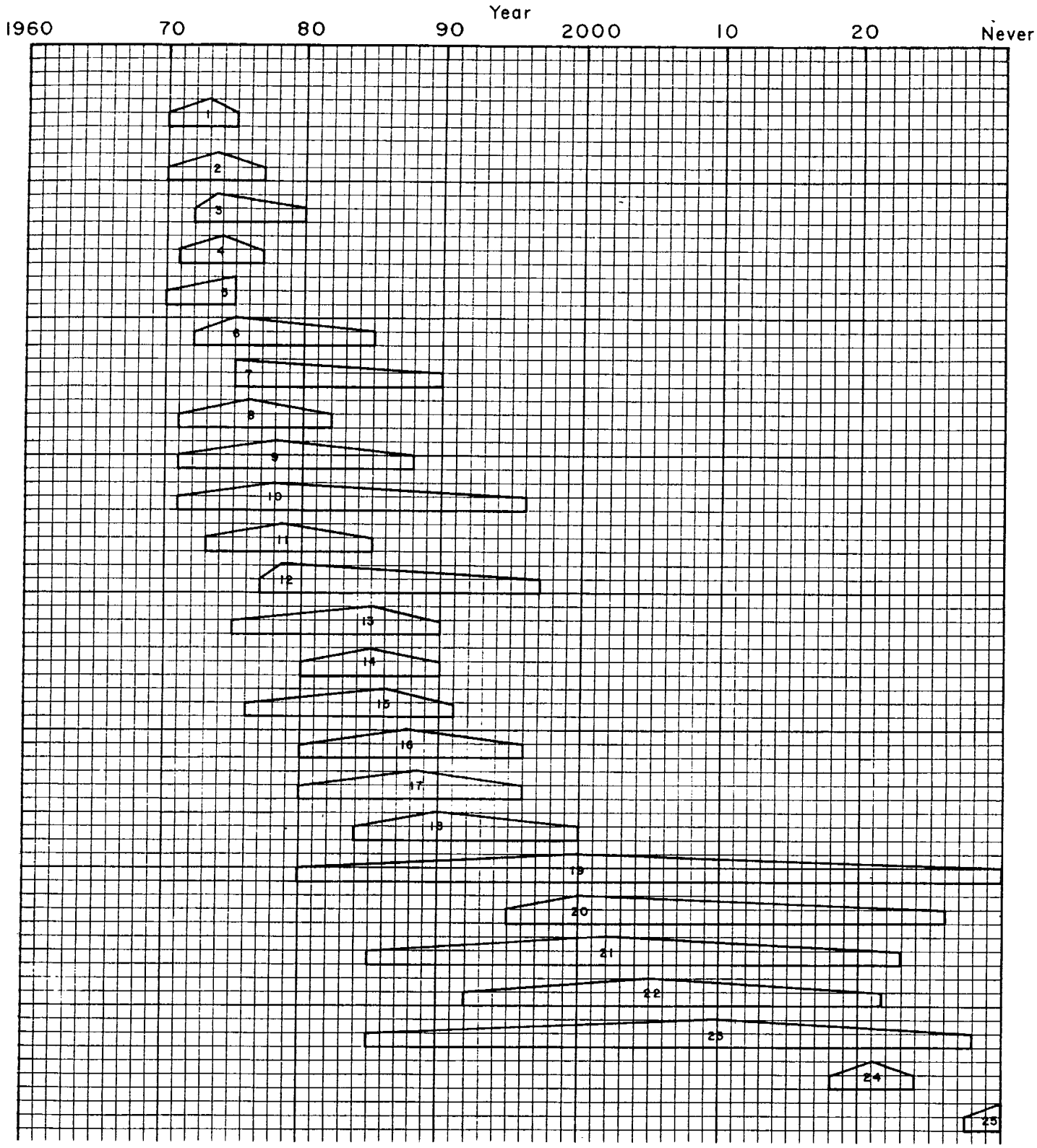


Fig. 8.1 – Consensus of Panel on automation
(medians and quartiles)

considered ineffective, undesirable, and improbable:

Proposed Measure	Average Effectiveness	Average Desirability	Average Probability
Creation of new types of employment	mod/high*	high	mod/high
Retraining of persons unemployed through automation	mod	mod/high	high
All-out vocational training program	min/mod	mod/high	mod/high
Education for better leisure-time enjoyment	min/mod	mod/high	mod/high
Massive aid to underdeveloped regions (including parts of the United States)	mod	mod	mod
Two years of compulsory post-high school education	mod	mod	mod
Legislation shortening the work week by 20%	min/mod	neut/mod	mod/high
Massive WPA-type programs	min/mod	neut	mod
Legislation lowering the retirement age by 5 years	min/mod	neut	mod
Legislation protecting household and service jobs from automation	nil/min	neg	min

*mod = moderate
min = minor
neut = neutral
neg = negative

9. PREDICTED PROGRESS IN SPACE

A graphical summary of predicted progress in space is given on the next page. We note that for events whose median break-even dates are within the next 15 years, the quartile ranges are remarkably narrow, reflecting no doubt the rather firm timetable of near-future space achievements to which our space specialists expect to adhere.

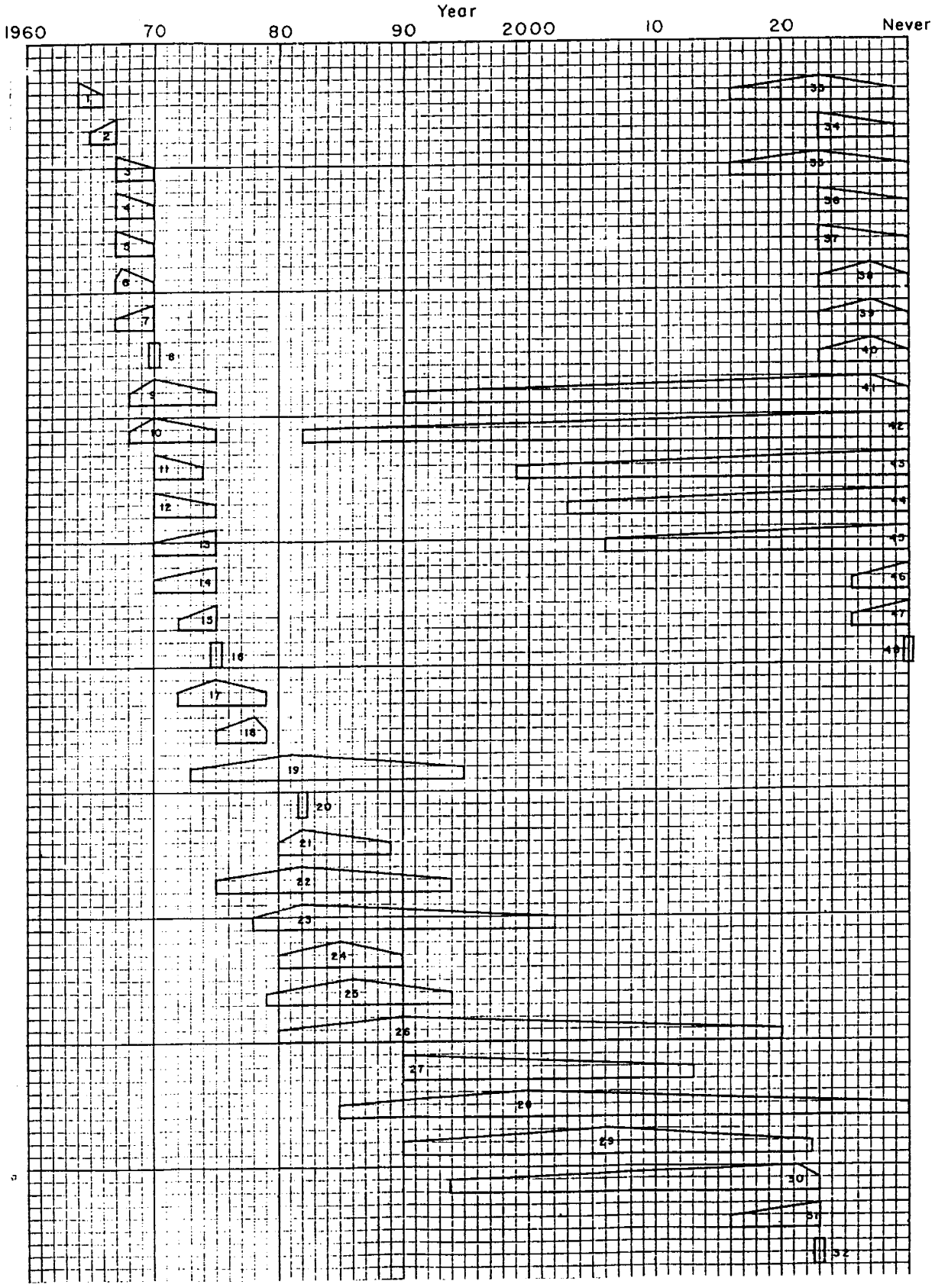


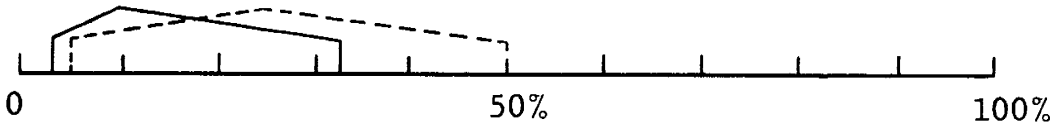
Fig. 9.1 – Consensus of Panel on space progress
(medians and quartiles)

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

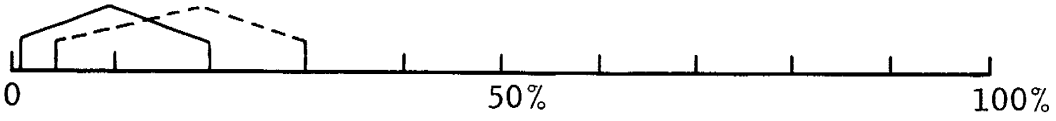
10. PREDICTIONS CONCERNING WAR AND ITS PREVENTION

The members of Panel 5, on War Prevention, were asked both in the first questionnaire (June 1963) and the last questionnaire (January 1964) to give us their personal probability estimates of the occurrence of another major war within 10 and within 25 years. The responses, in terms of medians and quartiles, were these:

June 1963 responses



January 1964 responses



Here, the solid bars refer to the probability of war within 10 years, the dotted bars to the probability of war within 25 years.

A significant decrease in the probabilities between the June and January responses is evident. Even in the case of the 10-year estimates, where the median remained at 10%, the shift of the quartile bar as a whole is quite pronounced. While the identity of the panel membership was not stable enough to draw the conclusion directly from this summary evidence that events of the intervening seven months had caused most of the respondents to take a rosier view of the future, examination of the responses of those individuals who participated in both the first and fourth questionnaires did tend to confirm this hypothesis. For example, none of them raised the value given to the probability of war within 10 years, and the median reduction of probability was 20% of the value originally given.

The panel's views as to the manner in which a major war might break out, if at all, did not change significantly between June 1963 and January 1964. When we average the minor differences in responses between these dates, the

panel's opinions as to the relative probabilities of the modes of outbreak may be summarized as follows:

Inadvertence	11%
Escalation of a political crisis	45%
Escalation in the level of violence in an on-going minor war	37%
Surprise attack at a time when there is no ostensible acute crisis	7%

We considered the main assignments of Panel 5 to be the proposal and appraisal of realistic and effective measures that might be undertaken in the future in order to reduce the overall probability of the occurrence of another major war. Members of the panel submitted a total of 42 distinct proposals for consideration. These were then resubmitted to the panel for appraisal.

Much of the response was in verbal rather than numerical form. Even numerical responses, such as effectiveness and probability-of-implementation ratings and desirability rankings, were subject to interpretation and relative weighting. Taking all these caveats into account, it appears that the picture which emerges can be described roughly by the following tabulation of proposed measures, arranged in the approximate order of decreasing overall desirability, with "effectiveness" to be understood as referring specifically to the lowering of the probability of war. A framed entry indicates a considerable consensus among the panel members:

Proposed Measure	Overall desirability	Effectiveness if implemented	Probability of implementation
Build-up of Western-bloc conventional forces	high	high	high
Increased security of command-and-control and retaliatory capability	high	high	high
Development on both sides of invulnerable delayed-response weapons that are incapable of surprise attack	high	high	high

Proposed Measure	Desira-bility	Effect-iveness	Proba-bility
Greater political and economic unity among free advanced democracies	high	high	medium
US–SU political agreement to seek peace and restrain other nations from developing nuclear weapons	high	high	medium
Establishment of a standing world-wide U.N. police force, not subject to veto	high	high	low
Improved defensive warfare techniques to reduce probability of escalation in limited wars	high	medium	medium
U.N. economic and military aid to areas threatened by political upheaval	high	medium	low
Development of a code of international law and establishment of effective world courts of justice and a world supreme court	high	medium	low
US–promoted rapid technological and economic advancement of under-developed nations	high	low	high
Strengthening of the U.N. with the objective of forming a world government	medium*	high	low
Bilateral US–SU arms control agreements	medium	medium	high
Studies by sociology, group psychology, etc., seeking clues to war prevention	medium	medium	high
US–SU political association against China or other third party	medium	medium	high
Holding the status quo against even minor aggressions	medium	medium	medium
Central–European disengagement to reduce military activity, induced by an improving SU–US atmosphere	medium	medium	medium
Instituting population control in all nations according to U.N. decisions	medium	medium	low

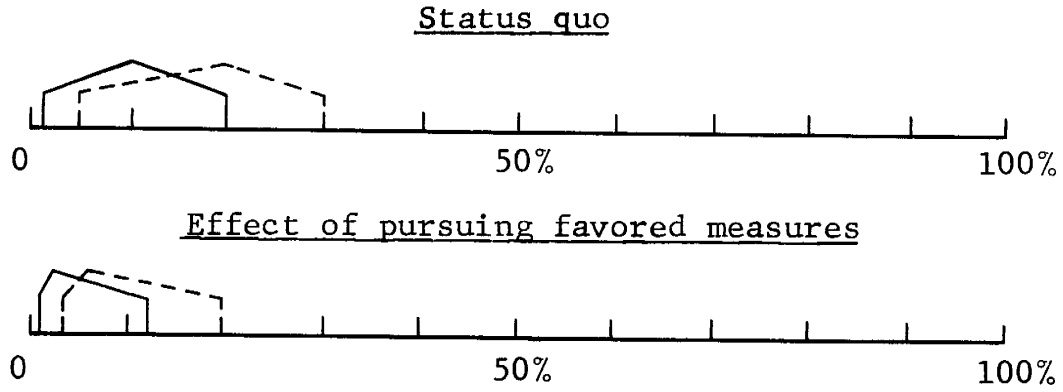
*The doubt, implied by this entry, on the part of some respondents regarding the unconditional desirability of this item appears to be unrelated to their opinion of the U.N. as such but reflecting their fear that a single world government might be subject to subversion of its original purpose.

Proposed measure	Desira-bility	Effect-iveness	Proba-bility
Establishment of national assessment centers which would evaluate crisis situations and transmit policy statements to the potential enemy to clarify U.S. intent	medium	medium	low
US or SU demonstration of the intent to use force of increasing levels (in identifiable steps) in response to specific provocations	medium	medium	low
Removal of trade barriers with Communist countries	medium	medium	low
Development of realistic understanding among western Allies of dynamics of nuclear warfare, by techniques including joint US/Allied crisis- and war-gaming and systems analyses	medium	medium	low
Settlement of the division of Germany on terms acceptable to West Germany and compatible with German membership in NATO	medium	medium	low
Development of a cadre of international U.N. civil servants dedicated to world values	medium	low	high
Military alliance between US and SU (plus possibly India)	medium	low	low
Support and promotion of a United States of Africa, Latin America, Europe, Asia	medium	low	low
Invitation to other nations to become member states of the U.S.A.	medium	low	low
Simulated US-SU war games, played by professional military planners of both sides (possibly with sides interchanged)	medium	low	low
Increased cooperative economic, political, and military ventures by the US with the SU and China to promote interdependency	?*	high	low
Bilateral reduction of armaments enforced by U.N. police force	?	high	low

*A question mark indicates that with respect to this item the respondents had not been asked to assess the desirability as such.

Proposed Measure	Desira-bility	Effect-iveness	Proba-bility
Strengthening of NATO alliance to insure a guaranteed response to prestated provocations	?	high	low
SU-initiated gradual improvement of political atmosphere	?	high	medium
Strategic arms control (halting production but not R-and-D)	?	low	medium
Clear US statement as to which national interests are to be protected by nuclear deterrents, and orientation of our policies to that end	?	low	low
Development of a new system of inter-national political cue "signals" which would indicate real intent to go to war unless political situation changes, such as general mobilization in the past	?	low	medium
Fostering educational and propaganda measures designed to amend or establish values of mutual toleration of various ideologies and the right to self-determin-ation	?	low	high
Sharing of technological innovations between US and SU	?	low	medium
Support of NATO, SEATO, and OAS to increase number of world forums where political differences can be resolved with minimum "loss of face"	?	low	high
Offer of nuclear weapons to countries which agree to support our stated national policies	?	low	medium
Organized encouragement of conscien-tious objection on the part of scientists to cooperation in the improvement of weapon systems	low	low	low
Creation of buffer zones to avoid direct confrontation of major powers	?	low	high
Recognition of Communist China and East Germany - creation of a realistic policy	?	low	medium
US-initiated unilateral steps toward disarmament	?	low	low

In order to obtain some idea of the potential impact that the above measures might have, we concluded our inquiry by asking each respondent his opinion of how much the probability of a major war in the next 10 and the next 25 years would be reduced if the measures which he favored were pursued vigorously. The result is shown below. The status-quo graph, shown for comparison purposes, repeats the January, 1964, estimates of the probability of war. The solid bars again refer to the 10-, the dotted bars to the 25-year period.



We note that the reduction in the median probability is 75% (for 10 years) and 70% (for 25 years). We also examined the record to find each individual's reduction in these probabilities; the medians of these reductions turned out to be 25% and 33% respectively, which--while not nearly so large--may still be considered strong evidence of the respondents' optimism regarding the possibility of reducing their own dire forecasts by taking appropriate preventive measures.

11. PREDICTED WEAPON SYSTEMS OF THE FUTURE

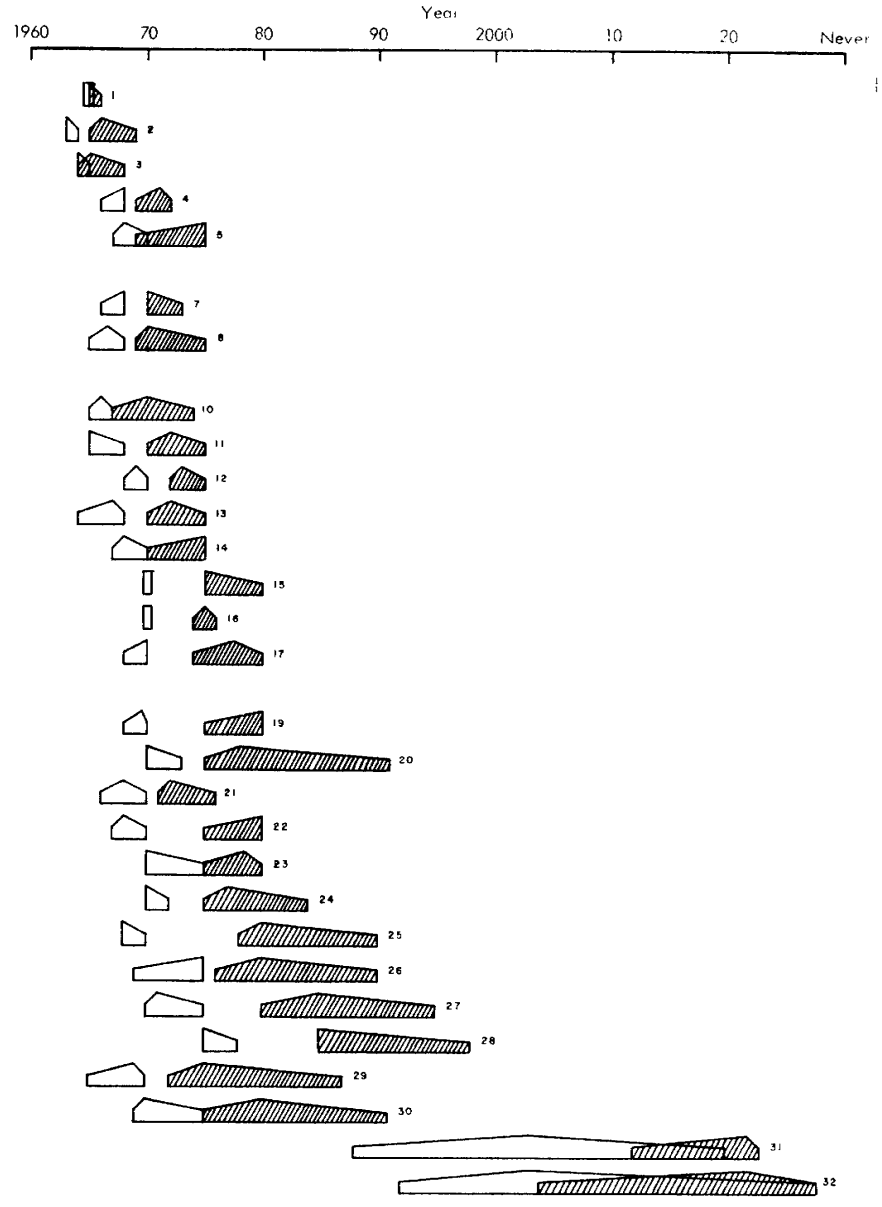
Panel 6, whose subject matter was future weapon systems, had to work under a slight handicap in that the details of such systems are generally not in the public domain because of military secrecy. This had the dual effect of putting a restraint on respondents who did have access to such information, and of keeping respondents without such access in the dark with regard to some of the current work being

done in this area. A classified inquiry on the same subject would presumably have yielded additional items and also more reliably dated forecasts.

The panel members suggested a total of 58 distinct weapon-system developments. Of these, all but 32 were eventually dropped from further consideration, because a majority consensus indicated either that their feasibility was so low as to make development in the foreseeable future very unlikely, or else that their effectiveness, even if developed, would be too low, or both.

The following page gives a graphical picture of the outcome. Again—as in the case of Panels 1, 3, and 4 (Science, Automation, and Space)—we used quartile bars peaked at the median. Figure 11.1 shows predicted dates in grey under the assumptions of the status quo prevailing (dark bars), and of a crash program (light bars). The green bars show the "absolute" predictions solicited in Questionnaire 4, in which the respondents had been required to estimate operational readiness dates on the basis of their own expectations as to the likelihood of a crash program being instituted. The items were arranged in the order of the median dates of the "absolute" predictions (green bars). (The three gaps appearing among the grey bars correspond to items representing afterthoughts that were not submitted to the panel until the final round.)

It should be noted that in a few cases the median of the operational-readiness estimates lies toward the right not only of the bar of crash-program estimates but even of that of the status-quo estimates. This may mean that the respondents had a change of mind between Questionnaires 3 and 4. More probably, though, in the last round the concept of actual operational readiness prevailed, while in the earlier rounds the contingency estimates may have been made subject to the additional, tacit assumption: "Suppose there is a decision to go ahead with the weapon system in question."



1 Tactical kiloton nuclear weapons for use by ground troops

2 "Economic showmanship": new foreign-aid techniques to influence nations

3 Extensive use of devices which persuade without killing (water cannons, tear gas, etc.)

4 Miniature improved sensors and transmitters for snooping, reconnaissance, arms control

5 Rapid mobility of men and light weapons to any point on Earth for police action

6 Incapacitating chemical (as opposed to biological) agents

7 Use of lasers for radar type range sensors, illuminators, communications

8 Incapacitating biological agents

9 Cheap, light-weight, rocket-type personnel armament (silent, plastic, match-lit projectiles capable of single or ding-a-ling

10 Lethal biological agents

11 Perishable counter-insurgent arms

12 Orbiting space reconnaissance station

13 Advanced techniques of propaganda, thought control, opinion manipulation

14 Accurate intelligence correlation through use of computers

15 Effective anti-submarine capability, at least against contemporary submarines

16 Longer-endurance aircraft, perhaps nuclear-powered, for logistic supply or bombardment

17 Biological agents destroying the will to resist

18 Penetrating nuclear weapons for deep cratering

19 Automated tactical capability (battlefield computers, robot sentries, TV surveillance)

20 Effective terminal defense by ground-launched anti-missiles

21 ICBMs with other than nuclear warheads (such as snipers)

22 Rapidly mobile public works and logistics units for war recovery and refugee support

23 Deep-diving submersibles made of materials which decrease detection probability

24 Directed-energy weapons (electro-magnetic radiation, particle beams, lasers)

25 Massive civilian defense and post-war recovery plan

26 Weather manipulation (for military purposes)

27 Effective terminal defense by air-launched anti-missiles

28 Effective terminal defense by directed energy beams

29 Large orbiting satellite weapons for blackmail

30 Domesticated porpoises or dolphins for anti-submarine reconnaissance

31 Mass hypnotic recruitment of forces from enemy population

32 Mind reading

Fig. II.1 - Consensus of Panel 6 on future weapon systems (medians and quartiles)

Figure 11.1 also carries, in the left-hand margin, a tabulation of the medians of effectiveness and feasibility, each measured on a scale from 0 to 10.

We have made an effort below to abstract from the responses of the other five panels such material as might be relevant for future weapon systems. No implication is intended that these are forecasts of military instrumentalities in the offing; we simply leave it to the reader to consider them for what they are worth as regards possible relevance to potential weapon systems of the future. The statement in the last column of this tabulation merely represents the authors' extrapolation of the item described in the first column into the field of weapons application.

Item	Panel	Predicted time of availability		Possible implication for weapon systems
		Median	Quartiles	
Establishment of a global satellite communication system	4	1968	1967–1970	Improvement in the security of command-and-control
Unmanned inspection and capability for destruction of satellites	4	1967	1967–1970	Potentially important defense against unauthorized reconnaissance or against satellites suspected of carrying bomb loads
Manned co-orbital inspection of satellites	4	1970	1970–1974	
Effective fertility control by oral contraceptive or other simple and inexpensive means	1	1970	1970–1983	Possibility of long-term manipulation of enemy's population size through covert seeding of his water supply with oral contraceptives (alternative non-aggressive version: contraceptive aid to underdeveloped nations in an effort to upgrade their economies and to remove a future cause for war through relieving population pressure)

Item	Panel	Predicted time of availability Median	Quartiles	Possible implication for weapon systems
Development of new synthetic materials for ultra-light construction	1	1971	1970-1978	New light-weight military equipment, including construction items such as bridges
Air traffic control - positive and predictive track on all aircraft	3	1974	1970-1977	Complete tracking of all aircraft by the Air Defense Command
Widespread use of automatic decision-making at management level for industrial and national planning	3	1979	1977-1997	More efficient military procurement planning; aid in strategic and tactical combat direction
Controlled thermonuclear power	1	1986	1980-2000	Mobile power plants for tactical use; possibly rocket propulsion
Limited weather control, in the sense of substantially affecting regional weather	1	1990	1987-2000	Destruction of crops; flooding of enemy territory
Biochemical general immunization	1	1994	1983-2000	Defense against biological-warfare attacks
Global ballistic transport (including boost-glide techniques)	4	2000	1985-never	Rapid mobility of men and arms to any point on earth
Man-machine symbiosis, enabling man to extend his intelligence by direct electromechanical interaction between his brain and a computing machine	1 3	2020 2010	1990-never 1985-2600	Greater adaptability to hostile environments, especially in space combat; more effective use of computing aids in tactical decision-making
Breeding of intelligent animals (apes, cetaceans, etc.) for low-grade labor	1	2020	2020-never	Use of animals for reconnaissance and other ground-combat tasks
International agreements which guarantee certain economic minima to the world's population as a result of high production from automation	3	2024	2018-2100	Removal of potential pressures toward war (i.e., a means for eliminating the need for weapon systems)
Control of gravity through some form of modification of the gravitational field	1	2063	2030-never	Weightless combat vehicles; raising the enemy forces off the ground

Item	Panel	Predicted time of availability Median	Quartiles	Possible implication for weapon systems
Manned maneuverable geocentric bombardment fleet	4	2500	1990–never	Possible follow-on to the Polaris concept
Feasibility of education by direct information recording on the brain	1	2600	1997–never	Potentiality of permitting deductions from vast amounts of collected data; possible edge in scientific and technological innovation
Military force on the Moon	4	never	1999–never	Self-explanatory
Heliocentric strategic fleet	4	never	2500–never	Self-explanatory

12. THE WORLD OF 1984

If we abstract the most significant items from the forecasts of all six panels, the following picture emerges of the state of the world as of 1984:

The population of the world will have increased by about 40% from its present size to 4.3 billion—that is, provided no third world war will have taken place before then. There is an 80 to 85% probability that it will not, if present trends continue, but this probability can be raised to 95% by appropriate policy measures.

To provide the increased quantities of food needed, agriculture will be aided by automation and by the availability of desalinated sea water.

Effective fertility control will be practised, with the result that the birth rate will continue to drop.

In the field of medicine, transplantation of natural organs and implantation of artificial (plastic and electronic) organs will be common practice. The use of personality-control drugs will be widespread and widely accepted.

Sophisticated teaching machines will be in general use.

Automated libraries which look up and reproduce relevant material will greatly aid research. World-wide communication will be enhanced by a universal satellite relay system and by automatic translating machines. Automation will span the gamut from many service operations to some types of decision making at the management level.

In space, a permanent lunar base will have been established. Manned Mars and Venus fly-bys will have been accomplished. Deep-space laboratories will be in operation. Propulsion by solid-core nuclear-reactor and ionic engines will be becoming available.

In the military arena, ground warfare will be modified by rapid mobility and a highly automated tactical capability, aided by the availability of a large spectrum of weapons, ranging from non-lethal biological devices and light-weight rocket-type personnel armament to small tactical nuclear bombs and directed-energy weapons of various kinds. Ground-launched anti-ICBM missiles will have become quite effective. Anti-submarine warfare techniques will have advanced greatly, but improved, deep-diving, hard-to-detect submarines will present new problems.

13. THE WORLD OF 2000

When we continue our projection to the year 2000, the following major additional features emerge as descriptive of the world at that time, judging from the forecasts of the six panels:

The population size will be up to about 5.1 billion (65% more than 1963).

New food sources will have been opened up through large-scale ocean farming and the fabrication of synthetic protein.

Controlled thermonuclear power will be a source of new energy. New mineral raw materials will be derived from the oceans. Regional weather control will be past the

experimental stage.

General immunization against bacterial and viral diseases will be available. Primitive forms of artificial life will have been generated in the laboratory. The correction of hereditary defects through molecular engineering will be possible.

Automation will have advanced further, from many menial robot services to sophisticated, high-IQ machines. A universal language will have evolved through automated communication.

On the Moon, mining and manufacture of propellent materials will be in progress. Men will have landed on Mars, and permanent unmanned research stations will have been established there, while on Earth commercial global ballistic transport will have been instituted.

Weather manipulation for military purposes will be possible. Effective anti-ICBM defenses in the form of air-launched missiles and directed-energy beams will have been developed.

14. CONCEIVABLE FEATURES OF THE WORLD IN THE YEAR 2100

When we try to look as far ahead as to the year 2100, there can be no pretense regarding the existence of any consensus among our respondents. We record the following developments, for which there was a median forecast of no-later-than 2100, not as a prediction of the state of the world world at that time but as an indication of what a number of thoughtful people regard as conceivable during the next few generations to come:

By the year 2100 the world population may be of the order of 8 billion.

Chemical control of the aging process may have been achieved, raising a person's life expectancy to over 100 years. The growth of new limbs and organs through biochemical stimulation may be possible. Man-machine symbiosis,

enabling a person to raise his intelligence through direct electromechanical tie-in of his brain with a computing machine, is a distinct possibility. Automation, of course, will have taken further enormous strides, evidenced in all probability by such things as household robots, remote facsimile reproduction of newspapers and magazines in the home, completely automated highway transportation, etc.

The problem of adequately providing the necessities of life for all peoples of the earth will presumably have been solved by international agreements based on the abundance of new sources of energy and raw materials opened up in the twenty-first century. As for materials, it is even possible that elaborate differential mining processes will have been abandoned in favor of commercially efficient transmutation of elements.

Conceivably, revolutionary developments will have become feasible as a result of control of gravity through some form of modification of the gravitational field.

A permanent lunar colony may well have been established, with regularly scheduled commercial traffic between Earth and Moon. A permanent base on Mars, landings on Jupiter's moons, and manned fly-bys past Pluto are likely accomplishments. Possibly even a multi-generation mission to other solar systems may be on its way, aided conceivably by artificially induced long-duration coma. Two-way communication with extra-terrestrial intelligent beings is a definite possibility.

15. EDITORIAL COMMENTS ON THESE FORECASTS

Before leaving the substantive aspects of this report and proceeding to a discussion of method, we would like to interject a few remarks reflecting our own reaction to some of the panel forecasts.

First of all, we would like to register our surprise at some of the ideas that have been propounded. To other

persons, of course, a different set of items might be the unexpected ones. These are among the 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 possibility that continued developments in automation will result in serious social upheavals; the almost complete acceptance of the necessity of regulative legislation.
>
> The probability, in the relatively near future, of very widespread use of personality-control drugs.
>
> The notion of an actual symbiosis of man and machine.
>
> The use of computers as "colleagues" rather than servants or slaves.
>
> The fact that control of gravity was not rejected outright.
>
> The relative confidence that the population curve would begin to level off during the next generation.
>
> The strong likelihood of the emergence of weapons of a nonkilling, nonproperty-destroying nature, covert perhaps, attacking on the psychological or biological level.
>
> The idea of perishable counter-insurgent arms.
>
> The general disagreement with the concept of deep-space military applications, such as heliocentric strategic fleets.
>
> The anticipated relatively high probability of another major war.
>
> The absence, on the one hand, of significantly new ideas for the prevention of war, and the confidence, on the other, that the application of what may almost be called traditional proposals to this effect hold great promise for reducing the probability of war.

Secondly, we feel it incumbent upon us to point out certain warnings which seem to be implied in the opinions of our respondents. Our motivation in doing so is not to prophesy doom but to indicate the areas, however obvious, in which a major effort will have to be concentrated in order to avoid future disaster. They can be subsumed under four headings:

War prevention. While the odds are considered to be

against another major war within the next generation even a 20% chance of this (within 25 years), which is the War Prevention panel's median prediction, is clearly intolerable. The main danger appears to be in mutually undesired escalation and downright inadvertence, hence a major effort to seek improved ways of forestalling such disaster is mandatory.

Equitable distribution of resources. While there is a consensus that eventually there will be an abundance of resources in energy, food, and raw materials, it is not at all a foregone conclusion that they will be plentifully available in time to keep ahead of the increasing world population, or what is more, that effective means of an equitable world distribution of such assets will have been found and agreed upon. To solve these problems in time will clearly be a great contribution toward the prevention of (big or small) wars.

Social reorganization. The anticipated explosive growth in the amount of automation is likely to reshape the societies of industrialized nations considerably, perhaps beyond recognition. While improved and highly automated methods of education will make the acquisition of technical skills available to a larger fraction of the population, only the very ablest people are likely to be needed to manage the new, automated, economy. Since robots are apt to take over many of the services, especially the more menial ones, large segments of the population may find themselves without suitable employment within an economy of potential abundance. Far-sighted and profoundly revolutionary measures may have to be taken to cope with this situation and to create new patterns within which a democratic form of society can continue to flourish. "Earning" a livelihood may no longer be a necessity but a privilege; services may have to be protected from automation and be given social status; leisure time activities may have to be invented in order to give new meaning to a mode of life that

may have become "economically useless" for a majority of the populace.

Eugenics. Finally, to mention a problem which, though not upon us as yet, will require much forethought and wisdom, there is the possibility—now just below the horizon but expected to be realized within a generation or two—of selectively extending an individual's life span through biochemical methods and of selective eugenic control through molecular genetic engineering. The potential dangers of mismanaging these capabilities are too obvious to require formulation.

16. CONVERGENCE OF OPINIONS

We now turn briefly to an examination of some of the methodological features of our experiment.

Many of the questions put before Panels 1, 3, 4, and 6 (Science, Automation, Space, and Weapons) were asked more than once. This gave us an opportunity to determine the amount of opinion convergence that was taking place in the process of interrogation.

A convenient measure of the spread of opinions is the quartile range, QR, of the responses. Figure 16.1 shows a scatter diagram of the final quartile range, QR_2, versus the original quartile range, QR_1, for each repeated question. (The numerals used to spot these points refer to the panel number.)*

It can be seen at a glance that the quartile range decreased, since the majority of the points lie well below the 45°-line. The median ratio of QR_2/QR_1 is almost exactly 5/8. Broken down by panels, the median reductions in quartile range are as follows:

Panel	Median or QR_2/QR_1
1 (Science)	.60
3 (Automation	.73
4 (Space	.63
6 (Weapons)	.61

*A detailed graphical report on the convergence of opinions, by individual questions, is given in the Appendix to this report.

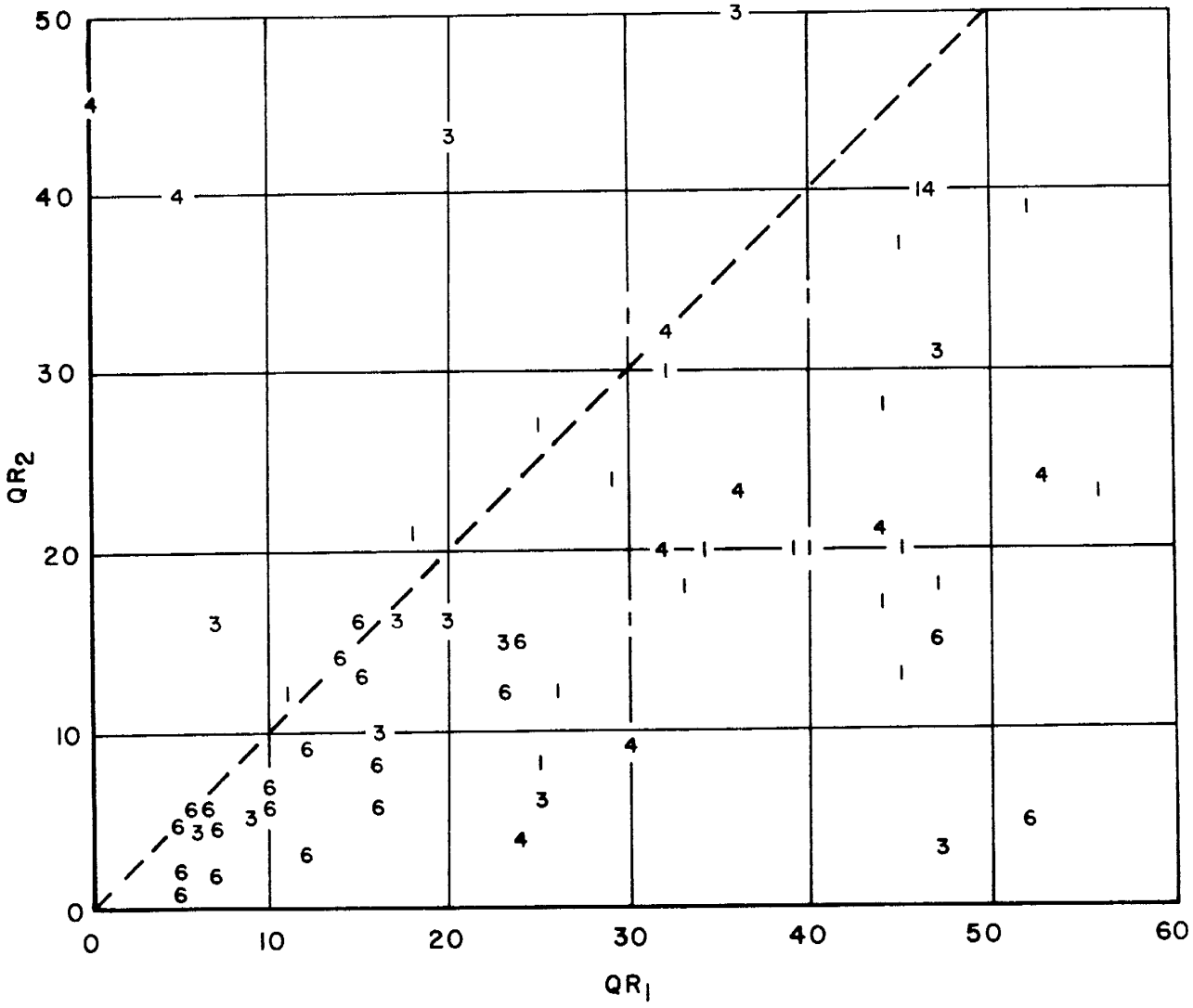


Fig. 16.1 — Opinion convergence: Final versus initial quartile ranges

The question for Panel 2 regarding future birth and death rates was also repeated, but the composition of the panel membership changed so much as to make a comparison not very meaningful. We report, for the record, that the median and quartile population curves computed on the basis of the panel's original and final responses did not differ significantly.

For Panel 5, the questions of the probability of war and of the likely causes of outbreak were raised twice. The response has already been recorded and discussed in Section 10 above. As for the questions relating to measures for reducing the probability of war, while the descriptions of these measures were repeated, the solicited modes of appraisal were too different to permit direct numerical comparison; qualitatively speaking, reasonably good convergence was generally observed.

In a number of "repeated" questions in Panels 1, 3, 4, and 6, the precise wording had been changed in an effort to eliminate ambiguities that had been brought to our attention. While we cannot point to a general pattern of success in achieving a better consensus through this device, an example may illustrate the effect which we had hoped to achieve:

The original wording of the question labelled "Social 6" addressed to the Automation panel mentioned

> "Computing machines becoming the most significant intelligence on earth";

this was subsequently changed to

> "Availability of a machine which comprehends standard IQ tests and scores above 150,"

and finally amended in the last questionnaire by the parenthetic addition

> "...where 'comprehend' is to be interpreted behavioristically as the ability to respond to questions printed in English and possibly accompanied by diagrams."

Here are the statistical characteristics of the successive sets of responses, which speak for themselves:

Questionnaire	Median	Quartile range
3.2	2050	2010 – never
3.3	1995	1985–2025
3.4	1990	1984–2000

While the results reported here indicate a reasonably satisfactory convergence of opinions—as exhibited in particular in Fig. 16.1—we do not wish to make exaggerated claims in this regard. Hence we are adding these cautionary comments:

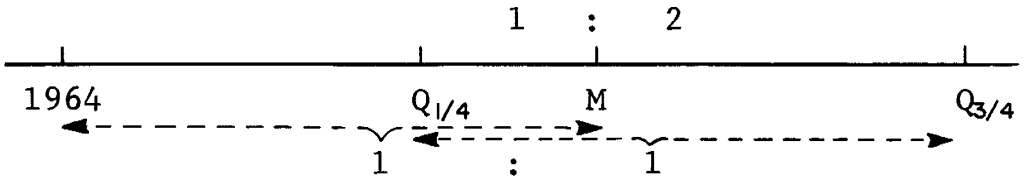
A number of questions were not pursued because of their relative unimportance in the face of an initial highly divergent response. We cannot guess whether a satisfactory process of convergence would have been observed, had we taken the trouble to continue the inquiry on these topics. Also, in a number of cases where a question was pursued through several rounds, a considerable divergence of opinions persisted. To cite just two examples, the Science and Automation panels each disagreed on predictions regarding the feasibility of direct electromechanical man–machine symbiosis (medians: 2020, 2010; quartile ranges: 1990 – never, 1985 – 2600, respectively); and in the Space panel there was a dissensus as to when (but not whether) propellent materials might be mined and manufactured on the Moon (median: 1990, quartile range: 1980 – 2020).

Whether or not the convergence observed in the Delphi procedure compares favorably in amount and rationality with that obtained by more traditional modes of consensus formation, such as a round-table discussion, is a moot question. We submit, though, that even if the effectiveness of the Delphi technique in producing a consensus is not superior to other methods, it can conceivably offer considerable advantages in cost and reliability—the former by avoiding the need for assembling the experts in one place, the latter by not subjecting them to the persuasiveness of oratory or to the bandwagon effect of prominent authority and of face-to-face confrontation with majority opinion, but merely to the milder form of anonymous social pressure exerted by the feedback of some information on the range of opinions held by the group.

17. PREDICTION PRECISION AS A FUNCTION OF TIME

The precision with which a panel as a group predicts the date of a future event, as measured by the narrowness of the quartile range, must be expected to diminish with increasing distance in the future. The scatter diagram in Fig. 17.1, which covers all items with a median date no later than 2020, not only confirms this but reveals the additional fact that the size of the quartile range on the average is about equal to the expected distance in the future. (The numerals again refer to the panel number; in the case of the Weapons panel (Panel 6), the absolute rather than the status-quo or crash-program forecasts have been used.)

We mention in passing that the position of the median within the quartile range, on the average, is about one third of its length from the lower end:



Hence, if an event has a median predicted date x years in the future then, on the average, the corresponding quartile range will span the interval from $\frac{2}{3}$x years in the future to $\frac{5}{3}$x years in the future (e.g., for an event with a median year of 2000, the ends of the quartile range would average approximately 1988 and 2024).

In this connection we may briefly refer to the rather special case of Panel 6, where we had asked for predictions of the availability of new weapon systems under two different assumptions—namely, that of the status quo and that of a crash program—to be followed in the final questionnaire by an absolute prediction.

As a preliminary observation we take cognizance, through Fig. 17.2, of the dependence of the potential speed-up due to a crash program (the quantity SQ-CP, where SQ

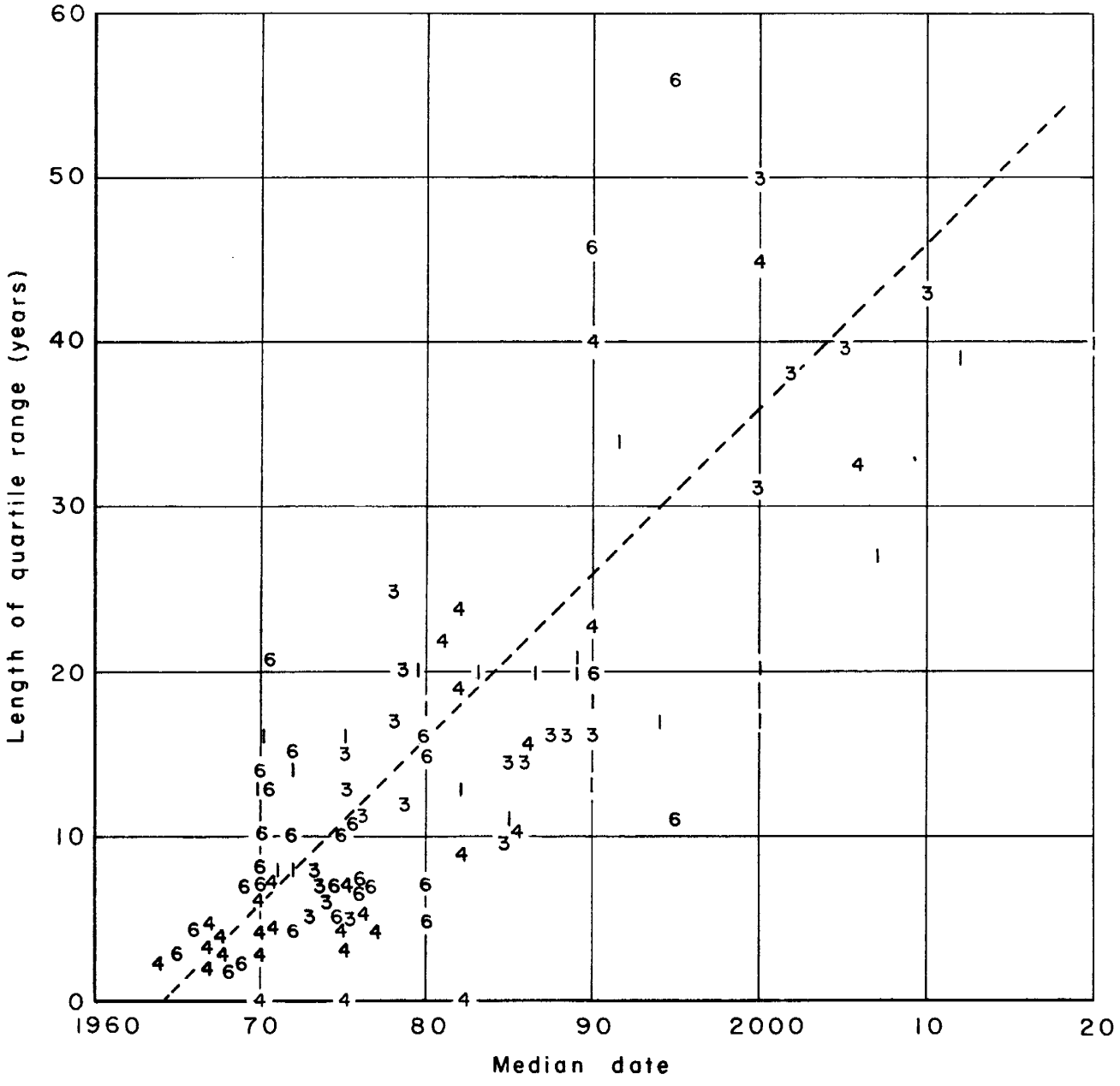


Fig. 17.1 — Prediction precision

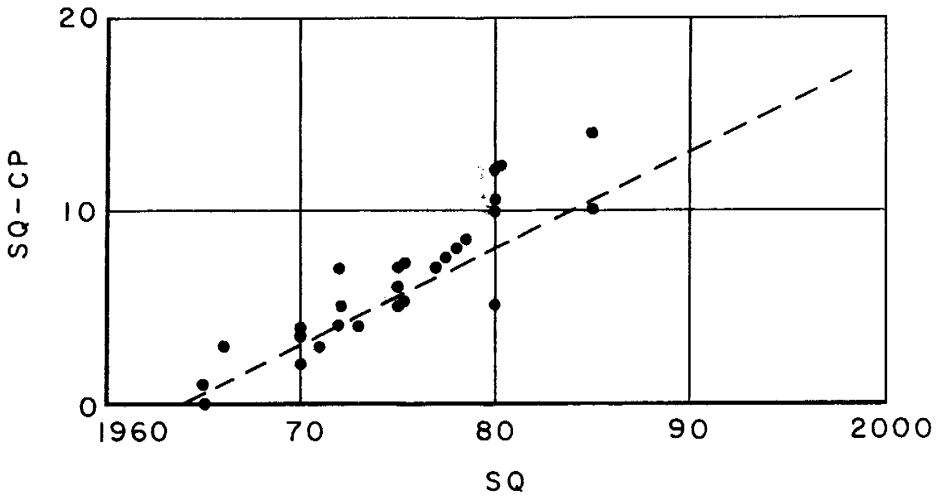


Fig. 17.2 — Speed-up due to crash program

and CP are the median dates of availability under the two assumptions) on the predicted date under the status quo (=SW). Points above the dotted line are those for which the expected time from the present to operational readiness is expected to be cut at least in half by instituting a crash program. The figure shows that this is the case for more than half the weapon systems considered.

The next figure, 17.3, gives the quartile range of each absolute prediction of a weapon system's operational readiness as a function of the quartile range of the corresponding status-quo prediction. The prediction precision, as measured by the inverse of the quartile range, is reduced in the median (broken line in Fig. 17.3) by 30% when we go over from status-quo to absolute forecasts. This deterioration is accounted for by the additional uncertainty as to the engagement in a crash program, which the respondents had to assess in naming absolute dates.

18. PREDICTION FREQUENCY AS A FUNCTION OF TIME

The median dates for which Panels 1, (Science) 3, (Automation) 4, (Space) and 6(Weapons) predicted occurrences in their areas of concern were distributed noticeably differently for these four panels, as shown in Fig. 18.1, where the relative frequencies of predictions by 10-year intervals are displayed separately for each panel.

Panel 1, on scientific breakthroughs, is seen to have the comparatively most uniform distribution over time. The forecast dates of Panel 3, on automation, show a surprisingly smooth distribution peaked at the 1975-84 interval. Panels 4 and 6 both produced U-shaped distributions, with the notable difference that Panel 4 gave almost equal weight to both ends of the time interval, while Panel 6 concentrated heavily on the decade lying immediately ahead.

Taking the median, marked M, of the predicted median dates as an indicator of how far, on the average, each

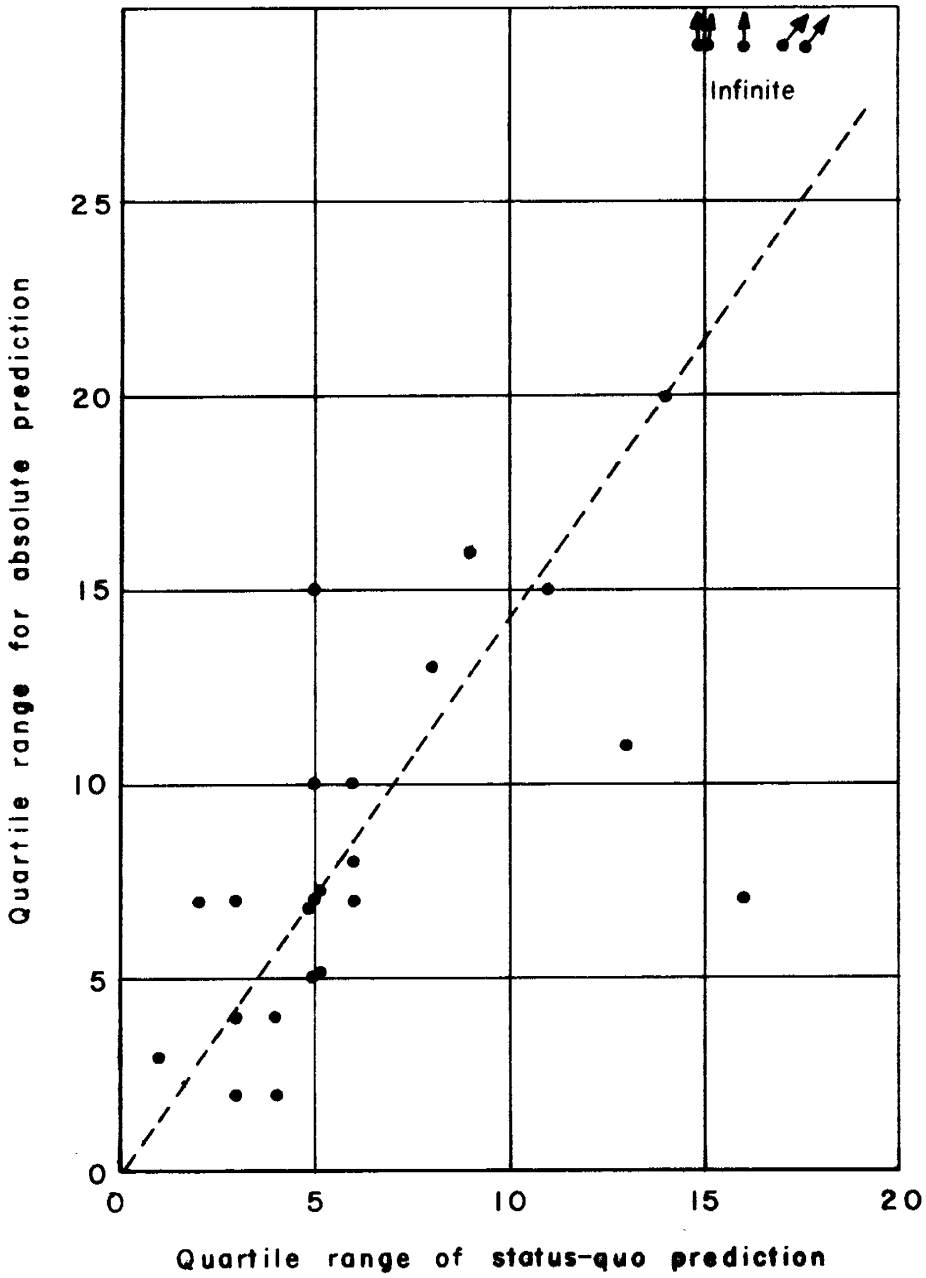


Fig. 17.3 - Comparison of prediction precision for absolute versus status-quo dates of operational readiness of weapon systems

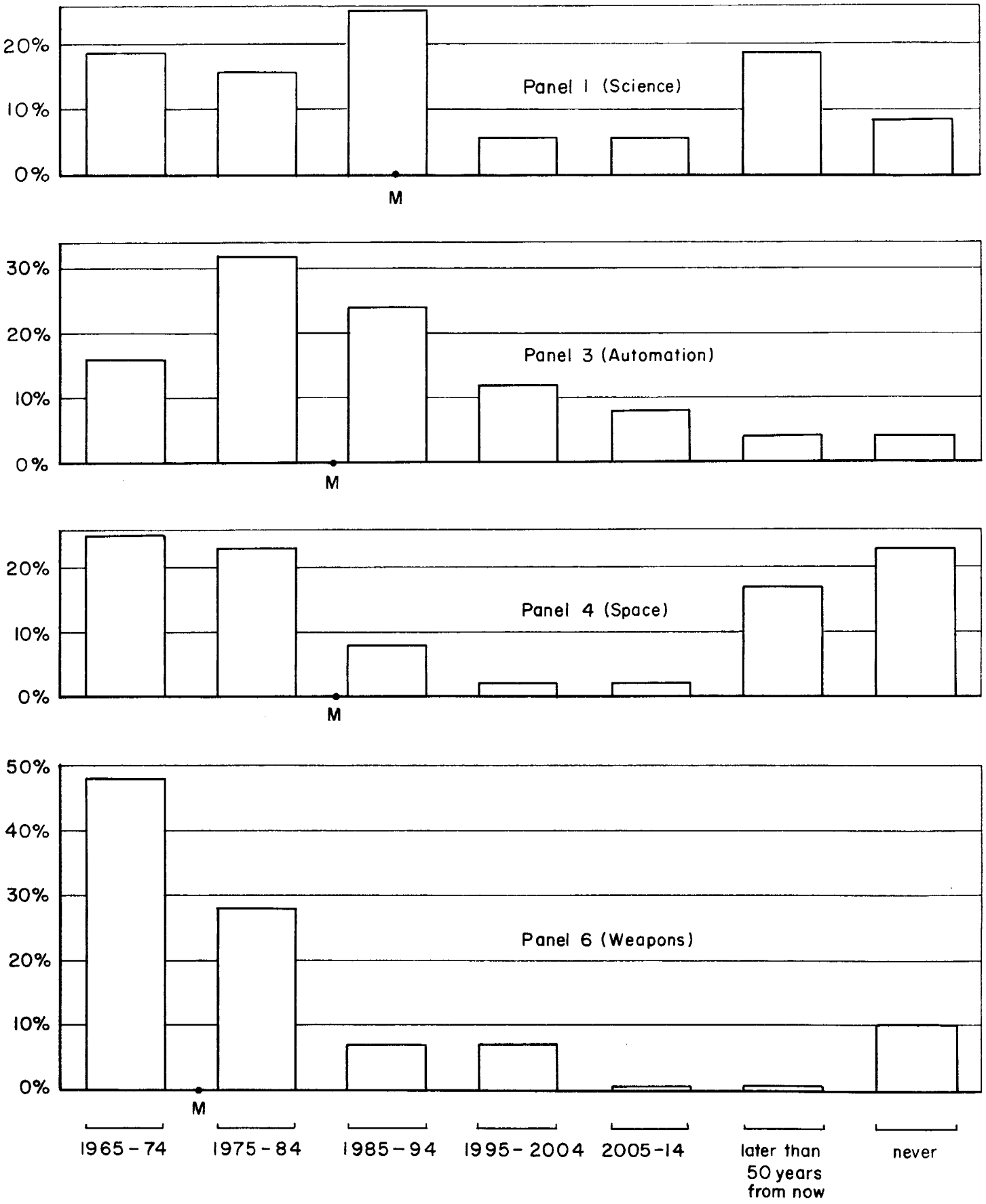


Fig. 18.1 — Frequency distribution of predicted median dates

panel is looking into the future, we note that this median time horizon is about 10 years for Panel 6, 20 years for both Panels 3 and 4, and 25 years for Panel 1.

While these differences are sizeable, they are not at all surprising, considering the subject matters of the panels concerned.

19. CONFIDENCE AS A FUNCTION OF PREDICTED DATE

The members of Panels 1, 3, and 4 were asked, in several questionnaires, to state not only the year by which they thought an event had a 50% probability of occurrence, but also by what year they felt 90% confident that the event would occur. In Fig. 19.1 we have plotted the medians of these 90%-confidence years against the medians of the corresponding 50%-confidence years for all events for which the latter was no later than 2000.

The graph, not unexpectedly, shows a close correlation. Denoting the distances in the future of the medians of the 50%- and 90%-years by $M_{.5}$ and $M_{.9}$ respectively, we note as a matter of curiosity that

$$\text{median } (M_{.9}/M_{.5}) = 9/5 = 1.8,$$

with a corresponding quartile range from 1.6 to 2.0, as indicated by dotted lines in the figure.

20. CRITIQUE OF EXPERIMENTAL PROCEDURE

The procedure we have followed in this experiment is open to many criticisms. Some shortcomings we were aware of from the beginning, some became clear as we went along, others were brought to our attention through comments by our respondents, still others will undoubtedly occur to the readers of this report.

It is precisely because of our conviction of the basic soundness of our approach that we wish to devote some space to a critical discussion of our procedure. In particular,

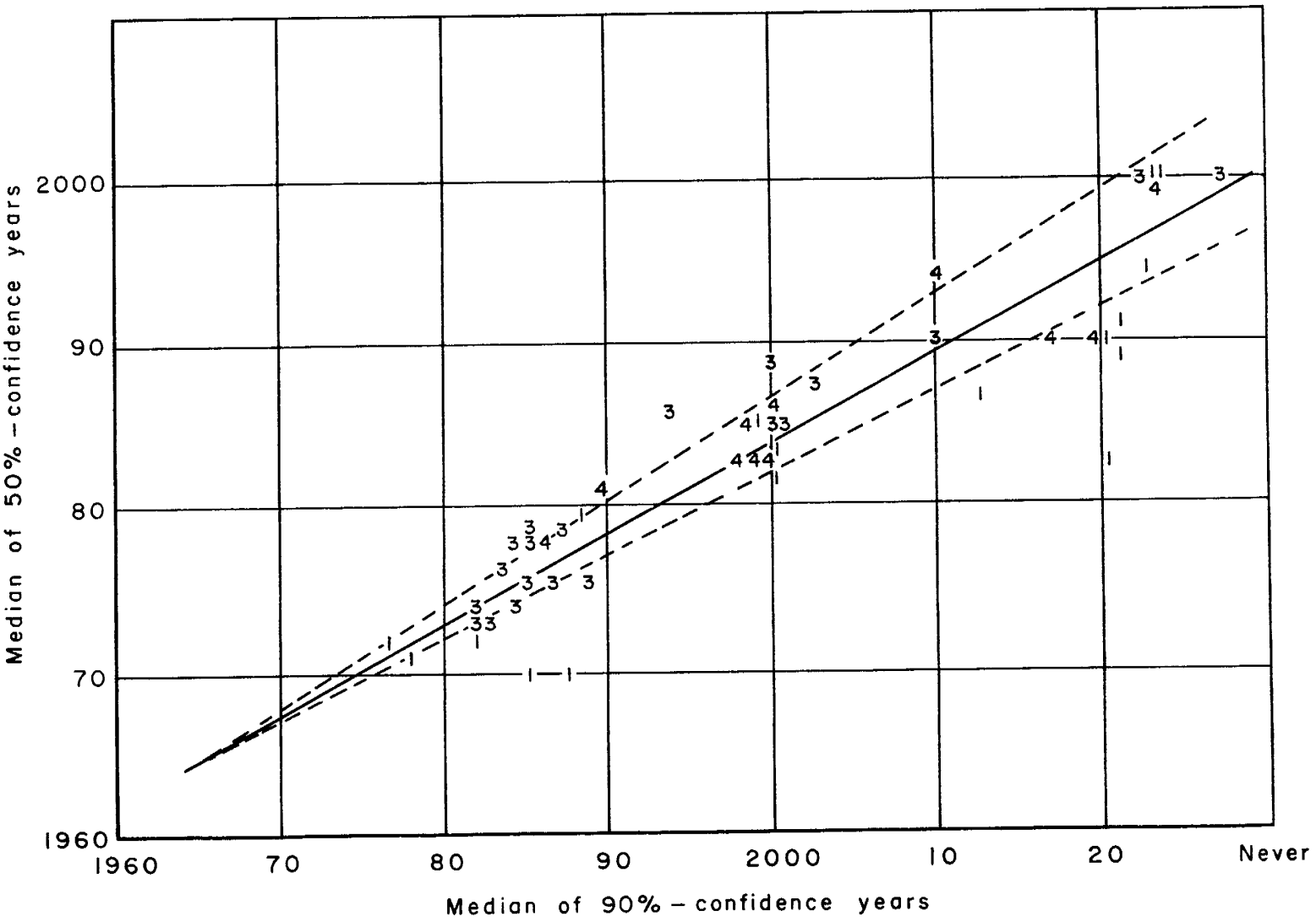


Fig. 19.1 — 50% Confidence versus 90% Confidence

we would like to establish, for possible future reference, which deficiencies could have been corrected and thus are in principle avoidable, and which others are weaknesses inherent in the method.

(a) Instability of panel membership. The make-up of each of our six panels of respondents fluctuated considerably; some early participants dropped out others were added after the initial round. While in principle we see no objection to some changes in panel membership—in fact, scientific progress in general relies on the constantly changing collaboration of many contributors— we have no doubt that the convergence of opinions is impeded by too many substitutions. To eliminate the latter entirely would be virtually impossible in view of unforeseeable circumstances and of the many competing demands on their time to which a group of experts is bound to be subjected. One means of keeping changes in personnel within reasonable bounds for the duration of an experiment might be to have some form of contractual arrangement with the participants.

(b) Time lapse. Too much time elapsed between successive rounds, the average lapse having been about two months. Better advance organization plus possibly the omission of overseas respondents might have reduced this to one month per round. The excessive length of time presumably was partly responsible for some of the drop-outs mentioned under (a); it also may have caused some genuine shifts of opinion due to the mere passage of time, with its concomitant change in the state of our knowledge generally.

(c) Ambiguous questions. Many of the questions put to the respondents, perhaps even a majority, were worded ambiguously. To some extent we regard this as unavoidable, because precision of meaning can often be bought only at the expense of legalistic phraseology, whose cumbersomeness would be repellent to many respondents. Yet an even greater effort should be made, by being reasonably specific, to

avoid the possibility that two respondents may form widely disparate interpretations of the same question. We are conscious of having violated this prescription in several instances—for example, when we asked for a specific date for the occurrence of an event that was inherently a matter of gradual development.

(d) Respondents' competence. The questions put to each panel ranged over a large field. With all due regard for our eminent respondents, it is not reasonable to expect that each could be equally competent with regard to all of the areas touched upon by our questions. Thus the answers by highly competent experts were somewhat diluted by less-highly informed estimates on the part of others. This effect was even slightly enhanced by including among the responses those of volunteers from other panels who submitted answers to questionnaires not addressed to their own panel. There are several remedies for this defect. On the one hand, the members of a panel might be selected for their known expertise within a narrowly defined area, and questions be confined rigidly to the latter. On the other, the respondents might be encouraged to leave blanks in the questionnaires whenever they feel unsure of their judgment, thus leaving the matter of their qualification to their own discretion. Our own preference would be in the direction of this second alternative, with the possible further modification that the respondents answer every question, but add in each case a self-appraisal of their degree of competence in answering it. Precisely how this should be done is an open question which might be made the subject of a separate study. We merely mention that there are problems concerning scale comparability of different respondents' self-appraisals and concerning the optimal use of such self-appraisals in devising a consensus formula.

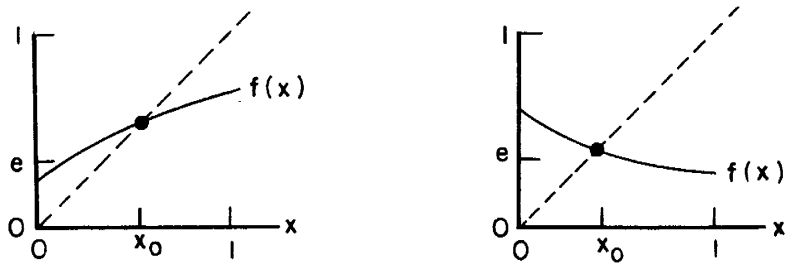
(e) Self-fulfilling and self-defeating prophecies. If a person of great authority and trustworthiness were to announce that the condition of the U.S. economy for the

foreseeable future is excellent, the strengthening effect on business morale might be such as to improve the state of the economy, thereby making the statement to some extent a self-fulfilling prediction. Conversely if, say, it were announced that we are about to lose our race with the Russians to the Moon, the effect might be a redoubling of our effort, thereby turning the statement into a self-negating prediction. It has been objected by one of our panelists that some of the predictions which we solicited might be of one of these types. Leaving aside the implication--to which we emphatically do not subscribe--that the publication of the answers to some of our questions might in fact affect the future course of history with regard to the subject of the questions (e.g., by hastening or retarding a predicted event), there still remains the possibility that a respondent's answer might be biased by his expectation (whether conscious or not) that the announcement may affect the truth of the prediction's content. If this were so, then the respondent would cease to be acting as a pure predictor but would in part become a would-be manipulator of the future; in addition, so it has been said, the very act of his stating a probability for some future event would involve a logical circularity, because by stating it he would affect it. While the first possibility, of attempting to play politics as it were, must be admitted to be a real one, which may place a respondent in the position of having to choose between what he thinks is right and what he thinks is true, there seems to us to be no real evidence of a logical circularity. In other words, if a respondent wishes to make an objective forecast, he can do so without getting involved in a logical fallacy. To see that this is so, let us consider the case where the probability of the event E at some future date is to be estimated. Let e be the probability, according to the respondent's opinion, that E will occur provided no public announcement of the outcome of the questioning process is made, and let f(x) be his estimate of that

probability if an announcement is made stating that the probability has been estimated to be x. Then, if the announcement in itself were ineffectual, we would have

$$f(x) = e$$

for all x. If it were self-fulfilling or self-defeating, f(s) would be monotonically increasing or decreasing respectively, as shown in the figure below.



In either case, there will be at least one point (in the second case, exactly one point) x_0 for which

$$f(x_0) = x_0,$$

so that a forecast of x_0 as the probability of E induces a probability x_0, thus making x_0 a logically consistent estimate.*

f. Consensus by undue averaging. The objection has been raised that the emphasis we place on the median as a descriptor of the group opinion and on the quartile range as a measure of the degree of consensus biases the outcome unduly against the far-out predictor, whose judgment may after all prove to be right while the majority opinion may be wrong. We regard this objection as not entirely unjustified with respect to the present experiment, but as invalid as a criticism of the technique in general. It should be remembered that it is an essential feature of our method that a respondent who disagrees with the majority is invited to state his reasons for such disagreement, and that all the members of the panel are given an

*Since writing this, our attention has been drawn to the following similar but more detailed treatment of this subject: Herbert Simon, "Bandwagon and Underdog Effects and the Possibility of Election Predictions," Public Opinion Quarterly, Vol. 18, 1954, pp. 245-53.

opportunity to accept or reject such reasons and to reevaluate their opinions on the basis of whatever merits they believe these reasons deserve. Thus a far-out opinion is in principle rejected only if its proponent fails to justify it before the rest of the panel. The valid part of the objection against the overly averaging influence of our procedure appears to us to be directed at our not having sufficiently observed this principle in practice. In retrospect, it seems that we should indeed have been more insistent on eliciting explicit reasons for minority opinions, and should have provided an opportunity for explicit critique of such reasons, even at the expense of an additional round if necessary. We might thus have retained items that were rejected early, and explored them more thoroughly through further questioning; this material still forms part of the record of the experiment (see the questionnaires reprinted in the Appendix), but without our having been able to make any satisfactory disposition of it.

(g) Substantive breadth. The above points are all concerned with method. Substantively, although we had aimed for coverage of most of the major aspects of the world of the future, we would have done better in this respect had we also included in our survey a panel explicitly devoted to exploring the future of international relations. The War Prevention panel, of course, was concerned with perhaps the most important issue in this area, and other panels incidentally touched upon various aspects of the international scene, but it would have been greatly desirable to attempt a more systematic examination of this subject.

21. CONCLUSIONS

In trying retrospectively to assess the merits of our experiment in forecasting, we may summarize the outcome as follows:

Substantive forecasts. For many items whose occurrence is generally expected within the next few decades, the

predicted time of this occurrence has been narrowed down somewhat. For others in the same category, we have found that even among experts there is little agreement as to the date, indicating perhaps that relatively greater uncertainties are involved, which preclude more precise predictions at this time. As for the more remote future, we have observed that some events are definitely expected to happen (though at an uncertain date), some are considered of dubious realizability, still others have been ruled out altogether by our respondents. None of these predictions should be endowed with excessive reliability, because of the smallness of the sample of respondents, the variability of their expertise, and the possible intervention of unforeseeable breakthroughs. Still, the number of surprises in store for us may have been reduced a little.

Warnings of potential dangers. Among the contingency forecasts implicit in the responses were indications of potential danger areas that call for preventive action (see Section 15 above). Among these are the possibilities of war, of a continuing maldistribution of food and other commodities in the face of plenty, of social upheaval due to progressive automation, and of unbridled biological applications of molecular engineering.

Effect on the participants. Although the filling in of our questionnaires must have had its nuisance aspects, there is evidence—or at least we like to think so—that the questions were thought-provoking to many of our respondents, who may have found some reward for their labor through the mental stimulation to which the experiment exposed them.

Expediency of the method. Nothing that occurred in the experiment seemed to us to discredit the method in principle, and at least moderate consensus was usually obtained without excessive effort. The dependence of the outcome on certain subjective features, such as ambiguity in the wording of questions, uncertainties regarding the degree of expertise

among the respondents, and the possibility of deliberate or subconscious bias in the answers (see Parts (c), (d), (e) of Section 20 above), while not totally unavoidable, is equally present—if not more so—in traditional modes of reliance on expert judgment in decision-making.

Feasible improvements in method. The experiment has pointed up the need for various kinds of methodological and procedural improvement. Some of these could be introduced without much difficulty. In particular, one would want to see to it that the panel membership remain reasonably stable, that the time between questionnaires be held within more acceptable limits, that questions be phrased with greater care to avoid unnecessary ambiguity, and that enough cycles be provided to allow for adequate feedback, not only of the primary reasons for opinions, but also for a critique of such reasons.

Potential improvements through further research. A more effective use of experts in a Delphi context might be achieved through further methodological research in several areas: (a) Improvements in the systematic selection of experts.* (b) Experimentation with various schemes for the respondents to give a self-appraisal of competence, either absolute or relative to that of their fellow respondents. (c) Methods of improving reliability of forecasts through suitable consensus formulas, possibly based on appropriate self-ratings. (d) Experimentation with various methods of leeding back information, in order to learn more about the sensitivity of opinion changes to both the form and the contents of such feedback. (e) Comparative analysis of social pressure and persuasive reasoning as determinants of opinion convergence. (f) Formulation of a statistical model of the question-and-answer operation of an expert panel, in which the latter would be viewed as a measuring instrument for the substantive quantities which form the subject of the

*See "On the Epistemology of the Inexact Sciences," l.c., p. 43.

questions; each respondent would here have to be represented by an error distribution, and some hypotheses would have to be stated as to the relative independence of the measurement thus obtained. (g) Development of techniques for the formulation of sequential questions that would probe more systematically into the underlying reasons for the respondents' opinions, in a deliberate effort to construct a theoretical foundation for the phenomena under inquiry.

This concludes our report. The appendix contains reprints of the essential portions of the questionnaires, a breakdown of the roster of respondents, a set of graphs exhibiting the amount of convergence observed in the case of repeated questions, and a small collection of comments, criticisms, and other opinions expressed by our respondents which we thought particularly worthy of quotation.

BIBLIOGRAPHY

There exists a large volume of literature concerned with serious forecasts of future trends. The following represents a small selection of publications, which the authors of this report found particularly useful and thought-provoking and which may be of interest to the reader.

Army Research Office, Long-Range Technological Forecast (1963)

Baade, Fritz, The Race to the Year 2000, Doubleday (1962).

Brown, Harrison, James Bonner, and John Weir, The Next Hundred Years, Viking Press (1958).

Clarke, Arthur C., Profiles of the Future, Harper and Row (1960).

Gabor, Dennis, Inventing the Future, Secker and Warburg, London (1963).

Galton, Lawrence, "Science Stands at Awsome Thresholds," New York Times Magazine (Dec. 2, 1962).

Goushev, Sergei (Editor), Russian Science in the 21st Century, McGraw-Hill (1960).

Institute of Radio Engineers, Symposium on Communications and Electronics - 2012 A.D., with contributions by Lloyd V. Berkner, Henri Busignies, J. H. Dellinger, Peter Goldmark, W. D. Lewis, G. A. Morton, Ernst Weber, Harold Wheeler, and Harold A. Zahl; I.R.E. (May 1962).

Landsberg, Hans H., Leonard L. Fischman, and Joseph L. Fisher, Resources of the Future, Johns Hopkins Press (1963).

Lundberg, Ferdinand, The Coming World Transformation, Doubleday (1963).

Neumann, John von, "Can We Survive Technology?," Fortune (June 1955).

New York Times Magazine, Symposium on The Future, with contributions by H. S. Commager, H. L. Dryden, J. B. S. Haldane, Margaret Mead, Clarence Randall, and Arnold Toynbee (April 19, 1964).

Scientific American, Symposium on Technology and Economic Development, with contributions (among others) by Asa Briggs, Kingsley Davis, J. W. Feiss, Frederick Harbison, Wassily Leontief, E. S. Mason, Roger Revelle, S. H. Schurr, and N. S. Scrimshaw (September 1963).