NORTH-HOLLAND

Technology Opportunities Analysis

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ABSTRACT

We present an approach to efficiently generate effective intelligence on emerging technologies. This approach draws on monitoring and bibliometrics to mine the wealth of information available in major public electronic databases. The approach uses new software to expedite secondary analyses of database searches on topics of interest. We illustrate the range of information profiles possible by examining research and development (R&D) publications and patents pertaining to electronics assembly and, more specifically, to multichip module development.

Introduction

Intelligence is a prime requirement for successful technological innovation. Organizations operating in competitive environments demanding process improvements, new product introductions, or technology-enhanced services must obtain and use information on emerging technologies. This paper presents an improved approach to secure such information quickly and inexpensively.

Beginning in 1990, the Georgia Tech Technology Policy and Assessment Center (TPAC) worked to identify emerging technologies for campus-wide strategic planning, shortcourses for IBM, and a National Technological University course, "Analysis of Emerging Technologies." This "technology opportunities analysis"[1] compiled information to create a database on some 20 emerging technologies. In 1993 we recognized that our electronic database, approaching 1000 abstracts, was totally inferior to publicly available technology databases (some 2000 times as large as ours!). We turned to analyze the 18 databases available through the Georgia Tech Electronic Library. More generally, there are some 8000 public electronic databases potentially accessible, hundreds through gateways such as Dialog. The approach described herein analyzes information gleaned from such databases to identify technology-related opportunities.

Technology Opportunities Analysis combines monitoring with bibliometric analysis. The following sections highlight pertinent developments in these two areas. These sections

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[1] The term was designated by our colleague, Joseph E. (Tim) Gilmour, Vice-President for Strategic Planning, as a sharper depiction of the intent than technology monitoring or forecasting.

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are followed by a description of our approach, illustrated through an analysis of electronics assembly opportunities, and a concluding discussion.

Monitoring

Monitoring[2] is "to watch, observe, check, and keep up with developments, usually in a well-defined area of interest for a very specific purpose" [1]. It is akin to "environmental scanning" and "issues management" – efforts to identify emerging developments likely to affect an organization over the coming few years. Monitoring assumes that technological change is foreshadowed by changes in related technologies and/or in the socioeconomic context. Thus, identifying those signals from the environment, and analyzing them with respect to one's organizational interests and capabilities, should contribute to technological forecasting and planning [2].

Monitoring is, perhaps, the most useful technique in forecasting. As Jim Bright pointed out long ago, monitoring, in its own right, can elicit discernible patterns, directly useful in forecasting [3]. John Naisbitt generates highly influential forecasts based on monitoring [4, 5]. More often, monitoring complements and facilitates other tech forecasting methods. Monitoring helps in identification of the variables to include in modeling or trend analyses, the populations of experts for Delphi and other expert opinion methods, and the critical issues for alternative scenarios. In a related foresight field, a survey of impact assessment practitioners found monitoring identifiable as a significant technique (typically one of several used) in 65% of 185 technology assessments, 58% of 155 environmental impact assessments, and 47% of 418 social impact assessments [6].

Monitoring comes in many guises. It may be conducted as a one-time study of a given topic or as an ongoing effort to track developments in that topic. It may key on "upstream" (research) or "downstream" (market) facets of the innovation process. Monitoring may focus on technological changes and/or changes in pertinent socioeconomic context factors that impinge on the technology delivery system [2, 7]. It can serve a variety of uses, such as: setting research funding priorities [8], designing technological systems [9], identifying opportunities for you based on someone else's new technology [10], seeking new markets (e.g., ALCOA) and competitive analyses [11], or even national technology planning (e.g., China) [2].

In monitoring it is critical to discern and communicate what the data say. That is, the forecaster must display patterns and interpret their implications for the study users.

Monitoring should gather data for a "specific purpose." Although the need for a sharp focus remains, modern electronic information sources drastically alter the notion that information *accumulation* must be specifically targeted. The availability of electronic databases and the Internet, with its searching agents (e.g., gophers), largely obviates the need to maintain topical monitoring files. A new era is opening for monitoring as a more potent and more accessible technique.

Bibliometric Analyses

Every working day more than 5000 scientific papers are published in reputable refereed scientific journals throughout the world; every working day 1000 or more new patent documents are issued throughout the world. . . . Clearly it is beyond the ability of any person or group to comprehend all of this new knowledge or its implications, or even to measure it, without the use of quantitative indicators [12].

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[2] This section draws on Chapter 8, "Monitoring," of [2].

Bibliometrics use counts of publications, patents, or citations to measure and interpret scientific and technological advances. Bibliometrics involve, first and foremost, activity measurement. These analyses assume that counts of papers and patents validly indicate research and development (R&D) activity in target subject areas and reflect emphases of institutions to which they are linked [12]. Of course, one would prefer to tap "knowledge increments" directly; papers and patents can only provide an incomplete picture of advances. Another key tenet is that one can ascertain important links by analyzing which organizations are producing what papers and patents, which topics occur together, and who cites what [12].

Modern bibliometrics are rooted in Derek Price's observations on scientific activity patterns (e.g., activity doubling every 15 years for three centuries) [13]. The establishment of a key database, the *Science Citation Index,* in 1961 fostered systematic bibliometrics and the development of new analytical approaches [14]. The biennial *Science and Engineering Indicators* [15] has evolved into a key source of bibliometric and other (e.g., R&D funding) data.

A country, company, or university research group needs to understand its position vis-à-vis its competitors to exploit potential opportunities and to avoid damaging head-to-head competition. Bibliometric applications range from national policy considerations (cf., evaluation of the performance of British science [16]) to tactical ones – e.g., providing information on particular domains to help managers make decisions on R&D project selection, new product design, or marketing approaches.

Various forms of analysis have been developed. Citation analysis [cf., 14] examines citation (referencing) patterns among papers and/or patents to detect seminal contributions, interaction patterns among fields or institutions, and even to forecast emerging research areas. Patent analysis, by such practitioners as Mogee Research & Analysis and CHI Research, tallies patent activity by patent classifications to ascertain company profiles, trends, and so on. Specialized patent citation databases and methods developed by those firms enable further analyses such as patent citation mapping [17, 18].

A key tenet of bibliometrics is that linkage can be detected. To develop this capability, an important class of analyses has emerged based on co-occurrences. Phenomena that occur together frequently in some domain are assumed to be related, and the strength of that relationship is assumed to be related to the co-occurrence frequency [19].

Co-citation, developed primarily by Henry Small and colleagues at the Institute for Scientific Information (ISI) [cf., 20, 21], identifies pairs or groups of articles that are cited together in other articles. From these, a cognitive structure is then derived, providing information on the evolution of R&D [22].

Co-word analysis, pioneered in Europe, dating mainly from the 1980s (although earlier roots exist [23]), looks for words appearing together. Often these are restricted to keywords (index terms) [cf., 24]. Kostoff has extended these analyses to whole text co-occurrence analyses, with powerful results [cf., 19, 23, 25]. Other variants are possible; for instance, an analysis of British science underway analyzes co-occurrences within article titles [26].

An important element in bibliometrics is presentation. Mapping is of particular interest in determining and showing relationships. Maps can depict the location of research domains relative to each other, institutional interests and overlaps, or national profiles. A variety of bibliometric maps enrich analyses [27, 28].

Bibliometric limitations must be noted. Not all R&D is published or patented. Counts don't distinguish quality. Publication and patenting practices vary across fields and institutions (e.g., one company publishes considerably; another, not at all). One important limitation of bibliometric analyses is the problem of classification—there is no perfect classification system to assure comparability or completeness [12].

Bibliometrics provide a powerful source of information on emerging technologies and their potential. Given their limitations, they ought to be combined with other forms of information, particularly semi-quantitative [29] and expert opinion, to develop a balanced assessment.

Technology monitoring and forecasting aims can be served by bibliometric analyses. Linkage counts provide evidence as to how R&D is impacting other R&D fields, indicate who is involved, and can suggest further applications. For instance, consider the development of scanning probe microscopy over the past decade and its applications ranging from electrical engineering to biology. Bibliometrics can help track the course of that development to date and suggest likely next steps. Kostoff builds network models that extend such direct observations by tabulating how new technology "A" impacts research area "B," which in turn impacts application "C" [30]. "Research forecasting" can be undertaken by combining bibliometric profiles (e.g., of an area such as materials science and engineering) with expert opinion (e.g., R&D performers and industrial customers use the bibliometric findings as a base on which to express their materials priorities) [31].

Technology Opportunities Analysis

TAPPING INTO THE ELECTRONIC DATABASES

Organizations engaged in research and technology development need to identify and explore emerging technological opportunities. The Technology Policy and Assessment Center at Georgia Tech has developed a process to gather intelligence and provide foresight analysis for developing technologies. This process, which we call *Technology Opportunities Analysis* (TOA), draws on bibliometric methods, augmented by expert opinion, to provide insight into specific emerging technologies. TOA performs *value-added* data analysis, collecting bibliographic and/or patent information and digesting it to a form useful to the research or technology manager, strategic planner, or market analyst. Some of the specific tasks that can be performed by TOA include identifying:

- component technologies and how they relate to each other;
- who (companies, universities, individuals) is active in developing those technologies;
- where the active developers are located nationally and internationally;
- how technological emphases are shifting over time;
- institutional strengths and weaknesses as identified by research profiles.

The Technology Policy and Assessment Center uses a customer software package, the *Technology Opportunities Analysis Knowbot* (TOAK), to scan major national and international publication databases, as well as a major U.S. Patent database. TOAK captures and analyzes pertinent publication data, including keyword, affiliation (company, state, and country), and co-word analyses. Further statistical analysis provides growth curves, institutional profiles, and technology maps. Initial findings can motivate more detailed investigations or facilitate expert group exploration of opportunities. TOAK thus offers an advanced monitoring capability that accesses information compiled in public databases and summarizes this information through bibliometric analyses.

We now illustrate TOA by applying it to the area of *electronics manufacturing and assembly*, sometimes probing a particularly important emerging form of electronics packaging, ***multichip modules***. This study was originally done to assist a national study mission on Japan to identify technology emphases and institutional activity patterns. This example serves to illustrate a range of TOAK strategic and competitive analysis capabilities. This exploration of electronics technologies is divided into three stages: Domain Specification, Data Collection, and Analysis.

DOMAIN SPECIFICATION

This initial stage identifies the technology to be studied, generates a list of potential keywords and search strategies, and selects target database(s). Brainstorming with the primary customer for this electronics manufacturing and assembly study was combined with a review of published articles on the topic to yield a list of 36 keywords to be used in the database searches. These search terms are listed in Table 1. The development of search strategies involved the choice of specific Boolean operators and combinations of keywords to generate comprehensive (inclusive), yet accurate (exclusive), searches. For instance, one might determine that a search should include all abstracts in which the terms "electronic" and "assembly" appear within two words of each other.

The database chosen for the sample searches is *INSPEC*.[3] *INSPEC* is a very rich source of information, as noted. One might well wish to analyze additional databases too. For instance, examination of patent behavior can often complement analysis of research publications. *INSPEC* was selected for this study due to its extensive coverage of electrotechnology. Most TOA work, although not all, has concentrated on *INSPEC* and *Engineering Index* (also favored by the Dutch [27], the *Computer Database, Business Index, Expanded Academic Index, National Technical Information Service (NTIS) Research Reports, Public Affairs Information Service,* and *U.S. Patents.* Those databases

TABLE 1
List of Keywords and Frequencies
[INSPEC Database]

Keyword	Number of articles	Keyword	Number of articles
ball grid array	19	microassembly	15
chip carrier	412	multichip module	1577
electric contacts	349	pcb	4802
electronic assembly	366	pin grid array	221
electronic packaging	2484	polymer film	6571
epoxy resin	1045	printed circuit	9969
flip chip	663	printed wiring board	609
ic, cmos	11625	pulsed laser deposition	919
ic, digital	10936	sc, bipolar	2120
ic, hybrid	3603	sc, mos	1841
integrated circuit	53632	semiconductor device	15795
laminate	3956	signal processing	38404
lead bonding	1089	soldering	3243
logic device	974	substrate	52659
lsi	5917	surface mount	4616
mcm-c	30	tape automated bonding	909
mcm-d	82	wafer bonding	242
mcm-1	60	wafer scale integration	1281

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[3] *INSPEC* is produced by the Institution of Electrical Engineers (IEE). It corresponds to the three *Science Abstracts* print publications: *Physics Abstracts, Electrical and Electronics Abstracts,* and *Computer and Control Abstracts.* As of November 1994, *INSPEC* contained about 1.9 million items on line, dating from 1986. About 84% of the source publications are in English.

are included in Georgia Tech's Electronic Library, facilitating access. The TOAK software is easily adapted to accept the field codes from other databases of interest. Such fields typically include title, author, author's affiliation, source (e.g., journal), abstract, and keywords.

DATA COLLECTION

In the sample study, the number of items (abstracts) returned for each search ranged from 15 for microassembly to 53,632 for integrated circuits (Table 1). These data were collected both in aggregate and yearly form. In addition to the raw number of hits for each term, we also determined the number of keyword co-occurrences. A keyword co-occurrence is the appearance of two keywords in the same database record (containing title, author, affiliation, keywords, abstract, etc.). This information is used later to develop technology maps. In using information from abstracts (including titles and keywords), we apply a co-word approach intermediate between the traditional keyword-only analyses [24] and Kostoff's full article text analysis [23, 25, 29]. We believe strongly in this strategy because abstracts capture the essence of an article and are richer than keywords alone; moreover, this approach accesses these tremendous electronic databases with, literally, millions of quite current R&D contributors. Full text analysis requires full-text databases and none of those are available with coverage approaching that possible with the abstract databases such as *INSPEC*.

ANALYSIS

The analysis of data is the most vital component of technology opportunities analysis. It is here that relationships and trends are explored, and emerging technologies are identified.

Our software, TOAK, facilitates the capture and analysis of publication data. For the electronics assembly study, TOAK extracted keyword and affiliation data from downloaded *INSPEC* entries and provided that information in several useful formats. The following illustrations focus on a subset of 1363 abstracts relating to *multichip modules*.

The first extraction by TOAK lists all phrases from the keyword field as well as the number of articles in which each phrase appears in the keyword field. An abbreviated example is shown in Table 2. It is quite useful in the early stages of analysis to identify

TABLE 2
Multichip Module Keywords and Frequencies
[INSPEC Database]

Keyword	Number of articles	Keyword	Number of articles
Multichip modules	842	Circuit layout CAD	69
Packaging	480	Tape automated bonding	68
Hybrid integrated circuits	317	Printed circuit manufacture	66
Module	271	Printed circuit design	65
Integrated circuit technology	248	Thin film circuit	62
Integrated circuit testing	127	CMOS integrated circuits	56
Substrates	101	Soldering	50
VLSI	98	Optical interconnections	48
Surface mount technology	93	Lead bonding	44
Flip-chip devices	93	Integrated optoelectronics	43
Integrated circuit manufacture	88	Printed circuits	42
Ceramics	85	Production testing	41
Circuit reliability	80	Reliability	41
Polymer films	79	Microassembling	38
Cooling	70	Circuit CAD	35
Metallisation	69	Microprocessor chips	35

synonyms and related technologies. For instance, we see here that multichip modules (MCMs) are mentioned very frequently with integrated circuits, particularly hybrid integrated circuits. [The reason "multichip modules" appears in only about 60% of the 1363 abstracts is that these include items in which "multichip modules" appears in the abstract per se and items captured by closely related search terms (e.g., MCM-L).]

TOAK also simplifies the collection of article affiliation information. *INSPEC* includes a field that lists the institutional affiliation of the author. The TOA Knowbot creates sorted lists of this information. An abbreviated version is shown in Table 3. Some of the 1363 retrieved records lack affiliation information. Note that the 19 leading MCM institutions, in terms of publications, are located in the United States.

We also searched for MCM patenting. Four of the five leading patenters in the U.S. are among the top six publishers—IBM (12 patents), MCC and TI (7), and Motorola (5). The other is Rogers Corp. (5 patents and 7 publications). This illustrates that publishing and patenting are distinct indicators of R&D activity. In this case they correspond quite closely; in other areas, they may not. Some companies avoid publishing. For instance, in exploring Japanese corporate activity in electronics assembly, we noted that some companies publish considerably (e.g., NEC), whereas others active in the same domain, don't (e.g., Sony). Patenting activity typically lags somewhat behind publication, so the two indicators can complement each other. No bibliometric indicator gives the total picture, but they do provide valuable intelligence. Figure 1 presents the patenting frequency in several areas related to multichip modules for the top two patenters, IBM and AT&T. Note the strong disparity in apparent patenting efforts. AT&T is very strong in optoelectronics, whereas IBM appears to emphasize substrates and thin film. In fact, the patent frequency correlation between IBM and AT&T across all 11 areas is only 0.18.

TOAK is also capable of performing an aggregated search at the country and state levels. Table 4 lists the affiliation totals by country and indicates strong U.S. dominance

TABLE 3
Multichip Module Author Affiliations
[INSPEC Database]

Organization	Number of abstracts
IBM	89
AT&T	53
GE	39
MCC	38
Motorola	37
Texas Instruments	19
Hughes	18
NTT	15
Rockwell	14
Rochester Polytechnic Institute	14
University of North Carolina	14
Alcoa	12
DuPont	12
Intel	11
NChip	11
BPA	10
Dow	10
GEC	10
Polycon	10

in publication of articles related to multichip modules. The dominant state within the U.S. is California with 180 affiliated articles.

Given the purpose of the analysis was to contrast Japanese and American activities in electronics assembly, we were quite interested in profiling each country's technology emphases. The simplest comparison is to look at the number of publications by the U.S. and Japan in each of the technology areas. Table 5 lists these values.

These totals don't reflect relative national emphasis, however, an indicator of both policy and strategic interest. *INSPEC* contains primarily English-language publications (84%), and about three times as many articles with U.S. affiliations as Japanese affiliations. So we chose to develop a scale factor to compare publication activity on a more equal footing. We define emphasis in a specific area as a higher volume of publication in that area relative to total publication. The method used can be described two different ways (which are mathematically equivalent).[4]

First, consider the entire *INSPEC* database. The ratio of articles with U.S. affiliation to those with Japanese affiliation is almost exactly 3.25. Multiply the Japanese totals by 3.25 and then compare to see who does "more" research in an area. The second method is slightly more involved. Define an *activity ratio* as the ratio of articles in a specific technology area affiliated with a country to the total number of articles affiliated with that country. Compare these activity ratios to determine who does "more" publishing in an area. In fact, the ratio of scaled articles is exactly equal to the ratio of the activity ratios. Based on this criterion, a comparison of research emphases was created. Table 5 shows the U.S. and Japanese totals, the scaled Japanese totals, and the publication ratio. The publication ratio is calculated as the ratio of the articles published by the "dominant" country to those published by the other. The dominant country is that which has a higher total number of articles after scaling. The negative sign is an artifice used to indicate Japanese domination. Areas of obvious Japanese emphasis include large scale integration (lsi), epoxy resin, electric contacts, and polymer film. Areas of U.S. emphasis include multichip modules, printed circuits, chip carriers, and surface mount technology.

Graphical methods also show publication emphases effectively. Two methods are explored here—a log-log plot of the scaled publication totals and a column chart of the scaled totals.

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[4] *Method 1—Scaled Volume*

Let U be the total number of U.S.-affiliated articles in the database.

Let J be the total number of Japan-affiliated articles in the database.

Let $T_{i,U}$ be the number of U.S.-affiliated articles in a specific technology area, i.

Let $T_{i,J}$ be the number of Japan-affiliated articles in a specific technology area, i.

The ratio of U.S. articles to Japanese articles is U/J. The publication ratio, P, is the ratio of the number of U.S. articles to the scaled number of Japanese articles (assuming U.S. dominance). Then,

$$P = \frac{T_{i,U}}{T_{i,J} \times \frac{U}{J}} .$$

Method 2—Activity Ratios

Define the technology ratio, $A_{i,k}$, as the ratio of articles in a specific technology area, i, affiliated with country k, to the total number of articles affiliated with country k. That is, $A_{i,U} = T_{i,U}/U$. Then the ratio of U.S. activity to Japanese activity is

$$P = \frac{A_{i,U}}{A_{i,J}} = \frac{\frac{T_{i,U}}{U}}{\frac{T_{i,J}}{J}} = \frac{T_{i,U}}{T_{i,J} \times \frac{U}{J}} .$$

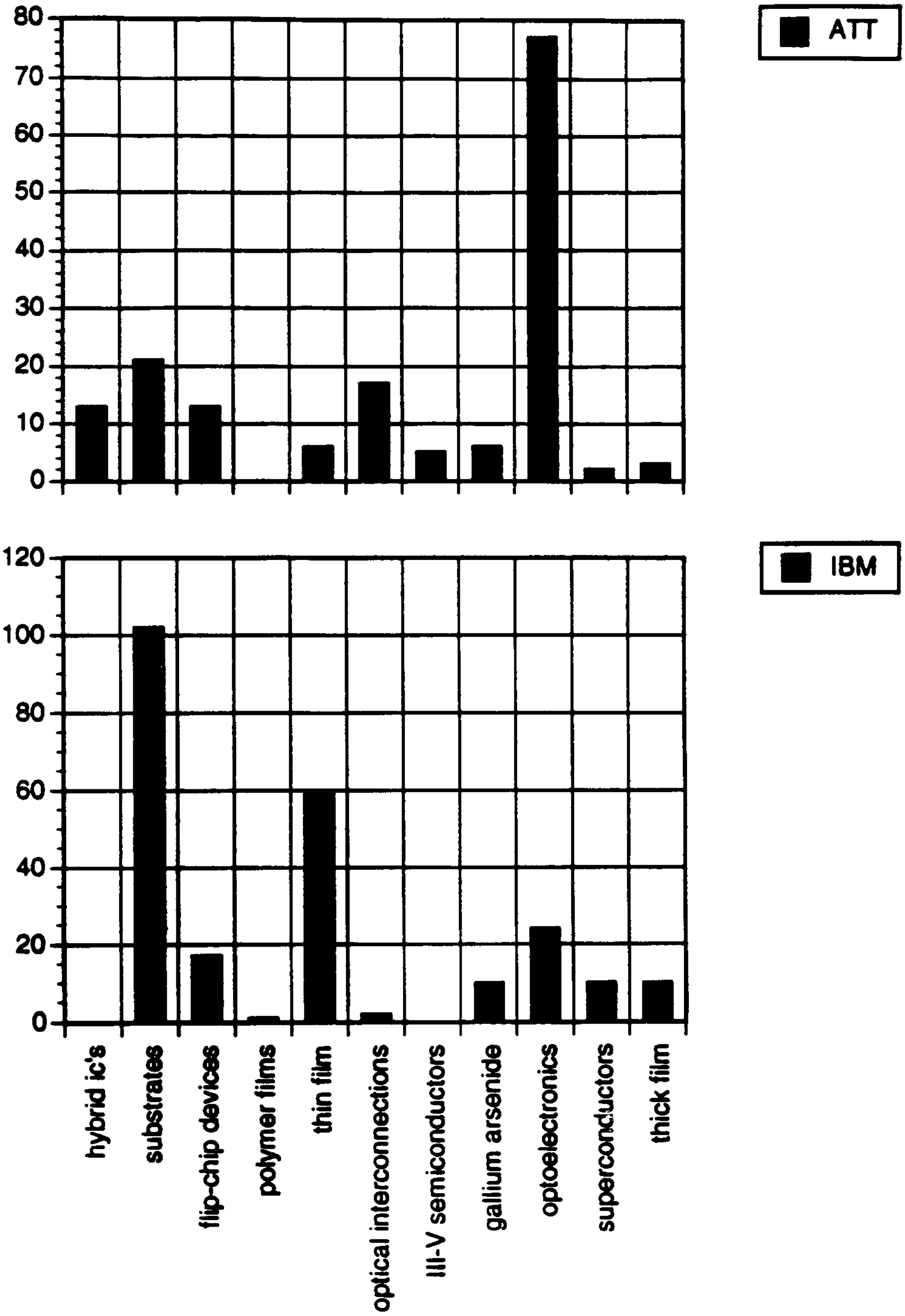

Fig. 1. U.S. patent frequency, IBM and AT&T, multichip module technologies.
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TABLE 4
Multichip Module Article Affiliations
[INSPEC Database]

Country	Number of abstracts	Country	Number of abstracts
USA	965	ITALY	4
JAPAN	90	HONG KONG	2
UK	46	KOREA	2
GERMANY	30	NORWAY	2
FRANCE	27	SPAIN	2
CANADA	14	TAIWAN	2
BELGIUM	8	AUSTRALIA	1
SWEDEN	6	INDIA	1
SWITZERLAND	5	IRELAND	1
ISRAEL	4	LEBANON	1

Figure 2 shows the log-log chart of the number of articles with U.S. affiliation versus the scaled number of articles with Japanese affiliation. The log transformation was used to add clarity to the graph by reducing the "gaps" in publication volume, which result from the inherent nonlinearity. The 45° line indicates equal emphasis. A technology's distance from this line increases with the relative emphasis placed on the technology by one of the countries. Note that this information directly matches that given in Table 5.

The publication profiles are shown in Figure 3. This format directly portrays internal emphases as "peaks" in the publication profile. For example, the United States publishes more articles on the subject of integrated circuits than in any other area. Some of these peaks have been labeled for easy identification. Determining the relative emphasis is only slightly more difficult. Notice that although the publication volumes have not been scaled, the *y*-axes are of equal height. This indirectly scales the totals. Relative emphasis can be seen by comparing column heights. For example, Japan emphasizes large scale integration.

The overall message here is striking—the U.S. and Japan generally compete head to head in electronics manufacturing and assembly interests. The U.S. has not focused efforts in certain domains with Japan emphasizing others; this is not a niche world. Furthermore, the Japanese are actively engaged in R&D in electronics assembly technologies. The old notion that Japan largely borrows from the R&D of other nations is countered by these data.

It is interesting to study recent publication data to identify trends and indicators of emerging technologies. For this section we return to the multichip module data. The cumulative number of articles published in *INSPEC* can be taken as a rough indicator of technological advance, in this case, for the increasing acceptance of multichip module technology. This form of technological advance/substitution may be modeled by a Fisher-Pry curve, one of the family of sigmoidal (or S-shaped) curves. Figure 4 shows a family of Fisher-Pry curves with limits between 1250 and 3000. The actual data, labeled "INSPEC," are the cumulative number of MCM articles. Each of these curves indicates that the publication growth rate peaked between 1991–1993. All forecast an end to the current growth cycle by the year 1996. Note that enthusiasm for multichip module technology by the Japanese would likely start a new period of activity growth. Studying yearly data such as these can help identify emerging technologies early in their growth phase, or can identify technologies reaching maturity.

The final method of data analysis presented is the technology map. A technology map is a two-dimensional representation of the relationships among technologies. The

TABLE 5
Publication Volumes and Ratios USA and Japan [INSPEC Database]

Keyword	USA	Japan	Japan*3.25	Publication Ratio[a]
lsi	833	3361	10923.25	-13.11
epoxy resin	150	233	757.25	-5.05
electric contacts	79	60	195	-2.47
polymer film	2084	1359	4416.75	-2.12
substrate	17889	9972	32409	-1.81
wafer bonding	93	51	165.75	-1.78
ic, cmos	4397	1807	5872.75	-1.34
lead bonding	444	176	572	-1.29
wafer scale integration	502	183	594.75	-1.18
integrated circuit	21500	7238	23523.5	-1.09
printed wiring board	377	126	409.5	-1.09
sc, mos	656	206	669.5	-1.02
pin grid array	127	38	123.5	1.03
ic, digital	4124	1205	3916.25	1.05
semiconductor device	5829	1613	5242.25	1.11
flip chip	362	94	305.5	1.18
sc, bipolar	856	219	711.25	1.20
tape automated bonding	475	117	380.25	1.25
ic, hybrid	1662	359	1166.75	1.42
ball grid array	14	3	9.75	1.44
signal processing	13401	2794	9080.5	1.48
pulsed laser deposition	417	86	279.5	1.49
logic device	415	71	230.75	1.80
laminate	1658	281	913.25	1.82
mcm-c	19	3	9.75	1.95
soldering	1720	262	851.5	2.02
microassembly	7	1	3.25	2.15
pcb	1890	264	858	2.20
surface mount	2414	329	1069.25	2.26
chip carrier	258	31	100.75	2.56
printed circuit	4974	569	1849.25	2.69
multichip module	1022	111	360.75	2.83
mcm-l	41	4	13	3.15
mcm-d	60	4	13	4.62
electronic packaging	2005	75	243.75	8.23
electronic assembly	203	3	9.75	20.82

[a] The ratio is based on the estimate that Japanese researchers produce the same number of articles in these areas as U.S. researchers, but that only 1/3 are included in INSPEC. The ratios shown here were calculated by multiplying the true number of Japanese articles by 3.25, then taking the ratio of the larger number to the smaller. Positive ratios indicate U.S. emphasis, negative ratios indicate Japanese emphasis.

Note that ratios between -1 and +1 are impossible. Absolute magnitudes up to 1.5 indicate roughly equal emphasis.

map created here is based on the co-occurrence data collected earlier. For the purposes of this paper, the strength of the relationship between two technologies is assumed to be reflected by how often they appear together in individual records (co-occurrence). Proximity on the map reflects the similarity of co-occurrence patterns across 36 electronics assembly technologies.[5] Figure 5 shows the technology map for electronics assembly and

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[5] The technology map calculation begins with the matrix of co-occurrence frequencies among the set of technologies. The co-occurrence frequencies are transformed to linearize the data. These data are factor analyzed to determine general correspondence. In this map, the two factors that account for the greatest variance among the 36 technologies are plotted on the x and y axes. These are named subjectively based on which technologies cluster together on each. We have eliminated the scaling on the axes because this adds more confusion than clarification, in our experience. It is possible to examine more than two factors through a series of maps.

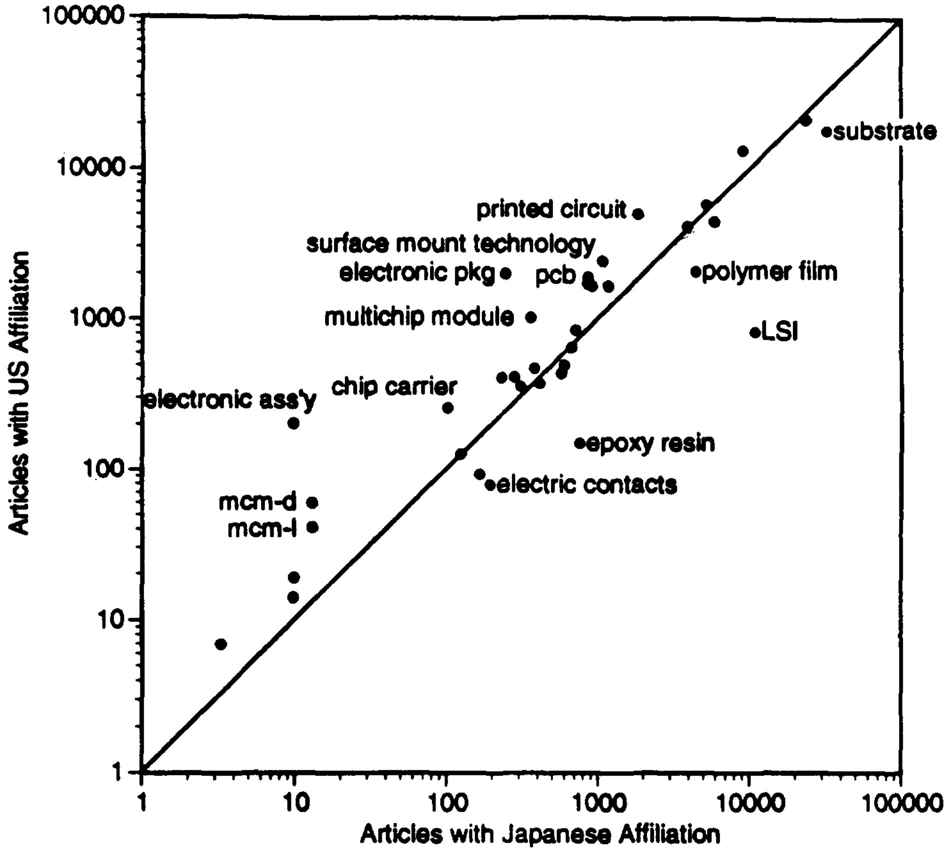
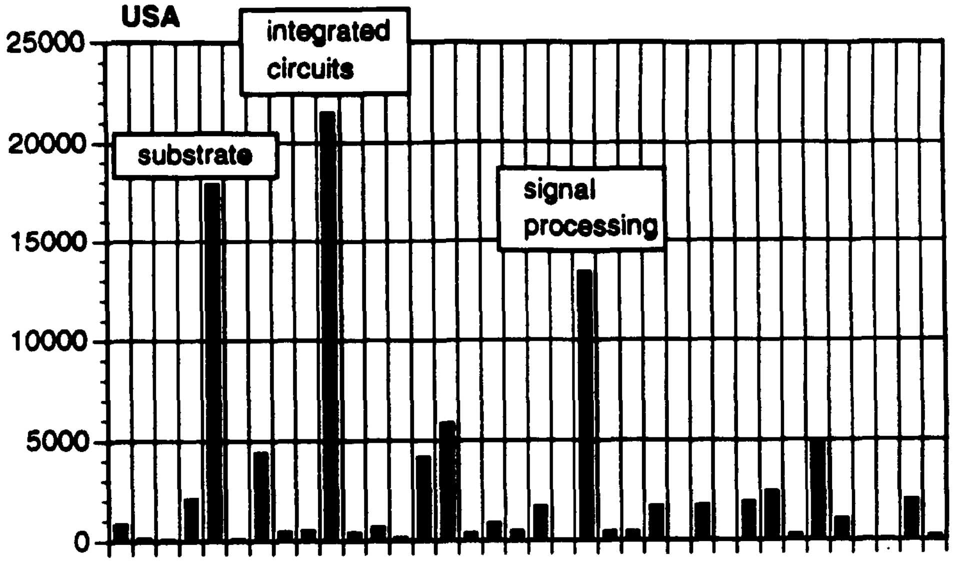


Fig. 2. Log-log graph of scaled publication volumes [INSPEC Database]. This model estimates that Japanese researchers produce approximately the same number of articles in these areas as do U.S. researchers, but that only 1/3 of these are included in INSPEC. The number of articles shown here for Japan is 3.25 times the actual number included in INSPEC.

manufacturing. Notice that the keywords largely fall into two groups, which we have chosen to call "Integrated Circuitry" and "Electronics Packaging."

Figure 6 presents a more detailed view of the Electronics Packaging group. The positioning of the "diamonds" reflects the weighting of the individual terms on each of the two factors. This provides more precise location than the words alone used in Figure 5 (same two factors). Factor analysis empirically yields these two "underlying tendencies" accounting for the greatest variance. The circles reflect our subjective grouping. This clustering helped us focus on subsets of the 36 technologies of primary interest for more detailed explorations (e.g., which companies are most active in the electronics packaging group?).

Updates in technology maps can spot emerging technologies and changing relationships. For example, we overlaid map position in 1992 with that in 1994 to look for changes (not shown). Multichip modules moved from an indeterminate area (between "Integrated Circuitry" and "Electronics Packaging") to become part of the Electronics Packaging Group. This suggests increased MCM application in electronics assembly.



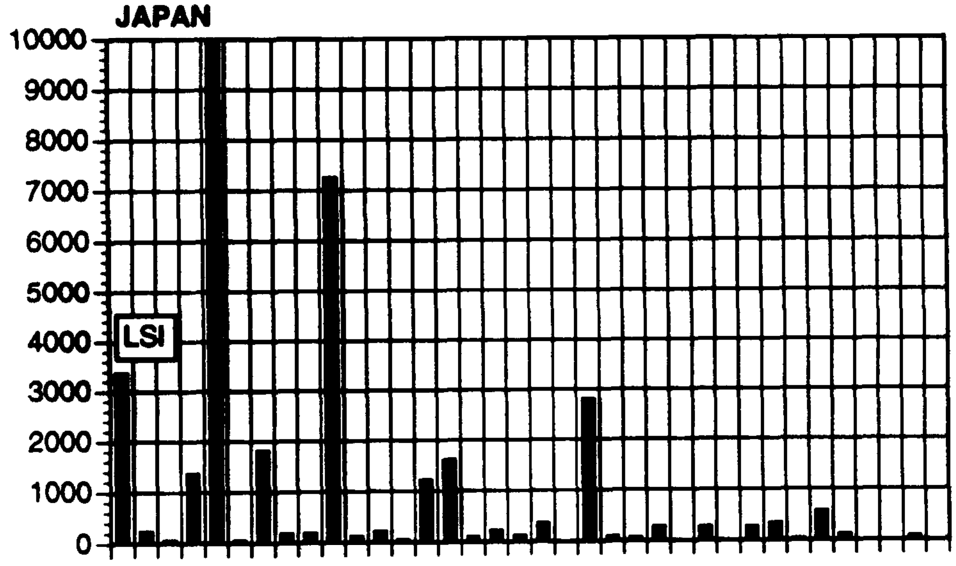


Fig. 3. Publication profiles [INSPEC Database] electronic assembly research profiles.

Discussion

The preceding illustration gives the flavor of technology opportunities analysis (TOA)—a modern version of monitoring based on bibliometric analyses. TOA addresses certain monitoring concerns particularly effectively. For one, the use of public databases may eliminate the need to maintain one's own databases. For another, TOA provides an objective measure of "how much" information is present, within bounds (namely, certain databases). In traditional monitoring the analyst is often hard-pressed to defend a set of information as "complete." The TOA approach, although not claiming completeness, does take a big step toward credibility of coverage. A third advantage comes in

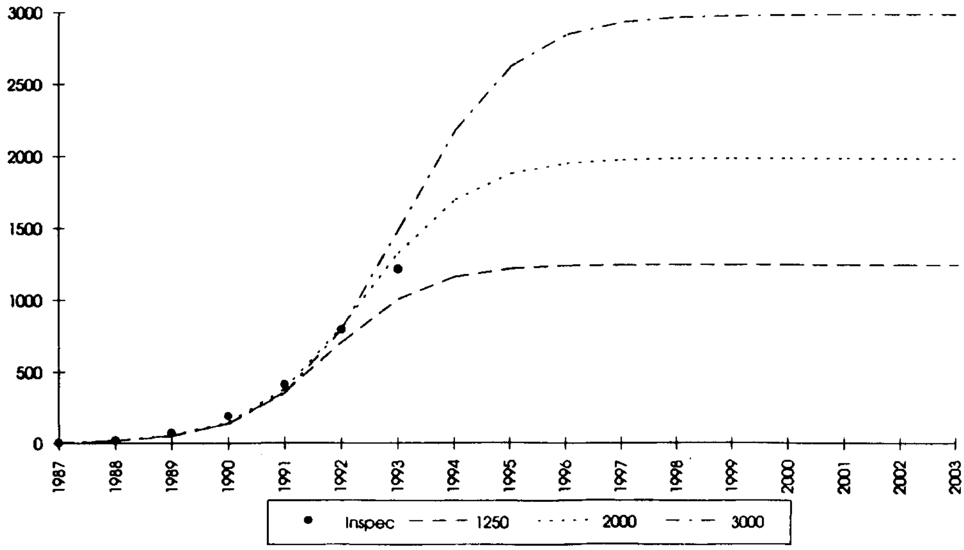


Fig. 4. Family of Fisher-Pry curves multichip modules—cumulative totals [Inspec Database].

interpretation of information. TOA performs secondary analyses of the raw data (abstracts) that can clarify what is happening in ways not possible by rummaging through abstracts or articles. It also lends itself to graphical presentations that summarize great amounts of data.

Figure 7 provides a general flowchart of the steps in conducting TOA. Formulating a good search often takes an initial iteration or two. The total TOA effort can be extremely low or considerable, depending on the issues probed and the detail desired. Few or many specific analyses may be in order. A major advantage lies in providing overviews, graphical or tabular, that allow managers to quickly grasp significant patterns. An interesting option is to update a TOA periodically to identify what's new and to profile changes over time (e.g., the entry of a new player; the appearance of a newly linked technology in a given area).

TOA adds to traditional bibliometric analyses in several key ways. First, it draws on a widely available, immense data resource "at our fingertips"—abstract databases. These offer far sharper topical coverage than, say, co-citation analysis, which is limited to very particular databases. Abstract databases are more accessible and better focused than whole text co-word analysis, dependent on acquiring whole text electronic databases.

Second, TOA is less constrained by imposed classifications as its searches use inductive, Boolean formats (e.g., MCM within 3 words of IBM). One can differentiate deductive from inductive search frameworks. For instance, most patent analyses deductively resolve on determination of the appropriate patent categories (prespecified by the producers of the patent database). In contrast, TOA usually begins with initial crude searches on the nominal target term. These are refined by scanning keyword cumulations for those initial searches to identify pertinent related terms on which to search in addition to, or instead of, the nominal target term. In this vein, Kostoff's whole text searching is even more inductive. He compiles word frequencies across the target database from which the user selects terms to create a taxonomy for the research thrust of interest. Kostoff then extracts words and phrases that occur physically close to those thrust terms [23, 25, 30]. His

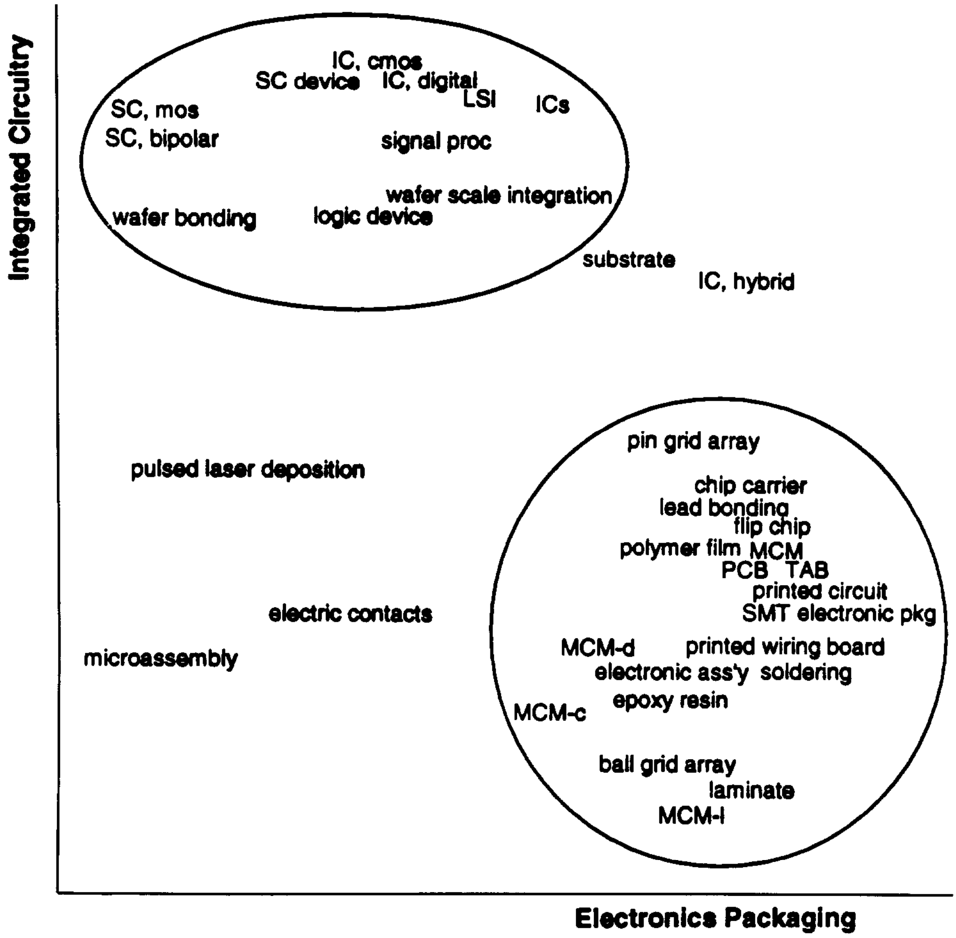


Fig. 5. Technology map [INSPEC Database] electronics packaging and integrated circuitry. Note: Some of the keyword positions have been altered slightly to improve readability.

approach could be applied, for example, to explore in depth a text database of proposals in a given research area.

Most significantly, TOA lends itself to a wide range of applications. It can contribute to strategic issues. For instance, we have performed analyses for the Critical Technologies Institute on aspects of metal casting. We were able to show dramatic downturns in U.S. research in this domain, not unlike patterns in Japan and Germany, but contrasting with increases in Russia and China. We showed that within the U.S. over the past 5 years, R&D in this area shifted dramatically from industry to academia.

On the other hand, TOA can zoom in on more tactical, managerial issues. For instance, we have performed studies for particular companies on particular technologies. Our analyses of "handheld computing" for one company included:

- plots of activity in wireless computing by selected companies, over time;
- identification of applications for handheld computing;
- contrasts among the selected companies in terms of relative publishing and patenting emphases.

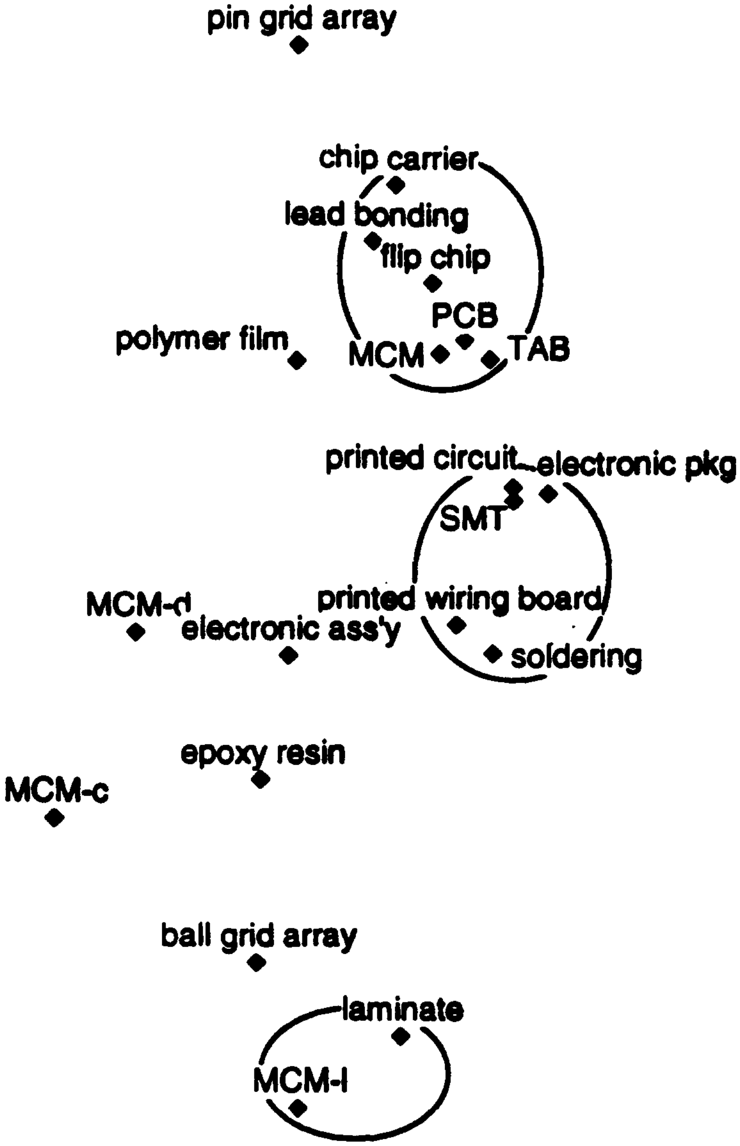


Fig. 6. Technology map zoom [INSPEC Database] electronics packaging.

TOA compliments other analytical approaches. It can help identify experts in a given technology to facilitate "networking"; and, in turn, be enriched by expert opinion. We are working with colleagues to explore ways in which TOA, in-depth patent analysis, and citation analysis can work together to present richer information profiles. An obvious enhancement would be to combine TOAK database-derived information (offering broad coverage) with Internet searching (unmatched for recent advances).

We are exploring further TOA development along several axes. We are working to embellish the searching capabilities with primitive "intelligence." For instance, our scans of affiliations include an option for "fuzzy" matches to help consolidate alternative forms

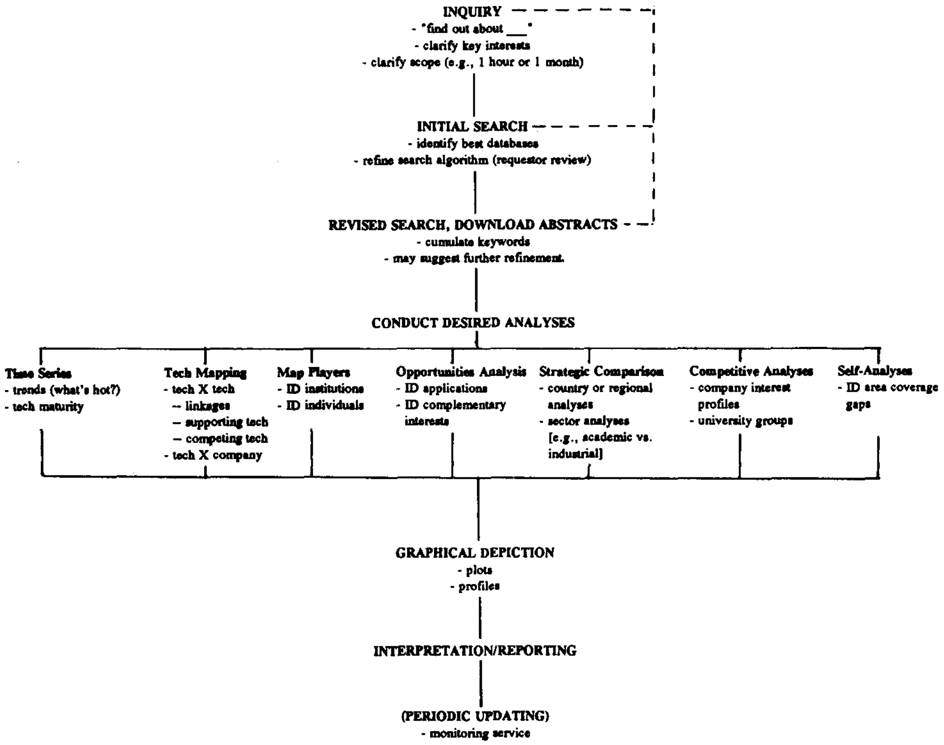


Fig. 7. Technology opportunities analysis flowchart. Note: "tech" = technology; "ID" = identify.

of a given institution's name. A major distinction looms between our performing TOA for others as a service and developing self-service forms. We have just begun research in collaboration with Search Technology, Inc., to embed TOA-like functions with information retrieval capabilities for one's own databases, strategic planning, and presentation management capabilities to aid R&D program managers.[6] Interesting issues present themselves in terms of autonomy (how much iteration should there be with the user versus embedded intelligence in the software?) and functionality (what information does the user want?).

Another development option moves from using TOA for one-time analyses of given topics to establishment of a technology-monitoring program. TOA provides several capabilities to monitor a technology, as well as to identify which technologies deserve to be studied on an ongoing basis. Keyword lists (e.g., Table 1) updated regularly can pinpoint terms that have recently emerged or are growing in usage. Growth curves (e.g., Figure 4) should be updated regularly to track a technology's location in its life cycle as such projections are highly dependent on the limit parameter and the most recent data point.

Technology Opportunities Analysis provides a new tool to efficiently and effectively use the vast amounts of data available in electronic publication databases to identify emerging technologies and related business opportunities.

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[6] Project on *Strategic Planning Tools for ARPA Managers,* Phase I Advanced Research Projects Agency STTR award, 1994–1995.

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