Emerging Technology Intelligence: Scanning and Monitoring for Strategic Planning

by

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Submitted to the Alfred P. Sloan School of Management
in Partial Fulfillment of the Requirements for the Degree of

Master of Science in the Management of Technology

at the

Massachusetts Institute of Technology

February 2004

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Abstract

In recent years we have seen a confluence of science and technology that portends great impact to business strategy and product development. Just as physicists, chemists and biologists have extended their knowledge to other fields in pursuit of their own research, so, too, must senior business managers extend beyond competency in finance and marketing to comprehend fundamental scientific principles in order to make strategic business decisions. In addition to technical knowledge specific to their particular industry, successful leaders of the very near future will have to understand the ebb and flow of new technology discoveries "emerging" from the lab to the market, and will skillfully leverage these dynamics to navigate their companies through waves of innovation.

The speed of scientific discovery and the convergence of multiple technologies to influence a single product create a compelling argument for corporate investigation of a range of emerging technologies and tracking of developments in multiple industries. "Technical intelligence" is knowledge, derived from analysis of appropriate metrics, trends and activities, which informs strategic planning and decision-making.

This research surveys the academic literature and examines some methods and tools for gathering and employing technical intelligence. We conclude that an amalgamation of strategic evaluation methods, but especially scanning and monitoring, can and should be used to effectively develop an objective, simple, and descriptive view of technology emergence that captures activity, momentum, and ultimately, viability, of emerging technology over time.

Thesis Supervisor: James M. Utterback
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Introduction

In recent years we have seen a confluence of science and technology that portends great impact to business strategy and product development. Synergistic and collaborative research has advanced the "severe sciences" (physics, chemistry and biology) beyond traditional boundaries to create entirely new scientific fields such as genomics, the study of gene sequences, and nanotechnology, the study and manipulation of matter at the atomic level.

Just as physicists, chemists and biologists have extended their knowledge to other fields in pursuit of their own research, so, too, must senior business managers extend beyond competency in finance and marketing to comprehend fundamental scientific principles in order to make strategic business decisions. In addition to technical knowledge specific to their particular industry, successful leaders of the very near future will have to understand the ebb and flow of new technology discoveries "emerging" from the lab to the market, and will skillfully leverage these dynamics to navigate their companies through waves of innovation.

Who would have predicted that tennis balls would be among the first beneficiaries of nanotechnology innovation? You can bet it wasn't the sporting goods competitors, though now they are investigating the technology. Tire manufacturers and the U.S. Department of Defense are also interested because the primary performance characteristic is preventing air leakage.

> Inmat Inc., a leader in nanocomposite barrier coating technology, counts sporting goods companies, tire manufacturers and the U.S. Army among their customers and product development collaborators. Wilson Sporting Goods applies the proprietary coating material to the inside of tennis balls which more than doubles their useful life by greatly slowing air pressure dissipation. The same technology is being evaluated for car and truck tires to improve traffic safety and fuel efficiency as well as a chemical barrier

> mechanism for gloves and other external clothing used by soldiers working in toxic environments (www.inmat.com).

And pants?

> Nano-Tex, LLC has revolutionized the characteristics of textiles by manipulating the molecular structure of fibers to be repellant to liquid and oil as well as resistant to wrinkles and stains. The success of the new fabric is credited with pulling the parent company, Burlington Industries Inc., through Chapter 11 bankruptcy protection and leading the company to global licensing opportunities and crucial new markets in Asia and the Middle East. It is not surprising to note that DuPont is now working to adapt its Teflon technology for clothes (Stuart 2003).

The speed of scientific discovery and the convergence of multiple technologies to influence a single product create a compelling argument for corporate investigation of a range of emerging technologies and tracking of developments in multiple industries. While successful innovators have always maintained an awareness of technical evolution, many compensated for lackadaisical or fragmented reconnaissance programs by leveraging their existing assets and taking advantage of the time lag due to delays in market response.

Historically, low levels of detail and vague projections had to be sufficient because of limitations of available information. The moderate pace of technical development allowed companies to respond just as technology was ready for commercialization. Sources of potential disruptions for a particular industry were usually concentrated in one or two areas.

All of this has changed. The advent of revolutionary discoveries in the "severe sciences" has launched new disciplines: biomedical engineering, microphotonics, silicon biology, nano-scale materials, pervasive computing, bioinformatics, and molecular machines, to name but a few. Each generates gigantic stores of electronic data and research. All are advancing at a blistering pace. And many will have application in ways we can only begin to imagine.

Why should this matter to business leaders? Because emerging technology will create disruptions on every link of the value chain from research, product design and development, and fabrication through delivery and support. Even the very nature of organizational structure and process is threatened. (Think Internet in the 1980s multiplied by a few technologies emerging at once.) Unprepared executives will be left out as new products and business models sweep in.

The good news is that there is plenty of time to prepare and a tremendous wealth of information to mine. Fortunately, tools to access and analyze that data are also available. The job ahead is to formulate a plan and develop a method that will provide the data in a format that is sufficient for strategic thinking.

However, firms are notoriously unsophisticated and informal in their approach to technology intelligence. In spite of the recommendation of a vast literature spanning three decades, companies are hesitant to implement formal data gathering, analysis and dissemination processes and typically rely instead, on the initiative of individuals within the firm, expensive consultants, or industry analyst reports.

Many studies tend to forecast the future based on expert opinion; a subjective and inexact method. Indeed, roadmapping has become a business education buzzword as research analysts, industry leaders and senior scientists make proclamations about the market value of new discoveries. Pundits may employ analytical models and other mechanisms to arrive at objective evaluations, but because they rarely publish their methods, it is difficult to evaluate their findings. Most rely on the acuity of previous predictions or the reputation of their employer for credibility. Of the models that are published, very few are reasonably intuitive and potentially useful in a decision-making context. Many are tremendously complex and difficult to grasp as a concept, let alone filled with data. We conclude that it is best to understand the origin of the data and to collect it yourself if you have to. This paper includes a review of various models and presents academic literature that describes some of these challenges.

The purpose of this paper is to examine some methods and tools for gathering and employing technical intelligence. We begin with definitions of key emerging technology constructs from the academic literature and present advanced innovation concepts. We review forecasting tools and analyze the utility of two three-dimensional data models followed by a discussion of scanning and monitoring approaches. Five measures are presented and explored to illustrate the value of metric analysis, although different elements or simply a subset may be more appropriate for a particular exercise, depending on the technology under consideration or the purposes for analysis. Finally, we consider the challenge of data presentation and offer some suggestions for further study.

We conclude that an amalgamation of strategic evaluation methods, but especially scanning and monitoring, can and should be used to effectively develop an objective, simple, and descriptive view of technology emergence that captures activity, momentum, and ultimately, viability, of emerging technology over time.

Emerging Technology Definitions

Technological Paradigms and Technology Trajectories

Italian economist, Giovanni Dosi, provides some emerging technology definitions that are as relevant today as when he wrote them in 1982.

> ***Technology*** is "a set of pieces of knowledge both directly "practical" (related to concrete problems and devices) and "theoretical" (but practically applicable although not necessarily already applied), know-how, methods, procedures, experience of successes and failures and also, of course, physical devices and equipment."
>
> It "includes the "perception" of a limited set of possible technological alternatives and of notional future developments." He further defines a ***technological paradigm*** as a "pattern of solution (sic) of *selected* technological problems, based on *selected* principles derived from natural sciences and on *selected* material technologies."

Dosi suggests that within the technological paradigm there exists a "positive heuristic" and a "negative heuristic" which guide the direction of technical change. That is, technical solutions that are accepted by the community and used to build new ideas or platforms become part of the "technology." Those that are rejected or simply ignored do not. These distinctions are useful when discussing momentum or ***technical trajectories***, the pattern of "normal" problem solving activity (i.e. of "progress") on the ground of a technological paradigm." (Dosi 1982)

We will find that evaluating technical trajectories can be a tremendously powerful exercise for understanding the viability of a technology paradigm.

Technical Intelligence

Academic authors on the topic present various definitions of technical intelligence and refer to it both as the information or knowledge itself as well as the process used to gather and process that information. Regardless of the perspective, they agree on key components: data gathering and analysis is an ongoing process and the knowledge derived from related activities provides information required to achieve competitive advantage. A sampling of definitions from the literature is provided below:

> Technical intelligence is business-sensitive information on technical events, trends, activities or issues that has sufficient competitive value to warrant special protection and handling against unintended disclosure or misuse (Ashton and Stacey 1995).
>
> Technical intelligence refers to the "practice of finding, analyzing and using the best information on technical developments, events and trends" for the following purposes:
>
> - to provide early warning of technical developments or company moves that could adversely affect the prospects for business success in an organization;
> - to identify new product, process or collaboration opportunities for a business created by changes in the scientific or technological environment;
> - to understand technical events or trends and the related competitive environment, as preparation for addressing potential threats to current or future products and markets and for exploiting significant new opportunities (Porter, *et al.* 1991).
>
> "The goal of technology intelligence is to exploit potential opportunities and to defend against potential threats, through prompt delivery of relevant information about technological trends in the environment of the company. Technology intelligence encompasses the activities related to the collection, analysis and communication of relevant information on technological trends to support technological and more general decisions of the company" (Lichtenthaler 2003).

Emerging Technology

We need a working definition of emerging technology to set an expectation baseline that limits the scope of this discussion, specifically stating what is *not* under consideration. For our purposes, ***emerging technology*** presents a concept, proven with scientific principles, that may or may not employ additional science to create a useful product that someone is likely to pay for. (Thus, the nanotechnology space elevator is *not* included.) This simple description will guide us in selecting the technologies to review and will describe the technology paradigm concept we will use to limit the boundaries of a technology intelligence exercise.

Innovation

"Most technology-based innovations are in fact part of a continuum of change."

(Utterback 1994).

If technological innovation moved along at a prescribed pace and developed only predictable improvements, companies could execute long-range strategic plans without the need for review or revision. This prospect, however, is absurd because new technology almost always appears at irregular intervals with influence that is unknown until the market evaluates the implications and accepts, rejects or applies the solution in new ways. Competition exists both between old and new technology and also among new technologies as the market demand is determined.

Once market acceptance of a product feature set is established, the dominant design emerges and sets the minimal requirements for a technology. Sustaining innovations are improvements on that dominant design that enhance the feature set and propel the technology along its current trajectory. Disruptive innovation, on the other hand, threatens an existing product with an entirely new feature set that may initially seem inane but eventually takes over a market.

Dominant Design

A ***dominant design*** is "the one that wins the allegiance of the marketplace, the one that competitors and innovators must adhere to if they hope to command significant market following (Utterback 1994). Acceptance of a dominant design reduces the uncertainty of market demand and decreases competition almost immediately as providers of products with un-adopted or non-dominant features leave the market. Demand for the QWERTY keyboard on typewriters and VHS versus Betamax videocassette recorders illustrate the point.

Sustaining Innovation

Some innovations provide a simple enhancement to a product feature or process. These ***incremental innovations*** have minimal impact on the strategic planning of individual industry players as they are easily anticipated and incorporated. Radical innovation along the trajectory, or ***technical discontinuity***, represents a major departure from the current technology resulting in a sweeping change in "a firm's existing investment in technical skills and knowledge, designs, production technique, plant and equipment" (Utterback 1994). Incumbents who are unaware of a disruptive innovation or fail to anticipate the impact of change are often left without an alternative strategy and are forced to exit the market. Utterback continues with some well-known examples that clearly illustrate the point: Typewriters – manual to electric typewriters then dedicated word processors followed by personal computers; Lighting – oil to gas lamps to incandescent lamps to fluorescent lamps. In each of these cases, major competitors were not able to adapt to the new technology and did not survive the evolutionary change.

Disruptive Innovation

Clayton Christensen continues Utterback's work with a discussion of ***disruptive innovation***, the emergence of a new feature set that underperforms, costs more and is generally undesirable to the majority of profitable customers (Christensen 1997). A small number of users typically adopt disruptive innovations for unusual or alternative uses that gain momentum and attractiveness as more creativity is applied to product development and application alternatives. During a period of disruption the range of technical possibility is wide open and competition increases. Incumbents often misinterpret the potential impact and dismiss the threat of a disruptive technology because it does not appear to have immediate relevance to their desired market or prescribed strategy.

Innovation Life Cycle

Innovation across a number of industries happens in predictable ways along multiple dimensions. In his classic text on innovation, Utterback defines the Dynamics of Innovation model for product, process, organization, and industry developments along a three-phase timeline.

1. **Fluid Phase** – rapid product development, great uncertainty and high risk are prevalent. Product development is the primary innovation focus. Organization is entrepreneurial and informal. Competition is increased by imitators;

2. **Transitional Phase** – dominant design emerges and innovation focus shifts to process. Organizational control becomes more structured. Firms begin to exit;

3. **Specific** – product and process innovations become incremental and tightly coupled. Organization is mature with formal structure. Few firms remain.

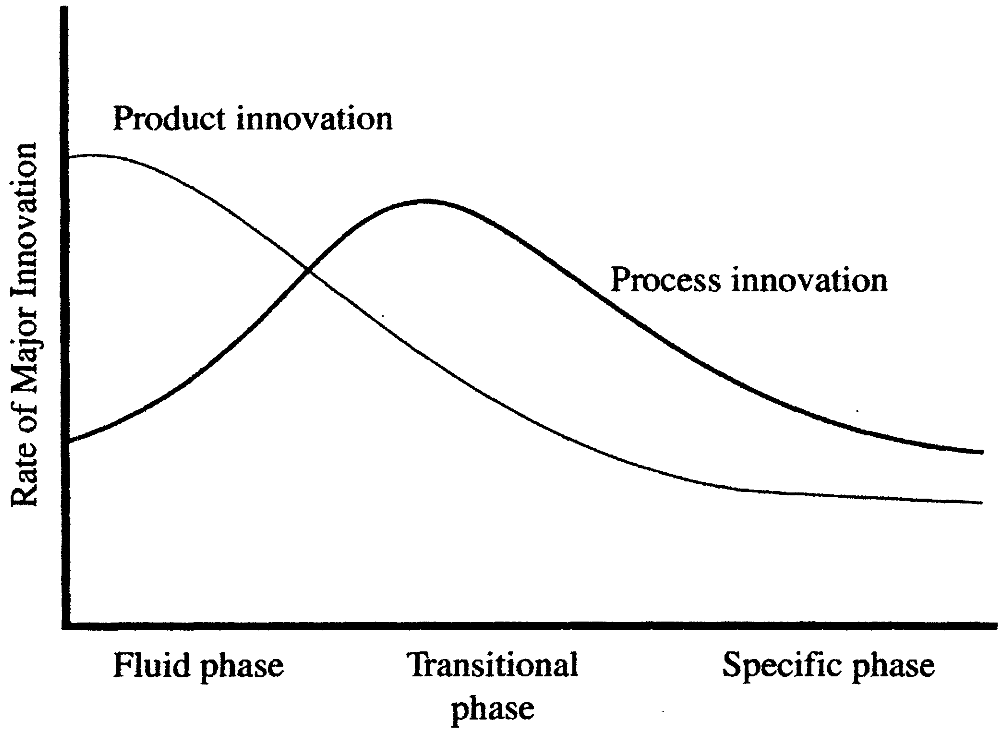

Figure 1. Abernathy-Utterback model of the Dynamics of Innovation (Utterback 1994).

This model is important because it shows the interrelationships between product and process innovation that are common across multiple industries, repeatedly, over time. It also illustrates the importance of the dominant design on the innovation cycles and addresses the entry and exit of competitive firms.

Similarly, technology paradigms typically emerge over a somewhat predictable life cycle with at least three components:

1. **Science** -- Fundamental Research / Scientific Discovery
   *indicates to the market what is **possible***

2. **Technology** -- Applied Research / Product Design and Development
   *provides bi-directional feedback to both the scientific community and the market about what is **feasible***

3. **Production** – Commercialization / Distribution / Sales
   *informs the scientific community about **accepted** applications and additional **potential** problems to solve for the market*

Hariolf Grupp uses the relationship among these three curves to describe innovation dynamics along eight phases. While his assessment is based on empirical data, he cautions that this particular depiction is a stylized model to fit a general description rather than an explicit representation of a particular product or industry.

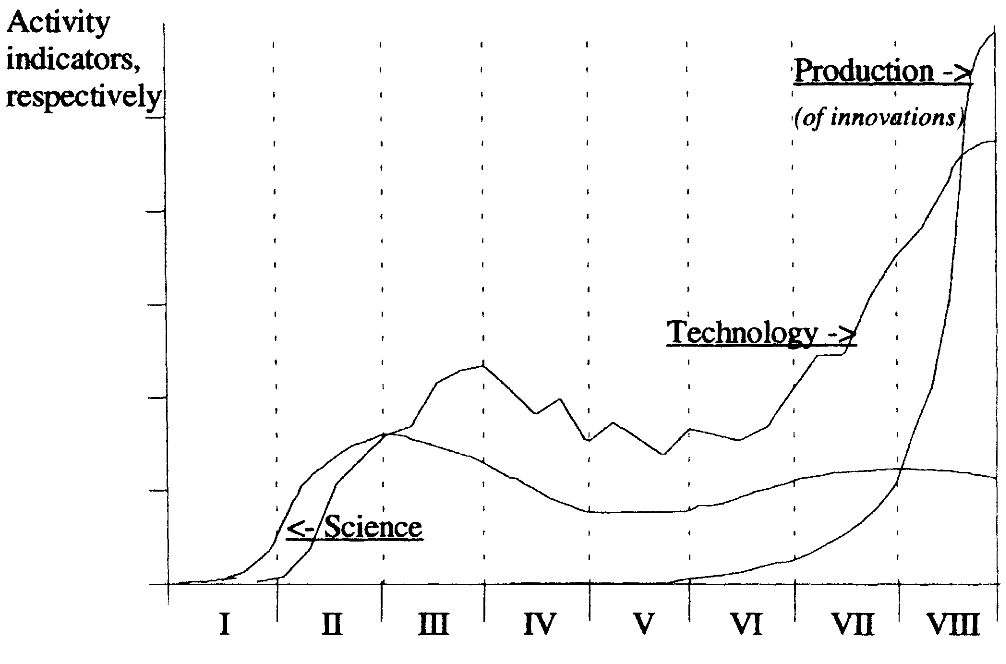

Figure 2. Reference scheme for classifying scientifico-technical progress in market formation using eight idealized standard situations (the plots of the curves representing the magnitude of the respective activities have been chosen arbitrarily.) (Grupp 1998).

I: First explorations in the scientific domain.

II: Properly developed science; first technical achievements.

III: Science fully developed; technology still capable of extensions; prototypes.

IV: Difficulties discernible in economic transposition.

V: Temporary stagnation in science and technology; reorientations.

VI: Industrial R&D envisages new possibilities; but still capable of expansion.

VIII: Penetration of all markets; importance of R&D waning relative to turnover. (Grupp1998.)

We can use this representation to see the interrelationship among the curves and see how progress along one dynamic influences the others.

- **Science** – Initially experiences slow then exponential growth, which drops off dramatically as basic science is understood. A slight surge indicates process innovation then declines as technology innovation tapers and production enters steep ascent or **"take-off"**.

- **Technology** – Emerges as science enters take-off then hits a peak and tapers or oscillates as technical difficulties are identified and resolved.

- **Production** – Emerges with prototypes as technology and science stagnate and experiences "take-off" as technology innovation enters the final surge.

With an understanding of the innovation life cycle dynamics, we can observe the technology develop in a structured way, thus enhancing our technology intelligence and building a knowledge base needed to formulate strategic plans. In essence, we can apply the technical intelligence to an innovation model to analyze the current position and forecast potential trends or pathways of development.

Technology Intelligence

Purposes for Study

Technology innovation simulates economic growth

MIT Professor and Nobel laureate, Robert Solow, determined in 1957 that technological progress was responsible for most of the increase in the U.S. standard of living, crediting 87.5 percent of increased output per capita from 1909 to 1949 to technological change. In 1990 Michael Porter noted that a nation's competitiveness depends on the capacity of its industries to innovate. Devendra Sahal integrates Schumpeter (1947) and Schmookler (1966) with this observation: "...technology both shapes its socioeconomic environment and is in turn shaped by it. Neither is a sole determinant of the other; rather, the two codetermine each other."

If the ability to confront technological change is a key indicator of firm success (Cooper and Schendel 1976, Foster 1986, Ashton and Stacey 1995, Iansiti 1995), then management capability to understand the evolution of emerging science and devise strategic plans to incorporate new technologies in their product offering, production process and service delivery becomes not only a competitive advantage but a required core competence. Ultimately, it is management decisions and not environmental factors that determine the success or failure of a firm (Christensen, Suarez, Utterback 1998). So, it is the responsibility of senior managers to guide our economy through the maze of high technology and choose well among the many available options.

Technical Literacy in Management

But how can management make decisions related to technology if they are not sufficiently aware of the environment in which they operate? Increasingly, strategies for potential competitive threats, technology investment, resource allocation, product development and collaborative partnerships are key internal policies (Ashton, *et al.* 1991, Ashton and Stacey 1995) that will define the firm's objectives and operating plans. These must be informed decisions.

Senior managers are used to trusting their intuition or "gut" to make decisions. Hopefully, that intuition comes from experience, a firm grasp of the facts, knowledge of the social and political environment and a clear idea of the principles guiding the company. They typically rely on advice from their scientists and management teams as well as hard data to inform their intuition. ***That data, more than ever, is based on emerging technology.***

Since scientific discovery precedes most, if not all, new technology developments (Grupp 1998), it logically follows that analysis of scientific progress provides a more conscious awareness of the innovation paths to real applications (Coates, J.F 2001).

Michael Rappa and Koenraad Debackere describe the work of researchers as three-fold:

1. They produce information;
2. They transform information into knowledge, or in other words, they solve problems;
3. They communicate information and knowledge to each other.

He proposes that the "rate of progress in a technology's emergence is a function of how quickly problems are solved, which in turn, depends on the amount of information produced." The more information available, the more likely useful solutions to a wide range of problems will be discovered (Rappa and Debackere 1989).

We can extrapolate that thought to include strategic direction: the more information or technology intelligence available to the strategist, the more solid his basis for decision making through more options to choose from and increased confidence that he has considered the major contingencies.

Just as successful managers currently wield a command of finance, accounting and marketing, a fundamental understanding of science is becoming an essential element of the leadership repertoire (Brockley, *et al.* 2003). As technology decisions are further integrated into business strategy, technical literacy must move up the management chain, even to the board level (Coates, *et al.* 2001) so the language of business can expand to include scientific concepts. Whether they choose to hire consultants or build internal innovation monitoring capability (Bright 1970), managers must be aware of emerging technologies in a variety of fields so they can anticipate technological change and remain competitive in tomorrow's market.

Every actor operating within a technology paradigm, including research scientists, engineers, marketing managers and senior executives, can derive useful information and knowledge from studying particular metrics available across the entire innovation spectrum.

The Time is Now

Innovation streams are increasingly unpredictable and a single scientific discovery must have many applications if it is to be commercially viable. So, seemingly unrelated research may have implications and potentially radical impact to well-established, mature product lines. Therefore, a wide investigative net must be cast across a range of technology paradigms.

Because the rate of technological progress continues to accelerate, firms that adopt a "wait and see" approach will eventually lose to those more proactively searching for new and innovative ways to meet market demand (Ashton and Stacey 1995). However, the pace of modern business, the need to resolve immediate issues, the awareness required to survive in our online, real-time world often lead us to focus solely on the short-term (Grupp and Linstone 1999).

> "Harold Linstone, in his years of scientific and technological research, observes that we have a near universal tendency to discount the future – that is to assign less and less importance of likelihood to events the further they are from us in time. The results of this are that we are often unable to see big changes, foresee impending negative consequences or anticipate enormous benefits in the future." (Coates and Coates 2003).

Therefore, it is of the utmost importance to gain and keep a firm grasp on the current state of important emerging technologies…starting immediately! There is plenty of time to observe science transform into applicable technology (Bright 1970), if you start early and observe the story as it unfolds.

Expectations for Learning

Timing

Timing the entry to market or adoption of technical innovation is a key success factor (Christensen, Suarez and Utterback 1998, Mitchell and Singh 1993) for high technology companies. Enter too early and you risk spending precious resources climbing a steep learning curve that may never pay off or choosing an inferior trajectory (Lieberman and Montgomery 1988) that falls short of the dominant design. Enter too late and you risk facing insurmountable barriers like R&D "catch-up" and customer loyalty to the new incumbent. Christensen, Suarez and Utterback (1998) describe a "window of opportunity", just before the emergence of a dominant design as the optimal time to enter a fast-changing industry. Since it is impossible to know the precise timing of the emergence of a dominant design, a clear understanding of a technology trajectory places a realistic timeframe around the market readiness of a technology and positions a firm to capitalize effectively.

Timing is also crucial for technology adopters or other parties who provide supporting assets like manufacturing capability or distribution channels. Prior to making a substantial investment in or commitment to an emerging technology, the early adopter would do well to thoroughly understand the technology paradigm and evaluate the trajectory closely as many of these decisions are irreversible (Choi 1994). Knowing when to wait can be as much a strategic advantage as getting a head start.

Threatening Technology

Discontinuous and disruptive innovations always threaten the status quo and can be most detrimental to the unwary. Incumbents who listen too closely to their customers and settle for an incremental improvement strategy are often left with extremely functional but unwanted products (Christensen 1997). In this case, a core competence becomes a strategic liability. Identifying a true discontinuity or disruption is never an exact proposition until after the market impact can be measured, which is too late for consideration in strategic plans. Once initiated, discontinuities and disruptions happen quickly and do not allow sufficient time for incumbents to design, develop and deliver an adequate response.

Those who are prepared, however, are perfectly positioned to capitalize on new opportunities.

Incremental improvement in product performance or cost reduction may have wide and deep ramifications on economic value, market share and ultimately, success or failure of the firm. Take, for example, Nano-Tex, described in the introduction of this paper. Adoption of the nanofiber technology in clothing did not change the style or function of the garments in any perceptible way; it simply reduced maintenance efforts like ironing and washing. But demand for the new features was so great, the company was rescued from the brink of failure. Identifying the potential of this new technology and adopting it just as it was ready saved the company. And potential competitors, e.g. DuPont, who find themselves in the unenviable position of scrambling to catch up, are scouring their intellectual property portfolios for solutions (they probably already have but previously ignored) that will answer this new challenge.

This raises an ancillary point – awareness of the emerging technology landscape, including both the problems and prospective solutions, can provide signals that existing but dormant capability or assets may provide value in new ways. For example, pharmaceutical companies are reviewing their chemical compound libraries for molecules that were effective for a subset of patients but rejected by federal regulators because toxicity levels for another subset were unacceptable. Developments in genetic analysis and testing provide tools to identify which patients have genetic disposition to benefit or harm from a drug so they can be targeted or avoided accordingly.

Corporate structure and organization

Discontinuous or disruptive product innovations, especially those that alter the "architecture" or way components are linked together (Henderson and Clark 1990), can dramatically impact the corporate structure or organization of the firm. Entire divisions as well as internal processes and communication pathways are established and strengthened based on market delivery requirements for core products and services and evolve in concert with efficiency and cost reduction initiatives. Dramatic or extensive product change forces organizations to rationalize those corporate processes and communication pathways when, in the face of new technology adoption, they are unable to respond efficiently. This can have a devastating effect on the unprepared firm as they struggle to rebuild or implement new systems at the same time they are responding to a more demanding market.

Henderson and Clark caution that corporations, like people, rely on embedded knowledge about the world as they know it. Established firms often misunderstand the impact of new technology paradigms and radical innovation because they are using a view crafted from the previous technology generation. They further suggest that successful exploitation of architectural innovation often requires equally radical or at least different, strategies and organization structure.

Organizations that evolve at the rate of technological change have improved prospects for survival (Utterback and Abernathy 1975, Cooper and Schendel 1976). Corporate agility, therefore, is dependent on disciplined evaluation of current data, correct interpretation of the findings, and the ability to put that knowledge to effective use.

Competitive Analysis

"Know your competitor" is one of the oldest recommendations in the annals of business advice. Competitive analysis should not be limited to competitors' activities but must include their short- and long-range strategic plans and commitment of resources (Utterback and Brown 1972). Those intentions, indicated by research grant awards, venture funding, investment strategies, strategic alliances for joint research efforts and product development are available in the public domain, usually in the form of press releases and news services.

It is no longer sufficient to rely solely on expert opinion from research analysts and technology pundits for competitive industry analysis unless they expose their methods to reveal a similar approach to metric analysis. This scenario is highly unlikely as such action would dilute their own competitive advantage. Besides, competitors are reading the same reports, which give you parity at best. Senior management must have better intelligence to stay ahead.

> "...management should be willing to allow new or experimental strategies, and should carefully monitor the approaches that are pursued by other entrants. Appraising the strategies of new competitors may be especially important, since they will often possess different resources and skill, different ideas about how to compete, and little interest in the status quo. Overall, the conventional wisdom may no longer apply. Those who view an emerging young industry through the lens of their experience in an established, threatened industry may see what is familiar more clearly than what is different." (Cooper and Smith 1992)

Theoretical Models and Practical Methods

Common Practice

Although the benefits to be gained from technology intelligence are well known and generally accepted, there is little documented evidence or published literature to describe successful methods or actual results (Ashton, *et al.* 1991, Hauptman and Pope 1992). Multiple theories and complex models are well documented in academic literature, but few have practical application in real business settings. Many corporations have little concept of formal technology assessment and very few pursue formal initiatives to gather and analyze technology intelligence. Most rely on individuals' judgment and personal pursuit of emerging technology evaluation. Participants in one study for the U.S. Congress Office of Technology Assessment, indicated planning departments typically used informal assessment practices to aid in planning exercises but none attributed such intelligence as contributing directly to the decision making of the firm (Coates and Fabian 1982, Coates, *et al.* 2001).

When companies do establish special projects for technology assessment, they are usually *ad hoc* and designed to answer specific questions about the potential of new products or business lines, rather than deliver persistent evaluation of technology trends. They are also more likely to provide qualitative information and opinions about new market opportunities than quantitative measures of technology metrics (Maloney 1982).

Hauptman and Pope studied the technology decision-making processes of 29 senior executives from eight companies in the magnetic resonance imaging industry when faced with the emergence of a new superconducting ceramic. They classified participants on a normative scale bounded at the extremes by "adaptive" behavior and "inertial" response. Adaptive executives proactively gathered information and studied the technology developments until they were personally satisfied they possessed a broad and deep understanding of the technical issues and business implications. They consistently considered the core competencies of the firm in their assessment and used an iterative approach, searching in multiple directions, e.g. reading multiple papers, attending conferences and engaging in conversations with experts both inside and outside the company. All adaptive managers, with the exception of one, held clear opinions about the competitive strategies of their market opponents. In contrast, inertial managers formed their opinions on the short-term potential business opportunity *they* perceived in the market and based this judgment on very high-level understanding of the technical implications. They rarely consulted internal technical experts, customers or suppliers. Once their impression was made, they discontinued their investigations, certain that someone else within the organization would alert them if a market opportunity appeared (Hauptman and Pope 1992).

Even though it appears the adaptive model was more thorough, it is not clear that the data or knowledge gathered was captured or disseminated in a procedural or permanent way. The information was kept within the confines (probably in the head) of the collector. It is interesting to note that not one of the companies in the study followed a formal process for gathering, analyzing or disseminating technology intelligence.

Environmental Influence

We are tempted to use simple concepts to explain our belief system because it is easier to understand the world and accept or dismiss complex issues. But single dimension analyses do not present a realistic view and ignore important information. For example, one-dimensional theories such as "demand-pull" and "technology-push" ignore the complex feedback system provided by environmental stimulants. Dosi points out three weaknesses in the "demand - pull" theory:

1. The assumption that technological change results from a passive reaction to market conditions;

2. The success of a particular technology over another is often unexplained;

3. Changes in inventive capacity are not correlated to the market.

The "technology-push" theory, on the other hand ignores the "obvious fact that economic forces are important indeed in shaping the direction of the innovative process."

Clearly, strict advocates of one or the other presumes "blindness" to the impact of the operating environment or the direct influence that technology development has on the market. "One realizes that, in actual fact, there is a complex structure of feed-backs between the economic environment and the directions of technological changes." Technology is not a "black box" to be wholly absorbed by a waiting market (Dosi 1982).

However, market drivers may influence the environment surrounding technology emergence and therefore participate in the "signaling process." These dynamics, of course, can be measured and monitored over time and must be included in any rigorous course of study.

Consider the science-technology-production sequence as a funnel:

- Only a subset of potential scientific theories are explored and actually solved;

- Of those only a fraction are "passed on" to applied science or technology development;

- And even fewer are actually accepted by the market.

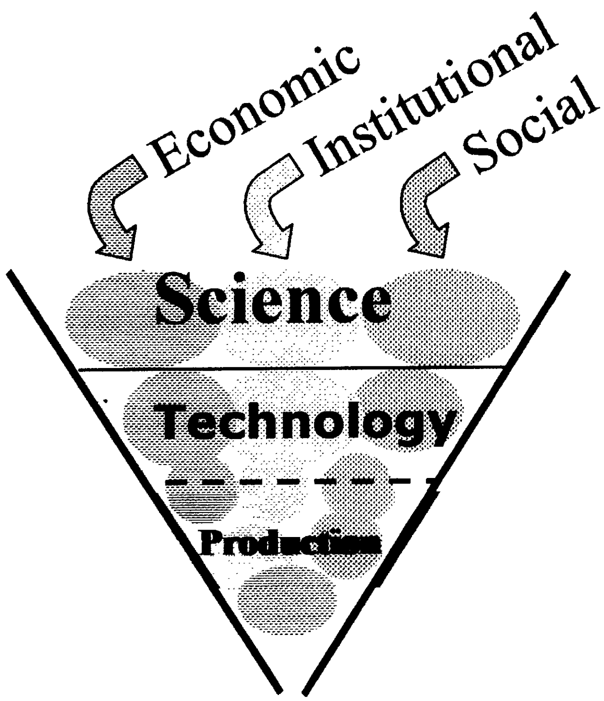

Figure 3. Based on the description by Dosi 1982.

Dosi hypothesizes that multiple variables influence the "natural selection" along the science-technology-production stream, namely:

- **Economic forces** including the economic interests of the R&D organization, its technological history and expertise;
- **Institutional variables** such as public agencies and the military;
- **Social variables** like the wave of public opinion.

In addition to considering facilitating factors, we must remember that constraining factors play even a more catalytic role in technological evolution, as barriers to progress almost always stimulate creative solutions (Sahal 1985).

Method Guidelines

Difficulty in gathering and assimilating emerging technology intelligence is no excuse for not doing it (Markides 1999), rather it is a rallying cry to mobilize and gain advantage over competitors who may not be so organized.

By far, the most prevalent advice found in the in technology intelligence and innovation management literature advocates adoption of a monitoring approach to identify potentially disruptive technology and to do it as early as possible. The reasons are fairly standard as well – awareness of important events, detection of technology trends, identification of new product development and collaboration opportunities, knowledge of competitors' activities, and alerts to potential threats – all provide competitive advantage (Ashton, *et al.* 1991, Porter, *et al.* 1991, Markides 1999, Utterback 1994, Bright 1970).

Obviously no single method or model will suffice for every technology assessment effort in every firm. Techniques should be applied only if they have relevance to the discovery. Management style, corporate personality, and individual creativity influence application of any theory and must be considered when designing the method. However, there are common components that should be included.

- Secure full sponsorship and resource allocation from management (Maloney 1982, Hauptman and Pope 1992).
- Establish a centralized competency located in the R&D or planning organization with responsibility for data aggregation and analysis –

relieve the burden from others and provide a central source of information and archive (Ashton, *et al.* 1991, Bright 1970).

- Collect requirements from all users of the technology intelligence and formulate a detailed plan including source identification, analysis procedures, resource allocation, validation, and success criteria (Ashton and Stacey 1995).

- Begin with a definition of the technology as well as a detailed hypothesis. These provide focus and a solid starting point (Ashton, *et al.* 1991, Maloney 1982, Utterback and Brown 1972). The objectives must be clear.

- Aggregate data for presentation in appropriate format for each user, i.e. different users of information may require different presentation format (Ashton, *et al.* 1991).

- Conduct an iterative process and apply incremental corrections to the method to accommodate changes in the environment or advancement of the technology. Technology intelligence is by its very nature, iterative, providing new information and insight with which to refine or recalibrate the investigation. (Utterback and Brown 1972, Porter,, *et al.* 1991, Ashton and Stacey 1995, Bucher, *et al.* 2003). Following each iteration, the method (e.g. key words and sources used) should be documented, including any modifications or other suggestions for future efforts. The method will evolve to maturity along with the technology under review (Watts and Porter 1997).

- Solicit participation of and consultation with individuals providing a variety of expertise and perspective, both inside and outside the firm (Ashton, *et al.* 1991).

- Create an inquisitive culture that embraces innovation, learning and change (Markides 1999, Day and Schoemaker 2000).

- Know the firm's core competencies and use them as guiding principles for the investigation (Hauptman and Pope 1992).

All of the technology intelligence in the world is of no use unless it can be assimilated into the corporate mindset. Technology intelligence often projects possibility that is far removed from current reality and sometimes just plain wacky. Our collective instinct is to reject those improbable, "out of our comfort zone", ideas out of hand. Bizarre technical ideas have launched tremendous business opportunities such as Internet search engines, electronic instant messaging, and mail order movies. Great discipline must be used to create an open environment that thoughtfully considers diverse viewpoints and encourages challenging discussion and discourse (Day and Schoemaker 2000).

Evaluation Tools

As is always the case, development of tools and analysis processes are driven by "institutional needs and motivations and by broad social changes" (Ashton 1995). Economic competition is now (or should be) motivating firms to gather technology intelligence. Rising R&D costs, shorter product development cycle times, and increasing numbers of high technology players on the competitive landscape are likely to encourage more firms to employ a structured science and technology intelligence program for informed strategic planning and decision making (Watts and Porter 1997).

Technical innovation, itself, has spawned new set of tools to enable the process including data mining, complex system analysis and chaotic behavior models. "A challenge for the future is to find tools that forecast when specific areas of science can be exploited commercially" (Coates, *et al.* 2001).

Forecasting

Innovation forecasting is the process of predicting the future based on historical evidence and ranges in scope from "do nothing" to various timeframes including short (1-5 years) and long (10-30 years). To accomplish effective forecasting the following questions must be answered:

- How far has the technology advanced along the development pathway?
- What is the growth rate?
- What is the development status of technologies on which this technology is dependent?

Firms that do not employ a formal or proactive forecasting program have actually adopted a passive forecast position by default, presuming that tomorrow will be the same as today. In a technology intelligence context, forecasting attempts to predict the dynamic dance among technology evolution, the market, the structure of the corporation and even government and society.

Difficulties always arise when trying to analyze the uncertain. There is no defined path for the development of most technologies and unforeseen events or incidents often trigger reactions that are surprising. Nevertheless, any guess is often better than no guess. Some systematic methods have been developed for gathering historical data and projecting it forward. These methods are based on generalizations and personal, although often expert, opinion. Because most forecasts are forward-looking, it is uncommon for forecasters to spend much time analyzing history.

> "The forecaster looks to theories of sociotechnical change to provide a perspective on the dynamics of technological change. Because no macrotheory exists, ad hoc techniques such as trend extrapolation, Delphi, and scenarios attempt merely to identify the outcomes and largely neglect the mechanisms that cause them" (Porter, *et al.* 1991).

In order for a forecast to be useful, it must be relevant to questions being asked and supported by the user of the information. It must be based on solid and accurate information, with a clear understanding of the basis for estimation and justification of the process. "When appropriate, the forecast should be quantified using legitimate units of measure. The significance, timing, and the probability of forecast events must be noted, and the confidence levels that can be placed on the forecast must be stated" (Porter, *et al.* 1991).

> "The forecaster must explore this future and convey the lay of the land to the decision maker. A balance must be struck between the *probability* that a given piece of future terrain will be traversed and the *detail* in which the trip can be described – that is, the finer the detail of the forecast, the lower the probability of that detail occurring" (Porter, *et al.* 1991).

Why Forecasts Fail

Noted futurist Joseph F. Coates cautions forecasters to avoid two common "pitfalls": overestimation of the speed with which an emerging development will become viable in the market and underestimation of the scope of impacts a new technology will have on society. He cites the following seven reasons these failures occur but advises that forecasting tools have matured to the extent that all of these errors can be avoided.

1. ***Unexamined assumptions*** – especially those "generally accepted" by individuals entrenched in a technology or by society as a whole;
2. ***Limited or misplaced expertise*** – make sure your "experts" truly are;
3. ***Lack of imagination*** – from those hostile to technology as well as a general societal tendency to perceive new concepts negatively;
4. ***Neglect of constraints*** – including resource requirements for fabrication and distribution;
5. ***Excessive optimism*** – from inventors and others with high psychological investment in the success of the new technology;
6. ***Mechanical extrapolation of trends*** – in the face of an uncertain future, forecasts can be overextended because alternatives are unknown;
7. ***Overspecification*** – too much detail limits creativity and promotes premature rejection if perceived to be too "far out" and also cuts off entire modes of application to whole domains (Coates 1993).

Another reason forecasts fail is simply because they are self-fulfilling and self-defeating if taken too seriously (Utterback 2003). Forecasters may want so much to be correct that they count only supporting evidence and miss the cues that could direct their attention more realistically.

Technology Roadmaps

Roadmaps project technology evolution through product development milestones and manufacturing solutions. They typically run through successive technology generations to derive a vision of the two- to ten-year time horizon and are intended to form the basis of an organization's action plan. Individuals with a variety of expertise and interest are often called together on roadmapping teams to form a collective opinion about the future development of a technology, an industry or corporate product portfolios (Kostoff and Scaller 2001). Using both qualitative and quantitative tools, participants develop a micro view of their own discipline while formulating a systems view of the overall objective (Coates, *et al.* 2001). Findings are usually written in a report and presented to appropriate management.

Foresight – Delphi and Scenario Planning

Foresight is the "process involved in systematically attempting to look into the longer-term future of science, technology, the economy and society with the aim of identifying the areas of strategic research and the emerging generic technologies likely to yield the greatest economic and social benefits" (Martin 1995). As opposed to a forecast, which attempts to predict the future, foresight recognizes multiple futures, accommodating multiple opinions. Two effective foresight mechanisms are the Delphi Method and Scenario Planning.

Delphi is an iterative method of collecting expert judgment on a specific topic via questionnaires. A target group of qualified individuals participates in multiple rounds until it is clear that opinions are convergent or non-convergent. Delphi does not force or otherwise encourage consensus, although participants are allowed to change their responses as they see, and are potentially swayed by, the opinion of their peers.

Because foresight is typically based on subjective information, it is impossible to determine or justify the basis of estimation used for the evaluation. The value of

Delphi is derived from the expertise of the participants and should be included in a qualitative evaluation of a technology paradigm. While certainly not adequate to establish a corporate technology strategy on its own, Delphi can be useful in postulating very long term (20 – 30 year) trends (Grupp and Linstone 1999).

Scenario Planning

The purpose of scenario planning is to evaluate the relationship between technology emergence and market response and generate new ideas about possibility and potential options. Schoemaker and Mavaddat, for example, evaluate the implications of the Internet on newspapers and consider questions such as a customer's willingness to pay for content, the role of intermediaries, target marketing, and customer privacy, among others – all known issues without known outcomes at the time of the study. While each of these is an issue that deserves individual evaluation, they exist together in the market and must be considered as a multi-layered, complex, whole.

Scenario planning steps are similar to other data gathering projects:

1. Secure senior management support and resources, define the issues;
2. Identify the stakeholders and play each role in likely scenarios;
3. Gather information from diverse and even nontraditional sources;
4. Evaluate environmental forces;
5. Identify known trends, prioritize key uncertainties;
6. Assess consistency and plausibility throughout the effort;
7. Plan for iteration as new information becomes available.

Assembling the possibilities becomes a massive "what-if" exercise as elements from each issue are mixed and matched to create various scenarios. Each scenario is then evaluated separately for viability and strategic response.

> "Planning for emerging technologies may seem like an oxymoron. Uncertainty and complexity undermine traditional planning approaches." Scenario planning embraces both by building a framework around the unknown issues and possibilities and organizes them in a way that is understandable and useful for analysis (Schoemaker and Mavaddat 2000).

Scenario planning should challenge the existing norms within the company and spark new thinking about the implications of the future. This method is highly subjective, as it is dependent on the judgment of team members to choose the issues, identify possibility and combine layers of potential outcomes for multiple issues to create likely scenarios. However, it can be a valuable strategic planning tool when developing a vision of the future and preparing a strategy of appropriate response.

Multi-dimensional Data Models

Technical intelligence data is complex due to the many variables and contingencies that operate simultaneously. Assimilation and presentation become tremendous challenges as one works to balance the trade-off between the vast amount of data available to evaluate a subject and the right amount of data needed to explain it. One method is to depict the data in three dimensions.

Hypercube of Innovation

Innovation has influential impact all along the value chain – what is an incremental impact to the innovator may be a radical change for suppliers, complementary innovators or customers. These must be considered before committing to an innovation strategy so a key link is not stressed or eliminated (Afuah and Bahram 1995).

The Hypercube of Innovation is a three-dimensional model with facing segments describing the Henderson Clark innovation matrix and depth provided by value chain components. Builders of the model evaluate whether an innovation reinforces or overturns a core concept and whether it changes the linkage between core concepts and components. Based on this information the innovation is classified as incremental, modular, architectural or radical (Henderson and Clark 1990). This exercise is carried out from the perspective of multiple players at various stages of the value chain and is especially useful as a comparison when considering two or more potential innovation strategies.

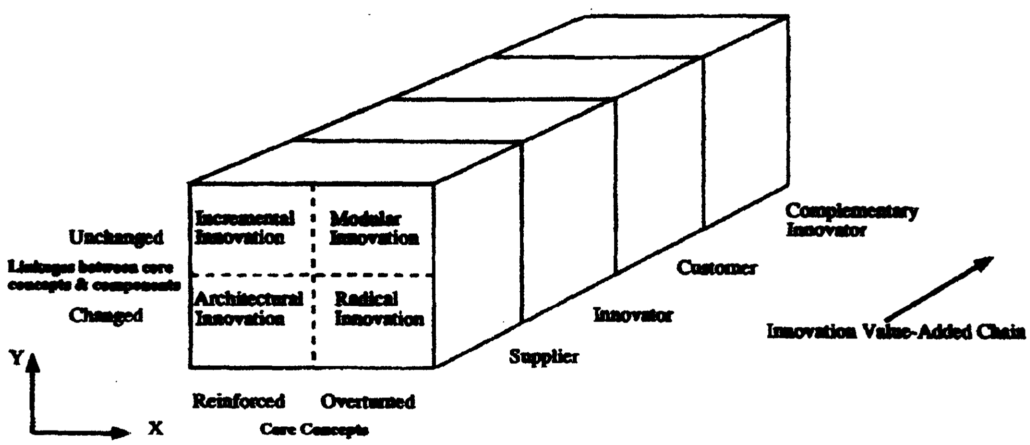

Figure 4. The Hypercube of Innovation (Afuah and Bahram 1995).

Data output from the Hypercube of Innovation can be presented in tables or a single "green-red zone map" that highlights the impact level for each link. The authors provide many examples including electric cars, the Dvorak Simplified Keyboard, the IBM OS/2 operating system vs Microsoft Windows, Reduced Instruction Set Computers, Complex Instruction Set Computers, and supercomputers.

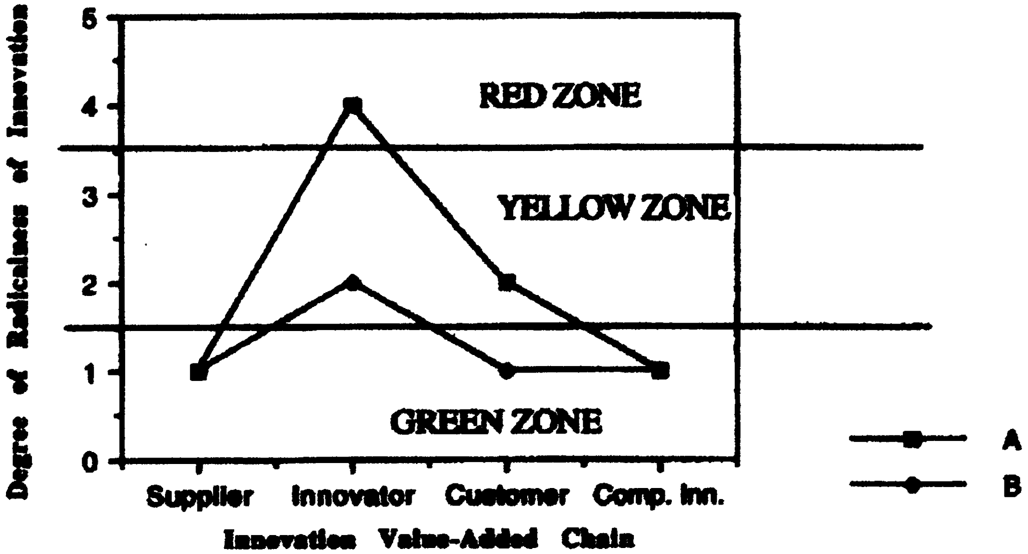

Figure 5. The green-red zone map (Afuah and Bahram 1995).

Admittedly, the model is based on qualitative data based on the users' perception of the impact of the innovation and does not include technology development issues or environmental influence. Builders of the Hypercube of Innovation must have a thorough understanding of the Henderson Clark model and use consistent guidelines for the subjective criteria that define the innovation type, especially when comparing innovations. As a result, users of the data, namely senior management and strategic planners must also understand the model and the basis of assumption in the same context as the builders.

Hypercube of Innovation models are used to analyze an innovation strategy based on value chain impact. The purpose for using it is to reinforce core concepts and competence and avoid destroying core competence and network effects or complementary assets along the value chain. It does not provide a complete picture of a technology paradigm but it could be a useful tool projection tool for analyzing the impact an innovation might have to various players in the value chain.

Supply – Demand - Information

Abdelkader Daghfous and George R. White add an information dimension to the classic supply-demand evaluation to describe internal causalities and external dynamics of an innovation.

In their opinion, one- and two-dimensional models are inadequate because they do not consider the information dimension, which they add in the form of the Transilience Matrix (Abernathy, Clark, Kantrow, 1983). In the matrix, the impact of an innovation on productive systems and market linkages is analyzed through four development phases.

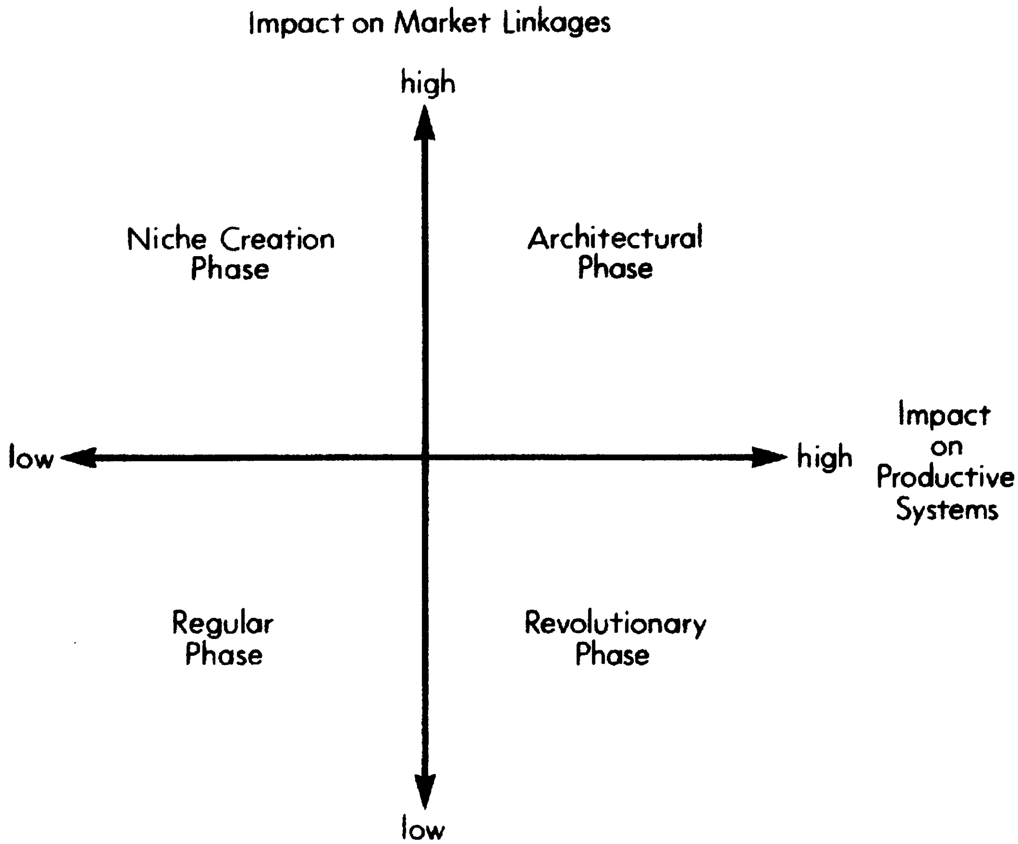

Figure 6. Evolution of Technology Transilience (Abernathy, *et al.* 1983).

Each of the three dimensions comprising the Daghfous-White model, i.e. product/process, market applications, and enterprise information, is segmented and ordered according to logical progression.

- **Product/Process** – the X-axis – Supply dimension (based on the model by White and Graham 1978)
    - Inventive Activity – new scientific principles
    - Embodiment Activity – complementary technology emerges
    - Operational Activity – internal support facilities are established
    - Market Evolution – innovation evolves through customer and supplier interaction

- **Market Applications** – the Y-axis – Demand dimension
    - Concept Definition – value to the customer
    - Utility Integration – business process modification to accommodate the innovation
    - Product Penetration – customer acceptance illustrated through use
    - Market Evolution – innovation evolves through customer and supplier interaction (identical to the Product/Process segment described above)

- **Enterprise Information** – the Z-axis – Information dimension (based on the Abernathy, *et al.* Transilience Matrix described above)
    - Conceivable Scheme – research indicates likelihood but not certainty of an innovation's success
    - Credible Plan – success prospects are positive
    - Rational Procedure – thorough analysis is complete and indicates rational probability of success
    - Optimal Policy – accurate and precise data indicate innovation's success to date and further evolution is recommended

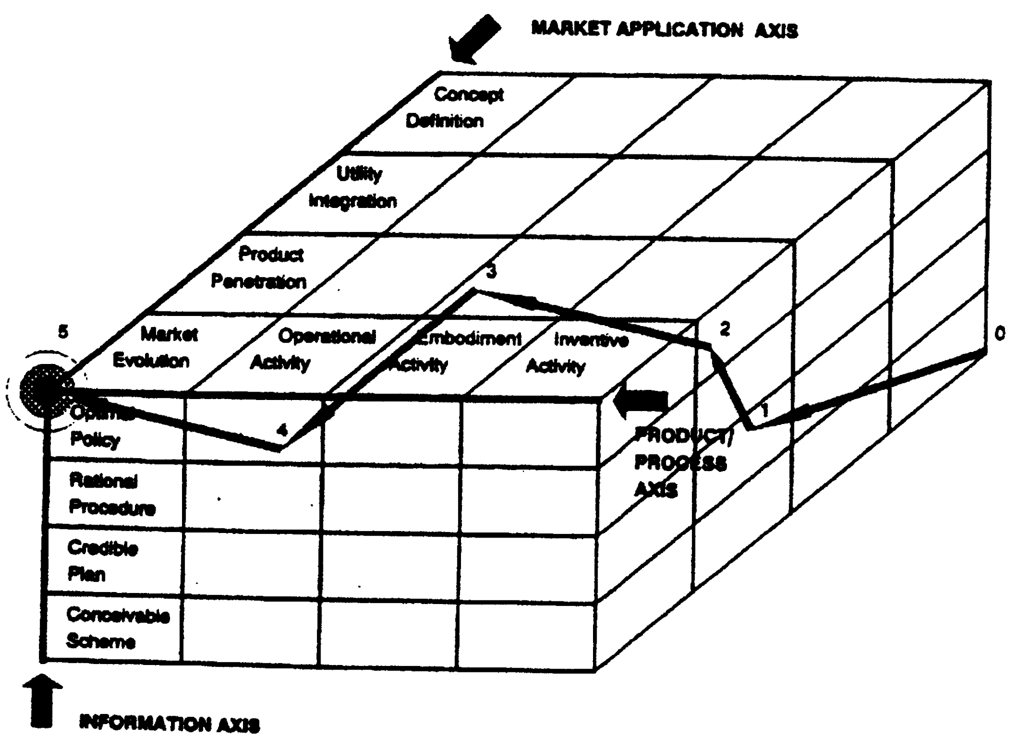

Figure 7. The three-dimensional model: Example (Daghfous and White 1993).

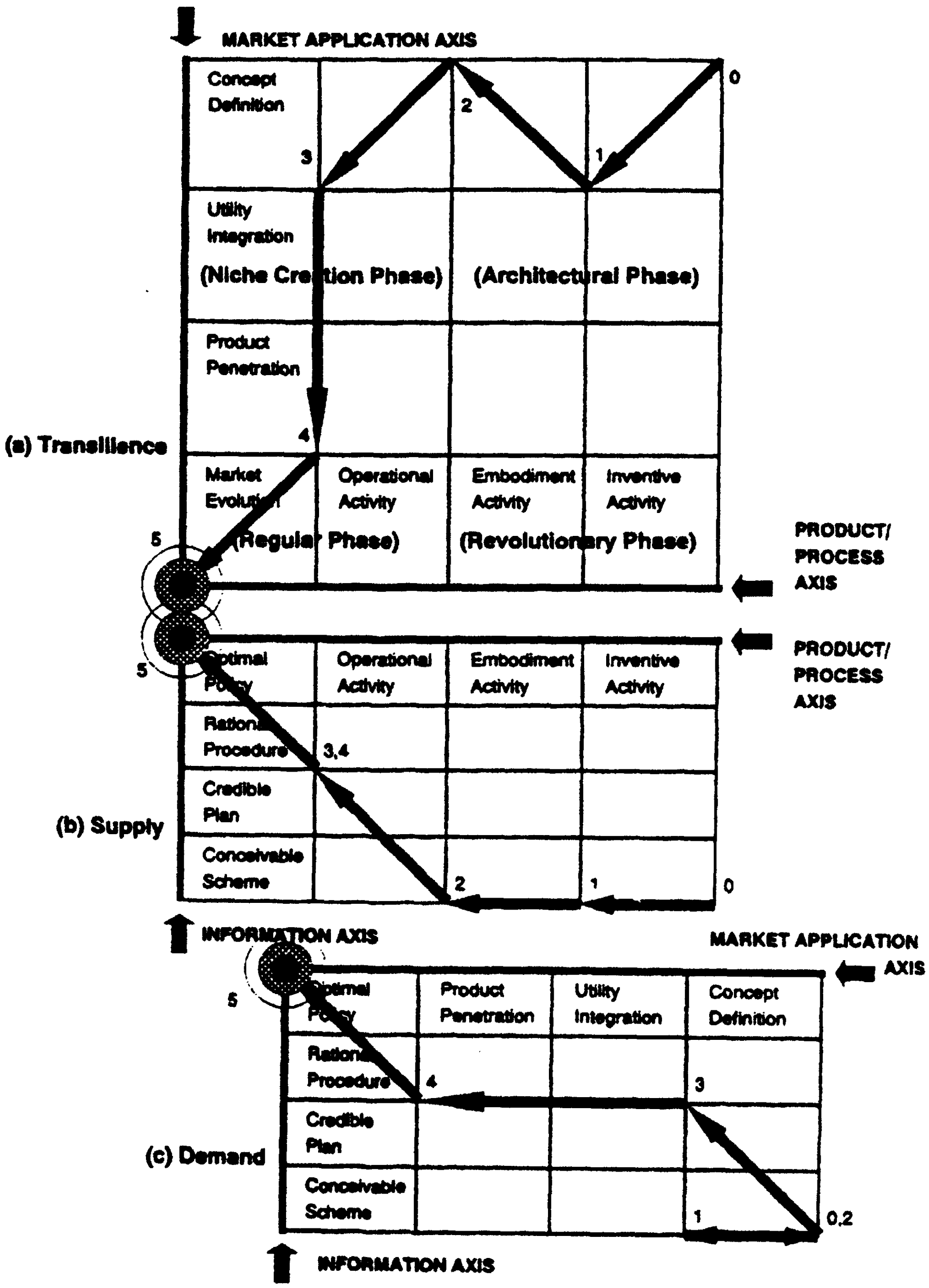

Figure 8. Planar projections: Example (Daghfous and White 1993).

The 3-D nature is difficult to conceptualize, requires three sets of charts to depict and does not provide an intuitive view of development trends. Rather, it tracks a single innovation (defined by the authors as a "new product which succeeds commercially, arising from a new technology") through many phases of development within a firm.

Population of data in cube is somewhat subjective and you have to understand the concept constraints of each line item in the model, which are somewhat vague. All builders and users of this model must share discrete definitions of each segment and a common interpretation of the relationships among them. It is not clear that two separate analysis teams would create similar depictions of the same innovation path so the process to create the model is probably not repeatable.

Daghfous and White illustrate the model with historical perspectives from Apple and Boeing. Comparison of the two is interesting because it shows a straightforward, successful case (Boeing) as opposed to a vacillating, less successful outcome (Apple). It could be useful in a scholarly evaluation of an innovation after emergence to describe the path from concept definition to market acceptance and compare strategies among firms. However, analysis of environmental factors, competitors' activities, commitment of resources or social constraints is not included and therefore does not lend itself to generating a complete view of technical intelligence during emergence.

Scanning and Monitoring

The approaches we have examined so far rely on significant expertise to derive meaningful insight; either facility with a complex data manipulation tool or framework or advanced knowledge about the technological paradigm under discussion. None are flexible enough to consider environmental influence. These do not meet our requirements for an emerging technology evaluation model: objective, simple to use, and presented in a format that informs a range of interest from engineering to marketing to senior management.

What if we took a step backward, to understand the evolution of a scientific discovery, and map progress of key development metrics from the lab to the market? We could use trends of objective metrics, or "signals," to inform intuition. That is, manage the uncertainty inherent in dynamic technology environments by identifying and evaluating "signals of change" (Utterback and Brown 1972) over time. We could gain an historical perspective of technology emergence, evaluate momentum and make some determination of the viability of future commercialization

> "The challenge is to recognize some momentum beginning to form around a given technology. Just as human leaders are defined for having followers, leading technologies can be recognized as *emergent* for their technical "following". Value in science and engineering can be measured by signals of a following such as the degree to which a discovery is cited, duplicated, imitated, and applied. Ultimately, signals of technological emergence – whether the distributed community of scientists and engineers has endorsed a particular technology – must be detected. (Doering and Parayre 2000).

Scanning, a continual and broad survey of the entire emerging technology landscape, can be thought of as the **"outside-in"** approach to technical intelligence. ***Monitoring***, on the other hand, the "**inside-out**" approach, is the in-depth observation of phenomena identified during scanning (Lichtenthaler 2000 and Peiffer 1992, translated from the German and presented by Bucher, *et al.* 2003).

Scanning

Before commencing a detailed technology intelligence exercise, it is helpful to scan the field for impact a technology paradigm may have. This can be done at a very high level, covering many types of entities or issues from other technologies, enablers, and complementary assets, to political, economic or social issues. The point is to ensure the entire spectrum of possible impact is considered and that major impacts are not overlooked.

The format may be as simple as a checklist or as complex as a series of interrelated maps. It may be brief or detailed (Porter, *et al.* 1991). Figure 9 shows a number of factors influenced by nanotechnology. Clearly, the central topic is too broad for a meaningful investigation as this map does not begin to identify all of the technologies, applications or issues involved and it is already quite complex. Any one of the balloons could be chosen and broken down to define a complete study.

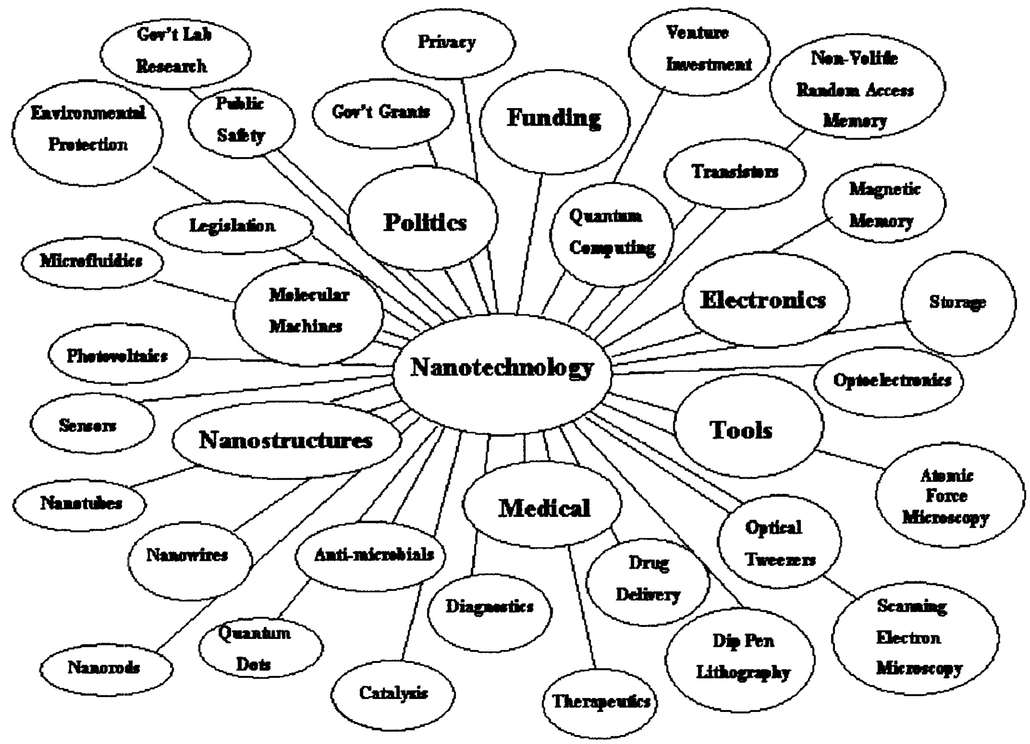

Figure 9. Map of technologies and issues relating to nanotechnology. By author.

Familiarity with the innovation dynamics concepts described above and a keen eye for innovation potential, provide strong cues and inform the "scanning" cycles of technology intelligence that recommend the topics for monitoring.

Monitoring

"To anticipate innovation, the political, social, and other factors influencing its progress must be systematically monitored." James R. Bright first described the monitoring approach in 1970 with these words, justifying his method with the following observations:

- A radical new technological advance is made visible to society first in written words, then in increasingly refined, enlarged, and more effective material forms, long before it achieves widespread usage.

- The potential impact of the innovation is usually evident years before the new technology is in use on a scale great enough to affect existing societal conditions appreciably.

- Social, political and, now to an increasing degree, ecological changes may alter the speed and direction of the innovation's progress.

- Innovation may be abruptly influenced by decisions of key individuals who control supporting resources or determine policies that affect their application.

"Technological capabilities – e.g. parameters such as speed, power, miniaturization, strength, and capacity—increase exponentially over time once bottlenecks are broken…but will begin to level off if they encounter scientific, economic, or social barriers. (Failure to accept or accurately gauge this characteristic of acceleration happens to be a principal reason why "expert opinion" from very competent technologists, economists, and study groups so often proves to be fantastically conservative, if not totally wrong.) (Bright 1970).

Bright includes four activities in his model of monitoring:

1. **Searching the environment** for signals that may be forerunners of significant technological change.

2. **Identifying the possible consequences** (assuming that these signals are not false and trends that they suggest persist).

3. **Choosing the parameters, policies, events, and decisions** that should be observed and followed to verify the true speed and direction of technology and the effects of employing it.

4. **Presenting the data** from the foregoing steps in a timely and appropriate manner for management's use in decisions about the organization's reaction.

"The cornerstone for innovation forecasting is *monitoring*" because current developments foreshadow future technological change, which is, itself, influenced by related technologies and socioeconomic influences" (Watts and Porter 1997).

It is not as important to capture an exact snapshot (that is, in fact, impossible), as it is to compare the current status of signal set to previous checkpoints. Then you can see patterns emerging and understand the momentum of development (Utterback 2003). You can also determine the stage of technology development, identify the players, think about potential applications, and prepare to accommodate the proposed product feature set.

Monitoring may not provide a complete technology strategy (expert analysis and opinion should be factored in) but deserves a central place in a multi-faceted intelligence program for the following reasons:

- Monitoring provides an objective view of the development of a technology paradigm – the data is descriptive rather than prescriptive;
- Collection and organization of the data can be independent of the analysis;
- Management calibrates the depth and breadth of the investigation and establishes appropriate filters according to information needs;
- The process is repeatable and provides the basis for trend analysis via periodic snapshots;
- Monitoring contributes to a defined method tailored to a defined purpose.

Parameters to Observe

Government Funding

Because of the direct correlation between technology innovation and economic leadership, the global competitive landscape is a fierce battlefield. The United States reigned supreme for over half of the twentieth century, then lost position in the 1970s and early 1980s to countries with healthy innovation and technology development programs, namely Japan and in some cases, Germany. Many factors influenced the slip, but the strongest catalysts were low cost competition in foreign lands and the inability of the US to leverage innovative technology to compete (Audretsch 2003).

Recognizing that small and medium enterprises were the source of greatest job growth, the United States Congress responded by launching the Small Business Innovation Research (SBIR) program in the early 1980s to fund early stage innovative research and technology commercialization efforts that eluded the interest of corporate funding and private venture capital. Among the greatest benefits is the incentive for research scientists to pursue commercialization activities related to their scientific discoveries and start companies to fully exploit the economic potential. SBIR has funded many start-ups that have seen tremendous commercial success and is credited as a major contributor to the US dominance of the biotechnology industry (Klette and Griliches 2000). In fact, program awardees grew significantly faster than matched firms over a decade and were more likely to secure venture funding (Lerner 1999). As a result, the US is back in the competitive race for global technology leadership.

The success of the SBIR program is only one example of the government commitment to the support of emerging technology through funding programs. Military sponsorship of advanced technology is a strong indicator that development will enjoy required financial support throughout subsequent phases. The armed forces, defense departments and space agencies are among the most prolific users of emerging technology and have extremely large budgets to ensure their requirements for technology solutions are met. Watch the progress of the national laboratories as well, e.g. Sandia National Laboratories, Los Alamos National Laboratory, for indications of technology potential. They have freedom and funding to pursue their own scientific research agenda without pressure for specific application and often make startling discoveries.

Most of the federally funded projects have long development cycles, so government funding is a strong signal that a particular technology paradigm will have the financial resources necessary to emerge through production.

Research Publications and Patents

Scientific Papers

Review of the scientific research literature tells what scientists are working on and illustrates progress, expansion of basic knowledge, and enhancement of tools for further discovery. Scrutiny of the content reveals optimization of previous discoveries and inventions, incremental innovations, and highlights new applications.

Various agencies catalogue academic publications by author and citations by other authors. Evaluation of the number of citations or publications in refereed journals identifies key innovators to a particular field. Analysis of the publication dates also indicates persistence, a strong signal of the value key innovators place on the potential of a scientific field or subfield.

> "It is reasonable to assume researchers are rational, in the economic sense that they are motivated by self-interest: that is, they are eager to solve problems because there are rewards for those who do (Rappa and Debackere 1989)."

Scientists do not make a one-time choice regarding their field of study; they are constantly evaluating the technological progress and searching for interesting problems to solve. We can leverage this understanding by monitoring the persistence of key innovators, drawing the conclusion that serial publishing within a scientific domain shows personal commitment to the technology paradigm. The fact that they have "bet their careers" provides a strong signal of traction and momentum.

> "It is strange but true that in this world of multimillion and multibillion dollar expenditures for technology, progress with radical technology sometimes stems from a single brilliant or inspired person" (Bright 1968).

As true today as 35 years ago! Citation analysis identifies key innovators, collaboration patterns and forecasts emerging research areas (Garfield 1978).

Patents

Monitoring the number of patent applications and awards in an industry can be a strong indicator of ability to transform scientific results into applications. Expect that the pattern of number of patents will follow the pattern of scientific articles with some time delay (Compano and Hullmann 2002). However, the value of monitoring patent activity varies by industry, as some companies rely on trade secrets or other unpublished means to protect their intellectual property and unused patents become "noise" as they are probably innovation dead-ends. Therefore, a lack of patents does not necessarily indicate lack of technical progress and the presence of patents doesn't necessarily indicate a surge in technical progress. Also, patent awards must be monitored from an international perspective as foreign intellectual property can very easily be introduced to domestic markets (Utterback 1972).

A Note on Bibliometric Analysis

Bibliometrics, a key monitoring technique, simply counts the number of scientific papers published and patents (pending or granted) for a specific technical domain to measure and interpret advances for a mid-term (3-10 years) time horizon. A great deal of information can be extrapolated from this data including R&D activity trends, expansion or contraction of scientific interest in the topic, key innovators and their persistence in the field, location of leading specialists and organizations, collaborations, especially across universities, national research labs and firms. Also, bibliometric time series data can provide growth rate information, especially helpful when evaluating the readiness of complementary technologies. (Watts and Porter 1997)

Key words must be chosen carefully and used consistently throughout the monitoring process. Changes to the key word list must be thoroughly documented with a clear reasoning for the change as well as anticipated effect on search results.

The following diagram depicting worldwide nanotechnology metrics shows a common relationship between scientific publication and patents.

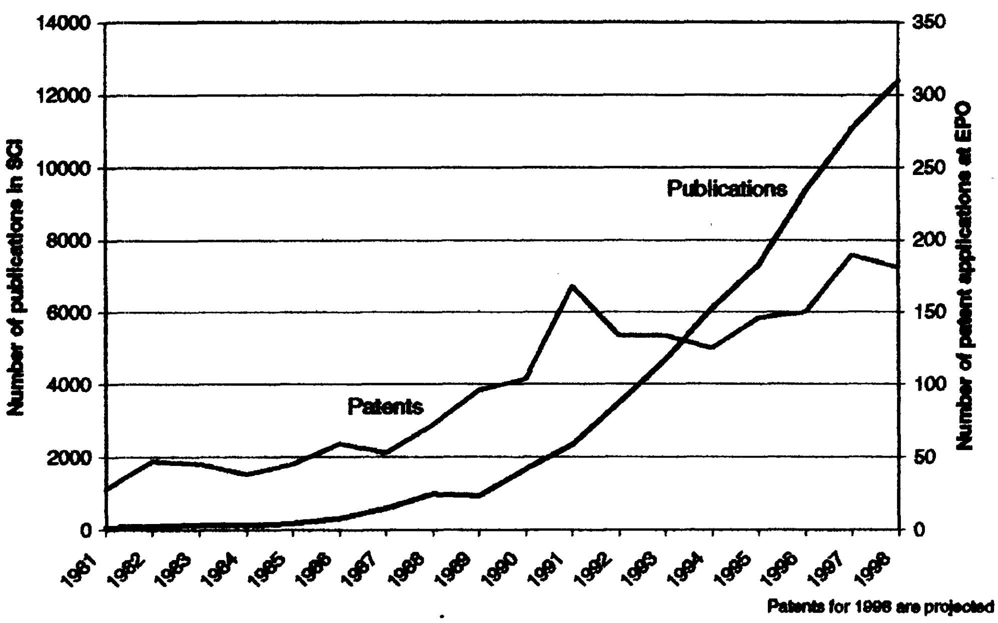

Figure 10. Publications and patents in nanotechnology from 1981 to 1998 world-wide. The number of publications comprises all nanotechnology-related articles published world-wide and covered by the SCI database. The number of patents comprises all nanotechnology patents at the EPO. The data have been extracted searching the same keyword list for both databases. Note the different scales for the two curves. Sources: SCI, EPO Database (EPAT) and authors' calculations (Compano and Hullman 2001).

Despite its value, bibliometric analysis suffers from several limitations. It doesn't comment on the quality of research and is not inclusive – many discoveries are not published in academic literature or included in patent claims. Counting scientific papers and patent grants may not give a current view of scientific activity due to publication lag and two- to three-year lead times for patent approval. (Watts and Porter 1997)

Alliances

Evaluation of emerging technology and development of an innovation strategy presents incumbent firms with a "menu of option" including: level of investment, timing, product selection, and how to acquire the knowledge necessary to compete successfully, among others (Mitchell 1989). Rather than make a full commitment of resources to each interesting technology, many incumbents, particularly stronger players, will participate in alliances with other firms to secure and coordinate complementary assets, skills and technologies before their standalone entry.

> "When an industry incumbent enters a new product area in which many supporting assets retain their value, the firm will often limit its investment exposure and expand its knowledge sources by using alliances with other firms before undertaking standalone entry." (Mitchell and Singh 1992).

Alliances take many forms: minor equity holding, joint ventures, development collaboration agreements, component manufacturing, and distribution. Collaboration provides incumbents the opportunity to "test the technical and market waters of emerging subfields prior to their full entry" thus allowing them to "leverage their specialized assets and gain access to market and product information, while spreading risks in uncertain conditions." (Mitchell 1989).

Formation and growth of alliance networks delivers a strong signal of legitimacy especially when the participants are well-known, successful firms. Analysis of alliance networks can also determine market saturation through analysis of the density of alliance relationships. If the majority of relationships are among a few players, the density is high and signals a crowding effect. "… participants are likely to intensify their relationships, thus excluding others left on the fringe of the network and providing a barrier to new participants." (Stuart 1998).

Product Development – Prototypes

Announcement and testing of prototypes signal the viability of constructing a product and indicate corporate or institutional commitment to pursuing further development. (Usually, only successes with development potential are announced publicly.)

For example, Sandia Laboratories, a US national laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration, recently revealed a quantum dot light-emitting device, which produces high intensity blue or white light. This major scientific breakthrough validates the application of nanoscale materials to the solid-state lighting industry.

This Sandia research is internally funded with an additional grant from the US Department of Energy Office of Building Technologies for a collaborative project with Lumileds Lighting, a joint venture between Agilent Technologies and Philips Lighting. The extent of the collaboration and the high profile of the participants signal strong support for the continued development of this technology.

Social and Political Factors

Single events, e.g. the passing of a law or initiative, must be factored into the technology assessment equation just as public opinion must be considered.

"You must have permission from a variety of stakeholders (e.g. public opinion, the board of directors, government, current and potential customers, employees of the company) to conduct business. For example, Philip Morris did not see the U.S. anti-smoking campaign as a dramatic influence on their business and certainly were unprepared for the regulation and litigation that followed." (John S. Reed, former Citigroup Chief Executive Officer and Philip Morris board member, addressing a seminar course at Sloan School of Management, February 2002.) Had Philip Morris senior management paid more attention in the mid-

1970s to the wave of public demand for designated non-smoking areas in public places and work environments, they might have anticipated the rapid reversal to designated smoking areas and eventual ban on public smoking. Advanced planning for these possibilities might have provided them with time to adapt their business model and proactively manage a damage control initiative that might have averted the extreme cost of lawsuit awards and negative publicity.

President George W. Bush recently signed the 21st Century Nanotechnology Research and Development Act, securing nearly $3.7 billion over the next four years for nanotechnology research and development. Ten federal agencies will award grants to support the discovery, application development and commercialization of products at the nano-scale as well as the tools and fabrication processes to support them. Federal legislation of this magnitude signals a deep commitment to future support and should provide a strong signal of potential to research and industry decision makers.

Not-for-profit organizations, professional scientific affiliations or special interest groups often support scientific development in specified fields through member publication, conferences or educational offering.

> "In particular, it is proposed that technological development is not the exclusive domain of firms—or for that matter, a collection of firms in a given industry – but rather an activity which cuts across many types of public and private organizations. Furthermore it is proposed that a new technological development may come about through the concerted efforts of a community of researchers which forms over time and that spans these diverse organizations. If this is indeed the case, then the progress of such communities may be better understood through a careful examination of how they function (Rappa and Debackere 1989)."

Data Presentation

Corporate reluctance to pursue technology intelligence programs may not lie in the difficulty of gathering data but in the near impossibility of presenting the information in an intuitive and useful manner. Complex relationships and dependencies are extremely difficult to explain and the variety of perspectives of the multiple users complicates matters further; the CEO will have different questions and views of technology intelligence than the marketing director or the head of engineering. A single presentation is not likely to meet the needs of all users.

Presenters of technology intelligence are tempted in at least two directions:

1. Simplify the presentation approach and risk losing the richness and subtlety of the data.
2. Create elaborate presentation schemes and lose intuitive understanding of the message through extensive explanation or learning about how to read the model.

When starting this project I was convinced that monitoring metrics could be effectively presented in a two-dimensional format with observation parameters on the vertical axis over time on the horizontal. Each parameter was to have its own scale but the combination of trend indication and the time lags and overlap would show momentum over chosen metrics to a wide range of users. While not meant to be the only output of a technology intelligence exercise, I thought that a single view prepared for a variety of users would provide a common language and understanding across the organization and would stimulate conversation and idea exchange across the board. It appears through my research that this idea is overly simple and would not provide meaning or value to a useful extent.

Devendra Sahal borrows a three-dimensional, multivariate model from biologist, C.H. Waddington to depict technical evolution as a rolling ball navigating the hills and valleys of environmental influence and chance.

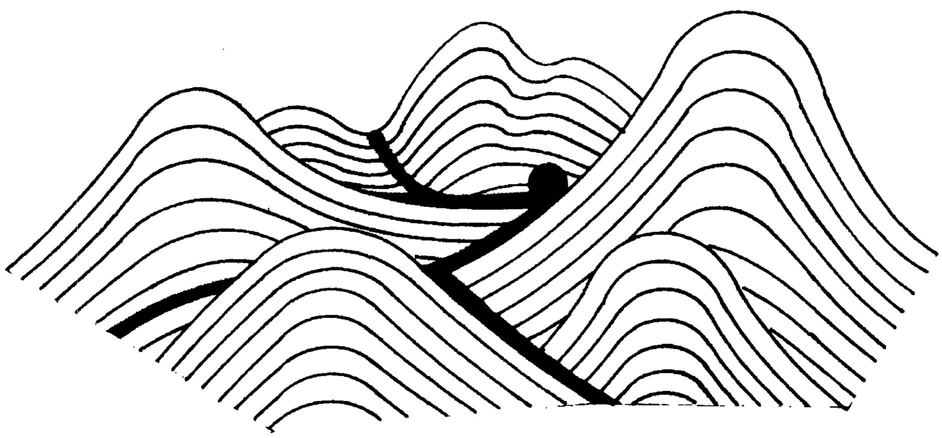

Figure 11. The topography of technological evolution (Sahal 1985).

While it appears to be an interesting and potentially useful way to illustrate technology emergence through a maze of variables, the immediate challenge in using this model for technology intelligence is to label the hills, identify the meaning of the valleys and code the software to generate consistent depictions based on multiple inputs.

The challenge of depicting technology intelligence is as challenging as designing the method in the first place. Research into this issue could be an entire thesis in itself.

Conclusion

Technology intelligence initiatives are designed to evaluate emergence metrics along the evolution from scientific discovery to commercial innovation. Design of the process is predicated on the orderliness of the innovation process (Watts and Porter 1997) and supposes that technology evolves in a logical sequence with consideration for lag and overlap.

With a thorough understanding of innovation metrics, strategic planners can make informed decisions regarding technology investments and position their companies to take full advantage of impending technology developments. This paper presented the following findings:

1. Extensive academic research describes multiple theories and complex models for evaluating emerging technology. Almost all recommend that firms take a proactive approach and institute formal technology intelligence gathering, analysis and dissemination processes within the company.

2. Most firms do not employ formal emerging technology evaluation programs and rely, instead, on proactive individuals taking the initiative to investigate technology development and forecast viability and impact on the firm.

3. Understanding emerging technology is a crucial management competence.

4. Many techniques can be combined to develop an appropriate technology intelligence program. Scanning and monitoring techniques provide objective information and are easy to use, but must be presented in a format that informs a range of interest from engineering to marketing to senior management. Expert opinion should be used to interpret and validate results.

For all of the positive reasons to establish a formal technical intelligence program, it seems that the popular business press as well as academic journals would be more interested in covering this topic and that more companies would have articulated their challenges and successes more proactively. One has to wonder why we have not seen a swell of activity toward this kind of organized investigation.

Three reasons are likely. First, technical intelligence is probably classified in most companies as "knowledge management", historically an ambiguous set of programs designed to capture information and knowledge from employees within the firm and make it available to the rest of the company. Most have not yielded fruitful endeavors or market successes. Development of suites of integrated programs and "best practices" by major software and consulting firms promised minimal implementation expense compared to the value of rich knowledge that would be available to all levels of an organization – the right information to the right individual at the right time. The promise was not realized in most cases and many firms cancelled their programs or let them lie fallow. Reluctance to commence or continue similar programs is understandable.

Second, personnel with the expertise necessary to conduct thorough and useful technical intelligence are not usually the type to be satisfied with administrative tasks like compiling and analyzing statistics. Unfortunately, some technical expertise is required to discern meaningful data from "noise" and conduct thoughtful analysis. As mentioned above, "knowledge management" is not typically a high corporate priority and therefore does not provide a desirable career path for those with valuable technical expertise. So, they look elsewhere.

Third, most leaders are more comfortable making decisions based on information and perspective from individuals they personally know and trust. Technical intelligence delivered from the "knowledge management pool" may not carry the same cache as an opinion from a trusted advisor. Managers seek out those scientists and engineers within their ranks and contact list to answer questions they need to make a pending decision, a behavioral tendency that is extremely difficult to change.

All legitimate views, however woefully short-sighted.

Technical intelligence is not knowledge management. As we have seen from the arguments presented in this paper, understanding the evolution of technology outside the company provides tremendous value and supports crucial innovation initiatives – an entirely different proposition than disseminating information within the firm. Ironically, the staffing issue is a negatively reinforcing loop; if management doesn't respect the analysis performed by a designated team, no one with the talent and expertise to do the work well will choose to join the team. And, the problem with management selectively polling for technical answers is the assumption that they will always know the right questions to ask.

Emerging technology intelligence is a crucial strategic planning device. Managers who understand the implications of a wide range of scientific discovery and technology evolution will gain a competitive advantage over those who merely react to developments as they occur. Initiative to establish structured technical intelligence programs must come from the most senior managers – as it should, for they have the most to gain.

Ideas for Future Research

1. Find out why companies do not formalize technology intelligence programs and why a standard method has not emerged.

2. Identify methods actually used by organizations to inform their strategic decisions.

3. Investigate alternative presentation technologies for complex data especially multi-dimensional representation. Visual Display of Quantitative Information by Edward R. Tufte (Graphics Press 2001) may provide interesting perspectives and ideas for further study.

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