IN -

CAT. 66

NASA Contractor Report 179577

NASA Lewis Research Center Futuring Workshop

Mark Boroush, John Stover,
and Charles Thomas

The Futures Group
Glastonbury, Connecticut

January 1987

NASA

National Aeronautics and
Space Administration

PREFACE

The kernel for holding this workshop originated at a staff meeting of the OTA last year. We were discussing our own involvement in technology assessment and strategic planning and how the uncertainty of the future could impact judgment. A suggestion evolved for some kind of training experience that would enable all who do strategic planning to feel more confident in dealing with evaluations of the future. Through some outside contacts, we were aware that systematic procedures had been developed and tested that dealt with forecasting. These approaches seemed appealing because they involved data acquisition, statistics and other mathematical processes which engineers and statisticians use.

Consequently, it was proposed that we investigate the possibility of holding a seminar or workshop in 1986 which would expose some of the Lewis staff to several of these forecast methods. The investigation revealed that such a workshop was feasible and the expertise for leading it was readily available. Following the usual NASA contract procedures, a Statement of Work and a Request for Proposal were issued. "The Futures Group" were awarded the contract.

What do we expect to derive from this two-day experience?

1. Each of us can expect to be more aware of several of the methods that are used by consultant organizations in forecasting tasks for business and industry. We will have some opportunity to execute a few of these methods, but our time of experience will be limited; we won't become experts. Enough information will be transferred to enable us to try to practice on the job what we have learned.

2. We should be better able to deal with the future. Even if we don't ever execute the methods as they will be taught, we will remember some of the parameters that influence forecasting. I expect many of us will think differently, at least readjust our thought process, when we are required to make long-range plans.

3. The workshop has been intentionally restricted to a comparatively small number. Nevertheless, this group represents all of the Directorates and includes management and non-management staff. Collectively, we are a cross section of the Center. It is an unusual opportunity for dialogue and interaction. Designed around the executing topic of the future, the interaction should be provocative and stimulating. At the conclusion of the Workshop, you will have the opportunity of judging whether this has been the case.

The future incorporates all of the major uncertainties we face. Primarily, we are not here to learn how to predict it. We are here to learn some approaches on how to cope with it, which perhaps may go as far as helping to determine it. Research, which is the lifeblood of this Center, is directed to the future. The future is the focus of this workshop. By deduction, we will be dealing with a topic of vital importance to the Center.

Those of us who were involved in planning and preparing for this workshop have anticipated this day with great expectation. I wish to thank George Prok, Loretta Shaw, Hugh Grimes and Betsy Torres from the Office of Technology Assessment; John Gregory from the Program Coordination Office; and Dick Clapper, Cindy Forman, and Debbie Griest from the Training Office.

Your interest as participants and willingness to commit two days to this workshop have inspired and challenged us. The mutual commitments of us all cannot help but result in a meaningful experience.

Robert W. Graham
Chief, Office of Technology Assessment

CONTENTS

FINAL REPORT ON FUTURING WORKSHOP
HELD AT NASA LEWIS RESEARCH CENTER

October 21 and 22, 1986

Introduction

On October 21 and 22, The Futures Group of Glastonbury, CT, ran a "futuring workshop" on the premises of NASA's Lewis Research Center under sponsorship of the Office of Technology Assessment (Contract No. C-21030). The goal of the workshop was to introduce to a varied audience of Lewis personnel, the range of forecasting techniques and methodologies available. From the perspective of The Futures Group personnel who delivered the workshop, it was a success. The audience/participants seemed interested in the topic from the outset and exhibited growing enthusiasm as the workshop progressed. The questions and discussions during both the plenary sessions and working groups were cogent and challenging and reflected a serious interest on the part of Lewis Research Center personnel. Perhaps more to the point, the workshop was deemed successful by Lewis personnel as well. As is examined more fully on pages 9-11, the evaluations completed at the end of the second day rated the workshop as very useful and effective. A very large majority indicated that the workshop should be repeated for other Lewis Research Center staff.

Workshop Goals

The Futures Group designed and presented a Futuring Workshop to NASA's Lewis Research Center with four principal objectives: (1) to acquaint the participants with the general history of technology forecasting--its generic success and failures; (2) to familiarize the participants with a range of forecasting

methodologies; (3) to acquaint the participants with the range of applicability, strengths, and limitations of each method; and (4) to offer the participants some hands-on experience by working through several forecasting case studies employing both judgmental and quantitative methods. The goal was not to produce polished forecasting experts--that would have been impossible in the time available--nor was it to advocate particular approaches. We believed the Workshop would be judged a success if the participants gained sufficient insight into technology forecasting techniques to (1) understand the range of methods available; (2) make judgments about the potential usefulness of various forecasting methods; and (3) have an understanding of where more detailed information can be obtained for application of the methods to "real life" problems of analysis and forecasting at the Lewis Research Center.

To achieve these goals required, first, that a good deal of information be conveyed in a short amount of time; and second, that the format evoke the interest of the participants. With respect to Lewis Research Center, our approach involved four elements. First, our examples were relevant to many LeRC interests since the workshop design and presentation team had backgrounds either in aerospace engineering or aerospace-related technology forecasting. Second, wherever possible, examples of each method were drawn from previous Futures Group studies that are close to interests of the participants. Third, meaningful hands-on experience in forecasting was achieved by employing relevant Futures Group data bases in quantitative forecast exercises of revenue passenger miles and turbine engine technology. Fourth, as part of the workshop materials package, The Futures Group provided an extensive technological forecasting reference list including available forecasting software so that participants can pursue use of these techniques after the workshop (see Appendix A). Finally, copies of all the material used in the presentations were made available to Lewis Research Center for distribution to the participants.

2

Agenda

The workshop agenda was designed to accomplish the above goals in a two-day conference conducted during regular business hours. The original agenda proposed to Lewis Research Center was modified slightly to fit in an extra Delphi questionnaire round and to reduce the size of the CONSENSOR^{TM} session to a more manageable number of people. The schedule below is the schedule that was followed during the workshop.

AGENDA

NASA Lewis Research Center
Futuring Workshop
October 21 and 22, 1986

Day 1

8:15	Registration
8:30	Introduction (Robert Graham, LeRC/John Stover)
8:45	Delphi Round I
9:00	Information Sources (Mark Boroush)
9:30	Break
9:45	Delphi Round II
10:00	Judgmental Methods (Mark Boroush)
11:00	Introduction to Seminar Topic: Supersonic Cruise Technology (Charles Thomas)
11:45	Delphi Round III
12:00	Lunch
1:30	Delphi Results (John Stover)
2:00	Quantitative Methods Part I (John Stover) ½ Workshop CONSENSOR Session (Charles Thomas, Mark Boroush) ½ Workshop
2:30	Quantitative Methods Part I (John Stover) ½ Workshop CONSENSOR Session (Charles Thomas, Mark Boroush) ½ Workshop
3:00	Break
3:15	Trend Impact Analysis (John Stover)
4:00	TIA Working Session: Four separate working groups
5:00	Adjourn

Day 2

8:30	Dealing with Uncertainty (John Stover)
9:00	Quantitative Methods Part II (John Stover)

10:00	Break
10:15	Cross-Impact Analysis (John Stover)
10:45	Scenarios (Charles Thomas)
11:15	Scenario Working Session: Four separate working groups
12:15	Lunch
1:15	Scenario Working Session (continued)
2:30	Scenario Results (LeRC personnel from each group)
3:00	Break
3:15	State-of-the-Art Technology Assessment (Charles Thomas)
4:15	Open Discussion of Workshop Content
4:45	Review Questionnaire/Evaluation
5:00	Adjourn

The contents of each major agenda item are described below.

Introduction. In this section of the workshop we discussed the recent origins of futures research, tracing the early work at Rand that was conducted in an effort to improve military effectiveness through gaming, Delphi, and systems analysis. We also explained the role of normative forecasting. In addition, we set up a basic taxonomy for methods that were examined later in the workshop.

Information Sources. In this section we described the range of information sources available to a forecaster. In particular, we described on-line data bases appropriate to LeRC work that are generally available today, how such data bases can be accessed, and the need for appropriate search terms to improve the efficiency of a given search (see Appendix A).

Judgmental Methods of Forecasting. In this session we described techniques for collecting judgments from groups. The differences between surveys designed to collect judgments from large samples that replicate larger populations statistically, and expert panels--generally small groups of experts in the subjects under study--were examined. Several approaches to the Delphi process were described; implementation through a series of questionnaires; data collection through interviews; and group meetings. Discussion of the Delphi process was enhanced by employing a Delphi session run in the workshop as an example (see Appendix B).

4

The Delphi process is designed to ask a series of questions to a large group of experts and to strive for <u>consensus</u> among the experts. It has long been clear that bringing experts together in a conference room setting often introduces spurious factors in arriving at a consensus. For example, in a group setting, the strongest personalities rather than the strongest arguments often carry the day. Experts are reluctant to abandon previously published positions in front of their peers. Position in the organizational hierarchy sometimes inhibits free discussion of the real issues. To avoid these conference room inhibitions to a true debate, the Delphi method was developed. In this approach, the experts interact through questionnaires rather than face to face. In the first questionnaire, the experts might be asked to provide their judgment about the timing of a particular future event. The range of opinions of the experts is analyzed and, in a second questionnaire, those that hold extreme positions are asked to provide reasons why they believe that the event is likely to occur earlier or later than the group as a whole. These reasons are collated and fed back to the group in a third questionnaire. Each member of the group is asked to review his position in view of the reasons for the extremes and provide a new judgment, if appropriate. Over literally thousands of applications of this method, it has been found that groups generally move toward consensus.

The two principal features of a Delphi are anonymity and feedback. Anonymity of the respondents (with respect to comments they provide) is important because it apparently permits respondents to change their minds through the sequence of questionnaires. The respondents receive feedback on their answers (and how they compare with other answers) during second and third rounds, which gives them extended time and more data on which to confirm or alter their original judgments.

The Delphi rounds in the conference at LeRC focused on the future of supersonic cruise technology (SCT). The conference participants were asked to

evaluate the likelihood of a series of future events that could have an impact on the development of SCT. Supersonic cruise technology was employed as a focus for much of the conference activity from this point on, since it relates to much of LeRC's research interests. The events and their likelihoods of occurrence derived from the Delphi rounds were later employed in the CONSENSOR session, Trend Impact Analysis, and scenarios construction exercise. The five events posed to the conference for which participants assessed likelihood of occurrence were:

- Event 1: A large-scale, coordinated international terrorist attack results in the downing of several jumbo jets flying out of a number of major European airports.

- Event 2: The People's Republic of China, in the span of just a few years, becomes the U.S.'s 13th largest trading partner (similar to Italy today).

- Event 3: Stagnant growth among the Western economies and sharp increases in protectionist sentiments create a major international trade war. In consequence, the volume of world trade declines by more than 30 percent.

- Event 4: A U.S.-ASEAN* Common Market is formed, giving rise to rapid growth in U.S. trade and business activities with Pacific Rim nations.

- Event 5: Rapid progress in the installation of advanced communications technologies (e.g., intercontinental fiber optic cable connections) makes communications with Europe and Asia as clear, reliable, and inexpensive as long distance connections in the domestic United States.

Quantitative Methods of Forecasting. This portion of the workshop consisted of explanations and examples of forecasting using quantitative methods including extrapolation of time series, regression analysis, and structural modeling using techniques such as system dynamics. The common feature of all these methods is that they are extrapolative. They build their forecasts on the basis of history. As

---

*ASEAN: Thailand, Indonesia, Philippines, Malaysia, Singapore, and Brunei.

such, all contain the implicit assumption that forces that have shaped the past will continue to shape the future. This assumption is bound to be wrong in the long term; therefore, it is necessary to deal with uncertainty, another subject of the seminar (see Appendix C).

Dealing with Uncertainty. A number of techniques exist that produce ranges of forecasts, rather than single values: in one approach, for example, time-series forecasts are amended to include the effects of future developments which, if they occurred, would deflect historical trends. In general, this section focused on quantitative techniques that utilize perceptions about future events, their probabilities, and their impacts to amend forecasts that otherwise would be deterministic. These techniques include: trend impact analysis, cross-impact analysis, probabilistic system dynamics, and others. We also explained risk analysis: decisionmaking in the presence of uncertainty. Finally, this section of the seminar examined how risk can be hedged using portfolio analysis techniques in which high-risk and low-risk items are combined (see Appendix D).

CONSENSOR Session. The CONSENSOR is a group voting machine designed to be used in meetings to collect judgments of participants. In this portion of the session, The Futures Group used its CONSENSOR in an exercise that allowed the group to learn about CONSENSOR-meeting processes as well as develop group judgments about future events concerning supersonic cruise technology. Each participant in the CONSENSOR meeting has a small terminal. Each terminal has two dials: one dial is used to indicate judgments about a question posed by a moderator, and the other dial, confidence in the judgment. When all participants have voted, a microprocessor samples the votes and "discounts" each voter for lack of confidence. The discounted votes of the group are displayed on a video monitor in the form of a histogram. In addition, the mean vote and average confidence are displayed (see Appendix E).

Scenario Exercise. This was one of the "hands-on" workshops conducted during the second day of our sessions. In this portion we explained the uses and limitations of scenarios, and then actually constructed some alternate future worlds during working group meetings focused on supersonic cruise technology. We explained the concept of "scenario space" and discussed how quantitative techniques such as trend impact analyses can provide quantitative content within a scenario (see Appendix F).

Trend Impact Analysis Exercise. This session demonstrated trend impact analysis using existing TFG software to demonstrate how time-series forecasts can be amended to include perceptions about future events and their impacts. Judgments concerning future events (their probability and impact) were obtained from the participants during the TIA working session. The original list of possible future events was derived from the previous Delphi rounds and CONSENSOR sessions. These were discussed, amended and assigned probabilities (of occurrence) and likely impact on the future of revenue passenger miles (as that would affect supersonic cruise technology). These judgments were then run on the TIA software using an LeRC-provided IBM-AT so that each group could see how its judgments deflected the "normal" extrapolative growth in revenue passenger miles (see Appendix G).

State-of-the-Art Exercise. This technique for measuring technology state of the art was developed by The Futures Group under contract to the National Science Foundation. In this method, expert judgment is used to identify a number of variables and their relative contribution to the excellence of a technology. This technique was illustrated using data on jet engine performance in the U.S., U.K., and USSR. The SOA software allows analyst judgment to alter the way in which the excellence of technology is measured. At the session conclusion, LeRC participants were invited to provide their own judgments concerning various measurements and see the impact on the assessments produced on the computer screen (see Appendix H).

Evaluations by LeRC Participants

At the end of the Futuring Workshop, an evaluation form was filled out by the participants. Below is a compiled summary of the responses. The number in each category represents the number of check marks given for each answer/evaluation. The numbers do not always sum to the number of conference participants. Participants left blank evaluation of those sessions for which they were not present. Additionally, some participants did not complete the forms in total.

Question 1: How useful did you find the substantive information presented at the workshop?

	Rating		
	Very Useful	Somewhat Useful	Not At All Useful
Information Sources	14	28	4
Delphi Exercise	31	13	1
CONSENSOR Session	31	15	
Quantitative Analysis	15	25	4
Trend Impact Analysis	22	23	2
Cross-Impact Analysis	18	26	2
Scenario Construction	28	16	2
State-of-the-Art Assessment	11	26	7

Question 2: If there are any areas of forecasting that you would have liked to see included in the workshop, please list them below.

More technology examples

More examples of previous forecasts and their results

Those specific to technology planning

Advocacy for the need for long-range planning

Sensitivity of results ,of forecasts. to technology advances

Introduction of bias, particularly in wording Delphi questionnaires

More information on economic forecasting

Question 3:   How would you rate the presentations made by the workshop staff in each of the main areas?

Topic	Rating			
	Excellent	Good	Fair	Inadequate
Information Sources	10	26	7	2
Delphi Exercise	20	23		1
CONSENSOR Session	24	20	1	
Quantitative Methods	11	27	6	1
Trend Impact Analysis	22	21	4	
Cross-Impact Analysis	12	30	2	
Scenario Construction	15	23	5	1
State-of-the-Art Assessment	6	24	11	2

Question 4:   How would you rate the usefulness of the workshop's workbook as an initial reference for your future forecasting activities?

Excellent	Good	Fair	Inadequate
10	31	5	1

Question 5:   How effective do you feel the workshop as a whole has been in introducing you to the forecasting techniques appropriate to your work?

Little Value							Modest Value									High Value	
1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10
		3	1	2		1	2	2		7	6	9	6	6	1	1

Question 6: Should the workshop be repeated for other members of the Lewis staff?

Unqualified	YES	14	

Qualified	YES	But only for appropriate offices/planning personnel	7
		Especially for Senior Management	2
		Also give a Strategic Planning Workshop	4
		But one week long; more selective attendance	1
		With more detail on mathematic techniques	2
		Also give special focused follow-up (e.g., TIA)	1
		But shorter	2

Total: 19

Total YES	33
Maybe	2
No	4

Acknowledgments

FORECASTING SOFTWARE FOR MICROCOMPUTERS

PRODUCT	OPERATING MODE	TIME SERIES	MULTIPLE REGRESSION	GRAPHICS	PRICE	VENDOR	TELEPHONE
1,2,3 Forecast	Interactive	Yes	Yes	Yes	$90	1,2,3 Forecast	(503) 585-8314
AREMOS/PC	Interactive & Batch	Yes	Yes	Yes	$1,000 to $3,000	Wharton Econometric	(215) 386-9000
BMDP Statistical Software	Interactive & Batch	Yes	Yes	Yes	$495 to $1,500	BMDP Staticstical Software	(213) 479-7799
CRISP	Interactive & Batch		Yes	Limited	$495	Cruch Software	(415) 564-7337
Economist Workstation	Interactive	Yes	Yes	Yes	$2,700 to $6,200	Data Resources Inc.	(617) 863-5100
ESP Version 2.0	Interactive & Batch	Yes	Yes	Limited	1295	Economica, Inc.	(617) 661-3260
Forecast Plus	Interactive & Batch	Yes	Yes	Limited	$595	Walonick Associates	(215) 386-9000
Microstat	Interactive & Batch	Yes	Yes	Limited	$375	Ecosoft, Inc.	
MicroTSP	Interactive & Batch	Yes	Yes	Yes	$595	Quantitative Micro Software	(714) 856-3368
Modler Blue	Interactive & Batch	Yes	Yes	Yes	$750	Alphametrics Corp.	(215) 664-6480
Modler Econometric Software	Interactive & Batch	Yes	Yes	Yes	$4,000		
Modler MBA	Interactive & Batch	Yes	Yes	Yes	$1,250		
NWA STATPAK	Interactive	Yes	Yes	Yes	$495	Northwest Analytical Inc.	(503) 224-7727
P-STAT	Interactive & Batch	Yes	Yes	Yes	$695	P-STAT Inc.	(609) 924-9100
SAS/STAT Software	Interactive & Batch	No	Yes	Yes	$2,000	SAS Institute	(919) 467-8000
SL-MICRO	Batch		Yes	No	$250	Questionnaire Service Co.	(517) 641-4428
Smart Forecasts II	Interactive	Yes	Yes	Yes	$695	Smart Software Inc.	(617) 489-2743
SPSS/PC+	Batch	No	Yes	Limited	$795	SPSS Inc.	(312) 329-2400
StatPlan III	Interactive	Yes	Yes	Yes	$179	The Futures Group	(203) 633-3501
STATGRAPHICS	Interactive	Yes	Yes	Yes	$795	STSC Inc.	(301) 984-5123
StatPac Gold	Interactive & Batch	Yes	Yes	Yes	$595	Walonick Associates	(215) 386-9000
Statpro 2.0	Interactive & Batch	Yes	Yes	Yes	$795	Penton Software Inc.	(800) 221-3414
SYSTAT	Interactive & Batch	Yes	Yes	Yes	$595	SYSTAT Inc.	(312) 864-5670
The Statistician	Interactive	Yes	Yes	Yes	$350	Quant Systems	(803) 571-2835
Trend Impact Analysis	Interactive	Yes	Yes	Yes	$7,500	The Futures Group	(203) 633-3501

AN ANNOTATED BIBLIOGRAPHY ON FUTURES RESEARCH
(Including Titles on Technological Forecasting)

Ackoff, Russell L., A Concept of Corporate Planning (NY: Wiley-Interscience, 1970).

Despite an abundance of literature on the subject of corporate planning, it is common to find confusion among managers concerning what a plan should contain, how planning should be conducted, and what values can be derived from it. Avoiding both extremes of easy platitudes and technicalities, which account for so much of the planning literature, an outstanding authority in the field explains in simple, straightforward language what should be done, who should do it, and why.

Ackoff, Russell L., Redesigning the Future: A Systems Approach to Societal Problems (NY: Wiley-Interscience, 1974).

Views a transition from the Machine Age to the Systems Age. The former is characterized by analytical thinking based on doctrines of reductionism and mechanics. But this is now being supplemented and partially replaced by the doctrines of expansionism and teleology, and a new synthetic mode of thought. This "postindustrial revolution" is based on automation, and its key idea is interaction.

Ackoff, Russell L., The Art of Problem Solving (NY: Wiley-Interscience, 1978).

Ackoff, Russell L., Creating the Corporate Future: A New Concept of Corporate Planning (NY: Wiley, 1981).

Synthesizes three earlier volumes--A Concept of Corporate Planning (1970), Redesigning the Future (1974), and The Art of Problem Solving (1978)--and adds experience from extensive work with corporations over the last decade. The new concept of planning, Interactive Planning, is a systems approach that is highly participative. Its objective is development rather than growth, providing opportunities for individual and corporate development by synthesizing operational, tactical, and strategic planning into the design of a desirable future and inventing ways of realizing it.

Ackoff, Russell L., A Guide to Controlling Your Corporation's Future (NY: John Wiley & Sons, 1984).

A guide to facilitate the use of interactive planning, based on Ackoff's more detailed book Creating the Corporate Future.

Armstrong, J., Long Range Forecasting: From Crystal Ball to Computer (NY: Wiley-Interscience, 1978).

A review of the research literature relating to predictive forecasting.

Ascher, William, Forecasting: An Appraisal for Policy Makers (Baltimore: Johns Hopkins University Press, 1978).

This innovative study examines the records of expert forecasting of national trends in population, economics, energy, transportation, and technology over a 50-year period. By examining forecast methods and sources, factors associated with greater accuracy as well as with systematic biases are identified.

Ascher, William and William H. Overholt, Strategic Planning and Forecasting: Political Risk and Economic Opportunity (NY: Wiley-Interscience, 1983).

Forecasting must be studied not in isolation, but in the context of a policymaking process. The authors seek to describe appropriate methods to use.

Ayres, Robert U., Uncertain Futures: Challenges for Decision-Makers (NY: Wiley-Interscience, 1979).

Provides a comprehensive global overview of current events and political and economic controversies, with a number of explicit forecasts for major countries, both developed and underdeveloped, over the next 50 years. Emphasis is given to the U.S., with alternative scenarios used to illustrate what might happen. Sociopolitical, demographic, economic and technological factors are considered, with the conclusion that these contemporary trends point toward major crises with highly uncertain outcomes.

Baier, Kurt, and Nicholas Rescher (eds.), Values and the Future: The Impact of Technological Change on American Values (NY: Free Press, 1969).

The 17 original essays are aimed "toward the discovery of ways of guiding social change in directions which are at the least not incompatible with the realization of our deepest values, and perhaps even helpful to it." (p.v) Some groundwork is laid for a new profession of "value impact forecasters," especially through methodological pieces by Rescher, Gordon, and Helmer. The other essays are largely focused on economics, and the editors readily confess the weakness of excluding views of anthropologists, sociologists, and psychologists.

Barney, Gerald (ed.), Global 2000 Report to the President: Entering the Twenty-First Century (Washington, D.C.: USGPO, 1980).

The first attempt by the U.S. government to produce an interrelated set of population, resource, and environmental projections, resulting in the most consistent set of global projections yet achieved by U.S. agencies. The Global 2000 Study has three major underlying assumptions: (1) a general continuation around the world of present public policy relating to population stabilization, natural resource conservation, and environmental protection; (2) that rapid rates of technological development and adoption will continue with no serious social resistance; and that there will be no revolutionary advances or disastrous setbacks; and (3) no major disruptions of international trade as a result of war, political disruption, or disturbance of the international monetary systems.

Beckwith, Burnham P., Ideas About the Future: A History of Futurism, 1794-1982 (Palo Alto CA: B. P. Beckwith, 1984).

One of the best ways to prepare to make scientific predictions about the future is to review the predictions made by the most able and/or stimulating earlier

futurists, and their reasons for making them. This book is largely devoted to critical essays on 25 writers on the future, each concluded with an assessment of strong points and weak points.

Bell, Daniel (ed.), <u>Toward the Year 2000: Work in Progress</u> (Beacon Press, 1969).

Essentially this is an anthology of 22 papers on specific social problems, sandwiched between two sections of dialogue resulting from Working Session I held in October 1965 (27 participants), and Working Session II held in February 1966 (33 participants).

Bell, Daniel, <u>The Coming of Post-Industrial Society: A Venture in Social Forecasting</u> (NY: Basic Books, 1973).

This widely reviewed tome is considered to be the definitive work on "Post-Industrial Society," and in certain respects it is. But it has many problems. It is a wordy assortment of essays and ideas--some fresh and challenging, some outdated, and some without empirical foundation despite the aura of thorough scholarship and Bell's reputation. There is some description, a great deal of covert prescription, and a few bare-knuckle assaults on "ecological radicals" and others such as Ivan Illich, who is seen as "a romantic Rousseauian" mouthing "cant words of modernity." Despite claims that the book was written in the past five years, the footnotes offer strong evidence of this book as a product of the 1960s.

Botkin, James W., M. Elmandjra, and M. Malitza, <u>No Limits to Learning: Bridging the Human Gap</u> (Elmsford, NY: Pergamon, 1979).

Learning and the individual human being, rather than material resources, are the key to the world's future. Unfortunately, while the world has moved to a new level of risk and complexity, human understanding remains rooted to a world view that is no longer relevant. Individuals and societies will have to develop "innovative learning," the two chief features of which are anticipation and participation.

Boucher, Wayne (ed.), <u>The Study of the Future: An Agenda for Research</u> (Washington, D.C.: USGPO, 1977).

This volume is concerned with forecasting. In particular, it is concerned with the various beliefs, methods, practices, and results associated with a kind of forecasting that has come to be referred to in the last 10 to 15 years as "futures research."

Boucher, Wayne, J. L. Morrison, and W. L. Renfro (eds.), <u>Applying Methods and Techniques of Futures Research</u> (San Francisco: Jossey-Bass, 1983).

Various chapters cover the evolution of futures research and its link with strategic planning; environmental scanning; multiple scenario analysis; and a non-technical introduction to futures research.

Boulding, Kenneth E., <u>The Meaning of the Twentieth Century: The Great Transition. World Perspectives, Vol. 34</u> (NY: Harper & Row, 1964).

Portrays a future era that depends upon a stable, closed-cycle technology.

15

Bowman, Jim, et al., The Far Side of the Future: Social Problems and Educational Reconstruction (Educational Futures, 1978).

A forceful, innovative proposal for the reconstruction of society through education. The authors outline a comprehensive model for transcending traditional education and emphasize the evolutionary changes that will help facilitate living and learning alternatives.

Branch, Kristi, Guide to Social Impact Assessment (Boulder, CO: Westview, 1983).

Seeks to provide assistance in the complex process of assessing social change, emphasizing an analytic approach and a theoretical framework that can be applied to assessing diverse events such as changes in the natural environment, the local economy, or the dominant technology. A major focus of the guide is the interrelationships that create social change.

Brown, Harrison, The Challenge of Man's Future (NY: Viking, 1954).

This can be considered the first genuinely futurist book. Utilizing a systems approach, the need for forecasting alternative futures is stressed.

Brown, Harrison, James Bonner, and John Weir, The Next Hundred Years: Man's Natural and Technological Resources (NY: Viking, 1957).

Contains summaries of conferences held to discuss industrial expansion and long-range planning.

Brown, Harrison, The Next 90 Years (1967).

A pessimistic forecast.

Brown, Harrison, The Human Future Revisited (NY: W. W. Norton & Co., 1978).

Brown, James, This Business of Issues: Coping with the Company's Environments (NY: The Conference Board, 1979).

A work on monitoring and issues management.

Brown, Lester, Building a Sustainable Society (NY: W. W. Norton, 1981).

The economic consequences of the throwaway society's disregard for environmental problems are becoming more apparent. Brown contends that it is demand-side rather than supply-side economics that holds the key to a sustainable society as world population and its inherent demand on resources continue to grow.

Burchell, Robert W., and George Sternlieb (eds.), Planning Theory for the 1980s: A Search for Future Directions (New Brunswick, NJ: Center for Urban Policy Research, Rutgers U., 1978).

Seeks to represent the current thinking on the course of future planning by the field's foremost experts, with 23 invited papers on physical planning, social planning, economic planning, macro-planning vs. local control, and what planners are and what they do.

Calder, Nigel, 1984 and Beyond (NY: Viking, 1984).

A look back at predictions published in 1964 to see how good the experts in various fields were at forecasting the future, pointing out particular hits and misses.

Cetron, Marvin, and Thomas O'Toole, Encounters with the Future: A Forecast of Life into the 21st Century (NY: McGraw-Hill, 1982).

An exercise in "professional forecasting," involving the analysis and synthesis of data and extensive use of computers.

Choucri, Nazli, and Thomas Robinson (eds.), Forecasting in International Relations: Theory, Methods, Problems, Prospects (San Francisco: W. H. Freeman, 1978).

The first collective efforts by an international group of scholars to sketch the boundaries and the content of forecasting as applied to international relations.

Clarke, Arthur C., Profiles of the Future: An Inquiry into the Limits of the Possible (NY: Harper & Row, 1964, rev. 1973).

Offers several examples from early 20th century of forecasting failures. A pioneering work in the field of forecasting scientific and technological break-throughs.

Commoner, Barry, The Closing Circle: Nature, Man and Technology (NY: Knopf, 1971).

This is a well-received popularized volume by a leading ecologist. The central message--that the cause of the environmental crisis is technology, rather than population or affluence--should not be ignored.

Commoner, Barry, The Poverty of Power (NY: Knopf, 1976).

Corn, J. J. (ed.), Imagining Tomorrow: History, Technology, and the American Future (Cambridge, MA: MIT Press, 1986).

Ten original essays on America's technological expectations over the past 100 years. Concludes that the vision of the future as a technological paradise has clearly been a central theme in American culture. A valuable contribution from the humanities, despite no mention of any recent attempts to systematically forecast technology and assess its impacts.

Cornish, Edward, The Study of the Future: An Introduction . . . (World Future Society, 1977).

A general introduction to futurism and future studies. Chapters discuss the history of the futurist movement, ways to introduce future-oriented thinking into organizations, the philosophical assumptions underlying studies of the future, methods of forecasting, current thinking about what may happen as a result of the current revolutionary changes in human society, etc.

de Jouvenel, Bertrand, The Art of Conjecture (NY: Basic Books, 1967).

A milestone in the development of social forecasting, it laid the philosophical bases for forecasting methods.

Dickson, Paul, The Future File (Glendale, CA: Avon Books, 1978).

An initial introduction to futurism.

Diebold, John, Making the Future Work: Unleashing Our Powers of Innovation for the Decades Ahead (NY: Simon & Schuster, 1984).

Makes the sweeping claim that "information technology is the basis of a new age of civilization, the Information Age." Americans may lose out to the Japanese and other competitors because our social, political and legal responses to the frentic pace of technological change are often inappropriate and almost always dilatory.

Dolman, Anthony J. (ed.), Global Planning and Resource Management: Toward International Decision-Making in a Divided World (Elmsford, NY: Pergamon Policy Studies, 1980).

A follow-up to Reshaping the International Order: A Report to the Club of Rome (E. P. Dutton, Oct. 1976), which seeks to identify ways in which global planning and resource management capabilities could be strengthened.

Drucker, Peter F., The Future of Industrial Man: A Conservative Approach (NY: John Day, 1942).

World War II is seen as being fought for the structure of industrial society, and as the first war to be fought as an industrial war--where industry is the main fighting force itself. Drucker also feels that only the U.S. can find a nontotalitarian way to a free industrial society, and this cannot be through centralized planning. It is argued that we should plan for a great number of varied alternatives and build genuine local and decentralized self-government, avoiding both totalitarian planning and 19th century laissez-faire.

Drucker, Peter F., America's Next Twenty Years (NY: Harper, 1955).

Examines future developments that are already under way as a result of population increases.

Drucker, Peter F., Landmarks of Tomorrow (NY: Harper, 1959).

"At some unmarked point during the last twenty years we imperceptibly moved out of the Modern Age and into a new, as yet nameless, era." This is essentially an early description of "Post-Industrial Society."

Drucker, Peter F., The Age of Discontinuity: Guidelines to Our Changing Society (NY: Harper & Row, 1969).

Focuses on four major discontinuities: new technologies, the world economy (including a chapter on the Global Shopping Center), a society of large organizations (including a chapter on the New Pluralism), and the changed position and power of knowledge such that we are becoming a knowledge society--"the greatest of the discontinuities around us."

Drucker, Peter F., <u>Managing in Turbulent Times</u> (NY: Harper & Row, 1980).

    The three decades from the end of WWII to the mid-1970s were a period of regular, almost linear, economic development for most of the world's developed nations. In the last five years, this straightforward development has turned topsy-turvy. We have entered an economically turbulent time, with new challenges facing the managers of all types of institutions. We are also entering a period of turbulence in technology: a time of rapid innovation, with fast and radical structural shifts.

Duignan, Peter, and Alvin Rabushka (eds.), <u>The United States in the 1980s</u> (Stanford, CA: Stanford U., Hoover Institution Publication 228, 1980).

    The 29 essays, written as unofficial background for the Republican Party, are arranged in two parts. Part I, "Domestic Issues," includes 14 essays on economic policy, government regulation, public opinions, tax and spending limits, tax policy, welfare reform, Social Security, energy options, environmental policy, health and the government, housing policy, neighborhood revitalization, and higher education. Part II, "Foreign Affairs," offers 15 essays on defense and arms control, international economics, and major nations and regions of the world.

Ellul, Jacques, <u>The Technological Society</u> (NY: Knopf, 1964).

    Epitomizes the pessimistic climate of opinion in post-World War II Europe.

Esfandiary, F. M., <u>Up-Wingers</u> (NY: John Day, 1973).

    New dimensions are seen as emerging, going far beyond right and left, conservative and liberal, defying all the old labels. The new dimensions are up. We are at the beginning of the Planetary Movement and the Cosmic Upheaval.

Etzioni, Amitai, <u>The Active Society: A Theory of Societal and Political Processes</u> (NY: The Free Press, 1968).

    A sociologist proposes a theory of societal self-control based on "valid social science theory" which could serve as a springboard for active participation in our "post-modern" society.

Falk, Richard A., <u>A Study of the Future Worlds: Designing the Global Community</u> (NY: Free Press, 1975).

    A detailed outline of the structures and functions of new world organizations necessary to ensure four overriding values: the elimination of war, poverty, social injustice, and ecological instability.

Feinberg, Gerald, <u>The Prometheus Project: Mankind's Search for Long-Range Goals</u> (NY: Doubleday, 1969).

    A physicist discusses the unity of mankind and the need for agreement on long-range goals for humanity in the light of "impending 'world-shaking' decisions."

Ferkiss, Victor, The Future of Technological Civilization (NY: George Braziller, 1974).

An important and well-written "exercise in utopian thinking." The four sections of the books are devoted to a criticism of the ruling ideology of liberalism, the development of a new political philosophy of ecological humanism, sketching some of the elements of a planetary society governed by ecological humanism, and describing how we will get there from here.

Ferkiss, Victor, Futurology: Promise, Performance, Prospects (Beverly Hills: Sage Publications, 1977).

An informative survey regarding "Futurology"--the art and science of predicting the future based usually on the premise that events, both natural and social, are determined by impersonal natural forces acting according to observable scientific laws, thus making these events subject to measurement and prediction.

Forrester, Jay W., World Dynamics (Cambridge, MA: Wright-Allen Press, 1971).

A "preliminary effort" to model world interactions, devised for a July 1970 meeting of the Club of Rome. The widely discussed Limits to Growth study followed from this work. The dynamic model described here interrelates six variables: population, capital investment, geographical space, natural resources, pollution, and food production.

Fowles, Jib, Handbook of Futures Research (Westport, CT: Greenwood Press, 1978).

Futures research is a new field of endeavor, hardly more than ten years old. Being so young, it is more amorphous than other disciplines and enterprises. Its relative lack of structure, coupled with its most remarkable subject matter, can make futures research appear obscure and puzzling. The present volume is an attempt to explain the aims and content of this field.

Freeman, Christopher, and Marie Jahoda (eds.), World Futures: The Great Debate (NY: Universe Books, 1978).

Examines the alternative visions of 16 futurists and discusses critical issues such as food, energy, mineral resources, and policies for technical change. Concludes with a discussion of three world views (conservative, reformist, and radical), scenarios of the future from each of these three perspectives, and a chapter on the prospects of war.

Fuller, R. Buckminster, Utopia or Oblivion: The Prospects for Humanity (NY: Bantam Books, Matrix Editions, 1969).

Twelve papers based on talks or articles prepared over the past several years, providing a good overview of Fuller's thought.

Galtung, Johan, The True Worlds: A Transnational Perspective (NY: Free Press, 1980).

The final volume of the Preferred Worlds for the 1990s series, sponsored by the Institute for World Order.

Gerlach, Luther P., and Virginia H. Hine, <u>Lifeway Leap: The Dynamics of Change in America</u> (Minneapolis: U. of Minnesota Press, 1973).

An attempt by two anthropologists to supply four basic conceptual tools for creative participation in shaping the future: the distinction between revolutionary and developmental change, and a description of systems, movements, and the evolutionary viewpoint. Although apparently written for high school and college students, and for perplexed citizens, this volume conveys some fundamental notions that would be useful to any professional.

Gordon, Theodore J., <u>The Future</u> (NY: St. Martin's Press, 1965).

A popular tour of largely technological matters by a space scientist who has since become a professional futurist.

Granger, C. W. J., <u>Forecasting in Business and Economics</u> (NY: Academic Press, 1980).

A textbook addressed to future economists and managers, showing how to critically and quantitatively examine the future. Chapters cover basic concepts of forecasting, trend-fitting and forecasting, forecasting from time-series models, regression techniques and econometric models, use of survey regression techniques and econometric models, use of survey data, leading indicators, evaluation and combining of forecasts, population forecasting, technological forecasting and the Delphi method, and world models.

Hamrin, Robert D., <u>Managing Growth in the 1980s: Toward a New Economics</u> (NY: Praeger Special Studies, 1980).

The objective of policy should be to maximize national economic welfare, which must take into consideration pollution, resource depletion, the quality of work, income distribution, and other aspects of welfare not reflected in GNP as now calculated. When issues are placed in this context, the bankruptcy of the "growth vs. no-growth" debate is clearly seen.

Harman, Willis, <u>An Incomplete Guide to the Future</u> (NY: W. W. Norton, 1979).

After an initial chapter on the methods of futures research, Harman describes the breakdown of the industrial era paradigm based on scientific method and material progress, characteristics of the emerging transindustrial paradigm, and four major dilemmas that encourage the development of this new paradigm.

Harman, Willis, and O. W. Markley (eds.), <u>Changing Images of Man</u> (London: Pergamon, 1982).

A reprint of a 1974 SRI report.

Harrison, Daniel, <u>Social Forecasting Methodology: Suggestions for Research</u> (NY: Russell Sage Foundation, 1976).

The consensus of critics is that social forecasting methodology is in an underdeveloped state. This paper suggests a number of areas in which methodological research could be usefully done.

21

Heilbroner, Robert L., The Future as History: The Historic Currents of Our Time and the Direction in which They Are Taking America (NY: Harper & Bros., 1960).

Examines our state of mind about the future, arguing that in the past we have had the sustaining beliefs of optimism, but that this idea of progress "has become a dangerous national delusion."

Heilbroner, Robert L., An Inquiry into the Human Prospect (NY: Norton, 1974).

A bleak essay by a prominent thinker expressing little hope that social problems can be solved due to runaway population, the prospects of obliterative war (particularly resulting from blackmail by underdeveloped countries), and the collapse of the environment.

Heilbroner, Robert L., Business Civilization in Decline (NY: Norton, 1976).

Heilbroner, Robert L., Beyond Boom and Crash (NY: W. W. Norton, 1978).

Author of The Future as History (Harper, 1960), An Inquiry into the Human Prospect (Norton, 1974), and Business Civilization in Decline (Norton, 1976), examines fluctuations of the capitalist system. Economic planning is seen as the next great change that may save the system.

Heilbroner, Robert L., An Inquiry into the Human Prospect: Updated and Reconsidered for the 1980s (NY: W. W. Norton, 1980).

In this updating for the 1980s, Heilbroner adds an afterword to each of the original chapters. He finds that the general relaxation of mood and posture, and the prevailing mood of apathy, does not change the nature of the human prospect.

Helmer, Olaf, Social Technology (NY: Basic Books, 1966).

A major contribution to forecasting methodology.

Hershel, Richard, On the Future of Social Prediction (1976).

Hoos, Ida R., Systems Analysis in Public Policy: A Critique, Revised ed. (Berkeley, CA: University of California Press, 1983).

Reprint of the 1972 edition, which reviews the ways in which systems analysis and the family of techniques to which it is related has created a management syndrome: the notion that all human affairs could be managed, and that using the tools of management science would solve society's problems "rationally."

Hughes, Barry B., World Futures: A Critical Analysis of Alternatives (Baltimore, MD: Johns Hopkins University Press, 1985).

This book seeks to aid those who are frustrated at the confusing array of possible futures, attempting to show how the bases of difference arise from alternative world views (or models or paradigms), competing theories and methodologies, and contradictory evidence or data.

Hussey, D. E. (ed.), The Truth About Corporate Planning: International Research into the Practice of Planning (Elmsford, NY: Pergamon, 1983).

The 30 papers deal with such topics as organized planning in major U.S. corporations, a survey of how planning works in 48 U.K. companies, the accuracy of long-range planning, pitfalls in multinational long-range planning, the state of the art in environmental scanning and forecasting, computer models for corporate planning, and a comparative study of long-range planning in Japan and the United States.

Jantsch, Erich, Technological Planning and Social Futures (NY: Wiley, 1972).

Sixteen previously published articles. In sum, "the entire process of rational creative action is spotlighted from forecasting and planning . . . to institutional and instrumental change."

Jones, Thomas, Options for the Future: A Comparative Analysis of Policy-Oriented Forecasts (NY: Praeger, 1980).

Identifies and examines the underlying assumptions that led to forecasts; presents evidence that some images of the future are more plausible than others; and sets forth an intermediate position between technological-socal optimism and limits-to-growth pessimism.

Jungk, Robert, and Johan Galtung (eds.), Mankind 2000 (Oslo: Universitetsforlaget, 1969).

Contributions to the First International Futures Research Conference, held in Oslo in 1967.

Kahn, Herman, On Thermonuclear War (Westport, CT: Greenwood Press, 1961, rep. 1978).

An analysis of nuclear strategies--should seek to prevent nuclear war as well as prepare to wage it.

Kahn, Herman, and Anthony J. Wiener, The Year 2000: A Framework for Speculation on the Next Thirty-Three Years (NY: Macmillan, 1967).

Considered to be a classic work by some futurists, this volume served as a conceptual baseline for the Commission on the Year 2000 as well as a foundation for continuing studies by the Hudson Institute. The final chapter on Policy Research and Social Change is still a valuable statement on methodology.

Kahn, Herman, and B. Bruce-Briggs, Things to Come: Thinking About the Seventies and Eighties (NY: Macmillan, 1972).

A shorter, updated, and somewhat more popularized version of The Year 2000. Considerable attention is devoted to international affairs, with chapters on the world of the seventies and eighties, sources of stability and instability in the international system, military-technological possibilities, and the rise of Japan.

Kahn, Herman, et al., The Next Two Hundred Years (NY: William Morrow & Company, 1976).

In this provocative work, Herman Kahn and his associates confront the issue of the second half of the twentieth century: whether technological and industrial growth will ultimately destroy mankind or bring the world peace and prosperity. According to the doomsayers, the population explosion, coupled with economic growth, could prove catastrophic for the future of humanity. Therefore, say the prophets of doom, economic growth must be severely limited.

"Not so," says Herman Kahn. "Not only will the world's population increase at a slower rate, but the world can afford prosperity."

Kahn, Herman, et al., World Economic Development: 1979 and Beyond (Boulder, CO: Westview, 1979).

A further elaboration of the Hudson Institute world view, as previously expressed in The Year 2000 (1967), Things to Come (1972), and The Next 200 Years (1976).

Kahn, Herman, The Coming Boom: Economic, Political, and Social (NY: Simon & Schuster, 1982).

A long-term perspective on mankind's economic past and present includes two watersheds: the agricultural revolution of some 10,000 years ago and the "Great Transition" in which we are living today.

Landsberg, H. H., L. L. Fishman, and Joseph L. Fisher, Resources in America's Future (Baltimore: Johns Hopkins University Press, 1963).

This work pioneered the extrapolation of quantified ecological trends.

Lapp, Ralph. E., The Logarithmic Century (Englewood Cliffs, NJ: Prentice-Hall, 1973).

"This book is really about a conjunction of sciences--ecology and economics, or eco-economics." There are numerous tables to illustrate the chapters on nuclear power, the consumer avalanche, the knowledge explosion, the question of growth, and the control of technology. The potential of disaster argues for application of restraints on size.

Laszlo, Ervin, A Strategy for the Future: The Systems Approach to World Order (NY: George Braziller, 1974).

World order "is not merely a new 'in' term for international relations theory or world politics. It is rather a new conceptualization in a field that embraces global ecology, geopolitics, human geography, international relations theory, anthropology, political science, and social ethics and philosophy. It is an attempt to grasp the contemporary situation on this planet in all its diversity without erecting, or conserving, artificial frontiers either between geographic or disciplinary territories."

Levenbach, Hans, and J. P. Cleary, <u>The Beginning Forecaster: The Forecasting Process Through Data Analysis</u> (Belmont, CA: Lifetime Learning Publications, 1981).

An introduction to the basic principles of statistical forecasting as currently practiced in leading corporations. Covers computer-based techniques, establishing a process for effective forecasting, analyzing data before attempting to build models, selecting techniques appropriate for the problem, and using robust/resistant methods in addition to traditional methods.

Linstone, Harold A., <u>Multiple Perspectives for Decision Making: Bridging the Gap Between Analysis and Action</u> (NY: North-Holland, 1984).

Describes an original multi-perspective approach. Unlike other decision models, this approach combines organizational/societal, personal/individual, and technical/analytical perspectives.

Linstone, Harold, and W. Simmonds (eds.), <u>Futures Research: New Directions</u> (Reading, MA: Addison-Wesley, 1977).

The interest in this book derives not from a logical assembly of linear, sequential, causal chains of thought between different people, but from the fact that some twenty-three well-known workers in this field have arrived at very similar conclusions from different interests and starting points, and differing experiences, in a variety of countries. They agree that we must move beyond the objective, analytic, reductionist, number-oriented, optimizing, and fail-safe approach to futures problems and learn to think with equal fluency in more subjective, synthesizing, holistic, qualitative, option-increasing, and safe-fail ways. For futures research the time has come to turn in new directions!

Lundborg, Louis B., <u>Future Without Shock</u> (NY: W. W. Norton, 1974).

Lundborg advocates and foresees trends such as more social responsibility for business, profit optimization rather than maximization, and a flattened (more egalitarian) organization chart.

Makridakis, Spyros, and Steven Wheelwright (eds.), <u>The Handbook of Forecasting: A Manager's Guide</u> (NY: Wiley-Interscience, 1982).

In a final summation on the future of forecasting, the editors foresee an increasingly important role for forecasting, but it will not become easier or necessarily more accurate. Business forecasting will have to be enlarged to include political forecasting, energy forecasting, technological forecasting, and related fields. Developing procedures to incorporate these other aspects into planning will be essential. Above all, planners and decision-makers will have to understand that forecasting cannot eliminate uncertainty.

Markley, O. W., et al., <u>Changing Images of Man</u> (Menlo Park, CA: Stanford Research Institute, 1973).

Chapters are devoted to discussing images of man in a changing society, some formative images of man-in-the-universe, economic man, scientific influences on the image of man, the characteristics of an adequate image of humankind, and the processes and strategies for promoting this "evolutionary transformational-

ist" image in contrast to the technological extrapolationist image that we presently have.

Mason, Richard, and Ian Mitroff, Challenging Strategic Planning Assumptions: Theory, Cases, and Techniques (NY: Wiley-Interscience, 1981).

Chapters consider such topics as the nature of real world problems, strategic assumption surfacing and testing procedures, dialectical debate concepts and cases, policy argumentation concepts and cases, and a comparison of approaches to business problem solving.

McHale, John, The Future of the Future (NY: George Braziller, 1969).

A wide-ranging overview, aided by scores of charts and photographs, with particular emphasis on ecology, technology, and planetary resources.

McHale, John, The Ecological Context (NY: George Braziller, Inc., 1970).

Meadows, Donella H., et al., The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind (NY: Universe Books, 1972).

The much-publicized highly controversial, computer-based study of an MIT Project Team headed by Dennis L. Meadows, based on the model of Jay W. Forrester and embellished with 48 figures and 6 tables.

Meadows, Dennis L., et al., Dynamics of Growth in a Finite World (Cambridge, MA: Wright-Allen, 1974).

Presents the methodology behind The Limits to Growth and the details of a model called "World 3," a device for testing the implications of alternative assumptions.

Mesarovic, Mihajlo, and Edward Pestel, Mankind at the Turning Point: The Second Report to the Club of Rome (NY: E. P. Dutton, 1974).

A new and improved computer model is employed, based on multilevel hierarchical systems theory and the division of the world into ten interdependent and mutually interacting regions, analyzing alternative patterns of development over a 50-year period.

Mesthene, Emmanuel, Technological Change: Its Impact on Man and Society (Cambridge: Harvard University Press, 1970).

An overview of the now discontinued research of the Harvard Program on Technology and Society woven into three chapters on social change, values, and economic and political organization.

Michael, Donald N., The Unprepared Society: Planning for a Precarious Future (NY: Basic Books, 1968).

Chapters on the following: On the Environment of the Futurist, One Way of Looking at Tomorrow (focusing on complexity, turmoil, and scarcity). Three Prepotent Technologies (cybernation, social engineering, and biological engineering), On the Changeover to Long-Range Planning, The Natural Resistances to Organizational Change, and Some Challenges to Educators.

Michael, Donald N., On Learning to Plan and Planning to Learn: The Social Psychology of Changing Toward Future-Responsive Societal Learning (San Francisco: Jossey-Bass, Inc., 1973).

Outlines a methodological planning system.

Mitchell, Arnold, The Nine American Lifestyles: Who We Are and Where We're Going (NY: Macmillan, 1983).

Analyzes and systematizes the values and lives of Americans in such a way as to yield insights into why people believe and act as they do.

Murray, Bruce C., Navigating the Future (NY: Harper & Row, 1975).

A fairly well-balanced introduction to a number of concerns.

Naisbitt, John, Megatrends: Ten New Directions Transforming Our Lives (NY: Warner Books, 1982).

The most reliable way to anticipate the future is to understand the present. America is a bottom-up society, where new trends and ideas begin in cities and local communities. Accordingly, the Naisbitt Group, located in Washington, D.C., has conducted a content analysis of 6000 local newspapers over the past 12 years.

O'Conner, Rochelle, Planning Under Uncertainty: Multiple Scenarios and Contingency Planning (NY: The Conference Board, 1978).

An overview of corporate strategic planning.

OECD Interfutures Group, Facing the Future: Mastering the Probable and Managing the Unpredictable (Paris: Organization for Economic Co-Operation and Development, 1979).

A three-year study to provide OECD member governments with an assessment of alternative patterns of long-term world economic development, in order to clarify strategic policy choices in managing their own economies and in relations among each other and with developing countries.

Okun, Arthur M., Equality and Efficiency: The Big Tradeoff (Washington: Brookings Institution, 1975).

Concludes that "A democratic capitalist society will keep searching for better ways of drawing the boundary lines between the domain of rights and the domain of dollars."

Peccei, Aurelio, The Chasm Ahead (NY: Macmillan, 1969).

An Italian industrial manager assesses the macroproblems of our time, with particular emphasis on the growing cleavage across the Atlantic brought on by the technological gap.

Polak, Fred, The Image of the Future (San Francisco: Jossey-Bass, 1973).

Expectations of the collapse of Western civilization.

Porter, Allan, et al., A Guidebook to Technology Assessment and Impact Analysis (NY: North Holland, 1980).

A comprehensive introduction to technology assessment (TA) and environmental impact analysis (EIA).

Prehoda, Robert W., Your Next Fifty Years (NY: Grosset & Dunlap, 1980).

A "projected history," or extrapolated science, describing practical developments that will grow out of present research, integrated with social and political trends.

President's Commission on National Goals, Goals for Americans (NY: American Assembly, 1960).

Findings of the "opening project of the modern futures movement."

Reich, Charles A., The Greening of America (NY: Random House, 1970).

"By polarizing the good guys and the bad guys, and seeing no seamy side to the younger generation, this polemic quickly became perhaps the best-known mis-forecast of our time. Still, as a critique, there is a bit of baby left in the bathwater of overkill."

Robertson, James, The Sane Alternative: A Choice of Futures (St. Paul, MN: River Basin Publishing Company, 1979).

Author of Profit or People? (Calder & Boyars, 1974) and Power, Money & Sex (Marion Boyars, 1976) declares that the industrial revolution and the age of European ascendancy is ending and that mankind is at a turning point.

Schmeikal, Bettina et al. (eds.), Impact of Technology on Society: A Documentation of Current Research (NY: Pergamon Press, 1983).

A guide to 207 projects in ten European countries. These recent developments appear to amount to a second wave of the industrial revolution, with prospects of impact on society even greater than that of the first.

Schwarz, Brita, U. Svedin, and B. Wittrock, Methods in Futures Studies: Problems and Applications (Boulder, CO: Westview, 1982).

The authors summarize the dimensions of futures studies, and illustrate in detail the ways in which different methods have interacted in some real-world projects at the national level of policy-making in Sweden.

Seidenberg, Roderick, Post-Historic Man: An Inquiry (Chapel Hill: University of North Carolina Press, 1950).

An essay offering insight into the future phase of man's development based on the direction and momentum of his past.

Seidenberg, Roderick, Anatomy of the Future (Chapel Hill: University of North Carolina Press, 1961).

Continues the theme of Post-Historic Man in viewing a world moving toward total organization--a trend that came about unheralded and without the fanfare of social prophets.

Simon, Julian L. and Herman Kahn (eds.) The Resourceful Earth: A Response to Global 2000 (NY: Basil Blackwell, 1984).

"Status of Futures Research" in Futures (August 1984), pp. 382-417.

Five articles describing the state of futures research, uses, and new directions.

Steiner, George, Strategic Planning: What Every Manager Must Know (NY: Free Press, 1979).

A step-by-step guide in non-technical language to the fundamental concepts, processes, and procedures of strategic planning. Concerns topics such as developing corporate objectives, organizing the planning function, and evaluating long-range planning programs.

Stine, G. Harry, The Hopeful Future (NY: Macmillan, 1983).

Stine asserts as a general forecast of the future that we can do anything we want to do if we are willing to pay for it. A baseline scenario from the present to 2001 is sketched, with current trends continuing essentially unchanged.

Taylor, Gordon Rattrey, The Biological Time Bomb (NY: New American Library, 1969).

Predictions in the field of biology.

Theobald, Robert, An Alternative Future for America (Chicago: Swallow, 1968, rev. 1970).

Outlines changes to bring about a participatory post-industrial age.

Theobald, Robert, Futures Conditional (Indianapolis: Bobbs-Merrill Company, 1972).

Collection of readings concerning the future can serve as an excellent introduction to futurists.

Theobald, Robert, and Stephanie Mills (eds.), The Failure of Success: Ecological Values vs. Economic Myths (Indianapolis: Bobbs-Merrill, 1973).

A reader of articles, cartoons, and quotations, organized in four sections: Economics vs. Ecologists, What Do We Mean by Development, The Search for a New Ethic, and Changing Personal Success Criteria.

Theobald, Robert, Beyond Despair: Directions for America's Third Century (St. Paul, MN: River Basin Pub. Co., 1976, rep. 1980).

A revised edition of Theobald's 1976 volume that has been called his most personal and persuasive statement. Believing unequivocally that a fundamental transformation is in progress, Theobald perceives American society shifting away from such goals as unlimited growth, top-down decision-making, and competition, toward a more humane, more generous, and more rational society based on "enoughness," participatory decision-making and cooperation.

Thompson, Alan, <u>Understanding Futurology: An Introduction to Futures Study</u> (North Pomfret, VT: David & Charles, 1979).

An introduction to futures studies, with brief chapters on topics such as the need for futures study, systems, the thermodynamic view, environmental impact, time and free will, wealth and growth, food, climate, education for the future, arms and defense, scale, and alternative technology.

Toffler, Alvin, <u>Future Shock</u> (NY: Random House, 1970).

"Like it or not, this provocative journalistic tour of the 'human side of tomorrow' (or, more correctly <u>some</u> of the human side for <u>some</u> people), is better known than any other item."

Toffler, Alvin (ed.), <u>The Futurists</u> (NY: Random House, 1972).

"The purpose of this collection is to make accessible a few of the works of the best-known and, at the moment, most influential futurists."

Toffler, Alvin, <u>The Eco-Spasm Report</u> (NY: Bantam Books, 1975).

"The eco-spasm or spasmodic economy describes an economy careening on the brink of disaster, awaiting only the random convergence of certain critical events that have not occurred simultaneously--so far."

Toffler, Alvin, <u>The Third Wave</u> (NY: William Morrow & Co., 1980).

We are witnessing the death of industrialism and the rise of a new civilization which can be more sane, sensible, sustainable, decent, and democratic than any we have known.

Toffler, Alvin, <u>Previews and Premises</u> (NY: William Morrow, 1983).

Based on a series of interviews with the editors of the leftist South End Press in Boston. The book is not a debate or an exercise in resolving differences (Toffler views himself as beyond the uni-dimensional right/left terminology of the industrial period), but an attempt to enrich past formulations in <u>The Third Wave</u> and <u>Future Shock</u>, extend them to new dimensions, and respond to critical questions rooted in the left-wing analytic perspective.

Tugwell, Franklin (ed.), <u>Search for Alternatives: Public Policy and the Study of the Future</u> (Cambridge, MA: Winthrop Publishers, 1973).

A collection of some of the best futurist writings in recent years.

Twiss, Brian (ed.), <u>Social Forecasting for Company Planning</u> (London: Macmillan, 1982).

Essays here consider the concepts and techniques of social forecasting, macro-social forecasting and areas of ignorance, leading indicators for measuring change in social attitudes, discontinuities in social attitudes, designing and installing a system for social forecasting, forecsts of trends in the post-industrial society, a psycho-socio-politico-economic view of the future, and case studies of social forecasting.

Ward, Barbara, <u>Spaceship Earth</u> (NY: Columbia University Press, 1966).

"Modern science and technology have created so close a network of communication, transport, economic interdependence--that planet earth, on its journey through infinity, has acquired the intimacy, the fellowship, and the vulnerability of a spaceship."

Whiston, Tom (ed.), <u>The Uses and Abuses of Forecasting</u> (NY: Holmes & Meier, 1979).

The articles here discuss specific matters such as contemporary economic forecasting, market forecasting in the private sector, the operations of the Swedish Futures Secretariat, transport forecasts that have attempted to fix the future, the Indicative World Plan developed by the UN, forecasts of physical changes in the environment, and population forecasting.

ADDITONAL TITLES ON TECHNOLOGICAL FORECASTING

Bright, James, <u>Technological Forecasting for Industry and Government: Methods and Applications</u> (Englewood Clifis, NJ: Prentice-Hall, 1968).

Bright, James R., <u>A Brief Introduction to Technology Forecasting: Concepts and Exercises</u>, 2nd Edition (Ann Arbor, MI: Books on Demand, 1972).

Cetron, Marvin J., <u>Technological Forecasting: A Practical Approach</u> (NY: Gordon & Breach, 1969).

Cetron, Marvin J. and Christine A. Ralph, <u>Industrial Applications of Technological Forecasting</u> (Melbourne, FL: R.E. Krieger Publishing Company, 1983).

Cleary, James P. and Hans Levenbach, <u>The Professional Forecaster: The Forecasting Process Through Data Analysis</u> (Belmont, CA: Lifetime Learning, 1982).

Gingrich, Newt, et al., <u>Window of Opportunity: A Blueprint for the Future</u> (NY: St. Martin's Press, 1984).

Lanford, H. W., <u>Technological Forecasting Methodologies: A Synthesis</u> (NY: AMACOM, 1972).

Linstone, H. A., and D. Sahal, <u>Technological Substitution: Case Studies in Forecasting Techniques</u> (NY: Elsevier, 1976).

Makridakis, Spyros and Steven Wheelwright, <u>Interactive Forecasting: Univariate and Multivariate Methods</u>, 2nd Edition (Oakland, CA: Holden-Day, 1978).

Martino, J. P., <u>Technological Forecasting for Decision-Making</u>, 2nd Edition (NY: Elsevier, 1983).

Rosenbloom, Richard S. (ed.), <u>Research on Technological Innovation, Management and Policy</u>, Volume 2 (Greenwich, CT: Jai Press, 1985).

Twiss, Brian C. and Henry Jones, Forecasting Technology for Planning Decisions (Princeton, NJ: Petrocelli Books, 1978).

UNESCO, Scientific Forecasting and Human Needs: Trends, Methods, and Message (Hayward, CA: Alemany Press, 1984).

UNIDO, Industry 2000: New Perspectives (NY: Unipub, 1982).

Wills, Gordon, et al. (eds.), Technological Forecasting and Corporate Strategy (Woodstock, NY: Beekman Publishers, 1969).

APPENDIX B - DELPHI APPROACH

DELPHI SURVEYS

The Futures Group has repeatedly found, over the last ten years, that much existing information about future technological possibilities is not published, for at least two highly understandable reasons. In many cases those involved are often at the forefront or leading edge of their fields and simply do not have time to publish about the status of their activities--the field is simply moving too fast. On the other hand, individuals and organizations often do not wish to publish since that would give competitors insight into their activities and, thus, would damage their competitive advantage. We have found that a Delphi survey is highly productive in uncovering and illuminating otherwise unknown and often unanticipated areas of technological progress and future possibilities.

An important aspect in using the Delphi method to uncover information is the anonymity provided to the respondents that is offered by an impartial third-party practitioner. Indeed, the Delphi inquiry embodies only two basic features: anonymity of the inputs and feedback to the respondents. But it is the anonymity offered to the respondents by a knowledgeable third party that appears critical in unlocking otherwise closely held information.

Before mailing a Delphi questionnaire, the information desired from the respondents is comprehensively thought-out, and a "protocol" or work package is designed and pretested. A highly important and demanding aspect of designing the inquiry package is to pay particular attention to ensuring that questions are as unambiguous as possible, and that proper ancillary material about each question (e.g., appropriate past trends and events and possibly important future events) is provided to aid the respondent's thought process.

Another important aspect in using the Delphi technique (in addition to the feature of anonymity offered to each respondent) is the ability to feed back results and allow the individual to reconsider his original answer based upon inputs from the other respondents or panelists. Delphi provides the feedback feature via a sequential round of questionnaires designed and processed by the practitioner.

The Delphi technique has its own unique strengths and weaknesses. Mailed Delphi questionnaires can obviously be processed for large numbers of respondents. Nevertheless, attrition in respondents' inputs occurs during every succeeding round, and there is really no way of ensuring that a respondent will return his completed questionnaire within the desired time allocated for each round. Furthermore, with mailed questionnaires, a practitioner is never really sure whether the respondent or someone designated by him has completed the Delphi form.

Selecting respondents and panelists is critical to a successful Delphi study. One must identify the potential respondents, contact them to describe the program, obtain their acceptance and schedule their participation.

Identification of candidates comes from several sources: a literature search and review; inputs from the client; and insights and contacts of The Futures Group's staff. As persons are contacted they also are asked to nominate others. When names become repetitive, we are usually certain that the range of viewpoints desired will be covered (if we obtain the participation of those persons). It also should be noted that the viewpoints sought out are those not representing unanimity or consensus. Rather, The Futures Group seeks divergent views because the basic purpose is to obtain insights about what the future holds along with the reasons behind the various eventualities. (Consensus will come only if it is truly present--not because it was designed into the study by only selecting "compatible" respondents.)

It should be noted that the Delphi technique is not an attempt to create a statistically valid sample size or conduct a large poll. It centers on obtaining insights from knowledgeable people. These insights and other inputs will then be analyzed and used to create valid forecasts. In other words, Delphi techniques are often referred to as attempts to create a "synthetic expert."

As noted earlier, the task of preparing the questionnaires, workbooks and other material to be used in the survey is quite important. Depending on the range of basic areas of investigation to be covered, the questions posed and the backup or ancillary material for the package can often be quite extensive. It is not unusual for a Delphi inquiry or questionnaire to include 75-100 pages. This number can grow if several subjects are to be researched. In multi-subject studies, since each respondent or panelist will have his own area of specialty, the complete Delphi inquiry is not mailed to each. During the initial arrangements with him, his areas of expertise and the areas he desires to cover are preselected and appropriate material is then made available to him.

An important aspect of the process is the designing and finalizing of the artifacts to be used. This requires pretesting--or in other words, the dry run of each. Typically this is done by employing members of the staff of The Futures Group and/or members of the client's organization. The design and pretest of the artifacts to be used is a nontrivial and demanding task. Clearly, all the artifacts to be used in the sequential rounds of the Delphi survey cannot be designed in its final form at the outset. This is the case since inputs from the preceding rounds will affect the designs of the later rounds.

To provide a "feel" for what is involved in a large Delphi study, the following short work statement is provided:

> Accomplishing the Delphi Inquiry. It appears desirable to include at least 100 respondents in the mailed Delphi inquiry. Since we will be treating at least five basic technologies, along with the subtechnologies of each, the panelists will be organized into subpanels. The

35

Delphi questionnaire will be completed, the material prepared and mailed to the panelists. The collating and analysis work will begin as the questionnaires are returned. Depending upon the specific design chosen, it may be appropriate to employ computer techniques to analyze the results, that is, to collate the median forecasts along with the upper and lower bounds (representing earliest and latest timing) and the factors associated with each of those projections. Since there will be many respondents involved, and since there is always an attrition (i.e., although persons agree, they do not always complete and return questionnaires during the time period requested), it will be necessary to maintain contact with the respondents to ensure that the material is obtained in a timely fashion and that it is comprehensive and meaningful.

In conclusion, the Delphi survey is a valuable tool for many research topics. It provides rich insights concerning the state of the art and the shape of the future. It can be considered for many research topics, especially those where peer pressure or competitive intiatives constrain the flow of information.

SIMULATION MODELING

Bivariate Linear Regression

Output Format

Values of a variable (e.g., GNP) as a function of predicted values of another variable (e.g., energy supply).

Input Requirements

- Paired historical values of both the predicted (or dependent) variable and the predictor (or independent) variable. There must be at least two such pairs of values, and ordinarily the results are valid only when there are at least ten pairs.

- Independently derived extrapolated or forecasted values of the independent variable; one for each time or occasion for which a value of the dependent variable is used.

Forecasting Period

Short to medium--depends upon the amount of past data and how well they are fitted by the regression function. It is rarely safe to forecast for more than half of the time range of the past data.

Procedure

The predicted or dependent variable (Y) is assumed to be a linear function of the predictor or independent variable (X). It is assumed that $Y = a_1 X + a_0$, where a_1 and a_0 are parameters that determine the linear relationship between X and Y. The computational algorithm computes a_1 and a_0 from the past history of the paired values of X and Y. The resultant values of a_1 and a_0 then are used to calculate predicted values of Y corresponding to the independently derived predicted or forecasted values of X.

The most common computational algorithm uses the method of least squares; i.e., the values of a_1 and a_0 are chosen so that when the equation $Y_c = a_1 X = a_0$ is applied to the historical values of X to compute theoretical historical values of $Y(Y_c)$, the sum of the squared differences between Y_c and the corresponding actual values of Y is minimized. An elementary application of simple differential calculus and solution of a simple system of two linear equations is sufficient to solve for the values of a_1 and a_0 that minimize the sum of the squares.

Major Strengths

- Is relatively simple to apply, as the technique assumes a simple relationship between X and Y. Since only two

parameters are involved, as few as two past-history X, Y data pairs suffice to provide a basis for prediction; and generally, except for assumptions about the relationship between X and Y that involve only one parameter, no other assumptions commonly give valid results with so little past-history data.

- Capitalizes on historical relations between the predicted (dependent) and predictor (independent) variable to determine the future values of the predicted variables, using all the information in the historical data pairs.

- The "goodness of fit" of the Y_c to the historical Y values can be used to compute a measure of the strength of the linear relationship between the historical X, Y pairs; and this can be used to calculate "confidence limits," or probable upper and lower bounds for the predicted values of Y. In general, the closer the Y_c to the historical Y values, the narrower the confidence limits, i.e., it is less likely that the actual values of Y will depart from the predicted values. The correlation coefficient is an index that can be used to calculate a figure of merit for the accuracy with which the calculated values of Y, Y_c match the actual past-history data. The square of the correlation coefficient ranges from 0 through 1. A value of 0 means total failure of the Y_c values to correspond with the corresponding Y values. A value of 1 for the square of the correlation coefficient means that the Y and Y_c values correspond perfectly. Values between 0 and 1 may be interpreted as expressing the proportion of the variability of the historical Y values that could be accounted for by the calculated linear relationship between X and Y.

Major Limitations

- The method of least squares, as commonly used, implies that the predicted values of the independent variable (X) are infallible or devoid of error uncertainty, i.e., that the only possible error or uncertainty is in values of the dependent variable (Y). Often this assumption is questionable. For example, the predictor variable is often forecasted in some fallible way. There may be past data about the Consumer Price Index (CPI) and the prime interest rate. A forecast of the future trend of CPI, then, may be used to generate a forecast of the future trend of the prime interest rate, using bivariate linear regression. But the accuracy of this forecast depends on how strongly the past values of CPI and prime interest rate are related and also on how accurately the future trend in CPI is predicted. The latter source of inaccuracy is not normally taken into account in calculating upper and lower bounds for the forecasted values of the dependent variable or, more generally, in evaluating the accuracy of this forecating technique.

- The assumption that X and Y are linearly related is an assumption that often is dubious. The technique fails when the actual relationship between X and Y is grossly different from a linear relationship, e.g., when it is a parabolic relationshp with Y initially increasing with increasing values of X and then decreasing. Moderate departures from linear relationships are not uncommon and are often difficult to detect. They lead to corresponding moderate inaccuracy in the forecasts obtained.

- When the past-history data are subject to error, the effect of the error is to make the predicted values of Y vary less than they should. Values of Y that should fall below the mean value of Y will generally be forecasts to fall below that mean, but less so than they should be, and similarly for values that should be above the mean. The greater the "noise" in the past history, the greater this effect; and there is no way, using this method, to distinguish a weak relationship between X and Y from a strong relationship which is obscured by noise or error of measurement.

- The procedure, as commonly applied, assumes that all past-history data pairs are equally important in determining the values of the unknown linear-equation parameters, a_1 and a_0. While the procedure can be generalized to "weight" data pairs, this is not the common procedure.

- The procedure is fundamentally one that generates a "regression forecast." The forecast of Y is made to depend upon a prior forecast of X. Similarly, the forecast of X might be made to depend upon a prior forecast of W. But somewhere in this series there must be a forecast that does not depend upon another forecast. One way to break the chain is to have time itself as the predictor or independent variable. This, however, has the necessary consequence that the predicted (dependent) variable that is taken to depend only on time must either increase or decrease without limit with the passage of time.

Initial Development

Regression analysis has had a long, slow development. The correlation coefficient was invented by Sir Frances Galton in about 1875. Simple bivariate linear regression is a special case of a more general method that may involve more than two variables and possible nonlinear (e.g., polynomial) relationships. Important initial development has generally dealt with the more general cases and includes:

M. S. Bartlett, "On the Theory of Statistical Regression," Proceedings of the Royal Society, London, A, Vol. 53 (Edinburgh, 1933), p. 260.

R. A. Fisher, "The Goodness of Fit of Regression Formulae, and the Distribution of Regression Coefficients," Journal of the Royal Statistical Society, Vol. 85 (1922), p. 597.

F. Galton, Natural Inheritance (New York: MacMillan, 1894).

K. Pearson, The Life, Letters, and Labours of Francis Galton, Vol. IIIa (Cambridge, Mass.: Cambridge University Press, 1940).

K. Pearson, "Mathematical Contributions to the Theory of Evolution, III: Regression, Heredity, and Panmixia," Philadelphia Transcript, Vol. 187-A (1896), pp. 253-318.

H. M. Walker, Studies in the History of Statistical Method with Special Reference to Certain Educational Problems (Baltimore, Md.: The Williams and Wilkins Company, 1929).

Selected Applications

K. Brix and E. Hansen, Dansk Nazism under Besaettelsen (Koben-Havn: Nordiske Studier, n.d.).

W. C. Clark, Economic Aspects of a President's Popularity (Philadelphia, Pa.: University of Pennsylvania Press, 1943).

M. Duverger, Les Partis Politiques (Paris: Armand Conlin, 1951).

Netherlands Economics Institute, Linear Regression Analysis of Economic Time Series (Haarlem, 1937).

F. A. Pearson and W. L. Myers, "Prices and Presidents," Farm Economics, Vol. 163 (New York: New York State College of Agriculture, 1948), pp. 4210-4218.

H. W. Lanford, "Analytical Techniques: Trend Correlation Analysis," Technological Forecasting Methodologies: A Synthesis (New York: American Management Association, Inc., 1972), pp. 92-113.

J. S. Burton and J. R. Torh, "Forecasting Secular Trends in Long-Term Interest Rates," Financial Analysts Journal, Vol. 30 (September 1974), pp. 73-86.

Multiple Linear Regression

Output Format

Values of the predicted (or dependent variable (e.g., GNP) as a function of predicted values of two or more other predictor (or independent) variables, one of which may be time.

Input Requirements

- Sets of historical values for each of the predictor variables and the dependent variable for the same time period.

- Independently derived extrapolated (or forecasted) values of the predictor variables for each time or occasion for which a value of the dependent variable is desired.

Forecasting Period

Same as for bivariate linear regression.

Procedure

The multiple regression linking the dependent variable and the predictor variables is a simple bivariate regression with a "best" linear combination of the predictors, i.e., that combination that gives the best, least-squares fit to the dependent variable past-history data. This best combination is found by one of several alternative computational algorithms, which typically involves inverting a matrix of order equal to the number of predictor variables. When there are more than three or four predictors, the task is not suitable for hand calculation. When the number of predictor variables is large (e.g., over 100), the task is quite onerous even for a large computer. The amount of computational effort required increases essentially in proportion to the square of the number of predictor variables.

Major Strengths

Strengths of bivariate linear regression also apply here. Additionally, this technique makes possible the determination of the relative contribution of various predictor variables.

Major Limitations

Limitations of bivariate linear regression also apply here. In addition:

- The contribution of each predictor is its unique contribution, after those from all predictors that make a stronger contribution have been eliminated. Therefore, if two important predictors are very similar, the results may suggest that the one that happens to contribute slightly more is a strong contributor, while the other is a weak contributor. A second analysis, using slightly different data, might provide reverse

41

results. Thus, results of this kind of analysis tend to be unstable with respect to the relative importance found for the contributions of different predictors.

- Therefore, results of use of this procedure do not meet a natural criterion for a useful statistical procedure; namely, they do not meet the requirement that a slight difference in the data will produce only a slight difference in the results.

Initial Development

Early uses were by psychologists applying the method to the theory of mental tests, where forecasts were of individual scores, e.g., college grades, not trends. In the mathematical development, however, it was soon recognized that the technique could apply equally to trends.

- T. L. Kelley, <u>Statistical Methods</u> (New York: MacMillan, 1924).

Selected Applications

This technique is popular in modern automated statistical packages (e.g., the Scientific Subroutine Package provided by Service Bureau Corporation).

Bivariate Polynomial Regression

Output Format

Same format as for bivariate linear regression.

Input Requirements

Same as for bivariate linear regression, except that the number of pairs of data values needed is at least one more than the degree of the polynomial. In practice, twice the degree of the polynomial is generally considered to be a practical minimum, with even more being desirable for low-degree polynomials.

Forecasting Period

No greater than for linear regression. In general, one more past datum is needed for each higher degree in the fitted function, with no corresponding increase in the forecasting period.

Procedure

Unlike bivariate linear regression, this technique does not assume that the variables are related by a linear expression. Rather, the relation is assumed to be the general polynomial:

$$Y = a_0 + a_1X + a_2X^2 + a_3X^3 \dots$$

The computational procedure is very similar to that for linear regresion, typically using the method of least squares. The calculations, however, tend to be more complex and usually require inversion of a matrix of order equal to the degree of the prediction equation.

Major Strengths

Strengths of bivariate linear regression generally apply here, except those that depend on the linearity assumption. Also, it is possible to uncover and make use of nonlinear relationships.

Major Limitations

Limitations of bivariate linear regression apply here, except for those that depend upon the linearity assumption, and

- More data are needed.

- There are various accepted ways of establishing precedence
  for possible alternative solutions which give different sets
  of parameters, but human judgment must choose among the
  alternative methods.

Initial Development

This technique has a long history, from early work on curve fitting, including work of Newton on the general theory of polynomial functions. The following references document early uses in fitting empirical time series and drawing inferences about the future of such series.

J. Wishart and T. Metakides, "Orthogonal Polynomial Fitting," Biometrika, Vol. 40 (1953), pp. 361-369.

M. G. Natrella, Experimental Statistics (Washington, D.C.: U.S. Government Printing Office, 1963), Chapter 6.

Selected Applications

W. W. Cooley and P. R. Lohnes, Multivariate Data Analysis (New York: John Wiley & Sons, 1971), pp. 85-94.

Linear Autoregression
(Also called Serial Correlation)

Output Format

Future values of a cyclic or periodic variable (e.g., seasonal employment), if the past history of its fluctuations cover at least two cycles. Also provides measures of the strengths of possible periodic components, or higher frequency cycles, that may underlie past and future fluctuations in the variable. Intermediate output is a correlogram, a figure (and the corresponding function) showing the serial correlation for various frequencies or lags.

Input Requirements

Historical or past time series for the predicted variable.

Forecasting Period

Depends on length of past history. Never appropriate for more than length of past history. Safe applications are usually less than half that length.

Procedure

This technique involves repeated application of the method of bivariate linear regression in which the predictor variable is always the same as the predicted variable, but with a time displacement. Thus, the predicted variable is forecasted from its own past values with some constant "lag" in time compared to the time for which predictions are to be provided. For example, suppose in successive years a variable had values of 8, 17, 23, 25, 24, 12, 9, 2, 0, 5. With a lag of two years, the predictor variable value of 23 would be paired with the predicted variable value of 24; the predictor variable value of 9 would be paired with the predicted variable value of 0; etc. The method typically is applied for a number of different lags. With each increment of 1 in the size of the lag, the number of historical data pairs available for computation of the linear-equation parameters is reduced by 1. Consequently, the largest possible lag that may be used is one of N - 2, where N is the number of historical values. This technique also requires either that the data be in the form of a continuous historical curve or, if discrete (as is typically the case for futures research applications), be tabulated for constant past time intervals. Generalizations of the technique are possible for irregularly tabulated past data, but they are cumbersome and rarely used. Finally, considerations of result reliability usually limit the actual size of lag so as to provide many fewer than N - 2 different lag magnitudes. There is, however, no generally accepted rule for what the largest lag should be.

Major Strengths

Strengths of bivariate linear regression also apply here.

Major Limitations

- Does not easily deal with data that are not recorded for regular time intervals.

- Requires quite a long time series, since the greater the lag, the more data must be discarded in calculating the regression.

Initial Development

The importance of cycles in trend data was noted by W. M. Persons in 1916. Early development was based on earlier work on adjusting for seasonal variations. For this earlier work, the cycle frequency was a priori. The major step, about 1925, was identification of cycle lengths rather than assuming them.

Selected Applications

- C. M. Stralkowski, <u>Lower Order Autoregressive-Moving Average Stochastic Models and Their Use of the Characterization of Abrasive Cutting Tools</u>, unpublished doctoral dissertation (Madison, Wis.: University of Wisconsin, 1968).

- G. E. P. Box and G. M. Jenkins, <u>Time Series Analysis: Forecasting and Control</u> (San Francisco, Calif.: Holden-Day, 1970), pp. 150-158.

Input-Output Analysis

Output Format

Forecasts of the level of activity associated with each element of a system included in the input-output matrix.

Input Requirements

An input-output table specifying the amount of output of a particular setor that is used as an input by another sector.

Forecasting Period

Generally short to medium term. The main determinant is the period for which the input-output coefficients remain realistic.

Procedure

First, the input-output table must be specified. If a table for the system being studied is not available, a considerable amount of time and money is usually required to collect the necessary data and construct the table. After the table is in hand, it is used to trace the changes that occur in all sectors as a result of changes in one sector. A computer is usually used to trace how a change in the output of one sector affects the inputs required by other sectors, affecting the outputs of still other sectors, and so on.

Major Strengths

Input-output analysis is an extremely powerful tool for analyzing the detailed interactions of economic sectors. No other technique handles the interrelationships between sectors as well as input-output.

Major Limitations

Since for most uses the resources required to construct an input-output table are not available, this technique is generally only useful when input-output tables already exist.

The large amounts of computation required also make this an expensive technique to employ.

Initial Development

The basic concept of input-output was developed almost 200 years ago by Francois Quesnay. Leon Walras developed much of the mathematics in the early 1900s. Wassily Leontief published the first national input-output table in 1936 and began the modern use of input-output analysis.

Selected Applications

W. Leontief, Input-Output Economics (New York: Oxford University Press, 1936).

H. W. Grubb, "Regional Economic Relationships Applying the Texas Input-Output Model to Production and Labor Employment Analyses," Report 0025-020-1174-NR (Austin, Texas: Office of Information Services, Office of Governor, November 1974).

C. Alnon, Jr., M. B. Buckler, L. M. Horwitz, and T. D. Reinbold, 1985: Interindustry Forecasts of the American Economy (Lexington, Mass.: Lexington Books, 1974).

System Dynamics

Output Format

Forecasts of the future behavior of a system as well as the individual components of that system.

Input Requirements

- Historical information on the behavior of the system, if available.

- An understanding of the ways in which the separate components of the system interact.

Forecasting Period

Variable--depends on the system being modeled and the goals of the modeling effort. Most models of large socioeconomic systems are medium-to long-term, however.

Procedure

The first step is to define the desired uses of the model and to define model boundaries consistent with those uses. A flow diagram is then constructed that depicts the variables to be included in the model and the linkages among those variables. The relationships depicted in the flow chart are then translated to mathematical form, usually using the DYNAMO simulation language. These equations are entered into a computer, and the model is tested and validated. Running the model into the future produces forecasts of system behavior.

Major Strengths

- Wide applicability. Virtually any system that involves feedback, is basically closed (with few exogenous influences), is continuous, and is nonprobabilistic is a candidate for system dynamics modeling.

- Assumptions made explicit. As with all modeling techniques, all of the judgments and assumptions involved in the forecast must be made explicit and are, therefore, available for evaluation by model users.

- Tool for experimentation. Once the model is constructed and tested, it can be used to test the sensitivity of forecasts to the different assumptions included in the model and to test the sensitivity of the forecasts to various policies or actions that might affect the system.

- _Ease of use._ A special computer language, DYNAMO, specially designed for system dynamics models, obviates the need for special computer expertise in constructing and using system dynamics models.

Major Limitations

- Models may become so large and complex that, even if they produce useful forecasts, it is often difficult to communicate the assumptions and structure of the model to others.

- Models do not include the influences of future events. Thus, when the model is used for forecasting, the potential impacts of these events are ignored.

Initial Development

System dynamics was developed by Prof. J. Forrester of the Massachusetts Institute of Technology in the late 1950s. DYNAMO was developed in the 1960s and is currently maintained and improved by Pugh-Roberts Associates. (See the DYNAMO II User's Manual, Alexander Pugh III, MIT, Cambridge, Mass.)

Selected Applications

J. Forrester, Industrial Dynamics (Cambridge, Mass.: MIT Press, 1961).

D. H. Meadows et al, The Limits to Growth (New York: Potomac Associates, 1972).

W. Schroeder III, Urban Dynamics in Lowell (Cambridge, Mass.: MIT System Dynamics Group, 1974).

KSIM

Output Format

Forecasts of the future behavior of a system as well as the individual components of that system.

Input Requirements

- Estimates of maximum, minimum, and current values of each variable.

- Estimates of the strength and direction of interaction between each pair of variables.

Forecasting Period

Variable--depends on the system being modeled and the goals of the modeling effort. Most applications are likely to be medium to long term.

Procedure

Each variable to be studied is assigned a value between 0 and 1, where 0 and 1 represent the limits on the variable. Interactions between variables are defined in terms of the strength and direction of the effect of one variable on another. Interactions are calculated by weighting the strength of the effect of one variable on another by the distance from the minimum value of the first variable. The interactions are solved by a computer for all variables for each solution interval. Sensitivity on policy runs can also be performed by changing initial conditions and rerunning the model.

Major Strengths

The simplicity of the approach makes this technique an easy one to apply. Most important, however, is the fact that the procedure and results can be communicated easily to others.

Major Limitations

The simplicity of the approach also leads to its major weakness--it is a superficial approach to modeling very complex systems. An in-depth analysis of system behavior is not accomplished.

Initial Development

KSIM was developed by Julius Kane at the University of British Columbia in the early 1970s.

Selected Applications

J. Kane, "A Primer for a New Cross-Impact Language--KSIM," _Technological Forecasting and Social Change_, Vol. 4 (1972), pp. 129-142.

J. Kane, I. Vertinsky, and W. Thompson, "Environmental Simulation and Policy Formulation," in A. K. Biswas (ed.), _Proceedings of International Symposium on Modeling Techniques in Water Systems_, Vol. 1 (Ottawa: 1972).

L. G. Antle and G. P. Johnson, "Implications of OEP Energy Conservation and Fuel Substitution Measures on Inland Waterway Traffic," U.S. Army Corps of Engineers, Institute for Water Resources (March 1973).

DECISION MODELING

The behavior of a large number of systems is determined, to a great extent, by decisions that are made by people or groups within those systems. In population systems the behavior of couples of child-bearing age determines the dynamics of the system; in market systems the collective decisions of consumers constitute market behavior; in industries, such as the electric utility industry, decisions by corporate executives on generator expansion determine many of the characteristics of the system behavior. Thus, in order to understand the behavior of these systems, it is important to understand the nature of the decisionmaking within the system.

The decision model approach is an attempt to develop a model of the decision process applied by the decisionmakers to the important decisions within the system. This approach assumes that decisionmakers consider a number of different factors in comparing the various alternatives and that some of these factors are more important than others. Although a decisionmaker may not actually list these decision factors or consciously weigh them, they are implicit in his perception of the value of the different alternatives. In order to choose the "best" alternative, it is necessary for the decisionmaker to make a judgment about what constitutes high value and low value. A choice that has low cost may be considered more valuable than one with higher cost, while one with higher benefits may be more valuable than one with low benefits. How does a high-cost, high-benefit technology compare with a low-cost, low-benefit alternative, though? To answer this question the decisionmaker must specify how important cost and benefits are to him. The low-cost, low-benefit alternative may be perceived to be the "better" alternative if

cost is much more important than benefits, or the reverse may be true if benefits are more important.

This approach to decision modeling assumes that this process of assigning values to alternatives can be replicated by defining the relevant decision criteria and combining this information with perceptions of the importance of each criterion and the degree to which each alternative meets each criterion.

The first step in such an approach is to list the decision criteria used to judge the alternatives. Relative importance weights are then assigned to each criterion. The degree to which each alternative choice meets each of the criteria is then estimated. The result is a matrix such as the one shown below.

DECISION CRITERIA	DECISION WEIGHTS	ALTERNATIVE RATINGS				
		A_1	A_2	A_3	A_4	A_5
C_1	W_1	A_{11}	A_{21}	A_{31}	A_{41}	A_{51}
C_2	W_2	A_{12}	A_{22}	A_{32}	A_{42}	A_{52}
C_3	W_3	A_{13}	A_{23}	A_{33}	A_{43}	A_{53}
C_4	W_4	A_{14}	A_{24}	A_{34}	A_{44}	A_{54}

C_1 through C_4 represent the decision criteria. W_1 through W_4 are the importance weights for those criteria, A_1 through A_5 are the available alternatives, and A_{11} through A_{54} indicate the degree to which a particular alternative meets a particular criterion.

Once these entries have been specified, the value of each alternative to the decisionmaker is computed by summing the products of the weights and ratings. Thus,

$$V_i = \Sigma_n \, W_n \times A_{in}$$

where: V_i = perceived value of alternative i

W_n = importance weight of criterion n

A_{in} = degree to which alternative i satisfies criterion n

Since the value, V_i, calculated in this manner is dependent on the scales used for weighting the criteria and rating the alternatives, these values are converted to relative numbers by dividing by the average value.

$$RV_i = V_i/AV$$

$$AV = (\Sigma_i \, V_i)/NOAA$$

where: RV_i = relative value of alternative i

AV = average value of all alternatives

$NOAA$ = number of alternatives available.

The alternative that has the highest relative value would be the expected choice for a given decisionmaker. When using this method to simulate the outcomes of a large number of decisions, however, the highest-valued alternative is not likely to be the choice in every case. In this case the importance weights and alternative ratings represent average values perceived by the decisionmakers. Thus while the highest-valued alternative should be chosen in more decisions than any other alternative, it may not be chosen in all decisions. (Because of differences in regional or individual perceptions, an alternative may have the highest value for a

particular individual but not for the group as a whole when average weights and ratings are used.)

It is necessary, therefore, to convert the relative perceived values calculated for each alternative into market penetrations. This step is accomplished by plotting relative perceived value versus penetration for some historical period for which data are available. The result is a function similar to that shown below.

Relative Perceived Value
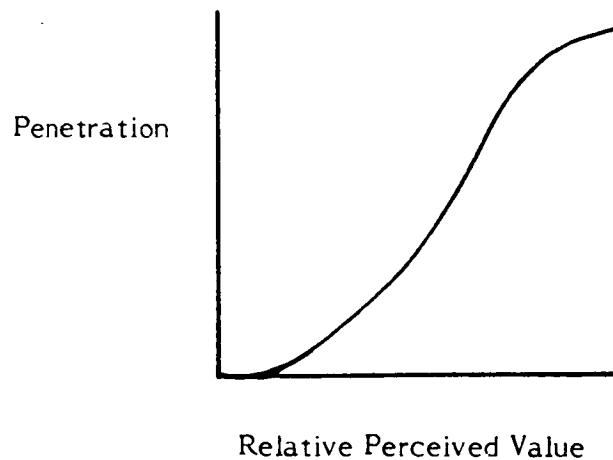
Once this relationship has been developed from past data, it can be used with future values of perceived value to determine penetration. Since there is no guarantee that the penetrations thus calculated will sum to 100 percent of the market, they must be normalized to sum to 100.

When new alternatives that were not available historically become available to the decisionmaker, it is necessary only to describe these alternatives in terms of the decision criteria in order to introduce them into the model. For most of these new alternatives, however, there is a learning period involved. Decisionmakers often are reluctant to choose a new alternative with which they have no experience. They also may be uncertain of cost and other figures and thus be

hesitant to consider fully a new alternative. As experience with the new alternative begins to accumulate, however, these problems disappear. In order to take this learning behavior into account, it is necessary to introduce a learning curve adjustment that reduces the perceived value of a new alternative in the first years after introduction. This learning curve usually affects the new alternative only in the first few years after its introduction.

This method, therefore, describes the decision process as a choice among competing alternatives made on the basis of how well each alternative meets several different criteria of varying importance. These perceptions are by no means static. The importance weights and alternative ratings can, and usually do, change with time. By incorporating this type of decision model into a description of the entire system surrounding the decision (possibly a simulation model of the entire system), a better understanding of the behavior of the system should result.

APPENDIX D - MODIFYING EXTRAPOLATION WITH JUDGMENT
(Dealing with Uncertainty)

A DISCUSSION OF SOME METHODS OF TECHNOLOGY ASSESSMENT

A technology assessment centers around a problem or a technology,

either of which may be prospective or current, social or scientific. An

assessment usually attempts to answer not only what the outlook is, who

will be affected and how, but also includes an analysis of how policies

which may be followed can influence the further development of the

technology or the problems and its effects.

There is no codified set of techniques, no simple crank to turn to

satisfy these objectives. The methods of technology assessment which

have been used in past studies have been drawn from many different

disciplines, including, most prominently, economics, social psychology,

statistics, and operations analysis. The choice of the appropriate

technique depends on the judgment of the researcher as well as the

nature of the problem and the level of funding of the project. As

Joseph F. Coates of the National Science Foundation recently put it:

> Technology assessment is an art form...It is separate,
> distinct, different from (existing disciplines) and as
> is any other art form, implies both a degree of creativity
> as well as the use of techniques. It also implies that
> not everyone is talented in undertaking or understanding
> the art form.*

Martin V. Jones, in an early set of technology assessments performed

for the Office of Science and Technology, defined seven major steps in

_____
*Joseph F. Coates, "Institutional and Technical Problems in Risk
Analysis," from Proceedings of a conference on Bulk Transportation of
Hazardous Materials By Water in the Future, sponsored by the Committee
on Hazardous Materials, July 9-10, 1973, College Park, Maryland (here-
after called Joseph F. Coates).

58

making a technology assessment. These steps included:

1. Defining the assessment task, in which relevant issues and major problems are discussed, project ground rules established, and the scope of the inquiry is set.

2. Describing relevant technologies including not only the technology being assessed, but other technologies supporting or competing with the technology under study.

3. Developing state of society assumptions, involving the identification and description of major non-technical factors which could influence the application of the technology.

4. Identify the impact areas, that is, societal characteristics that will be most influenced by the technology.

5. Making preliminary impact analysis: tracing and integrating the process by which the assessed technology makes its societal influence felt.

6. Identifying possible action options through the development and analysis of various programs for obtaining public advantage of the technology.

7. Completing the impact analysis through study of the ability of each action option to alter the previously established societal impacts.*

Most technology assessments go somewhat further than these seven steps. The identification of interest groups is an important inquiry in most studies. It is not simply enough to identify impact areas; the questions of who is affected, when, and how must also be addressed. In addition, the study of action options and state of society assumptions must include macrolevel alternatives to the technology under study. A technology assessment of solar energy, for example, should probe not only the means for producing and using solar energy and the effect of such

*Martin V. Jones, <u>A Technology Assessment Methodology</u>, MITRE MTR6009, 7 Volumes, (McLean, Virginia: The Mitre Corporation) 1971

technologies on society, but also whether solar energy or some other energy form is more appropriate, and the consequences of reducing energy demand.

Given the objectives of technology assessment and the major elements of such studies, a logic flow chart such as that shown in Figure 1 can be prepared. This chart was derived from a more elaborate logic flow being used in a study conducted by The Futures Group under contract to the National Science Foundation in the field of geothermal energy.* One of the first things apparent in this flow chart is that several iterative loops are involved (Joseph F. Coates suggests that a technology assessment should really be done three times: "the first time to define and understand the problem, the second time to do it right, and the third to burnish the results, fill in the details, and to bring the report to the best possible state within the available time, budget, and manpower."

Beginning at the left of the diagram:

Task 1. State of the Art. The state of the art is defined first. In this task, the major question is, "What do we know about the technology or problem under study?"

Task 2. Other Conditions. Here the focus is on other aspects of change which impinge on the subject under investigation. For example, this task may address concomittant technologies which, if successful, would limit or in some way amplify the basic technology. In addition, this task might center on external social conditions which could change
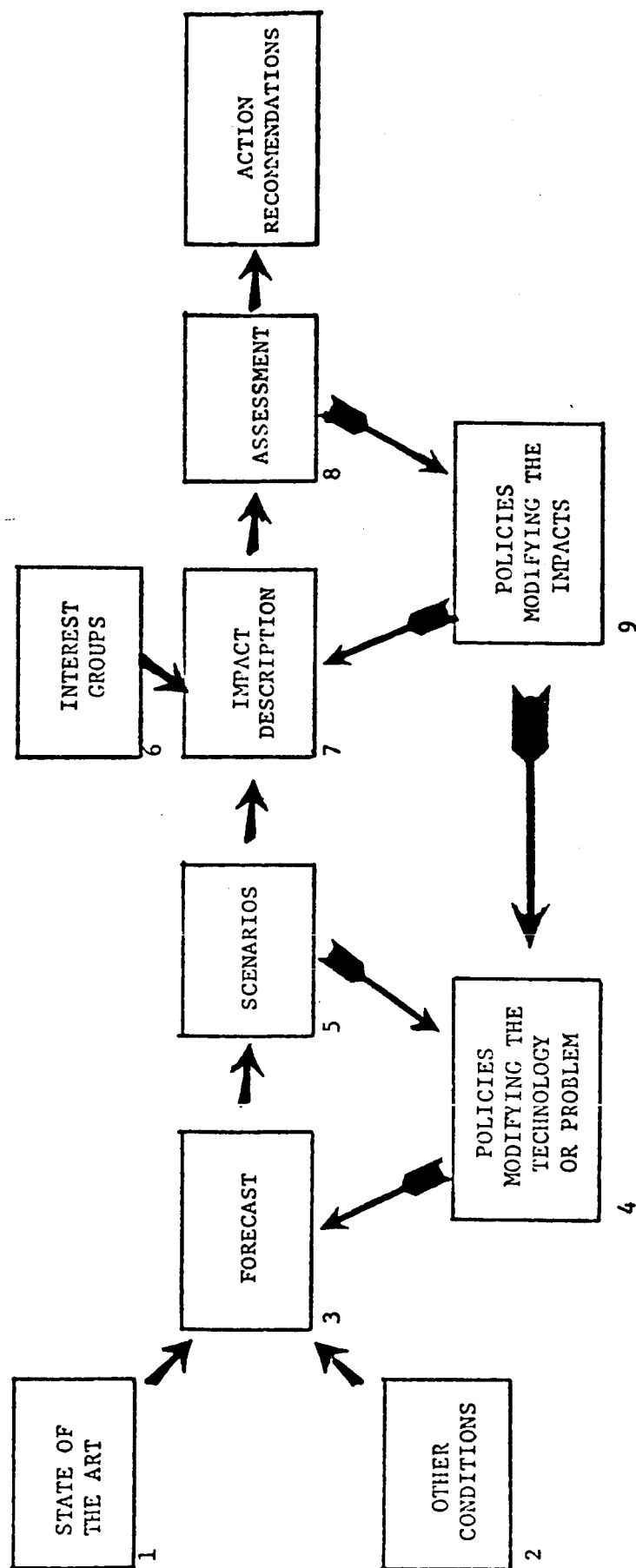
FIGURE 1.

TECHNOLOGY ASSESSMENT LOGIC FLOW

the impacts of the technology or the values by which the impacts are to be judged.

Task 3. Forecast. This task involves generating an image or set of images of the future of the technology under study. How might it evolve? What are the most important breakthroughs? When might they occur? What paces them?

Task 4. Policies for Modifying the Technology or Problem. In this task, policies are nominated and defined which might change the time scale or nature of the technology. Typically, the definition of a policy might include identification of the agency which could perform the action, the cost of the policy, its timing, and its intended consequences. Note that the output of Task 4 provides an input to Task 3; that is, the policies generated here are designed to amend the technological forecast.

Task 5. Scenarios. In this task, forecasts are grouped into self-consistent sets, alternative futures depicting the evolution of the technology or problem under study in the presence of policies considered in Task 4. In effect, the output of Task 5 is a statement of what the world might be like in the particular domain of the assessment. The remainder of the analysis is devoted to an identification of the consequences of these alternative worlds.

Task 6. Interest Groups. Here the groups likely to be effected by the emerging technology or problem are identified.

Task 7. Impact Description. Given the interest groups and the alternative futures produced in Tasks 6 and 5 respectively, this task

defines and estimates specific impacts. Thus, at this point in the study, an array can be constructed of interest groups, how they are ikely to be affected in the various worlds depicted by the scenarios, each scenario having been determined by a particular technological or problem-oriented policy set.

Task 8. Assessment. Now the problem is: are the forecasted impacts likely to be seen as good or bad? Of course, such judgments are value-laden and multidimensional. An impact seen as good for one group might be bad for another. Furthermore, "good" and "bad" are relative terms. Yet despite these difficulties, the assessment accomplished in this task necessarily must deal with these issues.

Task 9. Modifying the Impacts. The object of Task 9 is to invent policies which seem likely to improve the future state of affairs, that is, the conditions identified in Task 8. Nominated policies are fed back to Tasks 7 and 3. The loop to Task 7 is designed to test policies which have as their major focus the modification of impacts; the loop to Task 3 is designed to test policies which are designed to modify the technology itself. When policies have been found which produce the "best" world for the interest groups, they form the basis for action recommendations.

What methods are available to accomplish the objectives of these tasks? Figure 2 summarizes some which have been used in technology assessment. The basis for this chart is the comparative analysis of thirteen previous technology assessment performed by Martin V. Jones and experience with three additional studies conducted by The Futures

		Method	STATE OF ART	OTHER CONDITIONS	FORECAST	SCENARIOS	POLICIES/ TECHNOLOGIES	INTEREST GROUPS	IMPACT DESCRIPTIONS	ASSESSMENT	POLICIES/ IMPACT
REFERENCE TO HISTORY		LITERATURE DATA	X	X							
		HISTORICAL ANALOGY			*		*	X		*	*
JUDGMENTAL TECHNIQUES		GROUPS OR SYMPOSIA	X	X	*	*	X	*	*	*	X
		INFORMAL INTERVIEWS	X	X	*	*	*	*	*	*	*
		DELPHI QUESTIONNAIRES	*	*	X	*	X	X	*	*	X
		DELPHI INTERVIEWS	*	*	X	*	X	X	X	X	X
		POLLING					*	*		X	*
		STIMULATION GAMING			*	*	X		*	X	X
		INDIVIDUAL JUDGMENT	*	*	*	*	X	*	*	*	X
MODELING	EXTRAPOLATIVE	TREND EXTRAPOLATION			*						
		REGRESSION ANALYSIS			*				*		
		ECONOMETRIC			*						
		INPUT/OUTPUT			*						
		SYSTEM DYNAMICS			X	X	X		X	*	X
	PROBABILISTIC	TREND IMPACT ANALYSIS			*	X	X		X	*	X
		CROSS IMPACT				*			*	*	
		PROBABILISTIC SYSTEM DYNAMICS			X	X	X		X	*	X
	EXPLORATORY	MORPHOLOGY			*		*	*	*		*
		VALUE MATRIX								X	
		RELEVANCE TREE			X		*	*	*		*
		IMPEDIMENT REMOVAL			X		*		*		*
EXPERIMENTAL		CONTENT ANALYSIS					*		*	*	*
		CONTROLLED BEHAVIORAL SCIENCE EXPERIMENTS								X	

Figure 2 – Some Technology Assessment Methods

X = Prime Candidate

* = Potentially Useful

64

Group.* The "preferred" entries are obviously a matter of personal taste and bias and depend greatly on the case at hand. Other people would undoubtedly add other methods and designate different techniques as more useful than those shown. Nevertheless, the chart illustrates the wide range of interdisciplinary tools which are available to the assessor.

Several of the methods listed on this chart may be unfamiliar. These approaches are discussed in the appendicies of this report.

---

*Martin V. Jones, A Comparative State-of-the-Art Review of Selected U.S. Technology Assessment Studies, (McLean, Virginia: The Mitre Corporation) May 1973. The Futures Group's studies include: "A Technology Assessment of Geothermal Energy," for the National Science Foundation; "U.S. Ocean Shipping Technology," for the U.S. Department of Commerce, Maritime Administration; and a proprietary study in the field of energy.

PROBABILISTIC SYSTEM DYNAMICS

Introduction

Modeling techniques are widely used to predict the behavior of systems. Modeling is an exact science when applied to physical systems such as planetary motion. It also has been shown to be a useful tool in the understanding and prediction of the behavior of economic systems. Such models, however, are not entirely accurate. Applied to social systems, such models usually are even less accurate in predicting specific values, but are useful in displaying the basic behavior of the system under study.

A mathematical model is a detailed mathematical description of the relationships among the most important variables within some system. Thus, given values of these variables at one point in time (the condition of the system at that time), the state of the system at some later time can be calculated. The utility of mathematical models arises from the basic assumption that human judgment is not capable of reliably determining how complex systems will change with time. Although a person may have detailed knowledge about the parts of a system, the number of interactions taking place usually is too large for the human mind to handle. Thus, approximation, reduction of considered variables, and intuition are all used to produce a final judgment. Mathematical modeling assumes that by using human judgment to specify the parts of the system and how they interact separately (a simpler task with fewer variables involved), a model can be constructed that will display the behavior of the system in a more reliable manner. This model then can be used, through experimentation, to come to a better understanding of the system.

Probabilistic system dynamics (PSD) is a method of mathematical simulation that combines the system modeling concepts of system dynamics with the probabilistic event interaction techniques of cross-impact analysis.

System Dynamics

System dynamics was developed in the 1950s by Professor Jay Forrester of the Massachusetts Institute of Technology.[1] The original concepts were derived from servomechanism analysis in which systems are depicted as a series of interlocking feedback loops.

This simple feedback loop is basic to the theory of system dynamics modeling. Often many simple loops interact with one another, producing complex systems. Figure 1 depicts two of the feedback loops in a model of the Japanese economy developed by The Futures Group. In the positive feedback loop, increasing industrial production increases demand for energy. This increased demand normally will lead to increased supplies and increased stocks of energy supplies. These increased supplies will, in turn, allow increased industrial production. This is the growth loop and will lead to unrestrained growth unless a negative loop also is present. In the negative loop increased industrial production leads to increased energy usage which decreases the stock of energy supplies.
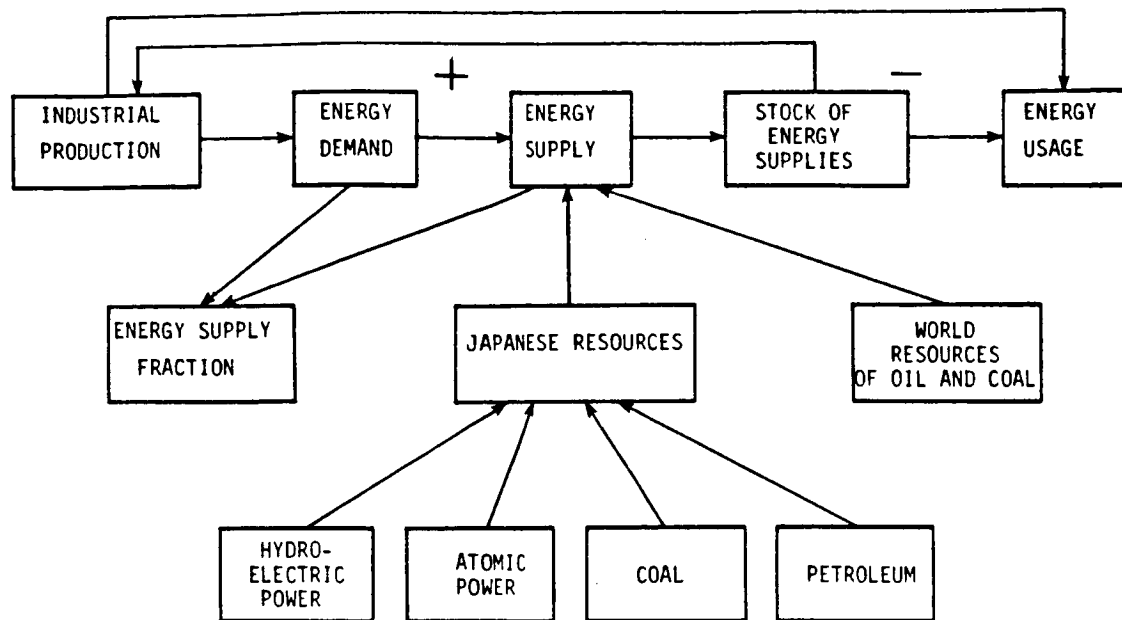
66

Figure 1. Energy Feedback Loops in the Japan Model

A second crucial point in this model of the decision-making process is the effect of delays. Often the decision-maker does not have up-to-date information about his environment. He is, therefore, making decisions on the basis of what the situation used to be, rather than what it now is, or is taking action that will not translate into concrete changes until some future time. The example of a television cameraman can be used to illustrate this point. Consider the technician at the Johnson Space Center in Houston who had the job of controlling the television camera of the lunar rover on the moon as it filmed the takeoff of the landing module. His job was to keep the picture of the landing module in the center of the screen as the module began the return trip to earth. The environment for his decisions (how to tilt the camera) was, of course, the picture he saw on the screen. However, due to the time necessary for the picture to travel from the moon to the earth he was seeing the scene as it had been a few seconds earlier. Furthermore, it took another few seconds for his adjustments to reach the moon and cause the camera to move. Thus, if he saw the lunar module moving out of the picture he would start to adjust the camera immediately, but would not know whether his adjustments had been too much or too little for several seconds. The fact that he handled his task so well is due mainly to his advance knowledge of the exact lift-off time and speed of the module. In most situations, such exact advance knowledge is not available. Thus, delays are an important consideration in decision modeling.

When system dynamics modeling is applied to a specific problem, the first task is to identify the feedback loops that appear to have bearing on the problem. The next step is to study these feedback loops to determine the decision points and, once these are identified, to describe the decision process, including the information used in these decisions. Building on this information a simulation model is built and tested by comparing its behavior with actual system behavior. The model

may be refined until it appears to accurately represent the real system. This model then is used as a tool for experimentation. Changes are made in the model in an effort to find methods of improving the system's behavior. These changes can then be instituted to the real system. It should be noted that this improvement of the real system is the ultimate goal of model building. The goal is not to forecast what future conditions actually will be, but rather to show how the system will behave given a certain structure. That knowledge should lead to an improvement of the system and thus invalidate the model "forecast."

The theory of system dynamics modeling appears to have changed very little from its first applications in the late 1950s. Emphasis has, until now, been on new applications of the technique rather than on improvements to the technique itself. The widespread use of the technique can be credited to its four major strengths. The first of these is the wide applicability of the technique. Feedback processes are a part of practically every decision system. As long as the system involves decision making (and, therefore, feedback loops), is basically closed (that is, with few important exogenous influences), is continuous and nonprobabilistic in nature, it is a candidate for system dynamics modeling.

The second major strength is one common to all analytical techniques. The judgments and assumptions involved in the analysis are made explicit. Almost any detailed study of a problem includes some real knowledge and hard data along with many assumptions and estimates. In many cases, it is hard to separate these components and even harder to determine the importance of each to the final conclusion. A mathematical model is explicit in terms of how the final results are determined. Anyone can trace the process, given the model. In discussing the system behavior described by the model, everyone is working from the same base point, the same set of assumptions. While everyone may not agree about the assumptions in the model, they are, at least, clearly visible and can be modified or discarded as necessary. By reducing the problem from one of estimating the total system behavior (as in mental models) to one of estimating only those parts of the system that are not known, a more reliable model should result.

The third advantage is that, once the model assumptions are accepted, the model can be used as a tool for experimentation. Experimentation with a mathematical model is usually much less costly and less risky than experimentation with the actual system. The advantage of a model as an experimental tool lies only partly in the ability to make a change in the model and observe the resulting behavior. The real power of such a tool is that the behavior resulting from an experimental change need not be believed as an act of faith. Results can be traced through the system and exact causes can be identified. Thus, if a certain change produces a counterintuitive result, the causes of that result can be isolated. They may prove to be errors in the model, in which case the errors are rectified, or they may prove to be real, in which case new knowledge is gained. In either case counterintuitive results cannot be lightly dismissed as obviously wrong or ridiculous.

The fourth advantage is ease of use. A special computer language and compiler, DYNAMO, has been developed for system dynamics models. DYNAMO accepts inputs in the form of normal mathematical equations, provides extensive error checking, and automatically formats the outputs. Thus, no extensive computer training is required.

Although system dynamics is a powerful technique and has been applied to many important problems, there are important drawbacks to the technique as well. System dynamics models do not account for probabilistic future events. In many systems the decision environment is directly influenced by discrete events that may or may not occur. The decision by Arabian oil-producing countries to cut oil production in late 1973 certainly had significant influences on the economic systems of many countries. Yet such an event would not be a part of that system. Events of this type--though exogenous to the model--may well be the most important influences on the system over time.

Another limitation is that model structure remains essentially fixed with time. Relationships among model variables are detailed once in the model and do not change. While this may not be a problem for simple systems and short time spans, models of the Limits to Growth type suffer from this rigidity. Relationships among model variables may change because of causal forces within the system because of events occurring within or outside the system. The changes should be a part of the dynamics of the system.

Probabilistic System Dynamics

Probabilistic system dynamics uses the concepts of cross-impact analysis to add the expected impacts of future events to system models. As an example of the influence of events on model structure, consider the energy feedback loops discussed in the last section and presented again in Figure 5.2. In this figure, however, new loops have been added (dotted lines) that correspond to the impacts of events. The energy supply fraction represents that fraction of demand that is filled by available supplies. Although abundant energy supplies have kept this fraction equal to or greater than one in the past, future energy shortages may well cause it to fall below one.

When this fraction falls below one (indicating energy shortages) the probabilities of various events are affected. Specifically, the probabilities are increased for two important energy events (that Japan and the USSR engage in the large-scale development of Siberia and that fusion power is developed and is implemented in Japan). The second event upon occurrence increases the supply of atomic power, thus increasing domestic energy supplies. The first event, upon occurrence, will add significant new supplies of natural gas to Japan's energy picture (natural gas supplies today are an insignificant energy source for Japan). Thus, not only is a new fuel added to energy supply (as well as all the important price and fuel trade-offs that are a part of that new fuel), but imports, balance of payments, and exports may be affected as well, depending on the exact nature of the trade agreements. These events may also affect other events in the cross-impact matrix that will, in turn, influence the model in other ways.

Of course, with only one or two events, probabilistic calculations have little real meaning. Fusion power will either become an alternative energy source or it will not. To say that atomic power will supply 25 percent of all energy needs in Japan because fusion power has a 50 percent probability of being developed, would be absurd. Rather, we should say that atomic power will provide 35 percent of
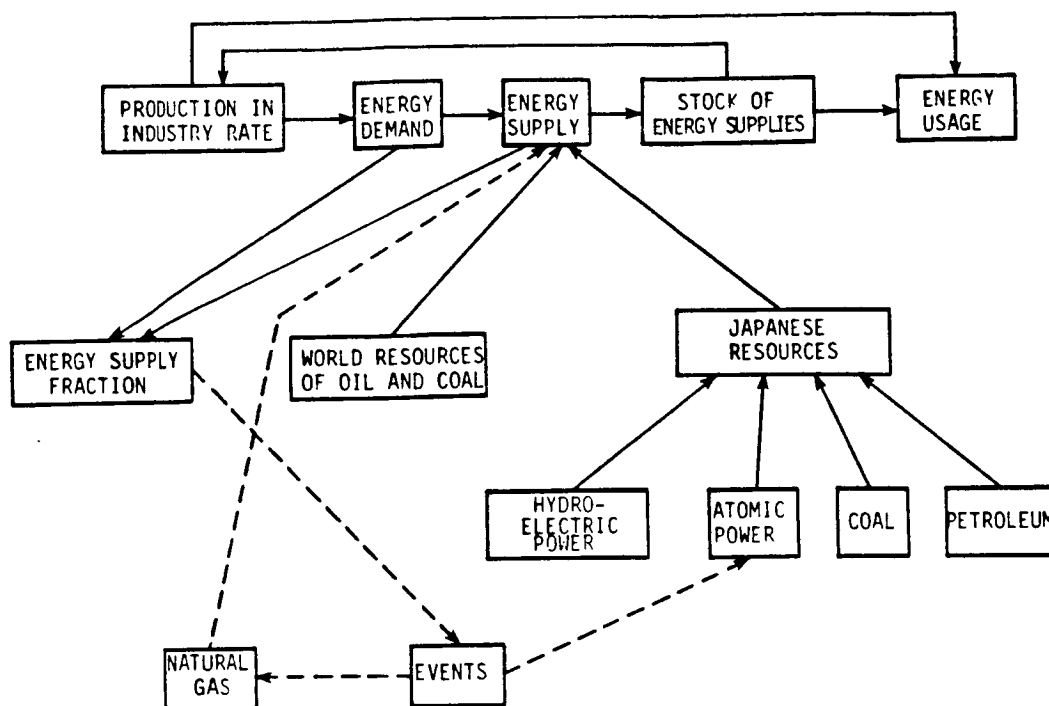
Figure 2. Energy Feedback Loops in the Japan Model

energy needs if fusion power is developed, and 15 percent if it is not. However, if our real concern is not the percentage of energy supplied by atomic sources but the total energy availability in Japan, then probabilistic considerations begin to make sense if we include a few more events in the model. Suppose we included events concerning the development of needed technology for oil shale, tar sands, solar electricity, geothermal drilling, etc. We may not be able to say with certainty that any of these developments will or will not take place, but we can say that some of them will probably happen while others will not. By combining the probabilities of occurrence of these events with their expected impacts, we can develop a model that will indicate the expected future supply of energy in Japan. It will not determine which events actually occur or what the real fuel-mix will be (as this will depend on actual event occurrences), but it can give a better indication of the total energy supply than if these events had been entirely omitted. Furthermore, the effects of policy decisions which can influence the development of different energy technologies included in the model (geothermal hot rock drilling, for example) can be displayed in terms of the expected influence on the total supply of energy. It is here that the main contribution of PSD lies.

In order to develop a PSD model of a system, two processes are followed simultaneously: the development of a basic system dynamics model and the identification of the elements of the cross-impact matrix. The identification of the event set and the estimation of probabilities and impacts can also serve as an excellent first step in the integration of decision-makers into the modeling effort. The Delphi approach to information gathering may, in many cases, be applicable.

Responses of a panel of experts (either to questionnaires or personal interviews) are used to define the set of events important to the study, the impacts

of these events on the model, the impacts of the events on each other, and the probability versus time characteristics of each event. The experts may also contribute initial information regarding the structure of the model itself. These questionnaires or interviews provide not only expert judgment in the areas already mentioned, but also indicate those areas in which there is not good agreement about present relationships or future developments. These areas, then, can become the subject of increased attention when the model sensitivity and policy studies are conducted.

Using the information supplied by the experts, a system dynamics model, showing the variables important to the area of study and relationships among those variables, and a cross-impact matrix, including the events, their probabilities and impacts, are constructed.

The first step in the development of the cross-impact matrix involves calculating the time dependent probabilities of each of the events. Each respondent supplies estimates of cumulative probabilities for two years for each of the events. By fitting an S-shaped curve to these two points a curve is developed describing the cumulative probability of each event versus time. By combining the curves from all the respondents for each event, the final curve is obtained. If there is a large amount of disagreement among the experts on any particular curve this result would, typically, be reported back to the respondents for further consideration.

The impacts of events on events are then described. For example, if one event is that a new method of reclaiming and recycling scrap zinc at one-third the cost of new zinc production is developed this event might originally have a probability of occurring by 1985 of .15. However, if another event, that proven world reserves of zinc quadruple through new discoveries, were assumed to occur, it would have substantial impact on the probability of the first event, possibly reducing its probability by 1985 from .15 to .05.

The impacts of the events on the model are then described. These impacts may come from expert judgment in cases where the impact is uncertain or they may be calculated when the impact is obvious and not judgmental. These impacts may take several forms. The actual structure of the model may change, coefficients of the equations may vary, new terms may be added to or subtracted from equations, etc.

Some variables in the model will also have impact on the event probabilities. These impacts are also estimated and included in the cross-impact matrix. As an example, assume that the supply of zinc to some country is a factor in an economic model of that country. The supply of zinc would undoubtedly depend on domestic demand for zinc, world demand for zinc (competing with domestic demand), domestic supplies of zinc ore, world supplies of zinc ore, and the price of zinc. However, if the event discussed earlier concerning the development of a low-cost zinc recycling technique were to occur, the above relationships concerning zinc supply would have to be altered. Zinc could now also be supplied through scrap recycling (an addition to the supply equation), and domestic and world stocks of products containing zinc and their obsolescence rates now become important as well. This illustrates one type of impact of an event on a model. In turn, model variables, the shortage of zinc, for example, would affect the probability of the events (by causing increasing exploration for new resources and increasing expenditures for new recycling techniques).

A run of an entire model constructed using probabilistic system dynamics involves the simultaneous operation of a DYNAMO computer program (the basic model) and a FORTRAN IV program (the cross-impact sector). The computational sequence consists of the following steps:

1. Initial values for the model variables are used to compute new values for those variables for the first solutuion interval (a year or part of a year).

2. These new values are transferred to the cross-impact matrix.

3. New values of event probabilities are determined from the original values and the impacts of the model variables.

4. The expected impacts of events on events are calculated using the probabilities of the events to weight the occurrence and nonoccurrence impacts.

5. The probabilities from the cross-impact sector are transferred back to the basic model, event impacts on the model are calculated, and the basic model is revised accordingly.

6. New values for the model variables are calculated for the next solution interval using the model as revised by the impacts from Step 5.

7. Steps 2 through 6 are repeated until the end of the time span under study.

Sensitivity analyses can be run to test the sensitivity of the model to the event probabilities, impact estimates and model assumptions.

Policy tests can be run by deciding how specific policies would change the model (event probabilities, model structure, impacts), making the appropriate changes and rerunning the model.

The main advantages of probabilistic system dynamics are:

1. The inclusion of events in the model allows occurrences outside the area of focus of the basic model to be taken into account in the model predictions. In this manner, any number of exogenous events may be included. Thus, the scope of the model is no longer limited strictly to the closed system defined by the system boundaries.

2. The structure of the basic model itself becomes dynamic. Relationships among variables and even among sectors of the model may change with time as the impacts from other parts of the model and from the events accumulate.

3. Policies can be tested in terms of their effects on the relationships among model variables, model structure or

72

event probabilities. Policies that have their main impact on areas outside the basic model can still be tested for impact through the effect of those policies on exogenous events. Thus, a much more complete description of the side effects of policy decisions is possible.

A Simple Example of Probabilistic System Dynamics

Figure 3 depicts a simple system dynamics model of an electric utility with events included. In this model, projected consumption of electricity and the average load factor determine the projected peak demand. This leads to a
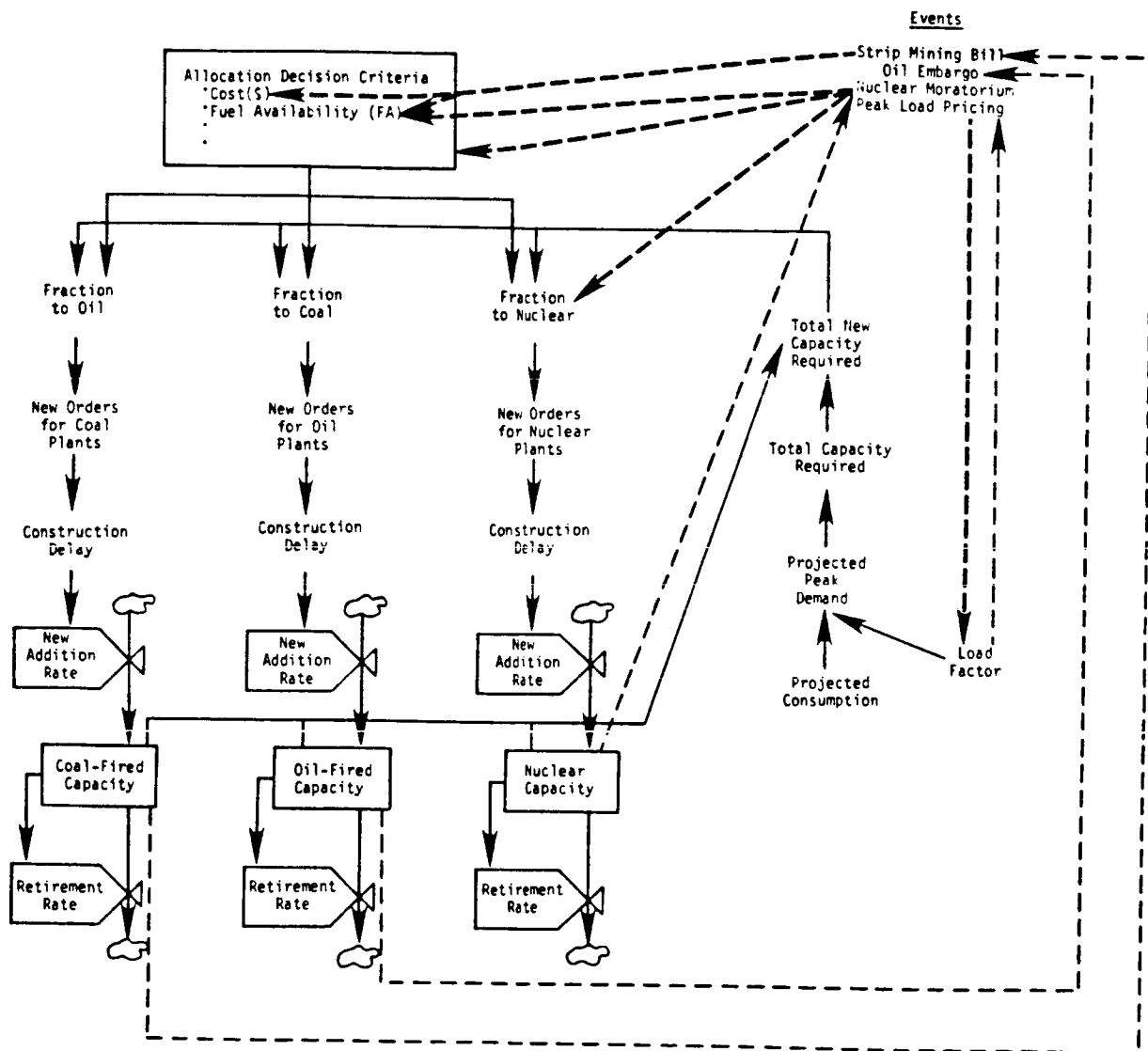
Figure 3. Simplified Probabilistic System Dynamics Model of an Electric Utility

determination of total capacity required, which, along with current capacity, determines the amount of new capacity that needs to be added. These additional requirements are allocated, on the basis of several decision criteria, to oil-fired, coal-fired, and nuclear plants. Orders are placed for these plants and, after planning and construction delays, new plants come on-line. After some period of time these plants wear out or become obsolete and are retired.

The dotted lines show some of the impacts of the events on the model. The strip mining bill will affect the cost of coal and possibly the availability as well, thus affecting coal's ability to compete for new capacity. Another oil embargo would affect the present and the perceived future availability of petroleum. A nuclear moratorium would remove the nuclear option from capacity expansion. Finally, the implementation of peak load pricing would shift the load curve and affect peak demand. As an example of these impacts, assume that the cost of coal generation (COAL$) is given in this model as a TABLE function of time.*

    A COAL$ · K = TABLE (TCOAL$, TIME · K, 1975, 2000, 5)
    T TCOAL$ = 10/13/16/19/21/25

With the strip mining event included in the model this TABLE function might be rewritten as

    A COAL$ · K = TABLE (TCOAL$, TIME · K, 1975, 2000, 5)*(1 + EL · K*CPI)
    T TCOAL$ = 10/13/16/19/21/25

where EL · K is equal to zero if the event has not occurred and to 1.0 if it has occurred. CPI would be equal to the percentage increase in the cost of generation if the event occurs.

As a second example, the fraction of new generation allotted to coal might be a function of the costs and other characteristics of coal, oil, and nuclear plants:

    COAL · K = f (COAL$, OIL$, NUC$, CRA, OFA, NFA...)

where this function actually represents a series of equations that compare characteristics and allocate new capacity. With the inclusion of events in the model, this part of the model might be expressed as:

    COAL · K = (1 - E3 · K)*f(COAL$, OIL$, NUC$, CFA, OFA, NFA,....) +
               E3 · K*f(COAL$, OIL$, CFA, OFA,....)

where E3 · K equals zero when the nuclear moratorium event has not occurred and 1.0 when it has occurred.

The impacts of model variables on events are shown in Figure 3 as dashed lines. The amount of electricity generated by coal, and therefore, the demand for coal, might affect the probability of strip mining legislation. Similarly, the amount

---

*The equations are written in DYNAMO, the computer language developed by J. Forrester for System Dynamics. (J. Forrester, Industrial Dynamics, MIT Press, Cambridge, MA, 1961.)

74

of oil generation might have some effect on the probability of an embargo, and the amount of generation by nuclear plants might affect the likelihood of a nuclear moratorium. The average load factor would have an influence on the likelihood of peak load pricing. The impact of nuclear capacity on a moratorium might be expressed in equation form as follows:

A INUC3 · K = TABLE (TINUC3, NUC% · K, .10, .40, .15)
T TINUC3 = .30/1.0/2.4

where INUC3 · K is the impact (in terms of odds ratios) of nuclear capacity on event 3 (nuclear moratorium) and NUC% · K is the percentage of total capacity that is nuclear.

Finally, the impacts of events on events can be handled in a number of ways depending on the calculational procedure used for the cross impacts. In some cases FORTRAN programs may be written to handle these calculations and link with the DNYAMO model. In the simplest approach, however, the equations can be written in DYNAMO. For example, if the event impacts are as shown in the example in Figure 1, the equations for event 3, the nuclear moratorium, might be written as follows:

A PROB3 · K = ODDS3 · K/(1 + ODDS3 · K)   (1)

PROB3 = Probability of event 3
ODDS3 = Odds of event 3

A ODDS3 · K = IODDS3 · K*I23 · K*INUC3 · K   (2)

ODDS3 = Odds of event 3
IODDS3 = Initial odds of event 3
I23 = Impact of event 2 on event 3
INUC3 = Impact of the amount of nuclear generation on event 3

A IODDS3 · K = IPROB3 · K/(1 - IPROB3 · K)   (3)
A IPROB3 · K = TABLE (IPROB3, TIME · K, 1975, 2000, 5)   (4)
T TIPROB3 = 0/.05/.10/.15/.18/.20   (5)

IODDS3 = Initial odds of event 3
IPROB3 = Initial probability of event 3

A I23 · K = FIFGE (.47, 1.0, E2, JK, .1)   (6)
R E2 · KL = MAX (E2 · JK, FIFGE (1.0, 0, PROB2 · K, .OL) (7)

I23 = Impact of event 2 on event 3
E2 = Indicator of occurrence or nonoccurrence of event 2
PROB2 = Probability of event 2
OL = Occurrence cut-off level

In Equation 1 the probability of event 3 is calculated from its odds. The odds are calculated as the initial odds times the impact odds ratios—in this case, one odds ratio for the impact of event 2 on event 3 and one for the impact of a model variable (the percentage of capacity that is nuclear) on event 3. The initial odds

are calcualted from the initial probability of the event (Equation 3) which is given in a TABLE function. The impact of event 2 on event 3 is set equal to 1.0 if event 2 has not occurred or to the odds ratio expressing the effect of event 2 on event 3 (.47 in this example) if event 2 has occurred. The occurrence of event 2 takes place when its probability exceeds some arbitrarily defined cut-off value, OL. Equation 8 is written as a rate with a MAX function to ensure that once an event occurs, E2 will remain equal to 1.0 for the rest of the run. In this manner any combination of events and impacts can be added to a system dynamics model using the DYNAMO computer language.

Conclusion

Discrete events do not constitute important forces in all systems. However, every modeling effort should at least include a consideration of whether or not events might be important influences on system behavior. In general, it is a fairly easy task to perform a preliminary test of the model's sensitivity to events. The analyst can simply use his own judgments about the probabilities and impacts of a set of events he feels might influence the system, add these judgments to the model, and test the sensitivity of the model behavior to the event impacts. If they do, indeed, cause important changes in model behavior, then a more extensive effort can be made to collect events and define event probabilities and impacts. Generally, the farther into the future the model is used to project, the more likely it becomes that the accumulation of event impacts will be important.

Assessing the validity of a probabilistic system dynamics model is not greatly different from a model without events. In both cases the model must be tested under a variety of future conditions in order to assess its ability to respond reasonably to likely changes. It is impossible, of course, to test the cross-impact matrix by comparing its output with historical data simply because all of the events are future events. It is possible to add past events to the model to show how they influenced past behavior, and, in fact, this has been done,[1] as have historical validations of the cross-impact technique.[2,3] This does not, however, validate judgments about future event probabilities and relationships. Nevertheless, even in a model without events there are usually relationships and judgments that do not affect historical calculations (such as areas of TABLE functions not reached by historical values of model variables) whose validity can only be assessed through a number of different runs to test the reasonableness of the model behavior.

Finally, it is important to note that the arbitrary nature of the timing of event occurrences should be taken into account when the results of model runs are interpreted. The model may give a good representation of the probability of occurrence of each event. However, the timing of actual occurrences is highly arbitrary. In the real world, events may happen if their likelihood of occurrence is only .10 and those with likelihoods of .90 may not occur. No computational procedure used (whether it be based on random numbers or on a probability cut-off level or on some other system) will accurately predict when events will occur. However, by understanding this fact the analyst can perform several sensitivity runs and gain insight into the behavior of the system in response to event occurrences, whenever they happen, and how model behavior is likely to affect the timing of those occurrences. In this manner a more complete understanding of system behavior can be obtained than if future events had not been included in the model.

REFERENCES

1. Hori, Hirosh, "Dynamic Properties of a Japanese Macro-Economic Model and Effects of Exogenous Shocks," <u>Proceedings of the 1973 Summer Computer Simulation Conference</u> (Montreal, Canada, July 1973).

2. Gordon, T. J. and H. Hayward, "Initial Experiments with the Cross Impact Matrix Method of Forecasting," <u>Futures</u>, Vol. 2, No. 2. (December 1968), pp. 100-116.

3. Gordon, Theodore J., Richard Rochberg, and Selwyn Enzer, "Research on Cross Impact Techniques with Application to Selected Problems in Economic, Political Science and Technology Assessment," Report R-12 (Menlo Park, Calif: Institute for the Future, August 1970).

CROSS-IMPACT ANALYSIS

The cross-impact analysis method is an approach by which the probabilities of an item in a forecasted set can be adjusted in view of judgments concerning potential interactions of the forecasted items. Most events and developments are in some way related to other events and developments. A single event, such as the production of power from the first atomic reactor, was made possible by a complex history of antecedent scientific, technological, political, and economic "happenings." In its turn, the production of energy from the first atomic reactor influenced many events and developments following it. In a sense, history is a focusing of many apparently diverse and unrelated occurrences that permit or cause singular events and developments. From these flow an ever-widening tree of downstream effects that interact with other events and developments. It is hard to imagine an event without a predecessor that made it more or less likely or that influenced its form--or to imagine an event that, after occurring, left no mark. This interrelationship between events and developments is called "cross-impact."

The first step in a cross-impact analysis is to define the events to be included in the study. This first step can be crucial to the success of the exercise. Any influences not included in the event set, of course, will be completely excluded from the study. On the other hand, the inclusion of events that are not pertinent can complicate the analysis unnecessarily. Since the number of event pair interactions to be considered is equal to $n^2 - n$ (where n is the number of events), the number of interactions to be considered increases rapidly as the number of events increases. Most studies include between 10 and 40 events.

An initial set of events is usually compiled by conducting a literature search and interviewing key experts in the fields being studied. This initial set is then refined by combining some closely related events, eliminating others, and refining the wording for others.

Once the event set is determined the next step is to estimate the initial probability of each event. These probabilities indicate the likelihood that each event will occur by some future year. In the initial application of cross-impact and in some current applications, the probability of each event is specified, assuming that the other events have not occurred. Thus the probability of each event is judged in isolation and the result of the cross-impact analysis is to adjust those initial probabilities for the influences of the other events.

The other approach to estimating initial probabilities assumes that the expert making the probability judgments has in mind a view of the future that serves as a background for his or her judgments. Thus in estimating the probability of each event, the probabilities of the other events are taken into account. In effect, the events are being cross-impacted in his or her mind. To ask that the effects of other events be disregarded would invalidate much of his or her expertise. In this approach the initial probabilities and impact judgments reflect the expert's view of the expected future situation. The cross-impact runs are used to show how changes in that situation (the introduction of new policies or actions, the unexpected occurrence of an event, etc.) would affect the entire set of events.

These initial probabilities may be estimated by individual experts but more commonly are estimated by groups containing experts from the various disciplines covered by the events. Delphi questionnaires or interviews also can be used to collect these judgments.

The next step in the analysis is to estimate the conditional probability matrix. Impacts are estimated in response to the question, "If event m occurs, what is the new probability of event n?" Thus, if the probability of event n was originally judged to be 0.50, it might be judged that the probability of event n would be 0.75, if event m occurred. The entire cross-impact matrix is completed by asking this question for each combination of occurring event and impact event.

When the initial probabilities have been estimated with reference to the other event probabilities (that is, not considering each event in isolation), there is some additional information that enters into the estimation of the impact matrix. For each event combination there are bounds on the conditional probabilities that can exist. These limits can be illustrated with a simple example. Suppose we considered two events, n and m, event n, with a 50 percent chance of occurring in the next year and event m, with a 60 percent chance of occurring. Thus, out of 100 hypothetical futures, event n would occur in 50 of them and event m in 60. Obviously, events m and n would occur together in at least 10 of the futures.

In this case, in answer to the questions, "If event m occurs what is the new probability of event n?" we are limited in our responses. A conditional probability of 0 for event n is impossible, for example, since if event n never occurred when event m occurred, the "overlap" of 10 combined occurrences would not be possible. The initial probability estimates specified that event n occurs in 50 percent of our hypothetical futures. Since, in this approach, it was assumed that the estimate of 0.50 for the original probability of event n included a consideration of the 0.60 probability of event m, an inconsistency in judgments has occurred. Either the original probability estimate of event n does not actually take into account the 0.60 probability of event m, or the probability of event n given the occurrence of event m is not equal to 0. One of these judgments is incorrect, because it leads to an inconsistency, but only the participants in the analysis can decide which judgment must be changed. They may decide that the initial probability estimate for event n did not fully account for the expected influence of event m, or they may decide that their original estimate of the probability of event n given the occurrence of m was too low. In either case, they have learned something about events n and m because of the cross-impact exercise. This learning process that occurs while the cross-impact matrix is being estimated is one of the major benefits of performing a cross-impact analysis.

The range of conditional probabilities that will satisfy this consistency requirement can be calculated easily. The initial probability of an event can be expressed as follows:

$$P(1) = P(2) \times P(1/2) + P(\overline{2}) \times P(1/\overline{2}) \tag{1}$$

where:

$P(1)$ = probability that event 1 will occur
$P(2)$ = probability that event 2 will occur
$P(1/2)$ = probability of event 1 given the occurrence of event 2
$P(\overline{2})$ = probability that event 2 will not occur
$P(1/\overline{2})$ = probability of event 1 given the nonoccurrence of event 2

This expression can be rearranged to solve for P(1/2):

$$P(1/2) = \frac{P(1) - P(\overline{2}) \times P(1/\overline{2})}{P(2)} \qquad (2)$$

Since P(1) and P(2) are already known (the initial probability estimates) and P($\overline{2}$) is simply 1 - P(2) only P(1/2) and P(1/$\overline{2}$), the conditional probabilities, are unknown. By substituting zero for P(1/$\overline{2}$) (the smallest value it could possibly have) the maximum value for P(1/2) can be calculated. Thus

$$P(1/2) \leq \frac{P(1)}{P(2)} \qquad (3)$$

Similarly, by substituting 1.0 for P(1/$\overline{2}$) (the largest possible value for P(1/$\overline{2}$), the minimum value for P(1/2) can be calculated:

$$P(1/2) \leq \frac{P(1) - 1 + P(2)}{P(2)} \qquad (4)$$

Thus the limits on the new probability of event 1 given the occurrence of event 2 are

$$\frac{P(1) - 1 + P(2)}{P(2)} \leq P(1/2) \leq \frac{P(1)}{P(2)} \qquad (5)$$

Using equation (5) we can now calculate the limits for the example used previously. If the initial probability of event n is 0.50 and for event m is 0.60, the permissible values for the probability of event n given the occurrence of event m are 0.17 and 0.83. Or, if the probability of event n given the occurrence of event m is actually 1.0, then the initial probability of event n must be 0.60 or greater. Figure 1 presents the results of these limits calculations for any combination of probabilities for occurring and impacted events.

Once the cross-impact matrix has been estimated a computer program is used to perform a calibration run of the matrix. A run of the matrix consists of randomly selecting an event for testing, comparing its probability with a random number to decide occurrence or nonoccurrence, and calculating the impacts on all of the other events due to the occurrence or nonoccurrence of the selected event. Impacts are normally calculated using odds ratios. To apply the odds ratio technique the initial and conditional probabilities of the events are converted to odds, using the following relationship

$$Odds = \frac{Probability}{1 - Probability} \qquad (6)$$

The impact of event n on event m is then calculated as the ratio of the odds of event m given event n to the initial odds of event m. Thus the cross-impact matrix shown in Figure 2 would become the matrix shown in Figure 3 when odds are used in place of probabilities. The ratio of the new odds to the initial odds is used to define the event impacts. Thus the occurrence of event 2 causes the likelihood of event 1 to go from odds of 0.33 to 1.50. The odds ratio expressing the occurrence impact of event 2 on event 1, therefore, is 1.50/0.33 = 4.5. Figure 4 shows the entire odds ratio matrix corresponding to Figures 2 and 3.

80

WHAT IS THE PROBABILITY OF THESE EVENTS

	E 1 .05	E 2 .10	E 3 .15	E 4 .20	E 5 .25	E 6 .30	E 7 .35	E 8 .40	E 9 .45	E 10 .50	E 11 .55	E 12 .60	E 13 .65	E 14 .70	E 15 .75	E 16 .80	E 17 .85	E 18 .90	E 19 .95
E 1 .05	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
E 2 .10	.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.50
E 3 .15	.33	.67	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.33	.67
E 4 .20	.25	.50	.75	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.25	.50	.75
E 5 .25	.20	.40	.60	.80	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.20	.40	.60	.80
E 6 .30	.17	.33	.50	.67	.83	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.17	.33	.50	.67	.83
E 7 .35	.14	.29	.43	.57	.71	.86	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.14	.29	.43	.57	.71	.86
E 8 .40	.13	.25	.38	.50	.62	.75	.87	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.12	.25	.38	.50	.63	.75	.88
E 9 .45	.11	.22	.33	.44	.56	.67	.78	.89	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.11	.22	.33	.44	.56	.67	.78	.89
E 10 .50	.10	.20	.30	.40	.50	.60	.70	.80	.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.10	.20	.30	.40	.50	.60	.70	.80	.90
E 11 .55	.09	.18	.27	.36	.45	.55	.64	.73	.82	.91	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.09	.18	.27	.36	.45	.55	.64	.73	.82	.91
E 12 .60	.08	.17	.25	.33	.42	.50	.58	.67	.75	.83	.92	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	.00	.00	.00	.00	.00	.00	.00	.00	.08	.17	.25	.33	.42	.50	.58	.67	.75	.83	.92
E 13 .65	.08	.15	.23	.31	.38	.46	.54	.62	.69	.77	.85	.92	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	.00	.00	.00	.00	.00	.00	.00	.08	.15	.23	.31	.38	.46	.54	.62	.69	.77	.85	.92
E 14 .70	.07	.14	.21	.29	.36	.43	.50	.57	.64	.71	.79	.86	.93	1.00	1.00	1.00	1.00	1.00	1.00
	.00	.00	.00	.00	.00	.00	.07	.14	.21	.29	.36	.43	.50	.57	.64	.71	.79	.86	.93
E 15 .75	.07	.13	.20	.27	.33	.40	.47	.53	.60	.67	.73	.80	.87	.93	1.00	1.00	1.00	1.00	1.00
	.00	.00	.00	.00	.00	.07	.13	.20	.27	.33	.40	.47	.53	.60	.67	.73	.80	.87	.93
E 16 .80	.06	.13	.19	.25	.31	.38	.44	.50	.56	.62	.69	.75	.81	.87	.94	1.00	1.00	1.00	1.00
	.00	.00	.00	.00	.06	.13	.19	.25	.31	.38	.44	.50	.56	.63	.69	.75	.81	.87	.94
E 17 .85	.06	.12	.18	.24	.29	.35	.41	.47	.53	.59	.65	.71	.76	.82	.88	.94	1.00	1.00	1.00
	.00	.00	.00	.06	.12	.18	.24	.29	.35	.41	.47	.53	.59	.65	.71	.76	.82	.88	.94
E 18 .90	.06	.11	.17	.22	.28	.33	.39	.44	.50	.56	.61	.67	.72	.78	.83	.89	.94	1.00	1.00
	.00	.00	.06	.11	.17	.22	.28	.33	.39	.44	.50	.56	.61	.67	.72	.78	.83	.88	.94
E 19 .95	.05	.11	.16	.21	.26	.32	.37	.42	.47	.53	.58	.63	.68	.74	.79	.84	.89	.95	1.00
	.00	.05	.11	.16	.21	.26	.32	.37	.42	.47	.53	.58	.63	.68	.74	.79	.84	.89	.95

Figure 1. Limits for Conditional Probabilities

If This Event Occurs	Initial Probability	1	2	3	4
EVENT 1	0.25		0.50	0.85	0.40
EVENT 2	0.40	0.60		0.60	0.55
EVENT 3	0.75	0.15	0.50		0.60
EVENT 4	0.50	0.25	0.70	0.55	

Figure 2. Cross-Impact Probability Matrix

The Odds of This
Event Become:

If This Event Occurs	Initial Odds	1	2	3	4
EVENT 1	0.33		1.00	5.67	0.67
EVENT 2	0.67	1.50		1.50	1.22
EVENT 3	3.00	0.18	1.00		1.50
EVENT 4	1.00	0.33	2.33	1.22	

Figure 3. Cross-Impact Odds Matrix

If This Event Occurs	Initial Odds	The Odds of This Event Are Multiplied			
		1	2	3	4
EVENT 1	0.33		1.5	1.9	.67
EVENT 2	0.67	4.5		0.5	1.2
EVENT 3	3.00	0.55	1.5		1.5
EVENT 4	1.00	1.0	3.5	0.41	

Figure 4. Occurrence Odds Ratios

A nonoccurrence odds ratio matrix also can be calculated from the information in the occurrence matrix in Figure 2. Again, using the equation

$$P(1) = P(2) \times P1/2) + P(\overline{2}) \times P(1/\overline{2})$$

the probability of event 1 given the nonoccurrence of event 2, $P(1/\overline{2})$, can be determined. From these probabilities the nonoccurrence odds ratios can be calculated just as the occurrence odds ratios are calculated.

Once the odds ratios have been determined the calculations proceed as follows:

1. An event is selected at random from the event set.

2. A random number between 0.0 and 1.0 is selected. If the random number is less than the probability of the event being tested, the event is said to occur. If the random number is greater than the event probability, the event does not occur.

3. If the event (event j) occurs, the odds of the other events occurring are adjusted as follows:

$$\frac{\text{New odds}}{\text{of event i}} = (\text{initial odds of event i}) \times \frac{\text{(occurrence odds ratio}}{\text{of event j on event i)}}$$

If the event does not occur, the same calculations are made but the nonoccurrence odds ratios are used.

4. Steps 1, 2, and 3 are repeated until all the events have been tested for occurrence.

5. Steps 1 through 4 (which represent one play of the matrix) are repeated a large number of times.

6. The frequency of occurrence of each event for all runs of the cross-impact matrix determines the new or calibration probability of that event.

If the initial probabilities of each of the events included the impacts of the other events (the balanced matrix approach), the calibration probabilities resulting from the program run will normally be within a few percent of the initial probabilities, since the cross-impact matrix was constructed to be consistent (to include the consideration of the influences of the events on each other). However, since consistency is ensured only for event pairs, it is possible that inconsistencies in event triplets or quartets or higher orders may exist. The nonoccurrence impact matrix is calculated according to the assumption that the initial probabilities are consistent with each other. Thus, the nonoccurrence impacts should exactly balance the occurrence impacts. But these calculations are based on event pairs. The combined effects of two or more events on one event may cause some changes in the initial probabilities. If any of the calibration probabilities differ from the initial probabilities by more than a few percent, the matrix should be inspected for these higher order effects.

If the initial event probabilities were estimated, assuming nonoccurrence of all other events, the calibration probabilities may be quite different from the initial probabilities. In this case the calibration probabilities are the new probabilities that result from the interactions of the events with each other. The cross-impact exercise has produced new estimates of event probabilities that take into account the interrelationships among the events.

At this stage in the analysis the cross-impact matrix is ready to be used for sensitivity testing or policy analysis. Sensitivity testing consists of selecting a particular judgment (an initial probability estimate or a conditional probability estimate) about which uncertainty exists. This judgment is changed and the matrix is run again. If significant differences occur between this run and the calibration run, it is apparent that the judgment that was changed is an important one. It may be worthwhile to spend more effort in making that particular judgment. If no significant differences appear, that particular judgment probably is a relatively unimportant part of the analysis.

Policy testing is accomplished by first defining an anticipated policy or action that would affect the events in the matrix. The matrix is then changed to reflect the immediate effects of the policy. This is accomplished usually either by changing the initial probabilities of one or more events or by adding a new event to the matrix. A new run of the matrix is then performed and compared with the calibration run. The differences are the effects of the policy. Often unexpected changes will result. When this happens these changes can be traced back through the matrix so that the chains of causality that lead to the unexpected changes can be determined and the effects of the policy understood. Used in this way the cross-impact matrix becomes a model of event interactions that is used to display the effects of complex chains of impacts caused by policy actions.

Performing a Cross-Impact Analysis

Suppose that a study of the future of the chemical industry was in progress. In the course of the study, a list of important future events might be generated. One part of that list might include the following events:

1. The use of plastics in transportation vehicles and construction expands sixfold from 1972.

2. Increased governmental intervention in the process of innovation results from demands for consumer protection and pollution control.

3. Chemical theory progresses to the point where much of chemical research can be done through computer calculations rather than actual experimentation.

4. The chemical industry expands into textiles through the development of nonwoven synthetic fabric.

5. Chemical companies realize a declining return or rising investment in conventional research.

The first step in using these events in a cross-impact analysis is to estimate initial probabilities for the events. Assuming that the balanced matrix approach is to be used, the probabilities might be estimated as follows:

Event	Probability of Occurring by 1985
1. Use of plastics expands sixfold	0.15
2. Increased governmental intervention in innovation	0.20
3. Chemical research performed on computers	0.25
4. Chemical industry expands into textiles	0.10
5. Declining return on conventional research	0.20

The next step is to estimate conditional probabilities. In this step a matrix similar to Figure 5 is constructed. Each cell of the matrix represents the answer to the question, "If event x occurs, what is the new probability of event y?" For example, the first completed cell of the first row of the matrix contains the new probability of event 2 given the occurrence of event 1. Thus the question answered here is, "If the use of plastics in transportation and construction increases sixfold (event 1), what is the likelihood of increased governmental intervention in the innovation process resulting from the demand for consumer protection and pollution control (event 2)?" Since the increased use of plastics is likely to increase demand for consumer protection and pollution control, event 2 should be somewhat more likely than initially estimated (0.20) if event 1 occurs. Thus we might judge that the new probability of event 2 becomes 0.30 if event 1 occurs.

Since the influences of the events on each other were included in the initial probability estimates, this judgment must now be tested for consistency with the initial probabilities. By finding the intersection of row 3 (the 0.15 probability of event 1) and column 4 (the 0.20 probability of event 2) in the chart in Figure 5, we

If This Event Occurs:		The Probability of This Event Becomes:				
	Initial Probability By 1985	1	2	3	4	5
1. Use of Plastics Expands Sixfold	.15		.30	.25	.10	.15
2. Increased Governmental Intervention in Innovation	.20	.10		.35	.07	.40
3. Chemical Research Performed on Computers	.25	.15	.20		.15	.05
4. Chemical Industry Expands into Textiles	.10	.15	.25	.25		.15
5. Declining Returns on Conventional Research	.20	.25	.15	.50	.20	

Figure 5. Sample Conditional Probability Matrix

see that the limits on the conditional probability of event 2 given event 1 are 0.0 and 1.00. Thus, no problem is presented by the judgment of 0.30 for the probability of event 2 given event 1.

In a similar fashion the entire matrix is completed. The next task is specifying policy or sensitivity tests to be run with the matrix. In this case, for example, we may wish to know the effect on the other events if event 3 (use of computers for much chemical research) occurs. Thus one test would be performed by assigning a probability of 1.0 to event 3 and rerunning the matrix. A second test might be performed to test the sensitivity of the events to event 2 (increased governmental intervention in the innovation process). These tests are shown below.

TEST OF OCCURRENCE OF EVENT THREE

Event	Initial Probability	Test Probability	Final Probability	Change
1	.15	.15	.14	-.01
2	.20	.20	.20	.00
3	.25	1.00	1.00	.00
4	.10	.10	.12	+.02
5	.20	.20	.13	-.07

TEST OF SENSITIVITY TO EVENT TWO

Event	Initial Probability	Test Probability	Final Probability	Change
1	.15	.15	.13	-.02
2	.20	1.00	1.00	.00
3	.25	.25	.30	+.05
4	.10	.10	.09	-.01
5	.20	.20	.29	+.09

A DESCRIPTION OF THE CONSENSOR™

The CONSENSOR is a decisionmaking tool that functions as an aid in the determination of group consensus. It facilitates anonymous, weighted voting and automatically averages a group's many shades of opinion while taking into account the feelings of confidence each person has in his own opinion. It enables each participant to express not only subtle changes in personal opinion, but also the various levels of confidence or conviction that support those opinions and even his own self-assessed qualification to vote on any given subject. In addition, this system enables each individual to participate fully with a highly flexible degree of anonymity.

The CONSENSOR enables all participants in a discussion to say how they feel about the subject at hand in two dimensions: (1) each expresses agreement or disagreement with a given problem statement by means of an electronic switch which is graduated through a range of eleven possibilities, identified by the numbers 0 through 10 (0 is usually assigned the lowest, least important, or least probable value, while 10 is the highest, most important, or most likely value) and (2) each participant selects one of the five "weighting" values on a second switch; these are graduated in 25 percent increments from 0 through 100 percent and actually qualify (give weight to) the previous selection according to the amount of confidence the participant feels or wishes to express.

Thus, "weighting" qualifies any opinion expressed by the "selection" control. The value or the quantity to which each weighting switch is set determines the intensity of that participant's vote or selection. A participant who sets the weighting switch at 50 percent registers an opinion (selection) at half strength.

Regardless of the vote or selection input by the _selection_ switch, it is counted as a full vote if the weighting switch is on 100 percent, but only as _half_ a vote if the weighting switch is at 50 percent. Therefore, if half of a given decisionmaking body votes with 100 percent intensity, and the other half of the group votes with 50 percent intensity, the average weighted input from the group as it appears on the display screen will be 75 percent.

When voting on a series of alternatives or a range of selections, each is assigned one of the 11 values around the selection switch from 0 through 10. Selections are registered anonymously, and the group's aggregate "weighted" position is displayed in a large histogram form, visible to all. Cumulative weighted input to each of the 11 selections is displayed as a distribution that is always normalized to 100 percent. Group consensus, when it occurs, appears on the display screen in the form of a bell-shaped curve generated by columns of light.

Relative degrees of consensus are shown by the distribution of opinions—the taller a normally distributed curve, the more harmonious the group's thinking. A bimodal curve indicates disparity of opinion (usually due to an ambiguous problem statement), while a low, wide curve shows diversity of opinion. In addition, the display screen shows the weighted _mean_ (average) opinion within the distribution and the average _weight_ (intensity) expressed by the group as a whole.

Highly flexible in its applications, the CONSENSOR is particularly useful to committees, review boards, and task groups. Its applications range from assessment of alternatives, plans and strategies, to advertisement pretesting, personnel evaluation, and simple "make your choice" voting situations. It forces clear problem definition, which itself produces shorter and more effective meetings. It encourages full participation and open discussion, thus providing a register of the true feelings of key people.

The value of this system to communication lies in its direct depiction of opinions on a visual scale. The display thus pictorially reveals areas of misunderstanding before time is wasted on misdirected discussion or on clarification measures that would be tedious to anyone present who might not require them.

The CONSENSOR Model 3000 offers the following major innovations in design and function:

1. A microprocessor technology that reduces the component count, thereby greatly increasing its reliability. In addition, a microprocessor provides the CONSENSOR with greatly expanded calculation capabilities.

2. Cathode ray display of all information within one digit accuracy. The full distribution of input to all 11 selection positions from each of the participants, as well as the average group weight and the weighted mean, is shown correct to the nearest decimal. In addition, the CONSENSOR Model 3000 calculates and displays by CRT previous iterations, stored in memory.

3. The unit is easily portable. The display is no heavier than a standard TV unit. The voter terminals are hardwired in modular units of 5, designed for simple installation by the users. The entire installation can be made on a conference room table or around the edges of both "U-" and "H-" shaped tables.

4. Permanent installations can be made by securing the wire connections under the table top where they are out of sight and out of the way when the CONSENSOR is not being used. The individual voter's terminals are permanently wired in modular units of 5. Each CONSENSOR system is delivered with 3 modules, each simply connected to the others in any sequence by the user, thus comprising a basic unit for 15 participants.

5. Design of a voter terminal unit that assures the anonymity of each participant (to the degree that each person desires it). Each "vote" is input by pressing a "vote activate" button, while both selection and weight settings are screened from view on each side.

Options are available for users who wish to expand the applications of the CONSENSOR or to extend the usefulness of data generated by any given meeting. Each option would carry a moderate additional cost.

1. Additional Terminals. Additional voter terminals can be provided in modular groups of 5, all of which are easily added to the basic set of 15. Any number of additional units can be "stacked," up to a total of 60.

2. Math Package. The Model 3000 can be programmed to display (or record on hard copy) any additional statistical data required by the users. Such information as median, mode, standard deviation, equivalent unweighted means, and skewness can be made instantly available to the group on a continuing basis, or only as needed. Control of displaying this information is by means of an optional "activate" switch on the moderator's panel.

3. Computer Connection. The system can be interconnected, by way of an RS-232 connection system, with a computer, permitting, in addition to increased storage capability, computer analysis of data generated during any given meeting for display on the CONSENSOR screen. This permits interaction of data from the group and from outside data banks.

4. Hard Copy Printout. Results are printed alphanumerically on a paper tape. Each CONSENSOR iteration is identified by a serial number so that a record can be kept of each series. The printer is designed with an "active" control and thus functions as a discretionary option throughout a meeting.

5. Cost Clock. A digital display of the running cost of a meeting, calibrated to show dollars rather than minutes, and adjustable based upon the average annual salary of participants.

Thus it can be seen that the CONSENSOR is a new computer tool to make it easier for planners and decisionmakers to discover how much they know and how strongly they feel about alternatives facing them. The CONSENSOR offers a way to make business meetings and public discussions shorter, more productive, and at the same time more democratic and representative of the participants' true beliefs.

SCENARIOS: THEIR CONSTRUCTION AND USE

What Is a Scenario?

A scenario is a policy analysis tool. It describes a possible set of future conditions. In general, the term scenario has been used in two different ways to describe future conditions: first, to describe a snapshot in time or conditions of important variables at some particular instant in the future; second, to describe a future history, that is, the scenario can describe the evolution from present conditions to a given point in time. The latter approach is generally preferred because it can provide causal information regarding developments within a given scenario. The most meaningful and useful scenarios are those that display conditions of important variables over time covering the period of interest. In this latter approach the evolution of conditions, or of the variables, is described by narratives that treat the important events and developments that shape the variables.

When scenarios are used in policy analysis, the nature of evolutionary paths is often important--since policies can act to deflect those paths. In policy studies families of scenarios often are used to illustrate the consequences of different initial assumptions, different evolutionary conditions, or both. For example, a study of transportation policy might involve constructing several scenarios that differ in their assumptions about birth rates, population, migration, economic conditions, and costs and availability of various forms of energy. When a set of scenarios is prepared, each scenario usually treats the same or similar parameters, but the evolution and actual value of the parameters described in each scenario are different.

Clearly, a set of scenarios can describe a range of alternative futures that differ only as a result of the initial conditions and/or the flow of events that shape the conditions described in the scenario. Sets of scenarios may be generated by changing one or several key assumptions. For example, in the above-cited case, birth rate might be assumed low in one scenario, moderate in another, and high in a third. In addition, it might be important to reach an understanding of conditions that result not only from demographic variations (e.g., birth rate) but also from other conditions such as the development and use of alternative energy systems. The dimensions usually are chosen to represent the leading or most influential variables (in the above example, birth rate, and energy costs and availability) from which other conditions will evolve.

In preparing scenarios, an analyst has to make several crucial choices:

- Specifically, what variables should be included in the scenario (e.g., those that are most important to shaping transportation demands)?

- If more than one scenario is to be used, in what way should the scenarios in the family differ? How large should the difference among scenarios be to make them distinguishable from one another in order to allow meaningful policy analysis?

- What conditions or issues should be studied?

- How can internal consistency be assured within each scenario (e.g., how can mutually exclusive events and trends be excluded)? This is an important question, since each scenario must provide a rational explanation of the sequence of events described.

Each scenario usually has several major components or dimensions, e.g., demography, the economy, natural resources, energy, social and institutional, technology, etc.

How Is a Scenario Constructed?

The process of scenario building begins by defining a candidate list of demographic, socioeconomic, and institutional variables that are important to the

subject being studied. (See Table 1 for a typical list used in recent studies.) Second, a list or set of characteristics of a particular system (transportation, energy, etc.) is determined. The first list is often compared with the second to assure that important external variables (e.g., to the transportation system) are included. The events that are described in a scenario, and that help shape projections of the variables, are critical. An event is best described as a discrete occurrence that has some finite chance of happening in the future time period under study. Clearly the likelihood of occurrence of certain events will--and should--differ in each scenario and, in fact, these events help discriminate between the scenarios. (See Table 2 for key events typical of those used in these studies.)

A scenario, or set of scenarios, composed only of extrapolation of past trends surely would be an unlikely descriptor of possible future conditions. In the real world, the occurrence of "unprecedented" events continually interrupts trends in progress. The chronological history of any system or subsystem is partially written in terms of unprecedented events (railroad development, the automobile, the OPEC oil embargo). They often are the essence of an era. When scenarios are constructed, it is important to search for events that are plausible and relevant to the subject at hand. Here the question focuses on: What important events-- technological, demographic, economic, societal, etc.--logically might be expected to occur within the time frame of interest? Sometimes interesting and instructive scenarios can be constructed by including low-probabiltiy, high-impact events. When low-probability, high-impact events are introduced, they often can become the focus of the scenario and can determine its outcome and the evolution of the variables that are described in the scenario(s). Such events can be used in "what-if" situations, e.g., What if nondepletable energy sources are discovered?

Yet there are no analytic methods that yield events for a scenario. The procedures employed to generate events can stimulate, collate, organize, extract,

C - 2

93

Table 1

PROJECTED INDICATORS

- Total U.S. Population (including armed forces abroad)

- U.S. Population Ages 5-19

- Resident Population in the Combined South and West Census Regions as a Percentage of Total Resident Population of the U.S.

- Population Living in Urban Areas (using the 1970 definition of urban areas) as a Percentage of the Total Resident Population in the Combined South and West Central Regions

- Percentage of U.S. Land in Urbanized Areas

- Number of Households

- Total Labor Force

- Total Labor Force Participation Rate (number of persons 16 years of age and employed or actively seeking work as a percentage of the total noninstitutional population 16 years of age and over)

- Gross National Product (constant 1975 dollars)

- Gross National Product Per Capita (constant 1975 dollars)

- Disposable Personal Income Per Capita (constant 1975 dollars)

- Total Government Expenditures (federal, state, and local) as a Percentage of GNP

- Total Federal Expenditures (constant 1975 dollars)

- AAA Bond Yield

- Final Sales of Goods as a Percentage of Total Final Sales

- Labor Productivity

- Nonresidential Fixed Investment

Table 2

IMPORTANT EVENTS USED IN SCENARIOS

- Government subsidizes relocation and training of needy rural workers to encourage migration to urban centers as a component of federal social welfare programs.

- Five new cities of 50,000 population are developed proximate to natural resources (i.e., coal) to facilitate new resource development.

- Increased capital demand puts upward pressure on interest rates.

- Selective wage, price, profit, and interest rate controls are periodically imposed to guide production, consumption, and investment patterns.

- Middle-class attitudes toward work are eroded by the rise of strong avocational interests, resulting in decreased demands for career advancement opportunities.

- Nearly all workers undergo job retraining because of technological obsolescence or voluntary career change with federal and state government support supplementing private industrial programs.

- R&D spending in the United States increases from the mid-1970 level of 2.5 percent of GNP to 5 percent of GNP.

- Accelerated depreciation allowances are approved and become law (20 percent increase over 1975 levels).

- Dislocations caused by governmental policies result in a cyclical downturn where capacity utilization in manufacturing fails to 70 percent and remains there for eight consecutive quarters.

- The stock of capital per worker averages 2.5 percent growth for a ten-year period.

- Legislation is passed providing a guaranteed minimum annual income for U.S. citizens.

- Legislation is passed that imposes effluent fees on industrial processes that are environmentally degrading; the fees collected are allocated to environmental R&D.

- Federal funds for community development, to revitalize cities, increase threefold over the 1975 level. (Community development funds totaled $3.2 billion in 1975.)

- Successful legislation is enacted guaranteeing full employment by specifying the federal government as the employer of last resort.

- European Community and Japan erect prohibitive trade and investment restrictions that restrict market access by the United States.

and file possible occurrences. They cannot, however, be expected to bring to the surface concepts that have not yet been articulated.

The projected values of variables and the general conditions of the scenarios must be examined since scenarios usually are developed from a large number of trends. The projections of the variables are examined to see whether they contain contrary implications about socioeconomic, demographic, institutional, and other behavior. The projected variables also are scrutinized for "reasonableness"--i.e., in terms of whatever knowledge there is about the growth process of the particular variables being discussed. (See Figure 1 for two trends projected in this type of work.) This process usually starts at the macro level and filters down to the details of the particular system for which the scenario was constructed.

Why Are Scenarios Used?

As noted earlier, scenarios provide a context for policy analysis. To be really meaningful, a set of scenarios should spotlight policy intervention points where critical roles are likely to be found. Certain actions, while producing some favorable public and private sector results, may produce others that are undesirable. Hence, the scenario set should provide material to spotlight policies and actions that are likely to maximize desired benefits.

In this regard, one of the most important factors in evaluating alternative policies and actions will be the ability, from the scenario work, to assess political and administrative feasibility. Such needs might include regulatory changes, new statutory authority, and even government reorganization. Also, budgetary costs, manpower, and other resources can be important considerations in policy analysis. Political and administrative feasibility of possible alternative actions cannot realistically be ignored in policy analysis.

A. PERCENT OF U.S. LAND IN URBANIZED AREAS
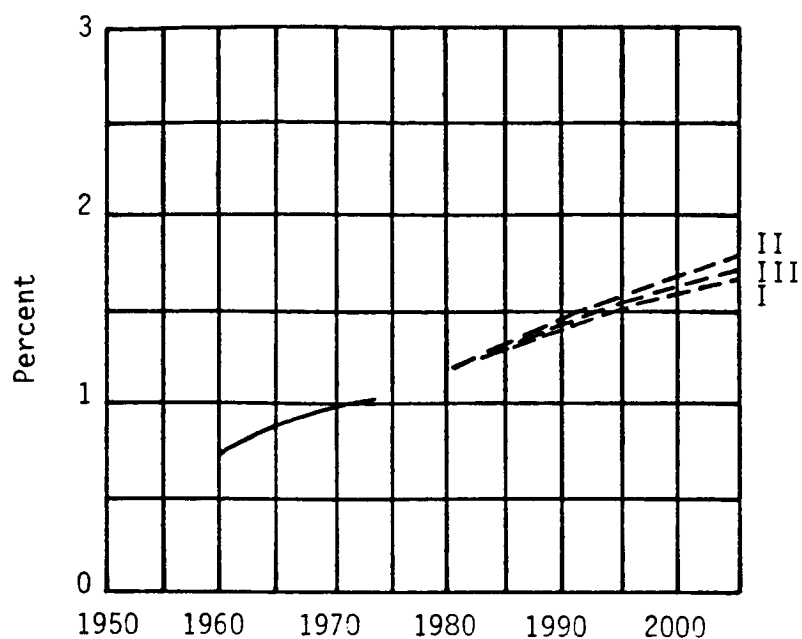
Scenario I   - low population,
               rapid economic growth
Scenario II - moderate population,
               moderate economic growth
Scenario III - low population,
               low economic growth

B. NUMBER OF HOUSEHOLDS (millions)
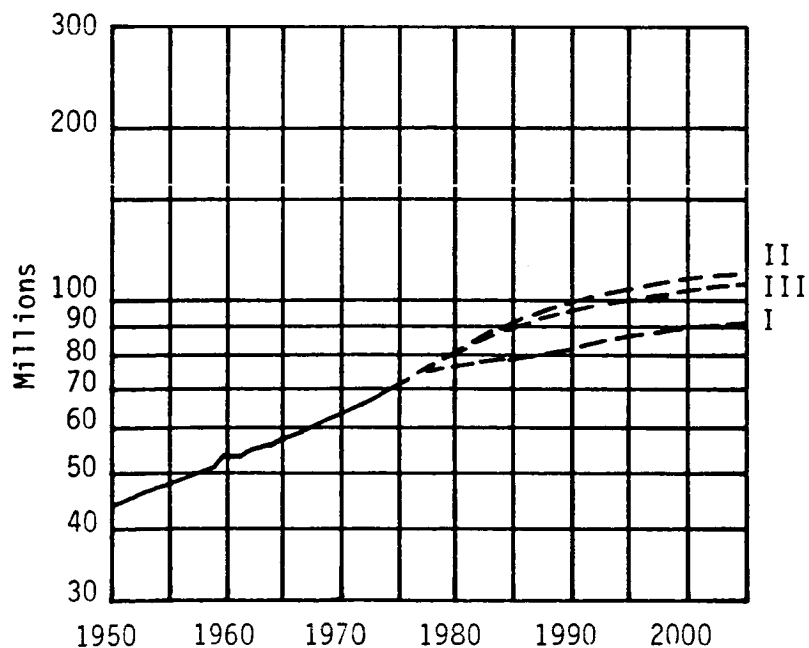
Figure 1. Two Projections Used in Scenarios

97

In summary, a scenario is not a forecast per se. Rather, it is a plausible description of what might occur. This form of presentation describes events and trends as they could evolve. The likelihood that any particular scenario actually will be realized is quite low for several reasons. There are a number of events and trends that are discussed explicitly in each scenario. Since the likelihood of occurrence of the bulk of these is less than unity, their product (that is, the overall probability of the scenario) must be small.

Furthermore, scenarios are necessarily incomplete for two basic reasons. In the interest of brevity, scenarios usually focus only on those aspects of the future believed to be crucial to the central problem being addressed. Also some future developments always will be unforeseeable; that is, they are inaccessible by any forecasting technique. Nevertheless, scenarios have proved to be an effective aid for preparing and testing policies, even though they do not "depict the future."

TREND IMPACT ANALYSIS

Trend Extrapolation

The ability to quantify various parameters and project them into the future is an important factor in accomplishing the various steps in the planning process. Many techniques are and have been used to obtain such time-series data. These range from highly judgmental, intuitive methods to highly complex mathematical treatments. In the former case, individual estimates (genius, expert, or nonexpert) or group consensus (obtained by polling, face-to-face conferences, Delphi conferences, or situation gaming) may be employed.

Unfortunately, both human judgment and mathematical extrapolation have their own fallibilities. Past combinations of the two have not been notably successful in combining the best features of each, while avoiding their weaknesses. A principal strength of judgment in trend extrapolation is that humans can take into account the possible impacts of unprecedented future events that may cause unique perturbations in the trends--for example, if a pharmaceutical industrialist or food manufacturer might be interested in how the discovery of a link between pancreatic cancer and the consumption of sugar would influence the trend in sales of artificial sweeteners. This influence, however, could manifest itself in quite novel ways, since, by its very nature, it has never been felt before. Common mathematical methods of extrapolation are unable to take into account potential future events since the past history of a trend cannot reveal how it would be influenced by such events.

On the other hand, subjective or unaided human judgment usually is inferior to mathematical formulas when it comes to fitting a set of points with a best-fit curve. Moreover, mathematical curve-fitting techniques are well established in theory and application. They can be readily communicated and used by others, thereby overcoming the stigma of arbitrariness or mere idiosyncrasy that attends subjective projections. At best, however, a mathematical approach simply produces a good estimate of how a trend would appear if it were not modified by unprecedented future events.

Three examples illustrate how the occurrence of unprecedented events can influence a previously stable trend.

1. Until about 1955 the fertility rate in the United States rose regularly and smoothly. The trend reversed dramatically in the 1960s when cheap and effective contraceptives permitted the expression of new values and attitudes about ideal family size (see Figure 1). Extrapolations based on the historical trend from 1950 through 1960 consistently overestimated the present birth rate in the United States.

2. Figure 2 illustrates the long-term drop in the cost of electricity in the United States. The trend toward diminishing costs began almost with the advent of the first electricity generating system and reflected the generally unstated goal of producing cheap power. Cost was reduced through economies of scale, improved technology and operating efficiency, more readily available fuels, etc. Recently, however, the cost of electricity has stabilized and begun to rise because of increasing costs of fuel, new requirements for costly antipollution devices, and restrictions on the size of generating plants that end or lower savings through economies of scale. An extrapolation based on all but the latest data would have missed the recent "turn around."

D.2 FERTILITY RATE*

NUMBER PER 1000 FEMALES AGE 15-44
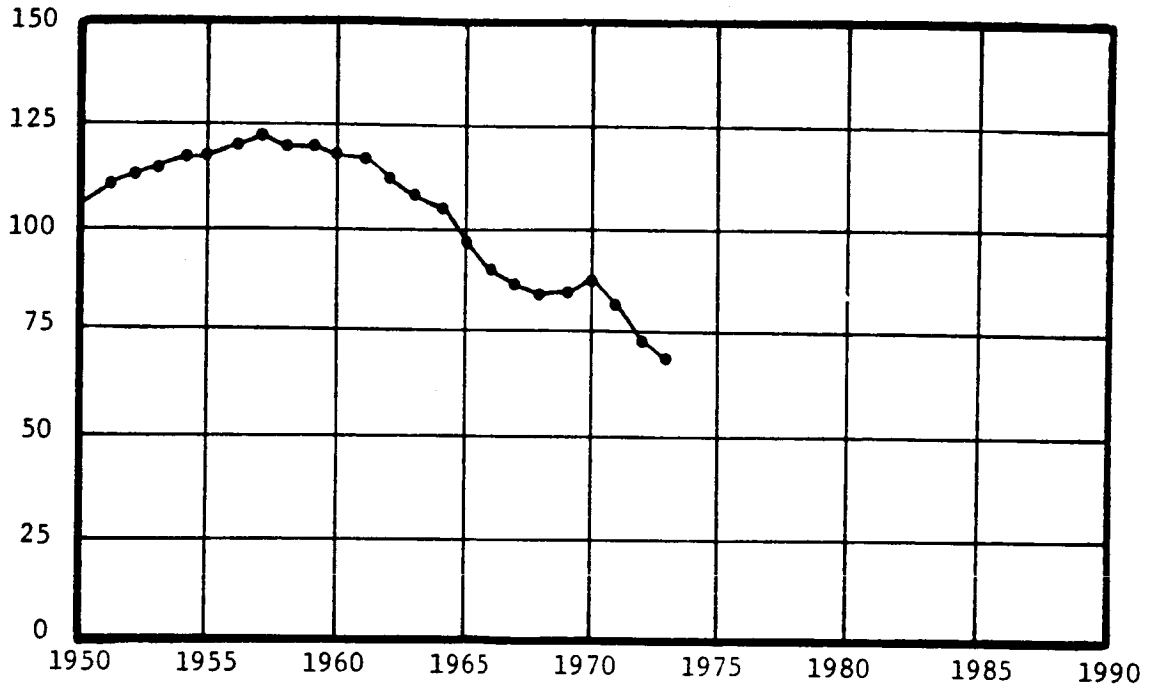
Source of historical data: Public Health Service, National Center for Health Statistics, <u>Vital Statistics of the United States, 1963</u>, Vol. 1, <u>Monthly Vital Statistics Reports</u>, Vol. 19, No. 13; Vol. 20, No. 13; and Vol. 21, No. 12, as cited in Executive Office of the President, Office of Management and Budget, <u>Social Indicators 1973</u>, Table 8/5, p. 252; U.S. Bureau of the Census, <u>Statistical Abstract of the United States 1974</u> (Washington, DC: U.S. Government Printing Office, 1974), Table No. 9, p. 11.

*General fertility rate is the number of births per 1000 resident females 15-44 years of age.

Figure 1. Fertility Rate in the United States
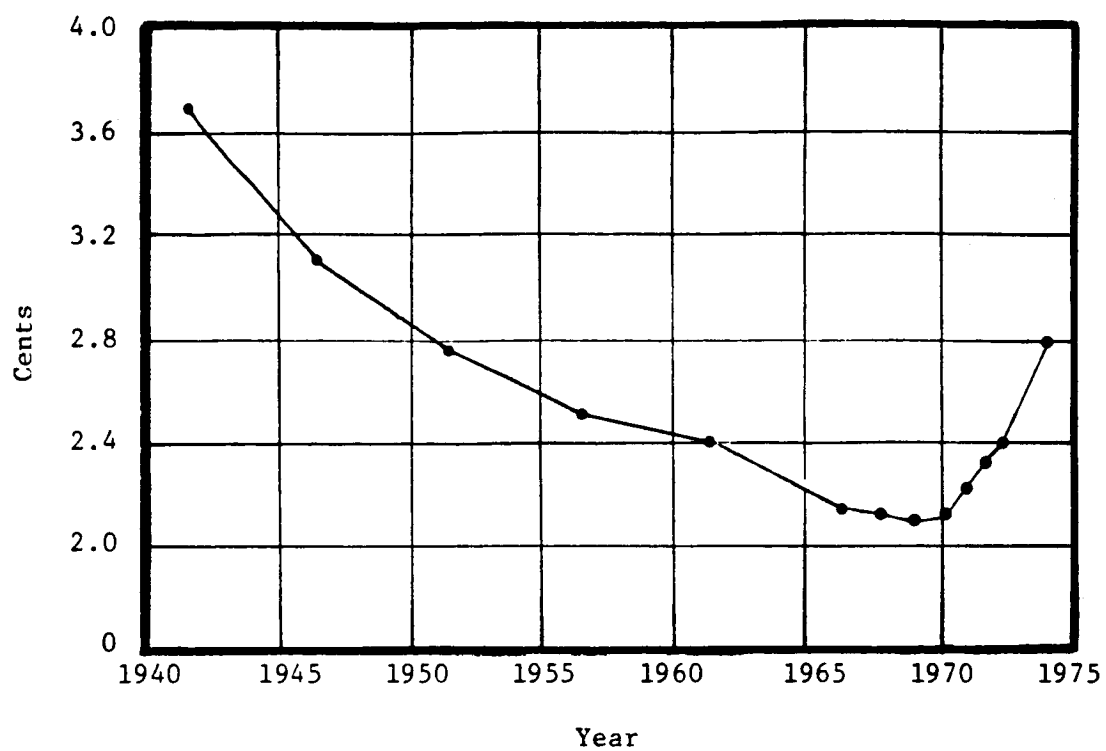
SOURCE: Edison Electric Institute, <u>Questions and Answers</u>
<u>about the Electric Utility Industry</u>, annual.

Figure 2. Electricity Used in the Home (average cost per
kilowatt-hour)

3. The long-term trend in the United States toward the sale of automobiles of increasingly greater weight and horsepower has begun to change appreciably in recent months. This change may be the result of concern about increasing costs of gasoline, new public attitudes about conservation of the environment, or both.

Many other examples can be cited, of course. The point is that deviations from historically based extrapolations usually seem to reflect the impact of unprecedented events.

Trend impact analysis (TIA), an analytic procedure developed by The Futures Group, divides the task of extrapolation in such a way that humans and computers are assigned precisely the task that each does best. First, the computer extrapolates the past history of a trend. Second, the human specifies a set of unique future events and how the extrapolation would be changed by the occurrence of each of these events. The computer then uses these judgments to modify the trend extrapolation. Finally, the human evaluates the resultant adjusted extrapolation and modifies the input data to the computer in those cases where the output appears unreasonable. Figure 3 shows this procedure schematically.

Mathematical Trend Extrapolation

The development of a surprise-free extrapolation is the first step in the TIA process. A computer program selects the "best fitting" curve from a set of alternative equations. This curve then is used to provide the surprise-free future extrapolation. At the option of the program user, in order to avoid unreasonable extrapolations, the program can either truncate extrapolations that fall outside upper or lower bounds, or select the "best fitting" curve only from among those that do not give rise

103
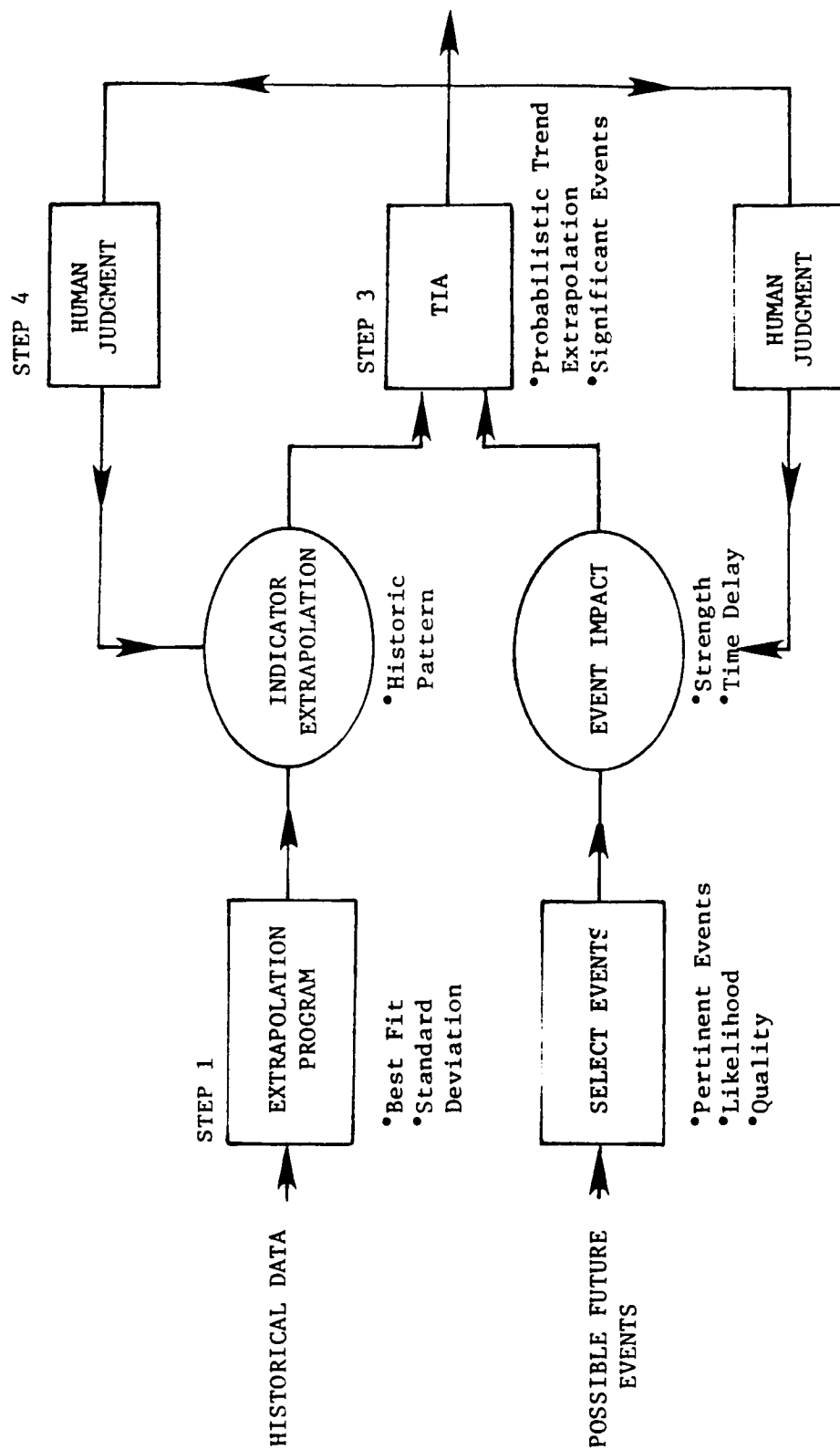
Figure 3. Trend Impact Analysis (TIA)

to extrapolations falling outside the specified bounds. Alternatively, the user can reject the mathematical extrapolation generated by the TIA program and supply an extrapolation developed by some other curve-fitting program or one based entirely on human judgment.

Several refinements in the programming of this aspect of TIA enhance the effectiveness of the best-fit test and extrapolation procedure.

1. It is not necessary that the data cover a continuous span of time. Data in which there are gaps are fully acceptable—the program makes use of whatever data are available, taking into account any gaps, but without being stymied by them.

2. The program does not give equal weight to all data. Rather, a year may be specified (normally the present year) for which data are to be given maximum weight. As the times to which the data refer are further removed from the year that has maximum weight, the data are given less weight.* This procedure thus takes into account the possibly lower reliability of data that are more distant in the past or, more important perhaps, the lower influence on the future of developments that have occurred progressively farther in the past. The formula chosen also makes the sum of an infinite number of weights infinite, rather than convergent, so that even very distant years continue to have a finite contribution.

3. Since there is no guarantee that a mathematical extrapolation will give a good fit to the given data, the TIA program reports to the human user just how good the fit was, using the same squared correlation coefficient that determined which mathematical formula should be used. As noted earlier, where judgment or analysis indicates a more realistic set of data should be used, they can be input directly as part of the specified data used for subsequent steps.

4. Upper and lower limits on the extrapolation may be set. In this case any curve that produces an extrapolation that exceeds these limits will be rejected. Thus the extrapolation is based on the best-fitting curve that does not exceed the specified limits.

---

*The weighting formula is $\dfrac{1}{1+ |y-y_o|}$, where y is a given year and y_o is the year given maximum weight.

Human Judgments of Event Impacts

Human judgment and imagination are central to the second step of TIA. Here, the program modifies the surprise-free extrapolation to take into account important, unprecedented future events. First a list of such events is prepared. These events should be unprecedented, plausible, potentially powerful in impact, and verifiable in retrospect. The source of this list of events might be, typically, a literature search, a Delphi study, or a consensus among consultants. Whatever the source, the events selected comprise an inventory of potential forces that could lead to a departure from a surprise-free future.

Several judgments are made about each selected event. First, estimates are made of the probability of occurrence of each event as a function of time. Second, the impact of each event on the trend under study is estimated. Impacts can be specified in several ways; our procedure (Figure 4) involves specification of the following:

1. The time from the occurrence of the impacting event until the trend begins to respond.

2. The time from the occurrence of the impacting event until the impact on the trend is largest.

3. The magnitude of that largest impact.

4. The time from the occurrence of the impacting event until the impact reaches a final or steady-state level.

5. The magnitude of that steady-state impact.

Each of the three specified times and the impact magnitudes associated with them are taken to be completely independent. For example, the maximum impact might be positive, and the steady-state impact negative, or the
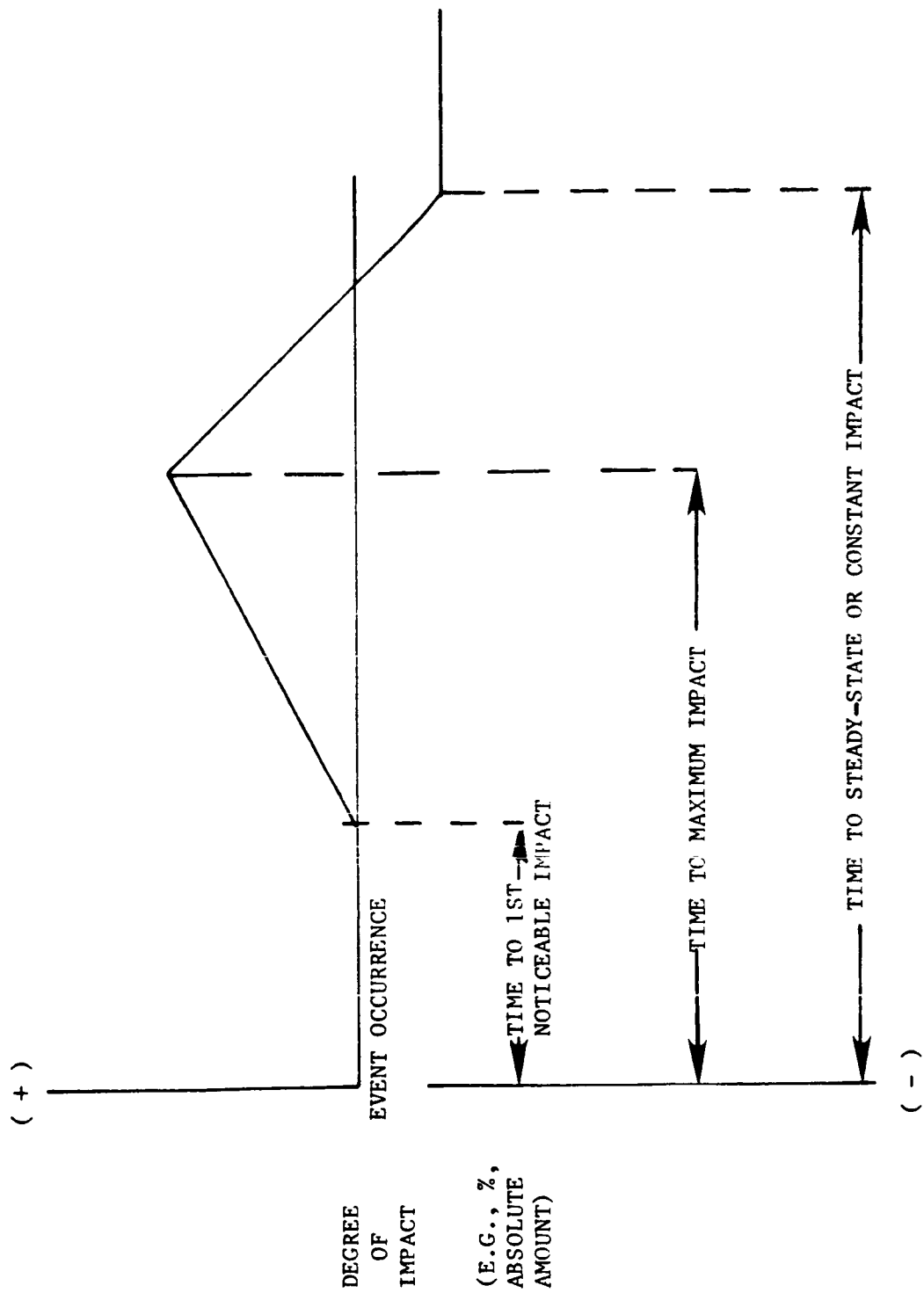
Figure 4. Event Impact Estimates

steady-state impact might be zero, meaning that the impact is only temporary. Finally, the maximum impact might be the same as the steady-state impact.

In addition, impacts can be specified in either relative or absolute units--i.e., they can be specified as percentages of the values of the trends at the time of impact, as a percentage change of that number, or they can be specified in absolute units of magnitude of the trend. For example, the impact of a particular event on the number of dentists could be specified either as 90 percent of that number, as a 10-percent decline of that number, or as a downward shift of 12,000. The form used to record these estimates is shown in Figure 5. These impacts are calculated, when sufficient information is available to do so. Otherwise they are judgmentally determined.

Computer Processing of Impact on Extrapolated Trends

The heart of TIA is the computer program that uses these judgments to calculate the expected impact of the selected events on the extrapolated trend. A closed-form procedure is used to solve this problem. The expected value, or mean, of the impact and upper and lower quartiles of the distribution of possible impacts are computed for each indicator. The expected value of the impact is computed by summing the products of the probabilities of the impacting events for each possible year times the magnitude of their impact, taking into account their specified time lags. Probabilities of events for years not specified are estimated by linear interpolation, assuming that an event has 0.00 probability at the present time. Similarly, impacts are linearly interpolated between the three specified impact magnitudes.

INDEX NO.		ESTIMATED PROBABILITY BY YEAR SHOWN		YEARS TO FIRST IMPACT	YEARS TO MAXIMUM IMPACT	MAXIMUM IMPACT (PERCENT)	YEARS TO STEADY-STATE IMPACT	STEADY-STATE IMPACT (PERCENT)
		PROB.	YEAR					
021277	SINGLE-UNIT DRUG PACKAGING ACCOUNTS FOR AT LEAST 50% OF DRUG PRODUCTS SALES.	.99	1975	1	10	-5	10	-5

ESTIMATES PROVIDED BY EXPERTS

Figure 5. Format for Event Impacts

This approach treats the coupling among the impacts of the various

events as negligible. Thus, the impact estimate is produced as the sum

of independent random variables. The net result is that the variance of

the impact-adjusted forecast is the sum of the variance of the trend

extrapolation (as measured by the square of the standard error of esti-

mate) and the variances of the impacts of the associated events.

Thus, where P_{ye} is the likelihood that event $\underline{e}$ will occur in year $\underline{y}$,

and $a_{y_k}-y,e$ is the impact that event $\underline{e}$ would give rise to (y_k-y) years

after its occurrence, the expected value of the impact in year y_k would be

$$\sum_e \sum_{y=y_o}^{y_k} P_{ye} a_{y_k}-y,e$$ where y_o is the present year (e.g., 1975). (See

Figure 6.)

Typical TIA Results

Use of the TIA procedure has revealed that important insights may be

obtained by utilizing this form of trend extrapolation. The development

of improved trend forecasts is only one of the advantages of this method.

Insight into how adjustments of event probabilities and impacts vary the

estimated future value of the indicator in question, in terms of both the

median and interquartile range, also can prove to be very useful in devel-

oping an understanding of the effectiveness of policies or actions that

may be available to us.

The forecast of the indicator shown in Figure 7, the average cost of a

prescription, is drawn from a recent report that is part of a data service

(called PROSPECTS®) developed at The Futures Group. The forecasts in the

YEAR OF
EVENT
OCCURRENCE

	1975	1976	1977	1978	1979
1979	–	–	–	–	$P_{79} X I_0$
1978	–	–	–	$P_{78} X I_0$	$P_{78} X I_1$
1977	–	–	$P_{77} X I_0$	$P_{77} X I_1$	$P_{77} X I_2$
1976	–	$P_{76} X I_0$	$P_{76} X I_1$	$P_{76} X I_2$	$P_{76} X I_3$
1975	$P_{75} X I_0$	$P_{75} X I_1$	$P_{75} X I_2$	$P_{75} X I_3$	$P_{75} X I_4$

- P_X = PROBABILITY OF OCCURRENCE IN YEAR X

- I_Y = IMPACT OF EVENT Y YEARS FROM OCCURRENCE OF THE EVENT

- $I_{TOTAL_Y} = \Sigma I_{E_{1_Y}} + I_{E_{2_Y}} + \ldots I_{E_{i_y}}$

– ASSUMES COUPLING AMONG EVENTS AND EVENT IMPACTS IS NEGLIGIBLE

Figure 6. Expected Value of an Event Impact

AVERAGE COST OF A PRESCRIPTION

(Constant 1970 Dollars)
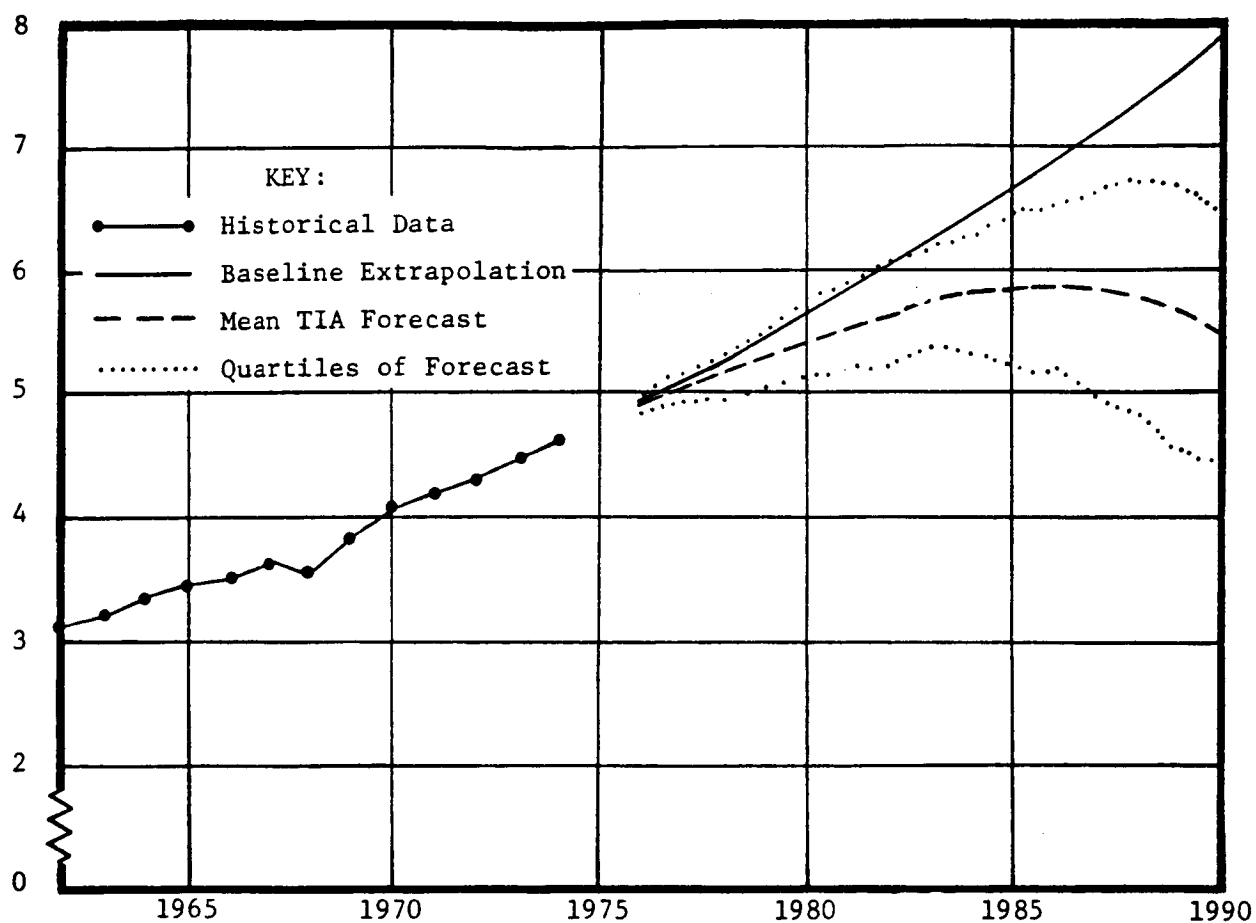
SOURCE: R. A. Gosselin & Company, IMS America

Figure 7. A Typical Forecast Obtained Using
Trend Impact Analysis (TIA)

PROSPECTS reports are prepared using the TIA procedure and, as they represent

material prepared to aid in real-world decisionmaking and planning, should

prove useful in discussing the insights obtained from using TIA.

Initial or Baseline Extrapolation

It should be remembered that the impacts assigned to each event describe

the estimated change in the surprise-free trend caused by the occurrence of

that event. In the case of the average cost of a prescription, an upper limit

of $8 per prescription (in 1970 dollars) was set for the extrapolation. The

extrapolation program rejected the first three curves generated because they

exceeded this limit. The fourth curve remained within the limit and produced

the solid-line extrapolation shown in Figure 7. This, then, became the base-

line to be impacted by future events.

Event Impacts

The events used in this TIA are shown in Figure 8. For example, the

first event, the abolition of all product brand names, was judged to have

a probability of .10 of occurring by 1985 and a probability of .15 of occur-

ring by 1990. If this event does occur it is expected that its first impact

on the average cost of a prescription will begin two years after the occur-

rence of the event. The maximum impact will occur after five years and will

be a 20-percent reduction in the average price. The steady-state impact

is judged to be the same as the maximum impact.

The combination of these events, probabilities, and impacts with the

baseline extrapolation is a forecast (Figure 7) markedly different from

the baseline extrapolation. The curve even begins to decline in 1987.

113

EVENT	ESTIMATED PROBABILITY BY YEARS SHOWN		YEARS TO FIRST IMPACT	YEARS TO MAXIMUM IMPACT	MAXIMUM IMPACT	YEARS TO STEADY-STATE IMPACT	STEADY-STATE IMPACT
1. Abolition of all drug product brand names; standard abbreviations for generic names.	.10	1985	2	5	-20	5	-20
	.15	1990					
2. Drug reimbursement in all federally funded health programs based on Maximum Allowable Cost.	.75	1976	5	5	-15	5	-15
	.75	1990					
3. Removal of all federal and state restrictions on prescription price advertising.	.20	1980	0	2	-10	2	-10
	.60	1990					
4. Decrease in the average size of prescription by 20 percent.	.10	1985	0	2	-10	2	-10
5. Comprehensive health care package initiated, federally run, federally subsidized.	.50	1980	2	10	-10	10	-10
	.50	1990					
6. Period of patent protection reduced to five years after market introduction of product.	.40	1984	5	15	-15	20	-5
	.45	1990					
7. Economic recession (similar to late 1950s).	.30	1980	0	2	-10	3	0
	.35	1990					
8. Federal and state legislation to allow para-professionals to perform more drug dispensing duties.	.25	1984	5	5	-5	5	-5
	.50	1990					
9. Anti-substitution laws repealed in most states.	.44	1985	1	10	-5	10	-5
10. Semi-automated drug dispensing equipment for use by pharmacists.	.50	1980	2	10	-2	10	-2
	.65	1985					
11. Number of prescriptions per user increases 10 percent over 1973 levels.	.40	1980	1	10	+5	10	+5
	.50	1990					

Figure 8. Events Used in TIA of Average Cost of a Prescription

114

The uncertainty is indicated by quartiles about 18 percent above and below

the mean forecast. (The quartiles indicated the middle 50 percent of future

values of the curve. Thus, 25 percent of the futures lie above the upper

quartile, 25 percent lie below the lower quartile, and 50 percent lie

between the two quartiles. Quartiles are presented here; however, since

the computer program calculates the standard deviation, skewness, and kurtosis

for each year, any part of the range could be printed out.) This uncertainty

shown by these quartiles results from the fact that many of the events that

have large impacts have relatively low probabilities--thus an uncertain

situation prevails.

At this juncture, it is desirable to determine the sensitivity of these

results to the individual estimates upon which they are based. For example,

one might raise valid questions about the estimates of event probability,

the magnitude of the impacts used, and the delay time associated with these

impacts. Having prepared these data in a disaggregated fashion, it is

extremely easy to vary such estimates and view the change in results. It

also may be observed that intervention policies, whether they be institutional

(such as lobbying, advertising, or new marketing approaches) or technological

(such as increased R&D expenditures), can be viewed as a means of influencing

the event probabilities or impacts.

Suppose, for example, a certain pharmaceutical company were in a position

to lobby for the immediate removal of restrictions on prescription advertis-

ing, or suppose an analyst thought that the removal of these restrictions was

much more likely than 20 percent in 1980. In each case, knowledge of the sensi-

tivity of the forecast to the removal of advertising restrictions would be

useful. This sensitivity can be tested by raising the probability of this

event from .20 in 1980 to .90 in 1980. The result of this change is shown in Figure 9.

Figure 9 shows the sensitivity of the forecast to an early occurrence of this event is mainly during the 1975-1985 period. During this period the forecast is reduced by about 7 percent and the quartiles are similarly reduced. By 1990, however, when the probability of the event had already reached .60 in the first forecast, the difference is slight. The sensitivity of the forecast to each of the other events, or combinations of events, can be determined in a similar manner.

Thus TIA can be used, not only to improve forecasts of time-series variables but also to study the sensitivity of those forecasts to policy. Of course, any policy considered should attempt to influence as many events as possible rather than one, as in this simple example. Realistically, corporate actions often have both beneficial and detrimental possibilities, as they may enhance both desirable and undesirable possibilities. The use of such procedures as described here, however, should make such uncertainties more clearly visible than is possible with techniques heretofore available and allow us to live more comfortably with, and even to reduce, the degree of risk in our endeavors.

AVERAGE PRICE OF A PRESCRIPTION

(Constant 1970 Dollars)
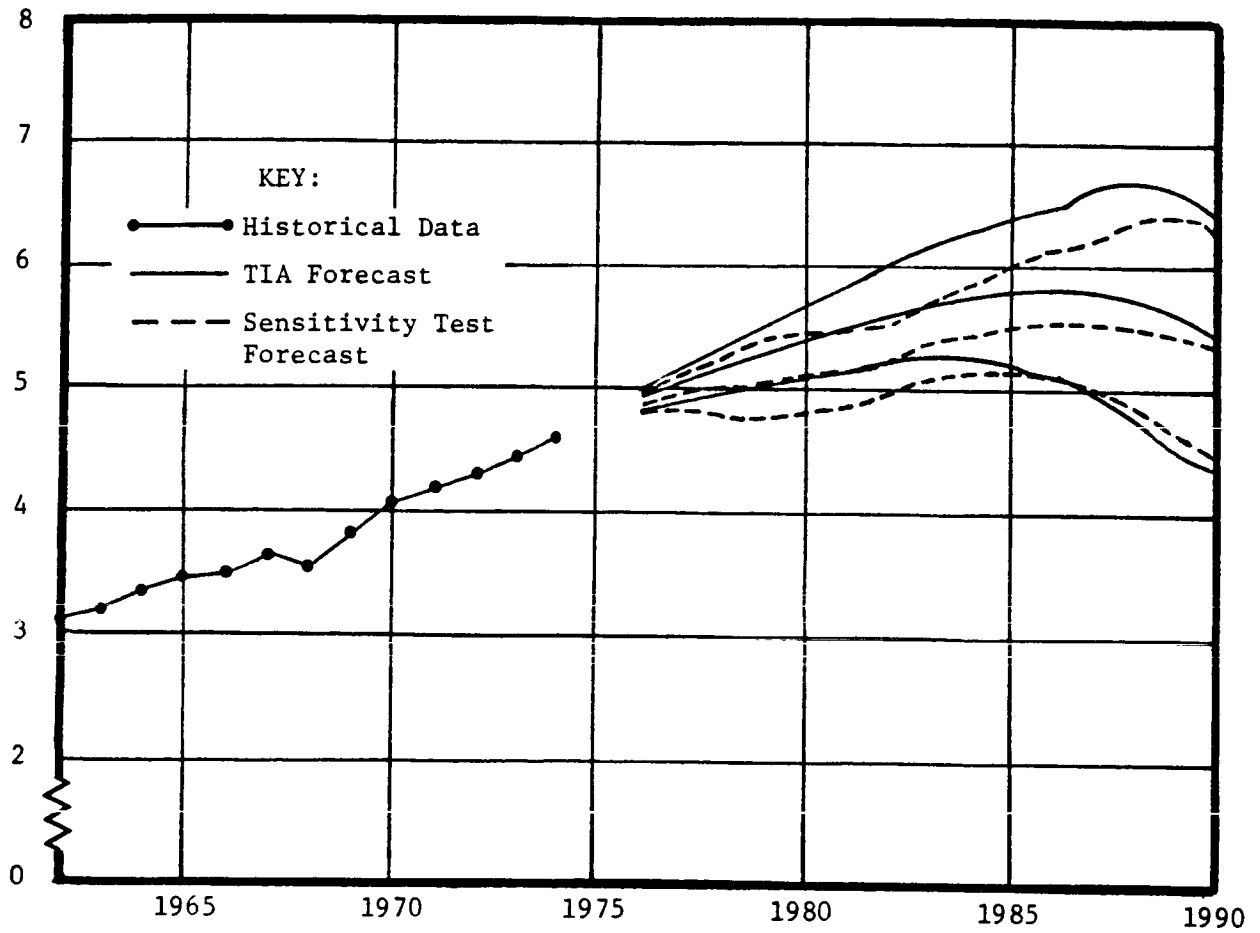
Figure 9. Sensitivity of Test TIA Forecast

APPENDIX H – STATE-OF-THE-ART ANALYSIS

STATE OF THE ART ASSESSMENT TECHNIQUE

This chapter describes our method for measuring and forecasting technology state of the art and how this method was utilized for cross-national comparisons of technology. (u)

The State-of-the-Art Measurement Techniques (u)

Definition of State of the Art. Although "state of the art" is a familiar term, it lacks precision. Generally, when a technology is described as state of the art, it is taken as an example of an advanced development in the field, but there is no way of indicating the degree of advancement. The Futures Group has developed a convention for measuring technology state of the art utilizing an index comprised of selected performance parameters that describe a particular technology. The approach has proved versatile in its ability to capture technological performance at various levels of system aggregation and in relating increases in state of the art to developments in component technologies and advances in design. By plotting the state-of-the-art indicator for each new product/innovation over time, the path of technological development can be quantitatively described. (u)

In this convention, the state of the art (SOA) of a particular product or process is defined as a linear combination of a number of factors or parameters descriptive of that product or process. While nonlinear equation forms can be used, the basic functional form of the state of the art is as follows: (u)

$$SOA = K_1(P_1/P'_1) + K_2(P_2/P'_2) \cdots K_n(P_n/P'_n) \qquad (1)$$

where n is the number of parameters that are used to define the technology, P_n is the value of the nth parameters, P'_n is a reference value of the nth parameter (used to nondimensionalize the equation), and K_n is the weight--that is, the relative importance of the nth parameter. (u)

This equation defines progress in the technology as improvements in the parameters selected to describe the technology. The relative contribution of each of the parameters to the overall state of the art is determined by the selected weights. Selection of the parameters which describe the technology and the weights with which these parameters are applied are key issues, and both judgmental and statistical methods have been developed for parameter and weight selection. (u)

To further explain the method, imagine its application to computers. Suppose we are interested in determining the state of the art of mainframe computers, used in a variety of scientific and commercial applications. We would begin by listing all mainframe computers for which data are available and their dates of introduction. The parameters used to describe these computers might include, for example: cost, memory size and speed of operation. In short, the parameters in the aggregate answer the question: "What is this technology designed to achieve?" An excellent technology--that is, one that is high with respect to its state of the art-- would be one that achieves its designed ends better than a lower state-of-the-art example. This implies that a mainframe computer that rates very high in its intended application may well rate very low when it is evaluated in another application. Technological progress is defined by a succession of products or

processes that continually improve in their ability to achieve the application for which the technology or process was designed. (u)

A measure of the sort proposed here has many uses: (u)

- A newly introduced product or process can be compared with other extant products or processes designed to perform the same mission; thus this approach can be used as a means for tracking progress in a particular field. The advancing state of the art of a series of machines designed to accomplish a particular purpose can be followed over time.

- Technologies produced in different countries can be compared to determine which country has the lead and the extent of the lead time.

- By having a time history of the state of the art of a given field, forecasting can be enhanced; an extrapolation of the historical state-of-the-art curve can lead to rational expectations about improvements in performance over a future time interval.

- The significance of "breakthroughs" can be measured by observing how a given improvement in a product is manifested in terms of a "jump" in the state-of-the-art curve.

- State-of-the-art indices for an industry or even an entire economy might be constructed by aggregating the state-of-the-art curves for key technologies within the industry or economy.

- Finally, the use of state-of-the-art convention enhances communication among technologists and between technologists and users of their products and processes since the state-of-the-art method requires that application and parameter weight assumptions be made explicit. (u)

Research at The Futures Group, sponsored by the National Science Foundation and others, has permitted us to investigate the application of the linear form of the state-of-the-art equation to a number of technologies including: computers, antibiotics, farm tractors, high-temperature materials for turbine blades and vanes, turbojet engines for transport aircraft, man-made fibers, and coal gasification. This prior research has also permitted us to examine and compare several

120

methods for collecting expert judgment about the specific parameters to be used as well as their weights, and to develop statistical techniques for computing the weights from historical data. It is worth reiterating that we were not attempting to construct a finely tuned and elegant theoretical model based on fundamental natural laws; rather, our intent was to devise a simple approach with a very wide range of applicability--and through its simplicity, to encourage its use. (u)

Technical Description of the Method. To use the method, an analyst must first define the application of the technology. By answering what the technology is intended to accomplish, the analyst generally has a first listing of parameters to be included in the equation. This emphasis on use is important since we believe that the state of the art of any technology depends upon how well it fulfills its design purposes. (u)

In most respects an advanced fighter aircraft outperforms a Cessna trainer; however, since the role of the trainer is to "fly around the pea patch on a Sunday afternoon," the state of the art of the Cessna trainer probably exceeds that of the fighter in its particular application. The measures that are important in the training mission would be fuel consumption, stability, required control coordination, etc. The measures important to the fighter mission would be speed, maneuverability, kill potential, range, etc. (u)

In some instances a single attribute of the technology is all that is required to specify its state. This is a pacing parameter; the approach is limiting, but we have been able to discover a few cases to which it applies. For example, in superconductivity research we might convey a great deal of information about the state of that research by simply reporting the highest temperatures at which

superconductivity has been achieved. The energy level of particle accelerators also provides an example. Similarly, a single measure of the state of telecommunications might be communication channel capacity expressed in bits/sec. With a single indicator as powerful as this, one might draw generalizations about progress in telecommunications: (in this instance it has been growing essentially exponentially over a period of a century or more, the growth as measured by channel capacity being an order of magnitude every 17 years or so). (u)

A bounded measure is one that has an upper and lower bound that is determined by theoretical or other constraints. When such bounds are known, the current value of the state of the art can be stated in terms of the percentage of the limit that has been achieved. Thus, for a class of equipment used in relativistic experiments, percentage of speed of light achieved may be a useful state-of-the-art measure. Efficiency measures also generally fall into this class since their limits are fixed by conservation laws. Resolving power of optical systems is also similarly limited. (u)

It is necessary to choose some means of making each of the parameters in the equation nondimensional. This is accomplished by dividing each parameter by some reference value of the parameter. Where we are lucky enough to know the maximum value that a parameter can ever achieve, the denominator can be that maximum value. However, in the usual case, the limit of the parameter (if one exists) is unknown and therefore a different approach must be taken. In our past work we have experimented with several different conventions. In some instances we have utilized the most recent example of the technology as the reference value. For example, if we were examining microcomputers, we might take the speed,

122

volume, memory capacity, and other descriptors of the IBM-AT computer and utilize these values as the reference values for all the other machines. If the weights assigned to the parameter ratios were chosen to add to 1, then the IBM-AT itself would receive a state-of-the-art score of unity, and the state of the art of all other machines would be measured with respect to the IBM-AT. (u)

A second approach to nondimensionalizing the parameters is to perform a transform for each parameter in which the lowest value achieved by any of the technologies in the set is assigned the value of 0, the highest achieved, a value of 1. Using this approach, a technology that had all of the lowest parameter values would score a zero state of the art, and a technology that had all of the highest parameter values would score unity on the state-of-the-art scale. (u)

A last approach to parameter nondimensionalization is to perform a regression on and forecast each parameter individually. This allows the use of either the maximum forecasted value or the projected value in any given future year as a denominator. All of the above approaches are described further below. (u)

There are, in general, two methods to determining specifically which parameters to include and their associated weights; these are expert judgment and statistical methods. In this study, expert judgments were relied on to select parameters and their weights. In this approach, experts are asked to provide their judgments about the list of factors important to the definition of the frontier of a particular technology and to assign weights to each of the factors. The opinions are then collated and used as the set of weights for the SOA calculations. (u)

A number of statistical approaches that aid in identifying unique sets of parameters--that is, parameters that do not exhibit collinearity--and for determin-

ing appropriate parameter weights also exist. Among these statistical techniques are: discriminate analysis,* cluster analysis,** seriation and multidimensional scaling,*** covariance analysis and factor analysis. In prior work for the NSF,**** The Futures Group has developed a particularly interesting iterative approach to estimate the technology used in a state-of-the-art equation. In this approach, we begin with an assumption that the state of the art versus time curve can be defined by some function such as: (u)

$$SOA = \left(\frac{U}{2}\right)\left\{[1 + \tanh A(t-T_0)]\right\} \tag{2}$$

where U is the upper limit of the variable, T_0 is the time of the inflection point, and A is a constant that depends on the maximum value of the slope. (u)

With the idea in mind that the state-of-the-art function follows a known curve shape, the complete state-of-the-art equation can be written as follows: (u)

$$\left\{1 + \tanh [A(t-T_0)]\right\} = C_1 \begin{pmatrix} P_1 \\ P_1, \end{pmatrix} + C_2 \begin{pmatrix} P_2 \\ P_2, \end{pmatrix} + C_3 \begin{pmatrix} P_3 \\ P_3, \end{pmatrix} \tag{3}$$

---

*Devendra Sahal, "The Generalized Distant Measures of Technology," <u>Technological Forecasting and Social Change</u>, Vol. 9 (1976), pp. 289-300. (u)

**Brian Everitt, <u>Cluster Analysis</u> (London: Heinemann Ed. Books Ltd. S.S.R.C., 1979). (u)

***W. S. Torgerson, <u>Theory and Methods of Scaling</u> (New York: John Wiley & Sons, Inc., 1958). (u)

****Contract No. SRS-810940, "Further Research into Technology Output Measures," by T. Gordon and K. Edwards, June 1982. (u)

where C_n is operationally equivalent to the weighting constant of the parameters, P_n is the value of a parameter for a given computer and P'_n is the normalizing value for the parameter. Thus, in this formation there are five unknown coefficients: A, T_0, C_1, C_2, C_3. (u)

An iterative solution has been used to solve this equation numerically. In this approach, values are assumed for the weights, and the state of the art is calculated for each of the products or processes under study. State-of-the-art values for each of the parameters are fit to a given S-shaped curve. There are a variety of formulations one can use in describing an S-shaped curve. Among these, the following equation was chosen for use in the SOA methodology: (u)
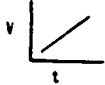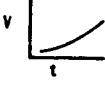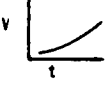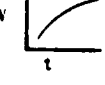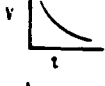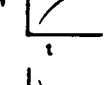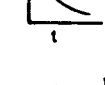
$$LN((V/L)/(1-(V/L))) = m * t + b \qquad (4)$$

where V is the value of the variable, L is the upper limit of the variable, m and b are constants, and t is time. This equation is estimated for each of the technology's parameters, for example, speed, volume and memory size for computers. The three parameters in this equation are the intercept, b, the slope, m, and the upper limit of the variable, L. The intercept and slope can be estimated after a linear transformation is performed on the left-hand side of the equation, which contains the values of the parameter under analysis, by fitting a straight line through the data set. The only unknown parameter is the upper limit of the variable, L. This upper limit can be derived in a variety of ways. This entire procedure, including the derivation of the upper limit, will be explained below in the forecasting section of this chapter. (u)

The formulation of Equation 4 was selected for use in the SOA methodology because the third parameter, the value the user needs to supply, is a variable that has a physical meaning--the upper limit of the parameter. Equation 4 also is symmetrical around the inflection point, making it easier to estimate computationally. (u)

The best-fit values for state of the art are assigned to each of the parameters. These values are then related back to their respective S-shaped curves, and aggregated to form a total state-of-the-art curve using the previously determined values of the weights. (u)

A curve-fitting module is available with the TFG STATPLAN software program. This module can fit a variety of curves to analyze which curve shape best describes the given parameter data. The formulations available to test are: (u)

1. $V = m * t + b$

2. $LN(V) = m * t + b$

3. $LN(V) = m * LN(t) + b$

4. $V = m * LN(t) + b$

5. $1/V = m * t + b$

6. $1/V = m/t + b$

7. $V = m / t + b$

8. $LN((V / L) / (1 - (V / L))) = m * t + b$

where: V = value of variable   b = constant
        t = time   L = upper limit of variable   (u)
        m = constant

126

Two other interesting formulations of the S-shaped curve examined in past studies are: (u)

$$SOA = B \left\{ T-T_o \right\} A \tag{5}$$

$$SOA = B \exp \left\{ A(T-T_o) \right\} \tag{6}$$

Both equations represent families of monotonically increasing state-of-the-art functions with time. In case studies in which rapid increases in the technology were occurring (such as computers) little difference was found in the statistical estimation of the value of the S-shaped curve when one or the other of the three families of functional forms was used. However, for more mature technologies that are in fact leveling off in their growth, the choice of the equation form would probably be very important. (u)

The choice of the curve shape to be used on the left side of the equation is tantamount to asking the question: "Are technological growth curves bounded or unbounded?" There are many technological variables that appear to have growth boundaries and within this class, many that appear to be "S" shaped, initially growing slowly, reaching some maximum growth rate, and then, passing the inflection point, diminishing in growth rate to approach some upper bound asymptotically. Several investigators have used this idea in technological forecasting: Pearl has suggested the use of an S-shaped "logistics curve" that depicts the growth in the number of organisms with limited nutrition in a closed environment.*

---

*R. C. Lenz, Jr., Technological Forecasting, 2nd ed., Aeronautical Systems Division, AFSC, ADS-TDR-62-414, Wright-Patterson AFB, Ohio, June 1962 (AD 408 085); J. C. Fisher and R. H. Pry, "A Simple Substitution Model of Technological Change," Technological Forecasting and Social Change, Vol. 3 (1971), pp. 75-88; and A. Wade Blackman, Jr., "The Market Dynamics of Technological Substitutions," Technological Forecasting and Social Change, Vol. 6 (1974), pp. 41-63. (u)

Empirical evidence exists that some parameters follow S-shaped curves. It may well be that most technologies grow exponentially at first and then become limited either in terms of their growth rate or in terms of their absolute level, but there is no well-developed theoretical basis to support these observations. Nevertheless, the S-shaped assumption is intuitively satisfying and empirically supported in many applications. (u)

Forecasting State of the Art (u)

If a technology improves in its capabilities over time, from primitive beginnings to maturity, then one might imagine its growth path as following an S-shaped curve. If this image of growth is realized, then the asymptote that the S-shaped curve approaches defines an upper limit of the technology, that is, an "ultimate" level of achievement that the technology can realize. This S-shaped picture of technological growth is satisfying: at the beginning, early technologies score low on the state-of-the-art scale, and the growth rate is slow. Then, as the technology begins to mature, the growth rate accelerates until, at the inflection point of the curve, growth rate is at a maximum. Further technological developments score higher on the state-of-the-art scale, but their growth rate diminishes, until finally, very mature examples of the technology show hardly any improvement in state of the art as the upper asymptote of the curve is approached. (u)

This concept of S-shaped growth embodies the implicit assumption that technology growth is bounded. A number of authors have pointed out that when one technology reaches an upper bound, another based on different operating

principles may grow past the limits that stymied the first technology and achieve new limits of its own. (u)

If one has an idea about the shape of the growth curve, then conventional curve-fitting techniques can be used to extrapolate the early growth history and forecast, for the near term at least, the future growth of the technology. Fitting an S-shaped curve to a set of points is a little more challenging than some other functions, but one particularly useful way to accomplish this fitting is to perform a transform that converts an S-shaped curve into a straight line and then fits the straight line to the state-of-the-art points using the method of ordinary least squares. The transform is: (u)

$$f^{(t)} = \ln\left(\frac{P/P'}{1-(P/P')}\right) \tag{7}$$

where $f^{(t)}$ is the value of the transformed variable, P is the observed value of the parameter and P' is the maximum value of the parameter. (u)

An example of this approach is shown below. Suppose that our sample includes five models of a technology, which have values for the first parameter as follows: (u)

Technology	Date	Parameter 1	
1	1950	.1	
2	1953	.15	
3	1967	.25	
4	1973	.3	
5	1980	.6	(u)

129

The transformed values to estimate the state of the art of this parameter are as follows: (u)

Technology	(P/P')/(1-(P/P'))	ln((P/P')/(1-(P/P')))	
1	.111	-2.197	
2	.176	-1.734	
3	.333	-1.099	
4	.429	-0.847	
5	1.500	0.406	(u)

Figures 2.1 through 2.3 show these data plotted in three different ways: Figure 2.1 presents the data with no transformation plotted on rectilinear coordinates. Figure 2.2 shows (P/P')/(1-(P-P')) plotted on semilog coordinates. Finally, Figure 2.3 shows ln ((P/P')/(1-(P/P'))) SOA/(1-SOA)) plotted on rectilinear coordinates. The solution of this equation thus represents the SOA of the individual parameter. This equation is estimated for each of the parameters needed to evalute the technology in question, then aggregated using the predetermined weights to calculate the total SOA index for the technology. (u)

Once the best fit to the historical points has been determined for each parameter, the line can be extrapolated. Of course, such a forecast requires the assumptions: (1) that the forces at work in the past will continue to operate in the future, and (2) that the SOA of the parameter will continue to follow the S-shaped path. The forecast for the given data set is: (u)

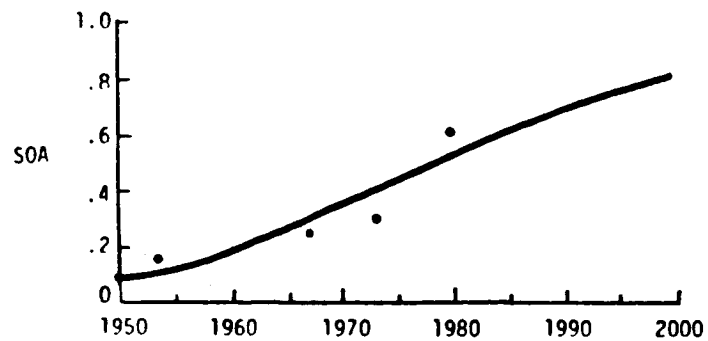| Date	Forecast	
1990	.684	
2000	.819	
2010	.904	
2020	.952	(u)

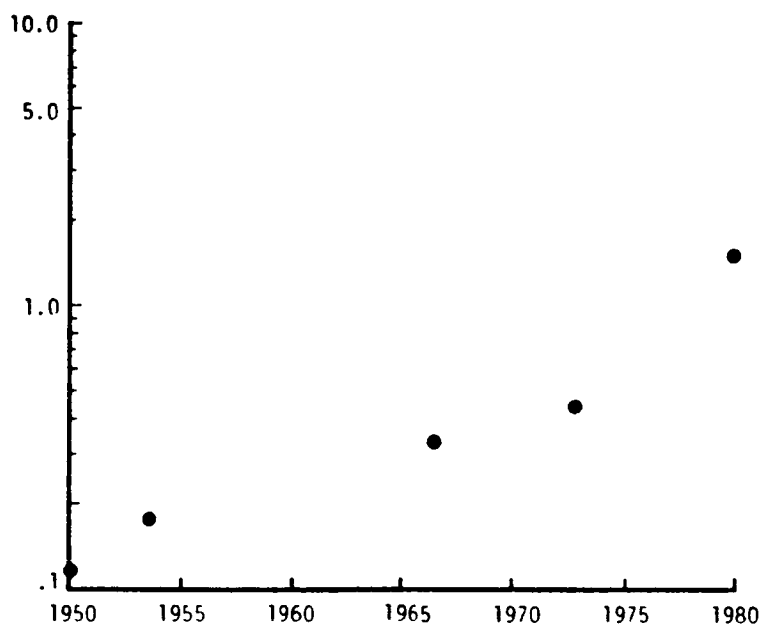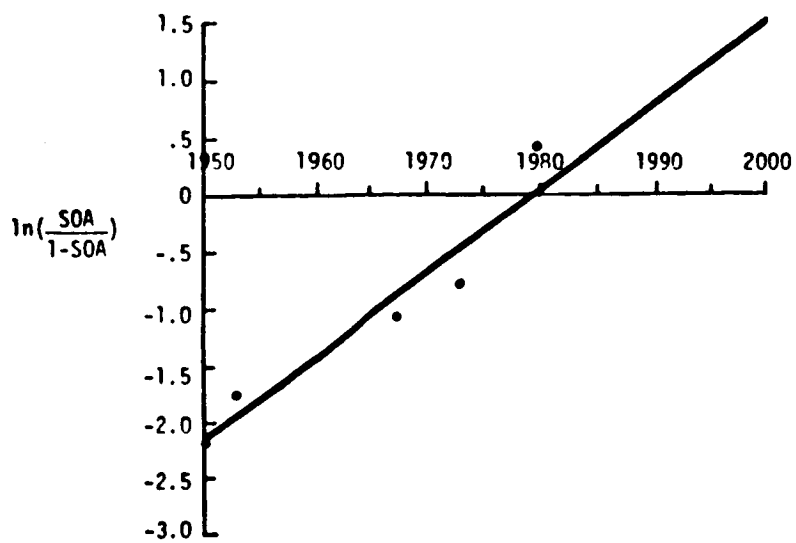Figure 2.1. Rectilinear Plot

Figure 2.2.

Figure 2.3 Plot of $\ln \left(\dfrac{-SOA}{SOA-1} \right)$

131

In sum, using the straight-line form of the S-shaped curve provides a very convenient means of tracking and forecasting the SOA of each parameter : given some initial points, $(P/P')/(1-(P/P'))$ is computed for each parameter and plotted on semilog coordinates. The best-fit "straight line" is placed through these points using an ordinary least squares estimation procedure. The extrapolation of the line past the given data points shows a reasonable expectation of how the state of the art of the parameter might grow, at least in the near term, if the growth continues in an S-shaped form. (u)

To take a concrete example, suppose we want to forecast the state of the art of electric motors. The parameters that describe the state of the art might be efficiency and torque, as described by the hypothetical data presented below:

Motor	Date Introduced	Efficiency	Torque
1	1930	.500	.091
2	1935	.576	.099
3	1937	.583	.104
4	1942	.636	.115
5	1947	.689	.129
6	1950	.718	.138
7	1953	.747	.145
8	1960	.806	.167

(u)

Suppose further that the weights we want to assign to efficiency and torque are .3 and .7, respectively. The SOA equation for the technology is: (u)

$$SOA = .3 \; \frac{efficiency}{reference \; efficiency} + .7 \; \frac{torque}{reference \; torque}$$
(u)

132

The remaining issue is, therefore, the choice of the denominators in this equation. In practice, we have used four approaches in determining the denominators. (u)

1. Specify an upper limit for each variable.

2. Use the given data to compute the upper limit.

3. Use the maximum historical value of the parameter as a reference (no forecast).

4. Use the computed value of the variables in 10 years as a reference. (u)

In the third case, the nondimensionalized parameters range between zero and one; if the weighting coefficients sum to unity, then the SOA values for the technology will also range from zero to one. (u)

Just how can a maximum possible future value of a parameter be determined? There can be theoretical or feasible upper limits, such as a physical upper limit of the speed of light or a limit of 100 percent, if the variable is in percentage terms. In these cases, upper limits can easily be specified for each variable. Usually, however, the upper limit is not readily apparent. (u)

Three methods have been developed to determine the upper bound of a parameter. The first method is to let the program compute the maximum by fitting S-shaped curves with a series of upper limits. If the growth curve of the parameter is itself assumed to be S-shaped and the early points are representative, the process involves: (u)

1. Selecting a possible upper limit for test; this test value begins at the historical maximum, increasing in steps until a maximum of 10,000 times the historical maximum is reached.

2. Using this test value, the historically achieved data points are nondimensionalized.

133

3. These are transformed to the ln $\left(\frac{P/P'}{1-P/P'}\right)$ space (where P is the observed value of the parameter and P' the test value of the asymptote).

4. Absolute errors between the points and the best-fit straight line are computed and summed.

5. A new test value of the asymptote is selected and the process is repeated.

6. Now the summed errors are compared based on some threshold criteria; the upper limit that creates the least error is selected as the most appropriate. (u)

In our application, the selection criteria have been: (u)

- When successively increasing multipliers bring a change in error of less than .5 percent, or

- When successively increasing multipliers result in a minimum value in the summed errors. (u)

This process can be seen graphically in Figure 2.4, where the fit of curves A, B and C to the set of datapoints, each with a successively lower limit, is compared. The user can then concur with the iteration the program selects or select one of the other iterations. (u)
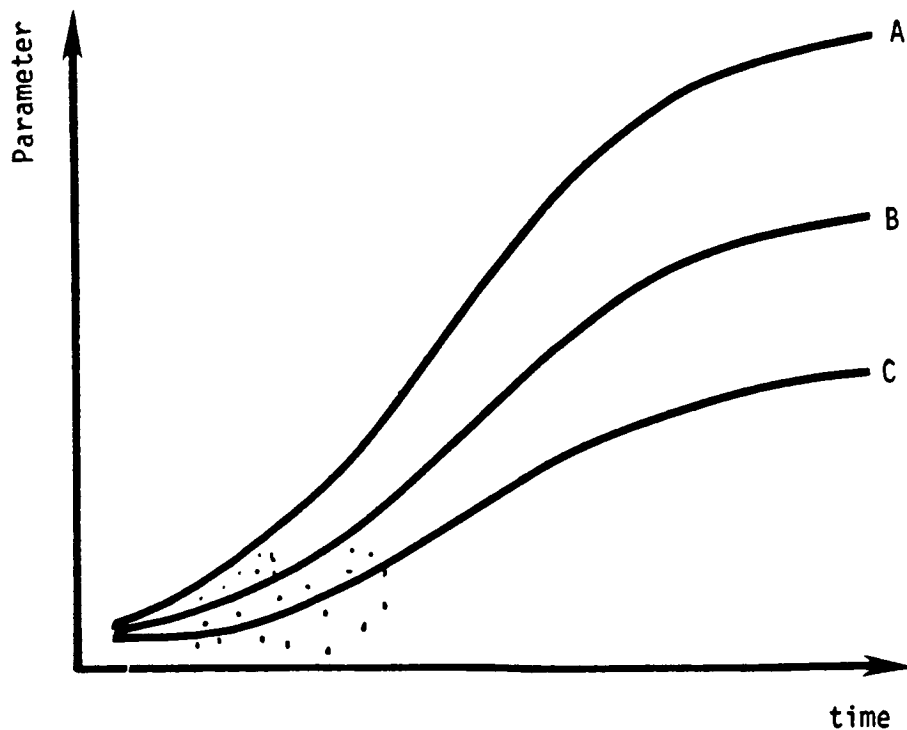

Figure 2.4

This approach works well if there are many data points available for the analysis, because then the estimated coefficients are reliable. If there are not enough data, however, or if the data are all grouped together at the beginning of the S-shaped curve, then the fit of the curve is not as dependable. It is in these cases that the analyst must combine expert opinion with the performance of the successive iterations to arrive at a reasonable upper limit. (u)

Another disadvantage of using the approach described above is that if the technology of the particular parameter is not very developed, that is, still at the beginning of the S-shaped curve, the upper limit generated by the program can be quite high. There are two consequences of this. One is that if the upper limits are too high, the SOAs are calculated at a very low level. Thus it is difficult to see the progress of the technology in the past or in the future because all of the data points are bunched together at the lower end of the SOA scale. The other result of a high maximum limit is that the weights become less important in the overall SOA score because the numbers are so small. For example, if a parameter doubles in value from 2 to 4, with an upper limit of 1,000, then the doubling in value is not very important. If, however, the upper limit had been 8, then the change in value becomes very important and that change is dominant in the SOA calculation of the parameter. The limit thus becomes more important than the weights, perhaps resulting in a different parameter dominating than intended, if it has a smaller upper limit. (u)

In the cases where one parameter is close to its upper limit and the other parameters are not, as in the example above, one of two options can be selected to correct for the potential imbalance in the SOA figures. The first possibility is to use the maximum historical value of the parameter as the reference point. This

places all of the parameters on an equal footing because all are in the same range; that is, all parameters attain the value of one at some point in the calculation. Thus the weights then become the important input to the SOA procedure. The disadvantage of this method, however, is that no forecast can be completed for the technology, as the SOA has already reached the maximum level for each of the parameters. (u)

Another approach was developed to ensure that parameters are basically in the same range and still able to be forecasted. The SOA program goes through the same procedure discussed under the second alternative above, that is, using the given data to compute successive upper limits. After the best fit is determined by the program and the analyst, the parameters are projected over the forecast horizon, using their respective maximum limits generated by the most appropriate S-shaped curve. The program then uses the parameter value in the tenth year projected as the reference point, and recomputes the SOA. Thus the parameters are put on the same relative footing, and are forecasted as well. Note that the actual forecast numbers for the parameters do not change; the relative positions within the SOA calculation change, due to the use of different maximum limits. (u)

Cross-National Comparisons (u)

Evaluating U.S. and foreign progress in key technologies has been for some time a major methodological challenge for intelligence analysts concerned with assessing implications for U.S. security and industrial competitiveness. As our previous work in this area demonstrates, the state-of-the-art (SOA) measurement method used for this study has shown considerable promise in measuring and

tracking technological advances. There seem to be several important advantages to the method. First, it gives precision, clarity and replication to the analysis of technological progress, gaps and lead time, areas of research that have generally lacked each of these qualities. Second, it provides an effective means of blending quantitative analysis with qualitative expert judgments on specific U.S. and foreign systems and industrial performance. Third, it enables an analyst to track systematically foreign state of the art and identify critical component technologies. Fourth, it provides a useful tool for effectively explaining technology leads and lags and for justifying controls on technology transfer. Finally, it provides a tool for analyzing the impact of specific transfers of technology and for helping to identify likely future technological advances. This section is an effort to illustrate some of these advantages as well as to report on promising areas of refinement and possible future development of the method. (u)

Using state-of-the-art measures permits increased precision in discussing the relative technological status of two countries. Consider, for example, the two very different situations displayed in Figures 2.5 and 2.6. In Figure 2.5, the technology of country A precedes the development of the same technology in country B; both state-of-the-art curves are displaced by a constant amount. In Figure 2.6, country A initially leads country B. However, A's rate of growth is slower than that of country B, so that eventually country B surpasses country A. In Figure 2.5, the lead time position of country A over country B is constant; in Figure 2.6, the lead time of country A gradually diminishes and then the situation reverses, with country B leading country A after the crossover. (u)
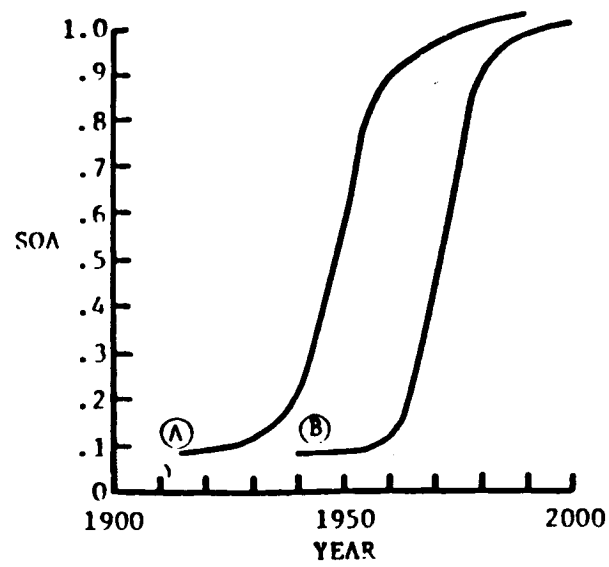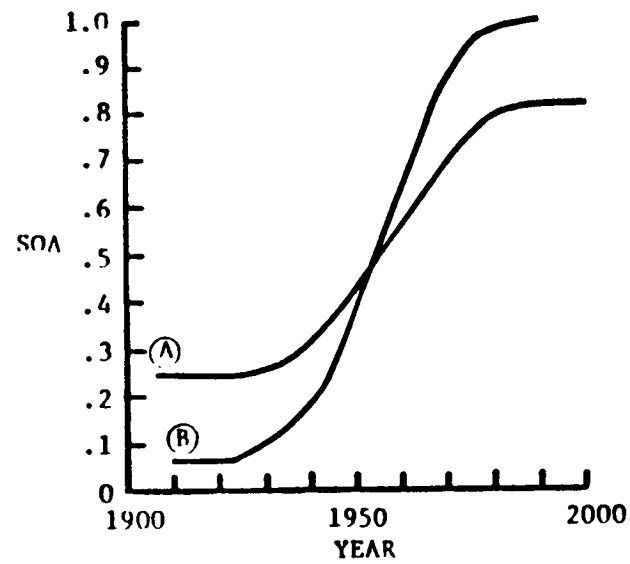
Figure 2.5. Constant Lead Time
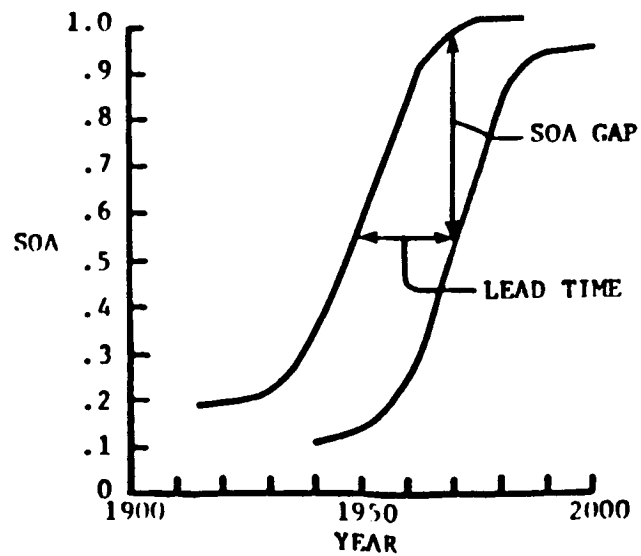

Figure 2.6. Variable Lead Time

Figure 2.7. Lead Time versus SOA Gap

138

These curves permit us to identify two different ways of describing the technological advantage of one country over another. "Lead time" is defined as the time difference between the attainment of a given state of the art by one country, as compared with another. It is the horizontal distance between curves A and B, in both Figures 2.5 and 2.6. The "state-of-the-art gap" is the vertical distance between curves A and B as shown in Figure 2.7. Note that even though lead time remains constant in Figure 2.5, the state-of-the-art gap does not. In Figure 2.6, both the lead time and state-of-the-art gap vary with time. (u)

In the analyses that follow, we have assumed that the state-of-the-art curves follow a hyperbolic tangent function of the following sort: (u)

$$A(3) = ((X-A(1))/(A(2) - A(1))) \tag{8}$$

$$Y = .5 +.5* (-EXP (-A(3))/(EXP(A(3)) + EXP (-A(3))) *2 + 1)$$

In this formulation of hyperbolic tangent function, the first coefficient, $A(1)$, represents the midpoint of the curve, that is, the time at which the state-of-the-art curve reaches a state-of-the-art level of .5. This is the inflection point, the point at which the curve changes from an increasing growth rate to a decreasing growth rate. It also is the point at which growth rate is a maximum. The second coefficient, $A(2)$, is the time at which the curve reaches a state-of-the-art value of .881; thus, the interval between $A(1)$ and $A(2)$ reflects the steepness of the curve. Figure 2.8 illustrates the shape of this function, where $A(1)$ equals 1950 and $A(2)$ equal 1960; Figure 2.9 illustrates the function when $A(2)$ is stretched to 1980. (u)

A computer program was written to explore the properties of S-shaped curves, particularly those associated with changing lead time and SOA gap. The first use of this program explored a constant lead-time situation in which the time
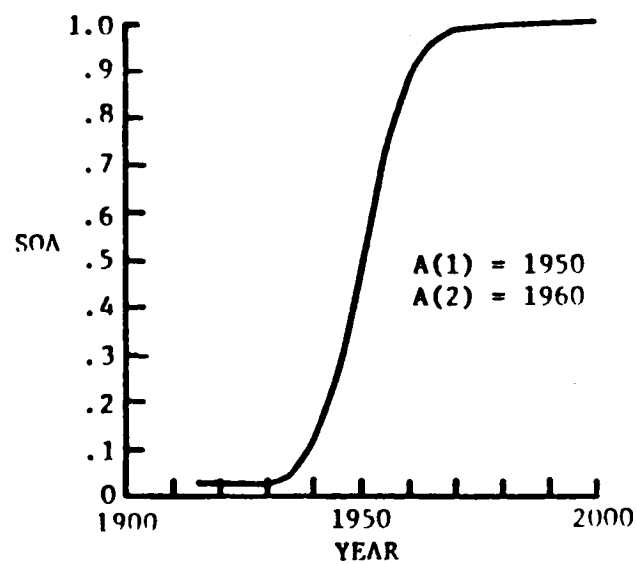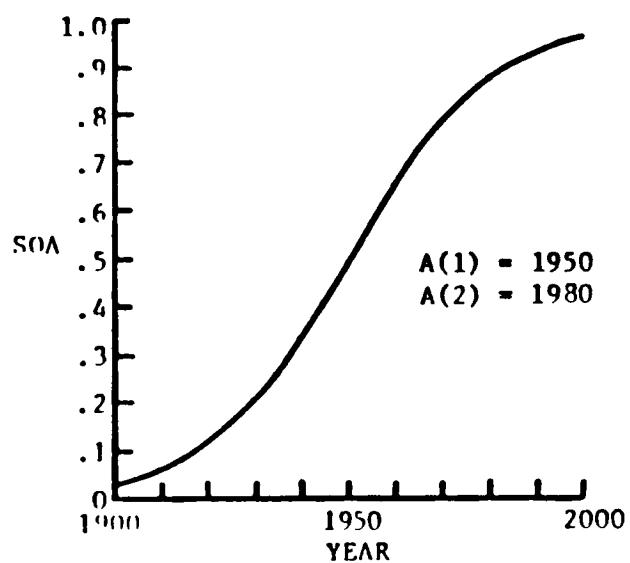
139

Figure 2.8

Figure 2.9

140

between .5 and .881 was 30 years for each of two hypothetical countries. A series of runs on U.S. and Soviet aircraft engine SOA was performed to determine the effects of varying lead time (that is, the time spacing between the curves). Figure 2.10 summarizes the results of these runs and shows how changing lead time is reflected in the state-of-the-art gap. (u)

A second set of runs was completed when the time between SOA = .5 and SOA = .881 is only 10 years. The results of this sharper growth case are summarized in Figure 2.11. Some very interesting results can be observed from these figures. (u)

> At the time the first country reaches a state of the art of .5 (that is, 1950), the state-of-the-art gap between the countries is still growing. This gap continues to grow until a later time. This continuing interval of growth is equal in duration to half of the lead time. (u)

Figure 2.12 shows the maximum state-of-the-art gap that exists as a function of lead time for the two cases examined (the sharp-rising case in which ten years were assumed to exist between SOA = .5 and .881, and the slow-rising case in which 30 years were assumed to exist between SOA = .5 and .881). The data in this figure are presented in nondimensional form in Figure 2.13 which depicts the relationship between the maximum SOA gap, and the ratio of the lead time to the time between SOA and .5 and .881. (u)

> For any given curve shape, the maximum SOA gap that will exist continues to increase as lead time grows; when the lead time and the time between SOA = .5 and .881 are equal, the maximum SOA gap will be .462. (u)

These relationships are important. Imagine the situation as seen through the eyes of country A in Figure 2.5. Suppose this country is interested in maintaining its technological lead. Even though it observes the increasing technological
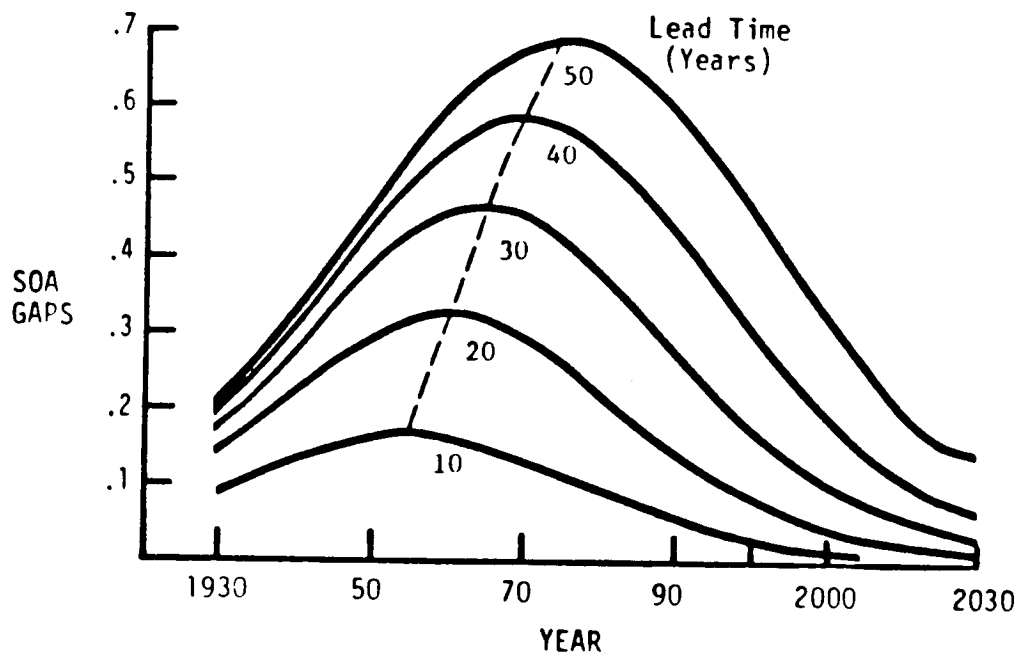
Figure 2.10. SOA Gaps Resulting from Varying Lead Times
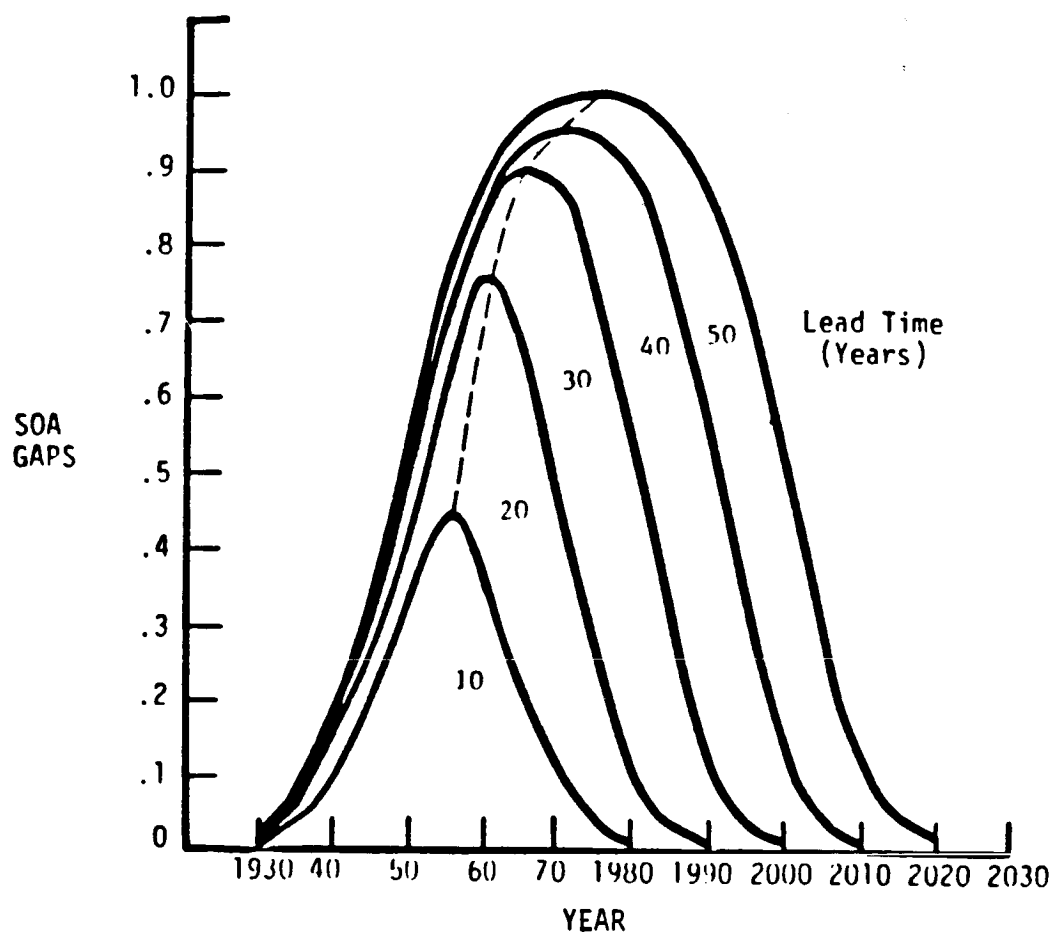Midpoint of 1st Curve = 1950
.881 = 1980

Figure 2.11. SOA Gaps Resulting from Varying Lead Times
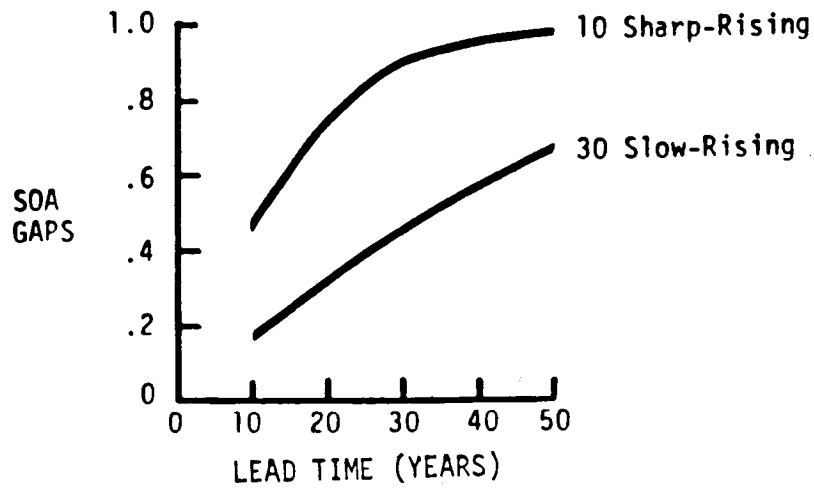in a Sharp Growth Scenario

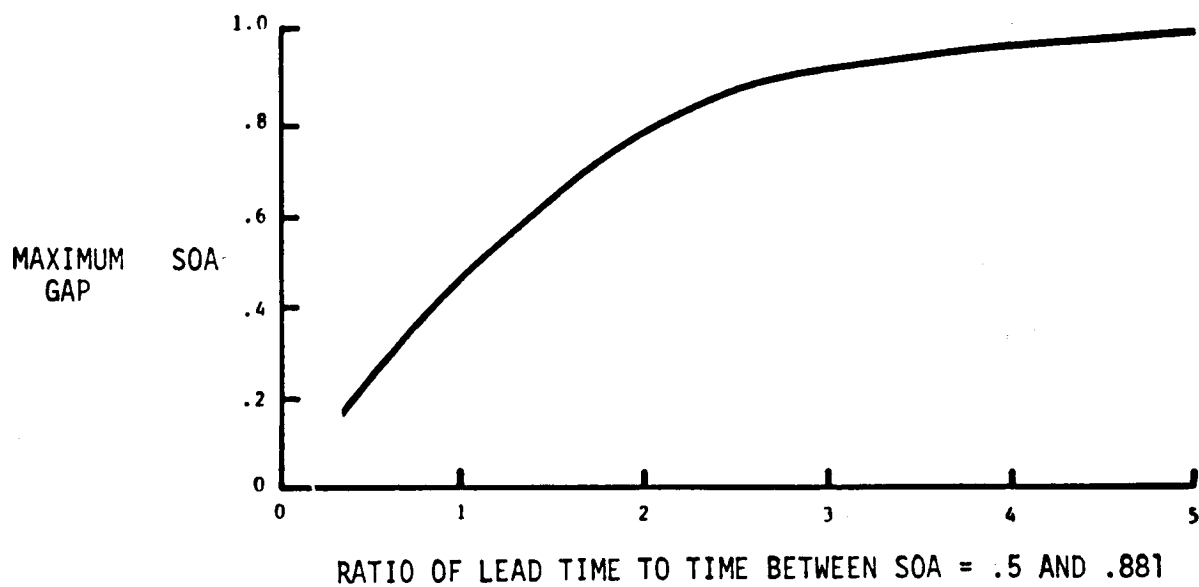Figure 2.12. Maximum SOA Gap
versus Lead Time

Figure 2.13. Relationship Between Maximum SOA Gap,
Lead Time, and SOA Curve Rise

competence of country B, it observes an <u>increasing</u> technological gap until <u>after</u> it has passed an SOA of .5. In fact, country A's position continues to increase until a time that is one-half of the lead time after passing SOA = .5. By then, of course, the die has already been cast and country B, following the same growth curve, cuts the gap ultimately to zero. Country B actually begins to diminish the SOA gap before it reaches its SOA of .5. Country A would say, "How did they do that? We kept our lead time constant." True enough, that lead time was kept constant, but lead time is most important in terms of state-of-the art gap only near maximum SOA growth rate, that is, near SOA = .5. (u)

Now let us examine the situation that occurs when the lead time between countries changes, as depicted in Figure 2.6. Figure 2.14 shows the results of a set of runs on U.S. and Soviet aircraft engines in which the time between SOA = .5 and .881 is different between hypothetical countries. In all instances, the second curve has a slower growth, and both curves intersect at SOA = .5. Considering the pre-1950 curves, the SOA gap is seen to increase for the slowly growing country until just a few years before the faster-growing country "takes off." Then the state-of-the-art gap closes rapidly until all the advantage of the slow country is lost. Note that the time of reversal of the growth of the gap varies from 7 years from crossover to about 13 years from crossover for the conditions examined in Figure 2.14. These runs lead to several conclusions: (u)

> If the growth rates are different, and the higher growth curve lags the slower, the curves will always cross. (u)

> If the SOA curves intersect at SOA = .5, then the gaps will be symmetrical with respect to time before and time after the crossover period. (u)
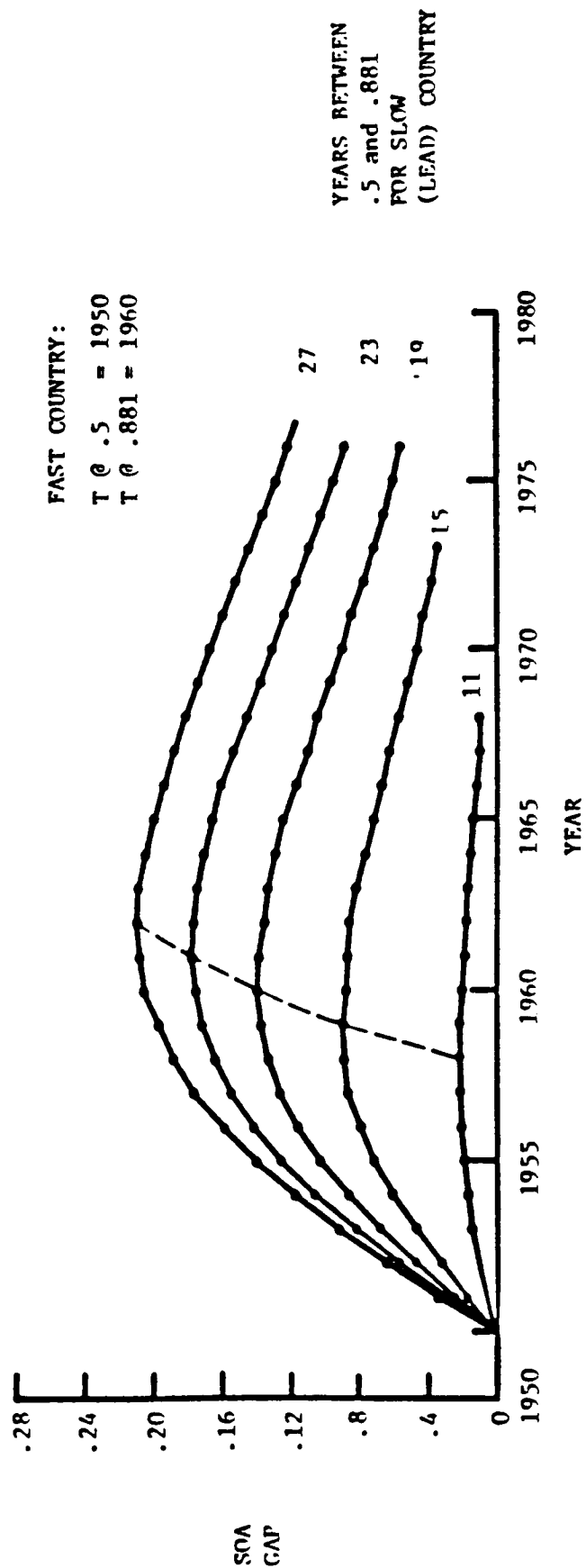
145

Figure 2.14. SOA Gap as a Function of Different Growth Rates

When two countries have technologies growing at different rates, the SOA gap will always hit a maximum and then diminish before the crossover period. (u)

If the SOA curves intersect at SOA = .5, then the country that is initially slow, but in the lead, will see a maximum SOA gap at some period before crossover. The lead that this country has increases slowly at first until the maximum value is reached; then it rapidly disappears as the lagging but faster country crosses over and takes the lead. The shape of these curves is such that the catch-up phase is quite compressed in time and therefore it may be surprising that the country that has been in the lead is slower growing. (u)

So in this situation, the slower-growing but leading country might say, "We were tracking our competitor, and our SOA gap was increasing over time, and then before we knew it, the gap disappeared." (u)

For the late but rapidly growing country, immediately after cross-over its SOA advantage grows sharply, reaches a maximum and then the SOA gap diminishes over time as the slower-growing country continues to gain technological competence.* (u)

In the real world, both lead time and growth rates are likely to vary when comparing state of the art of a particular technology between two countries. Therefore, to some degree, all of the effects stated above are likely to be experienced. (u)

Sample SOA Run (u)

The next pages contain a selection of the output from a sample SOA run. Table 2.1 shows the tabular results of the total SOA solution for 10-100 kW generators. (u)

---

*One reviewer, upon seeing this description of SOA gap resulting from differential technological growth rates, commented that it aptly described the pattern existing between the United States and Japan in the automobile industry. The United States had an SOA lead for a long time. Japan's growth in this industry was very rapid, and almost before it was recognized by the United States, the SOA gap diminished and in some ways the Japanese took leadership. Now, with steady but slow continued technological growth in the United States, Japan's lead is being eroded again. (u)

147

TECHNOLOGY TO BE EVALUATED

THE DIFFERENCE BETWEEN THE ACTUAL COMPUTED SOA SCORE/GIVEN DATA AND THE FITTED SCORE ON THE REGRESSION LINE

THE OVERALL SOA SCORE OF THE TECHNOLOGY/PARAMETER IN THE FUTURE

Table 2.1

10-100 KW AC GENERATORS (u)

Computed Data:

Technology	Year	SOA Computed	SOA Fit	SOA Error
AB12-T230	56	0.12522	0.17272	-0.04750
AB10-T230	56	0.12416	0.17272	-0.04856
AB20-T230	56	0.13079	0.17272	-0.04194
AD50-T230	56	0.13954	0.17272	-0.03318
AD75-T230	56	0.17265	0.17272	-0.00007
AD30-T230	60	0.16316	0.19134	-0.02818
UX-19	60	0.22852	0.19134	0.03718
-19	61	0.15630	0.19625	-0.03992
MEP01BA	62	0.13909	0.20121	-0.06212
3304bna	65	0.29067	0.21671	0.07395
3304bt	65	0.32074	0.21671	0.10402
3304bt2	65	0.34961	0.21671	0.13289
MEP004A	67	0.21355	0.22752	-0.01397
MEP006A	67	0.25685	0.22752	0.02932
SF-100-MD	67	0.28742	0.22752	0.05989
MEP005A	68	0.22496	0.27207	-0.00811
HF30MD	69	0.22645	0.23871	-0.00227
MEF-40?A	69	0.17609	0.23871	-0.06262
MEF?04A	69	0.33491	0.23871	0.09620
3208na	70	0.28289	0.24444	0.03845
3208na	70	0.3866?	0.24444	0.11219
3208t	70	0.38743	0.24444	0.14300
MEP003A	71	0.20450	0.25026	-0.04576
MEF007	72	0.30546	0.25617	0.04728
MEF105	72	0.26385	0.25617	0.00765
29dh	78	0.23645	0.29354	-0.05711
50dh	78	0.29701	0.29354	0.00347
dps15	82	0.20999	0.32014	-0.11015
dps30	82	0.25375	0.32014	-0.06659
dps60	82	0.28853	0.32014	-0.03181
dps100	82	0.30346	0.32014	-0.01668

SPECIFIC MODEL BEING EVALUATED

YEAR IN WHICH MODEL WAS INTRODUCED

THE COMPUTED TOTAL SOA SCORE FOR SPECIFIC MODEL OR GIVEN DATA FOR PARAMETERS OF A SPECIFIC MODEL

THE CORRESPONDING POINT ON THE REGRESSION LINE OR FITTED S-SHAPED CURVE

Forecast based on S-shape extrapolation of variables:

Year	Average SOA Forecast	Upper Frontier Forecast	Lower Frontier Forecast	Forecast
83	0.30617	0.41273		0.34567
84	0.31272	0.42156		0.35307
85	0.31935	0.43050		0.36056
86	0.32605	0.43953		0.36812
87	0.33282	0.44865		0.37576
88	0.33965	0.45787		0.38348
89	0.34656	0.46717		0.39127
90	0.35352	0.47656		0.39914
91	0.36055	0.48604		0.40707
92	0.36764	0.49560		0.41508

YEAR OF FORECAST

(u)

The SOA paths of 10-100 kW generators for the U.S. and the USSR are indicated in Figure 2.15. The relative paths can be traced only until 1982, which is the last available U.S. data point. Using the U.S. generator MEP404A in 1969 as a reference point, the SOA gap between the U.S. and the USSR is the vertical distance between the MEP404A and the Soviet SOA line--a gap of approximately .15 in 1969. The lag between the two countries is the difference in time from when the U.S. has attained a certain state of the art to when the USSR achieves the same level. (u)

LARGER ELECTRIC GENERATORS (10-100KW) (u)

THE TOTAL SOA SCORE FOR A PARTICULAR MODEL --POSSIBLE RANGE IS 0 TO 1

MODEL NAME OF SPECIFIC GENERATOR

FORECAST OF THE STATE-OF-THE-ART GENERATOR IN 1990

THE PREVAILING STATE OF THE ART IN THE U.S

MEP404A (gas turbine)

SF-100-MD

Caterpillar 3208T

Caterpillar 3304BT2

Forecast (.48)

SOA

U34A

MEP007
MEP105

Fermont 50DH

Fermont DPS100

AD-75-T230

MB-19

MEP018A

MEP005A
MEP006A
MEP004A

MEP003A
MEP403A
(gas turbine)

THE PREVAILING STATE OF THE ART IN THE U.S.S.R.

YEARS IN WHICH SPECIFIC MODELS WERE INTRODUCED

Year

Parameter	Weight	Upper Limit
Power ÷ Weight (watts per pound)	.40	126.0
Efficiency Measure (energy produced (Kwh) per gallon of fuel)	.35	20.0
Power ÷ Volume (kilowatts per cubic foot)	.25	3.2 (u)

SUMMARY OF PARAMETERS, WEIGHTS, AND UPPER LIMITS USED IN SOA CALCULATION

LEGEND

———— U.S. Development

•••••••• USSR Development

Caveats:

. Several desirable parameters were not included due to lack of sufficient data: reliability, running time, noise level, infrared and electromagnetic emissions, quality of electric output and ruggedness.

ISSUES THAT MAY QUALIFY THE SOA RESULTS

. Some dates are approximate.

. Data on recent Soviet developments, including possibly two gas turbines, was not available. (u)

Figure 2.15

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-179577		

4. Title and Subtitle	5. Report Date
NASA Lewis Research Center Futuring Workshop	January 1987
	6. Performing Organization Code

7. Author(s)/Presenters	8. Performing Organization Report No.
Mark Boroush, John Stover, and Charles Thomas	None
	10. Work Unit No.
	760-66-15

9. Performing Organization Name and Address	11. Contract or Grant No.
The Futures Group 76 Eastern Boulevard Glastonbury, Connecticut 06033-1264	C-21030
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Contractor Report Final
National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135	14. Sponsoring Agency Code

15. Supplementary Notes

Project Manager, George M. Prok, Office of Technology Assessment, NASA Lewis Research Center.

16. Abstract

On October 21 and 22, 1986, The Futures Group ran a two-day Futuring Workshop on the premises of NASA Lewis Research Center. The workshop had four main goals: 1) to acquaint participants with the general history of technology forecasting; 2) to familiarize participants with the range of forecasting methodologies; 3) to acquaint participants with the range of applicability, strengths, and limitations of each method; 4) and to offer participants some hands-on experience by working through both judgmental and quantitative case studies. Among the topics addressed during this workshop were: information sources; judgmental techniques; quantitative techniques; merger of judgment with quantitative measurement; data collection methods; and dealing with uncertainty.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Technology forecasting; Senario Data collection; Judgment collection Delphi	Unclassified - unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price*
Unclassified	Unclassified	156	A08

*For sale by the National Technical Information Service, Springfield, Virginia 22161