NORTH-HOLLAND

Tech Forecasting
An Empirical Perspective

ALAN L. PORTER

Introduction

In inviting these perspectives, Hal Linstone wrote that technology forecasting (TF) seems to have peaked around 1970 with a decline in methodological advance thereafter. That stimulated me to conduct a bibliometric analysis of TF activity over the past dozen years. Results support Hal's contention, but also point toward "next wave" possibilities.

Before digging into the data, it is worth considering what is different today from the earlier "heydey" periods for TF. In the 1950s and 1960s, TF was driven by military competition with the Soviet Union. TF was initiated primarily as a tool to help anticipate military technology needs and to help plan and prioritize R&D and systems development. Many of these technologies had long development times (for example, anti-ballistic missile program, new fighter planes).

Today, military technology development has been supplanted by commercial technological competition as the primary motivator for TF. *Competitive technological intelligence*—a remarkable growth area of the 1990s—conjures images of companies, more than intelligence agencies, most actively trying to find out "who's doing what." This interest in tracking and forecasting others' technology development has been heightened by tendencies to constrain corporate R&D to more immediate and more applied targets. In addition, both industry and government (even in the United States) evidence interest in trying to plan, prioritize, and evaluate their R&D programs, placing a premium on information about relative prospects and performance metrics. National *technology foresight* initiatives and industry or product *technology road maps* are important emerging forms of TF [30].

The defining characteristic of today's technology is that we are in the Information Age. While cases could be made for various emerging technologies (for example, advanced materials, biotech) as flowering, it is clearly IT—information technology—that defines our era. That poses a challenge for TF in that typical IT life cycles are much shorter than military systems technology life cycles of 40 years ago.

In addition to targeting rather different technological targets these days, TF draws on different resources. The availability of electronic information in several forms pro-

ALAN PORTER is Professor of Industrial and Systems Engineering Georgia Institute of Technology Atlanta, GA.

Address correspondence to Alan Porter, ISyE, Georgia Tech, Atlanta GA, USA 30332-0205. E-mail: <alan.porter@isye.gatech.edu>.

Technological Forecasting and Social Change 62, 19–28 (1999)

0040-1625/99/$–see front matter
655 Avenue of the Americas, New York, NY 10010
PII S0040-1625(99)00012-8

vides a qualitative change from the heydey TF situation. Nowadays, one can access internal and external time series data compilations, mine R&D databases and worldwide web sites, and pose e-mail queries to experts worldwide. These enhance TF data resources and offer new analytical opportunities. Admitting to my personal bias toward development of tools to mine such electronic information resources for TF ends, I assert that this is the key enabler for a potential next wave of TF capabilities.

The following bibliometric analysis of TF publication activity has dual objectives—to profile recent activity in the field and to illustrate the application of certain electronic monitoring capabilities that offer special TF promise.

A Bibliometric Profile of TF

One of the potent information resources becoming increasingly accessible and useful is the bibliographic database. On the order of ten thousand information databases are compiled and publicly available (usually for a charge). Of these, perhaps a few hundred concentrate scientific or engineering development information gleaned from publications, patents, projects, or citations. Of those, perhaps a few "tens" concentrate huge volumes of R&D information in field-structured abstract databases with particular foci (for example *Medline* for medical research, *ChemAbstracts* in chemistry, *Science Citation Index* for fundamental research).

For this study, I searched three such databases available through the Georgia Tech Electronic Library. Each complies over 3,000,000 abstracts generated during the past dozen or so years. I experimented with several search strategies, concentrating most attention on TF and Tech Futures.[1] Overall results were as follows:

	TF Search	Tech Futures Search
General Periodical Abstracts	72	459
Business Index	1023	716
Engineering Index (EI Compendex)	3673	1898

These absolute values are of some interest in their own right, showing how frequently the terms appear in abstract records (in the abstracts themselves or as title or keyword phrases). We can note that TF/Tech Futures are not uncommon in technical and business literatures.

Analysis of such sizable quantities of bibliographic information is aided by "bibliometrics"—counting and statistically seeking relationships. The present analyses are facilitated by use of bibliometric/text-mining software.[2]

Given that the *Engineering Index* is considerably the richest resource, I focus most attention on those results. To give the flavor of the sources reflected in the *Business*

[1] Boolean searches varied the proximity of "technology or technological" with "foresight or forecast or forecasting" [for the TF searches], with "future or futures" [for the Tech Futures searches], and with "trend or trends" and other candidate terms (for example, scenarios) [for not very productive searches]. More focused TF searches linked explicitly to "method or methods, technique or techniques, approach or approaches," too. Those reported reflect searches with the proximity set within two words (for example, "technology" within two words of "forecast"). There is remarkably little overlap between the TF and Tech Futures abstracts—for instance, of the total 5571 such abstracts in *Engineering Index*, only 100 are common to both searches.

[2] The Georgia Tech Technology Policy and Assessment Center in partnership with Search Technology, Inc. and IISC, Inc., with support of the Defense Advanced Research Projects Agency (DARPA) and the U.S. Army, has been developing text-mining capabilities for technology management. We call this approach "Technology Opportunities Analysis" (TOA). The analyses reported here use the TOA Knowbot software. Example analyses and description of TOA are available on our website: <http://tpac.gatech.edu> and in several articles [c.f., 1–3].

TABLE 1
Top 10 Keywords in 1995–98 TF/Tech Futures Articles

In 498 abstracts containing TF		In 330 abstracts containing Tech Futures	
Keywords	Number	Keywords	Number
Technological forecasting	338	Process control	32
Marketing	60	Marketing	21
Economic & social effects	57	Information technology	20
Information technology	35	Technology	19
Strategic planning	33	Mathematical models	18
Competition	33	Telecommunication services	18
Telecommunication services	33	Technological forecasting	18
Industrial economics	28	Cost effectiveness	17
Mathematical models	27	Computer simulation	16
Research & development mgt.	27	Computer software	14
Cost effectiveness	27	Standards	14

Index, I note that of 73 methods-oriented TF records from the *Business Index* 13 come from this journal (*TF&SC*) with no more than 3 from any other source. Of the 459 *General Periodical Abstracts* on Tech Futures, 13 each come from *Aviation Week & Space Technology*, *The Economist*, and *Choice*; 11 from *Computerworld*, 10 each from *Futures*, *Vital Speeches of the Day*, and *InfoWorld*, and 9 each from *Chemical & Engineering News* and *Library Journal*.

Unless otherwise noted, the following discussion pertains to the *Engineering Index* searches. I wondered whether TF/Tech Futures was central or incidental to these abstracts. "Tech Futures" appears in the title of 339 of the 1898 incidences or as a keyword (subject index term) only 21 times—so most of these abstracts don't focus heavily on Tech Futures. In contrast, TF appears in a title only 62 times, but as a keyword 3285 times of the 3673 incidences, so it is quite important to these journal and conference papers (at least in the eyes of the *EI* indexers).

We might consider two types of TF/Tech Futures publications—those focusing on methods and those just doing some form of TF. Based on Linstone's initial premise, we might expect relatively few methodological pieces. And this is what we find! Of the combined 5471 TF/Tech Futures abstracts in *Engineering Index* (100 are common to both searches), only 113 (2%) used the terms "methods, techniques, or approaches" in proximity (within 2 words) of TF/Tech Futures. Furthermore, visual inspection found precious few of those 113 articles describing a methodological development of any sort. Nearly all of this TF/Tech Futures literature reflects application, not development.

One might then ask to what TF/Tech Futures are being applied. Grouping the abstracts in time slices helps ascertain patterns. For the recent period of 1995 to 1998, this results in 498 *Engineering Index* abstracts containing TF and 330 containing Tech Futures. To provide contrast, sometimes I compare results to abstracts grouped for 1986 to 1988: 998 abstracts on TF and 402 on Tech Futures. Table 1 shows the "Top 10" (plus ties) keywords in the 1995 to 1998 abstracts. Interests are quite varied, with marketing appearing prominently, and applications to specific IT domains notable in both lists. Models and simulation show relatively strongly also.

Engineering Index also classifies the articles (typically journal and conference papers) using its own set of class codes. These provide another perspective on the issues

TABLE 2
Top 10 Classifications of 1995–98 TF/Tech Futures Articles

In 498 abstracts containing TF		In 330 abstracts containing Tech Futures	
Class	Number	Class	Number
Impact of technology on society	224	Semiconductor devices & IC's	46
Industrial economics	76	Computer applications	45
Management	74	Electronic equip., radar, radio, & TV	39
Computer applications	58	Control systems	37
Marketing	51	Automatic control principles & ap's	32
Electronic equip., radar, radio, & TV	50	Industrial economics	29
Semiconductor devices & IC's	40	Impact of technology on society	25
Engineering research	37	Optical devices & systems	24
Comp. software, data handling, & ap's	32	Management	21
Information science	28	Digital computers and systems	20
		Marketing	20

on which these papers focus (Table 2). Forecasting of various IT developments appears prominently (for example, computer applications, semiconductor devices & IC's). Management and marketing interests strongly link to TF and, somewhat less prominently, to Tech Futures. Most intriguing is the prevalence of "impact of technology on society" classifications. This result depends on the judgment of the *EI* indexers deciding which controlled vocabulary terms describe the contents of a particular paper. Nonetheless, it suggests at least some form of continuing technology assessment consideration in these literatures.

In analyses of this sort, we often like to generate "technology maps" showing the concentration of topics and their linkages.[3] These did not prove informative for the TF/Tech Futures searches in that most of the top 200 keywords (or other terms) splatter widely over specific technologies being studied (for example, wide area networks, software engineering). Were there a concentration on methodological aspects in these articles, which there is not, this would have been of interest.

It is interesting to note who is publishing on TF/Tech Futures. In terms of nationality, the United States dominates. Of the 1995 to 1998 TF articles for which country of affiliation is specified, 140 indicate the United States, followed by 29 for the UK, 20 for Japan, and 10 for the Netherlands. Similarly, for the Tech Futures articles, the United States leads with 118, followed distantly by Japan (23), Germany and the UK (10 each), and Canada (7). (*Engineering Index* does abstract non-English sources, but it favors English language.) Figure 1 maps the 1995 to 1998 TF papers by country and leading keywords. The size of the circle reflects the number of articles. Linkages and proximity reflect commonality in emphases. Most interesting are the apparently widespread prevalence of concern about effects of technology and industrial competitiveness considerations.

Pursuing the "who" behind these articles, it is interesting to note the mix of academic and industry authorship. Consistent, but not exhaustive, classification (based on simple

[3] The TOA approach (see footnote 2) provides for ready mapping of term clusters, affiliations, and so forth. These are based on co-occurrence patterns across the set of abstract records being analyzed. The maps are based on statistical analyses of those patterns, with results depicted by using a proprietary form of multidimensional scaling (to locate nodes) and path-erasing (to show selected links). At present, we can generate seven maps and "innovation indicator" graphs in about ten minutes from completion of the database search—an illustration of the potential in mining electronic bibliographic resources for TF.

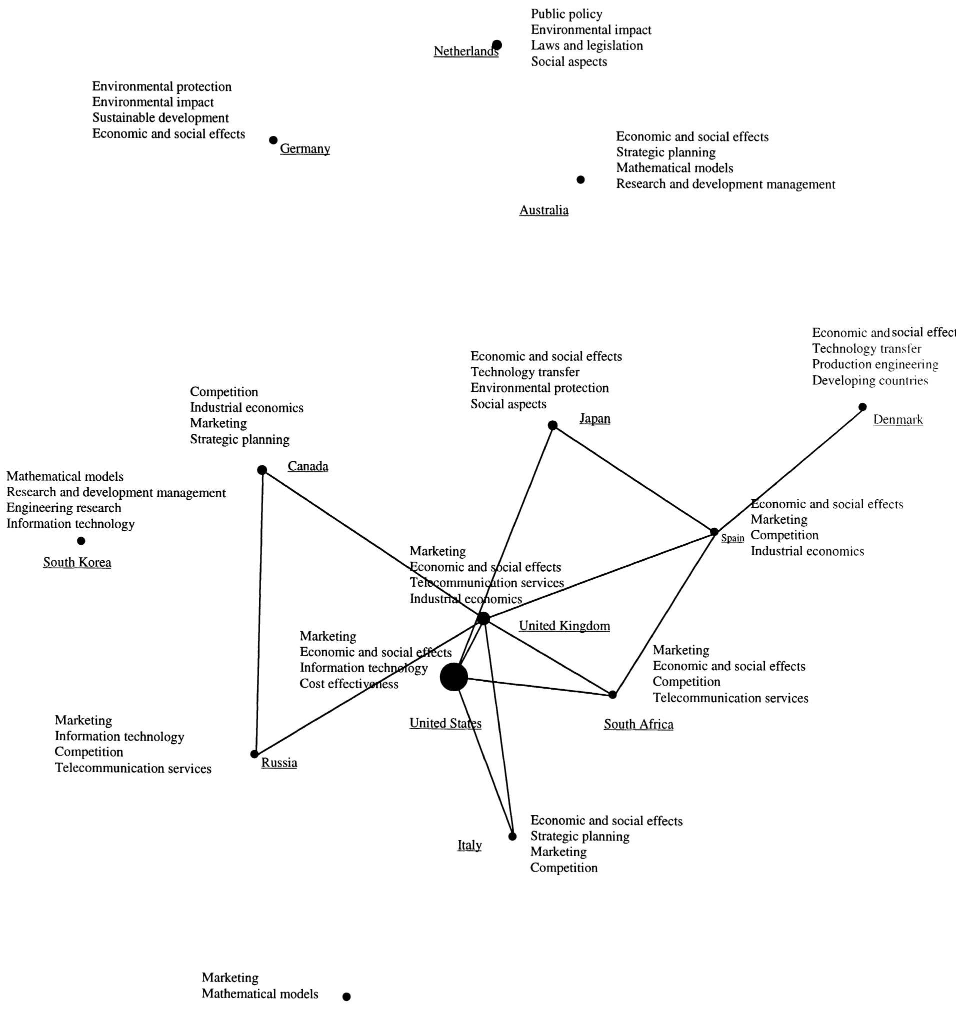

Fig. 1. Countries' TF emphases map.

coding of "univ" or "inst of technology" as university; "Ltd" or "Inc" and so forth as industry) finds a rough ratio of academic to industry-authored publications as shown in Table 3.[4]

The striking change is the decline in relative academic TF interest. Given that TF publication activity was greater in the earlier period, the absolute decline is also quite pronounced—a drop from some 371 university-based TF publications in 1986 to 1988

[4] The categorization into academic and industrial is not complete; many articles just aren't categorized in this simple analysis. However, the results appear robust. They are not an artifact of fewer articles being indexed. The overall number of *Engineering Index* entries actually increased from 500,054 for 1986 to 1988 to 859,389 for 1995 to 1998 as of the date of the search. The 998 articles mentioning TF indexed in 1986 to 1988 thus represent 0.2% of the overall database for that time period; the 498 articles mentioning TF in 1995 to 1998 represent 0.06%. Overall prominence of TF in the engineering literature has dropped precipitously in a decade, to about one-third its level in 1986 to 1988.

TABLE 3
Ratio of Academic to Industrial Authorship of TF/Tech Futures Articles

Time Slice	In abstracts containing "TF"	In abstracts containing "Tech Futures"
1986–88	3.2:1	1.1:1
1995–98	1.6:1	1.3:1

to 88 in 1995 to 1998, in *Engineering Index*. The net result is that both the TF and Tech Futures articles are fairly evenly balanced presently between academia and industry.

Given that the publications indexed reflect diverse applications, rather than methodological advance, listing of specific institutions or authors would add relatively little here.

Profiling the sources of these articles helps understand the state of the TF/Tech Futures literature. See Table 4. There is a profound and unsettling concentration phenomenon in TF. Contrast the prominence of one source (journal), *TF&SC*, recently with the wider interest in TF a decade earlier (Tables 4 and 5).

Figure 2 shows the trends in TF publications compiled in *Engineering Index*. Note that the upper curve (publications mentioning TF) has been divided by 10 for scaling purposes. So, for instance, the number at the temporary peak in 1994 is actually 353. The precipitous one-year decline from 1994 to 1995 is so abrupt that one wonders if it might be an artifact—that is, perhaps *Engineering Index* changed its indexing terminology at that point. I have not investigated such possibilities because the current interest lies in the general trend, not precise changes, and the downward slope of the overall trend dominates the figure.

The lower curve, TF methods, reflects the number of abstracts in which "TF" phrases appear in proximity to "methods" terms (see footnote 1). These are real numbers (no division by 10). They are distressingly low—fewer than 5 such publications per year from 1992 to 1997. My optimism at the upsurge for 1998 was short-lived—inspection of those abstracts found no real methodological development. (The search phrasing just asserts proximity, not methodological development work, as per footnote 1.) The lower curve is just a rough gauge of methodological interest in TF. Authors developing, say, new scenario methods, might not use "TF" or "methods" terms per se, no less in proximity. Nonetheless, the drop-off and the minimal numbers of hits are quite disturbing indicators of the lack of development of TF methodology.

Recent Methodological Highlights

This is not a comprehensive review of methodological development in TF; rather, it spotlights recent work noted in this literature search and other items brought to mind. Let's consider recent methodological contributions in terms of six prominent

TABLE 4
Top Sources of 1995–98 TF/Tech Futures Articles

In 498 abstracts containing "TF"		In 330 abstracts containing "Tech Futures"	
Source	Number	Source	Number
TF&SC	145	*ISA Tech/Expo Technology Update Conference*	62
IEE Colloquium (Digest)	10	*NTQ (New Telecom Quarterly)*	57
Proceedings of the IEEE	8	*IEE Colloquium (Digest)*	12
IEE Aerospace Ap's Conf. Proceedings	6	*Proceedings of SPIE*	5

TABLE 5
Top Sources of 1986–88 TF Articles

In 998 abstracts containing "TF"

Source	Number
TF&SC	53
Transportation Research Record	39
International Journal of Production Research	34
Journal of the Operational Research Society	33
IIE Transactions (Institute of Industrial Engineers)	22
Operations Research	21
Production & Inventory Management	21
Transportation	20
Society of Petroleum Engineers of AIME	17
Long Range Planning	16
Materials and Society	14
IEEE Aerospace and Electronics Systems Magazine	12
Computers & Industrial Engineering	12
Engineering Costs and Production Economics	12
Energy Policy	12
Management Science	10
Electronics	10

methodological approaches to TF: creativity methods, monitoring, trend analysis, modeling, expert opinion, and scenarios [4].

Recent developments in creativity approaches include planning-oriented work, such as Nadler's *Breakthrough Thinking* [5] and Rouse's *Best Laid Plans* [6]. "TRIZ," based on systematic patient analysis, has demonstrated creative utility in engineering design [7–10].

Monitoring potentials have expanded tremendously due to the dramatic rise in accessibility of electronic bibliographic databases and worldwide websites. Such sources provide information on emerging technologies in several forms: research project descriptions (for example, U.S. National Science Foundation project compilation on their website—<www.nsf.gov>), publications (for example in abstract databases such as those analyzed in this article), patents (for example, *Derwent's Worldwide Patents*), and citations (for example, the *Science Citation Index*). This paper illustrates how these electronic resources can be exploited to profile technologies and help assess their future prospects [see also 1–3, 11]. Others use electronic resources to identify experts and initiate networking on technological topics [12].

Attention to trend analysis methods is surprisingly thin in the TF domain. Work of Meade and Islam is a notable exception [13, 14].

Modeling is, of course, highly diverse. Concern about systems behavior is an aspect receiving some consideration. Adapting trend models to short life cycle products is important given the short development cycles for information technologies [15]. Whether chaos phenomena have a useful role in modeling emerging technologies has received some attention [c.f., 16], as have systems' behaviors [17, 18]. Broadening TF emphases to include explicit consideration of contextual factors offers particular promise for generating more robust forecasting [c.f., 2,3, 19, 20].

The proliferation of national Delphis deserves note. For decades, the Japanese have compiled expert opinion on over 1000 specific technological issues about every five years. In the 1990s, Germany and other nations have developed similar broadscope

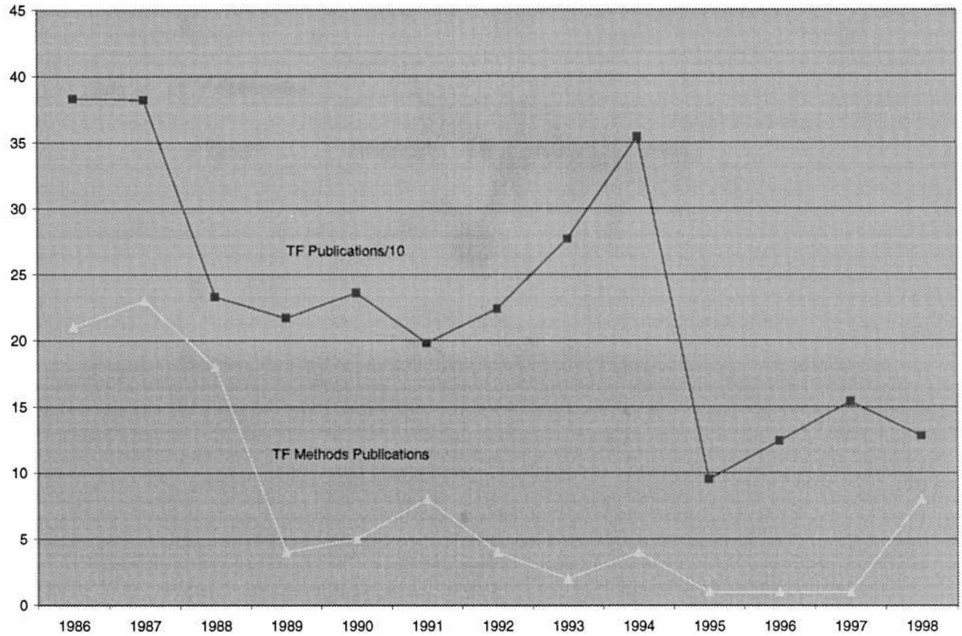

Fig. 2. Trends in TF publication.

[c.f., 21] or narrow domain [c.f., 22] national Delphis. Britain has undertaken major, ongoing technology foresight activity drawing upon expertise through a series of activities, including panels, workshops, and Delphi [23]. Another important form of TF has emerged in the technology road map. This actually encompasses a range of perspectives, importantly including science/research maps, industry road maps, technology road maps, product development road maps, and product-technology road maps. Kostoff and Schaller are presently completing an overview of technology road mapping based on a workshop held in late 1998, with a rich overview and over 900 references available on Kostoff's website [24].

Interesting scenario approaches are being applied [25, 26]. Particularly impressive, in my view, is the work by Gausemeier and colleagues [c.f., 27] and the attention being directed to "alternative futures" generation [28].

Conclusion

TF is alive, but is it well? Signals are mixed. The bibliometric analyses are disheartening, but not unduly so. As with many fields, it appears that TF activity is dispersing under a variety of labels. "Competitive technological intelligence," "technology foresight" (I note a new journal, *Foresight*, just announced), and "technology road mapping" are each growing strongly. Each is essentially a variant of TF. TF contributes importantly to consulting practice [c.f., 29]. It is also de facto reflected in many market research reports. So, TF application appears healthy. Likewise, despite the demise of the U.S. Office of Technology Assessment, it appears that many authors are addressing technology impact assessment, as per the present bibliometric results.

In my view, methodological development is vital to the health of a field such as TF. Again, the bibliometric results are disquieting in the extreme. However, probing for development activity in particular methods and approaches is more encouraging.

While we cannot claim a boom in such activities, neither does TF appear stagnant. The previous section finds worthy methodological development on several fronts. Funding for research in TF and technology assessment methods would go far toward rejuvenating methodological development and stimulating academic interest. That would yield long-term gains in TF and impact assessment practice. Given the importance of technological change as the key driver of current information economies, we ought to press hard to advance technology forecast and assessment methodology.

The highest priority ought to lie in devising better ways to use electronic information resources for technology monitoring, forecasting, and assessment.

References

1. Porter, A. L., and Detampel, M. J.: Technology Opportunities Analysis, *Technological Forecasting and Social Change* 49 (2), 237–255 (1995).
2. Watts, R. J., and Porter, A. L.: Innovation Forecasting, *Technological Forecasting and Social Change* 56, 25–47 (1997).
3. Watts, R. J., Porter, A. L., and Newman, N. C.: Innovation Forecasting Using Bibliometrics, *Competitive Intelligence Review* 9(4), 11–19 (1998).
4. Porter, A. L., Roper, A. T., Mason, T. W., Rossini, F. A., and Banks, J.: *Forecasting and Management of Technology*. Wiley, New York, 1991.
5. Nadler, G., and Hibino, S.: *Creative Solution Finding: The Triumph of Breakthrough Thinking*. Prima Publishing, Center for Breakthrough Thinking, Los Angeles, CA, 1999.
6. Rouse, W. B.: *Best Laid Plans*. Prentice Hall, Englewood Cliffs, NJ, 1995.
7. Altshuller, G., and Altov, H.: *And Suddenly the Inventor Appeared: TRIZ, the Theory of Inventive Problem Solving*. GOAL-OPC, 1996.
8. Royzen, Z.: *Product Innovation Using TRIZ*. Addison-Wesley, 1997.
9. Terninko, J.: *QFD, TRIZ & Robust Design: Synergy*. Responsible Management, Inc., 1998.
10. Tsourikov, V.: Faster Time to Market—Key to Communications Equipment Manufacturing Success in the Global Marketplace, *IEEE/SEMI Advanced Semiconductor Manufacturing Conference and Workshop Proceedings*. IEEE, Piscataway, NJ, 427–429 (1997).
11. Kim, S. H., and Lee, C. M.: Nonlinear Prediction of Manufacturing Systems Through Explicit and Implicit Data Mining, *Computers and Industrial Engineering* 33 (4), 461–464 (1997).
12. Pauli, G.: Technology Forecasting and Assessment: The Case of Zero Emissions, *Technological Forecasting and Social Change* 58 (1–2), 53–62 (1998).
13. Meade, N., and Islam, T.: Technological Forecasting—Model Selection, Model Stability, and Combining Models, *Management Science* 44 (8), 1115–1130 (1998).
14. Islam, T., and Meade, N.: Diffusion of Successive Generations of a Technology: A More General Model, *Technological Forecasting and Social Change* 56 (1), 49–60 (1997).
15. Kurawarwala, A. A., and Matsuo, H.: Product Growth Models for Medium-term Forecasting of Short Life Cycle Products, *Technological Forecasting and Social Change* 57 (3), 169–196 (1998).
16. Phillips, F., and Kim, N.: Implications of Chaos Research for New Product Forecasting, *Technological Forecasting and Social Change* 53 (3), 239–261 (1996).
17. Keller, P., and Ledergerber, U.: Bimodal System Dynamic: A Technology Assessment and Forecasting Approach, *Technological Forecasting and Social Change* 58 (1–2), 47–52 (1998).
18. Li, Y., Zhang, J. H., Li, C., and Wu, X.: Boundary of Sets in Pansystems Information Systems, *Kybernetes: An International Journal of Cybernetics and General Systems* 26 (4–5), 596–601 (1997).
19. Berry, B. J. L.: Technology-driven Forecasts, the Phillips Curve, and Monetary Policy-Making, *Technological Forecasting and Social Change* 53 (2), 155–167 (1996).
20. Salomon, I.: Technological Change and Social Forecasting: The Case of Telecommuting as a Travel Substitute, *Transportation Research, Part C: Emerging Technologies* 6 (1–2), 17–45 (1998).
21. Shin, T.: Using Delphi for a Long-range Technology Forecasting, and Assessing Directions of Future R&D Activities—The Korean Exercise, *Technological Forecasting and Social Change* 58 (1–2), 125–154 (1998).
22. Chakravarti, A. K., Vasanta, B., Krishnan, A. S. A., and Dubash, R. K.: Modified Delphi Methodology for Technology Forecasting: Case Study of Electronics and Information Technology in India, *Technological Forecasting and Social Change* 58 (1–2), 155–165 (1998).

23. Martin, B. R., and Johnston, R.: Technology Foresight for Wiring Up the National Innovation System: Experiences in Britain, Australia, and New Zealand, *Technological Forecasting and Social Change* 60 (1), 37–54 (1999).
24. Kostoff, R. N.: Science and Technology Roadmaps, <http://www.dtic.mil/dtic/kostoff/mapweb2index.htm>.
25. Rienstra, S. A., and Nijkamp, P.: Role of Electric Cars in Amsterdam's Transport System in the Year 2015: A Scenario Approach, *Transportation Research, Part D: Transport and the Environment* 3 (1), 20–40 (1998).
26. Schubert, H., and Ziegahn, K-F.: Environmental Conditions for Industrial Production in the 21st Century, *Institute of Environmental Sciences—Proceedings, Annual Technical Meeting*, 334–340, Institute of Environmental Sciences, Mount Prospect, IL (1996).
27. Gausemeier, J., Fin, A., and Schlake, O.: Scenario Management: An Approach to Develop Future Potentials, *Technological Forecasting and Social Change* 59, 111–130 (1998).
28. Institute for Prospective Technological Studies, *Procedures of Profutures Workshop: Scenario Building*. European Commission Joint Research Centre, IPTS, Seville, Spain [EUR-17298-EN], 1996.
29. Price Waterhouse Global Technology Centre: *Technology Forecast: 1999*, Menlo Park, CA, 1999.
30. Foresight Activities; Special Issue on National Foresight Projects, *Technological Forecasting and Social Change* 60 (1), 1–3 (1999).

Received 3 February 1999; accepted 20 February 1999