

1 **MAKING SENSE OF TECHNOLOGY TRENDS IN THE IT LANDSCAPE:**
2 **A DESIGN SCIENCE APPROACH**

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3
4
5 **ABSTRACT**
6

7 A major problem for firms making IT investment decisions is predicting and understanding the
8 effects of future technological developments on the value of present technologies. Failure to ade-
9 quately address this problem can result in wasted organization resources in acquiring, develop-
10 ing, managing, and training employees in the use of technologies that are short-lived and fail to
11 produce adequate ROI. The sheer number of available technologies and the complex set of rela-
12 tionships among them make IT landscape analysis extremely challenging. Most IT-consuming
13 firms rely on third parties and suppliers for strategic recommendations on IT investments, which
14 can lead to biased and generic advice. We address this problem by defining a new set of *con-*
15 *structs* and *methodologies* upon which we develop an *IT ecosystem model*. The objective of
16 these artifacts is to provide a formal problem representation structure for the analysis of informa-
17 tion technology development trends and to reduce the complexity of the IT landscape for practi-
18 tioners making IT investment decisions. We adopt a *process theory* perspective and use a com-
19 bination of *visual mapping* and *quantification* strategies to develop our artifacts and a state dia-
20 gram-based technique to represent evolutionary transitions over time. We illustrate our approach
21 using two exemplars: digital music technologies and wireless networking technologies. We
22 evaluate the utility of our approach by conducting in-depth interviews with IT industry experts
23 and demonstrate the contribution of our approach relative to existing techniques for technology
24 forecasting.
25

26 **Keywords:** Design science, IT ecosystem model, IT landscape analysis, management of tech-
27 nology, technology evolution, IT investment.

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4 1. INTRODUCTION 5

6 The landscape of information technology (IT) is in a constant state of change. An overwhelming
7 number of technologies are available for use by organizations and that set continues to grow.
8 Additionally, the economic scope of IT investments is typically very large. Inappropriate IT in-
9 vestment decisions can have major adverse effects on organizational performance. These factors
10 contribute to the difficulty of making IT investment decisions. Additionally, our discussions
11 with IT managers indicate that, in their opinion, it is difficult to accurately forecast advances and
12 trends in IT. Nevertheless, IT investment decisions must be made. Senior managers must under-
13 stand the nature of technological change and be able to accurately interpret the IT landscape¹ to
14 position their firms' high-value technology investments and to achieve success with emerging
15 market opportunities.

16 Through interviews with IT industry experts we gained significant insights about how firms
17 analyze the IT landscape. What we found is that the IT landscape analysis along with the IT stra-
18 tegic decision-making process are often outsourced to third parties.

19 *"It's kind of a funny thing. In IT it's okay to outsource your future decision-making, but with the business*
20 *you would never do that...[Companies] outsource their IT decision making just because it's so compli-*
21 *cated."* -- VP of Global IT Infrastructure at a Fortune 500 company.

22 The difficulty of making these decisions lies in the need for skills and expertise beyond the capa-
23 bilities of most firms. As a result, many firms rely on reports produced by consulting companies
24 such as Gartner, Forrester, and IDC, and advice provided by their existing IT partners and sup-

¹ Throughout the paper we often use the terms IT landscape and IT ecosystem. *IT landscape* is commonly used by practitioners to describe the overall IT environment. *IT ecosystem* is a term that we operationally define as a portion of the IT landscape centered on a specific set of technologies in a specific context that is the subject of analysis using the methods and artifacts that we will shortly propose.

1 pliers. We recognize that such input can be helpful in the decision-making process; however,
2 our in-depth interviews with IT experts identified two key concerns. First, advice provided by
3 existing partners and suppliers is often biased; existing suppliers have an incentive to encourage
4 firms to continue their investment. Second, reports produced by third parties are usually too
5 general and often lack formal analysis of the IT landscape, relying primarily on expert opinion
6 and simple extrapolations to make recommendations.

7 *“The main challenge is the dynamic nature of the whole rapidly changing IT environment...what we need*
8 *are more formal frameworks and tools to help see more clearly the current and potential future technology*
9 *landscapes. There is definitely room for improvement in developing these types of tools for managers.” --*
10 *Senior Academic Researcher and IT Industry Consultant*

11 To address these problems, we propose a new theory-based conceptual approach, a set of
12 new constructs, and a novel methodology for formally analyzing the IT landscape and identify-
13 ing trends in IT evolution. Adomavicius et al. (2007) proposed a new *ecosystem model* of tech-
14 nology evolution for understanding the dynamic and complex nature of technological evolution.
15 Building on this model, we use a *process theory approach* (Mohr 1982, Langley 1999) to de-
16 velop a new set of problem representation constructs and a novel methodology for identifying
17 and visualizing patterns of technology evolution in the IT landscape. The goal of our new ap-
18 proach and methodology is to complement existing techniques and provide firms that make IT
19 investment decisions with a more formal technique for analyzing specific IT ecosystems, making
20 sense of the interdependent relationships among the technologies they contain, and aiding in IT
21 trend prediction.

22 We adopt a design science research approach (Hevner et al. 2004, March and Smith 1995).
23 *Design science* research involves the construction and evaluation of IT artifacts, constructs,
24 models, methods, and instantiations, by which important organizational IT problems can be ad-
25 dressed. Our proposed set of artifacts include constructs and a model for representing relation-

1 ships between ITs and a new method for identifying and representing patterns of technology evo-
2 lution. These constitute a novel process for representing, understanding, evaluating, and fore-
3 casting the IT landscape, thus enabling managers to make more effective IT investment deci-
4 sions. As noted by Benbasat and Zmud (2003), the IS research discipline includes the develop-
5 ment of methodological practices and capabilities involved in the planning, construction, and
6 implementation of IT artifacts. This research follows in that vein by providing a new set of tools
7 for analysts involved in the IT investment and development decision-making process.

8 An important aspect of design science research is the evaluation of the proposed artifacts; in
9 other words, the utility of the proposed artifacts must be demonstrated. To perform this evalua-
10 tion we first present two cases to establish validity of the proposed constructs and methods and
11 demonstrate their use in characterizing specific IT ecosystems and IT evolution. We then assess
12 the use of the proposed constructs and methods through in-depth semi-structured interviews with
13 a set of knowledgeable IT industry experts including senior IT executives, consultants, industry
14 research analysts, and academic researchers. These interviews were conducted to provide: (1)
15 further understanding and motivation for the business and organizational IT problem we address;
16 (2) an evaluation of the utility of our proposed approach in real-world settings; and (3) sugges-
17 tions for improvements and future work.

18 The remainder of the article proceeds as follows. Section 2 reviews the conceptual founda-
19 tions of the research and discusses sense-making from process data and the IT ecosystem model.
20 Section 3 outlines the new problem representation structure and defines our analytical constructs,
21 including the concepts of IT ecosystem, technology roles, technology paths of influence, and pat-
22 terns of technology evolution. In Section 4, we present a state-diagram-based visualization ap-
23 proach for representing trends in IT evolution and illustrate the application of the constructs with
24 a qualitative example from the digital music industry. Section 5 further demonstrates the appli-

1 cation of the constructs with a quantitative analysis of the wireless networking IT ecosystem us-
2 ing a new empirical method for identifying trends in IT evolution. Section 6 provides an evalua-
3 tion of the utility of our proposed approach using in-depth interviews with IT industry experts
4 and an analysis of complementarities with existing techniques for technology forecasting. Sec-
5 tion 7 provides a summary of contributions and limitations of our work as well as opportunities
6 for future research.

7 **2. CONCEPTUAL FOUNDATIONS**

8 Decision-making and justification for IT investments is of strategic importance for modern firms
9 and can be difficult for even the most-seasoned and knowledgeable managers in the presence of
10 technological, organizational, and market complexity (Clemons and Weber 1990, Bacon 1992).
11 An important aspect of the IT investment decision-making process is analyzing the market land-
12 scape to identify and predict trends in IT development, which is often helpful for investment
13 planning and product development strategies. Formal analysis in this domain has traditionally
14 been difficult primarily due to the sheer number of available technologies and the complex inter-
15 relationships among them. Compounding this problem is the fact that practitioner knowledge of
16 the historical drivers, relationships, and patterns of technology evolution is often limited, and
17 rarely is it well-structured knowledge outside the realm of the IT forecasting and consulting firm
18 ‘gurus.’ The objective of our research is to address this problem by providing industry practitio-
19 ners with a new set of tools for analyzing the IT landscape and predicting IT trends. We use ex-
20 isting theory on technology evolution and IT innovation and use a *process theory* approach to
21 guide the design of the constructs upon which we formulate and develop our proposed tools.

22 **2.1. The Process Theory Perspective for Design Science Research**

23 Process theory provides the ideal lens for developing tools to analyze the IT landscape. Under-

1 standing the complex IT landscape and changes that occur within it over time requires *sensemak-*
2 *ing* (Weick 1979) of an environment that consists of many technologies and relationships. *Proc-*
3 *ess theories* are concerned with explaining how outcomes evolve or develop over time (Mohr
4 1982, Markus and Robey 1988), and, therefore, the process theory perspective is an appropriate
5 foundation for developing tools for evaluating changes in the IT landscape.

6 The process theory approach has been used extensively in IS research, most notably as a base
7 for *structuration analysis* (Orlikowski and Robey 1991, Orlikowski 1993) and for modeling se-
8 quences of events (Abbot 1990, Newman and Robey 1992). In each of these cases, the process
9 theory approach was applied to inform the development of new techniques for analyzing com-
10 plex process data. Process data are difficult to analyze and manipulate because they deal mainly
11 with sequences of events, often involve multiple levels and units of analysis, vary in terms of
12 temporal precision and duration, and tend to focus on eclectic phenomena such as changing rela-
13 tionships (Langley 1999). This description matches the type of data available to analyze and
14 predict trends in an IT landscape – event data (e.g., new technology introductions) consisting of
15 multiple types of technologies with differing attributes and various measures of time. Our tools
16 should be designed to help practitioners understand how technologies evolve over time and why
17 they evolve in a certain way, which is also a key objective of process-data-related research (Van
18 de Ven and Huber 1990).

19 Langley (1999) outlines seven strategies for sensemaking and theorizing with process data,
20 and our current research uses a combination of two of them – the *quantification strategy* and the
21 *visual mapping strategy* – to develop the proposed artifacts. The quantification strategy, as ex-
22 emplified by the research of Van de Ven and Poole (1990), involves the systematic coding of
23 events according to predetermined characteristics. It further involves gradually reducing the
24 complexity of the process data to a set of quantitative time series that can be analyzed using em-

1 pirical methods (e.g., Garud and Van de Ven 1992, Romanelli and Tushman 1994). The visual
2 mapping strategy, which can be used for the development and verification of theoretical ideas,
3 involves producing graphical representations of process data to present large quantities of data in
4 relatively little space (Miles and Huberman 1994). Visual mappings allow simultaneous repre-
5 sentations of a large number of dimensions and can be easily used to show precedence, parallel
6 processes, and the passage of time (Langley 1999). Visual representations can help researchers
7 look for common sequences of events, patterns, and progressions in process data (Langley and
8 Truax 1994). A common use of visual mapping strategy is the development of process maps, as
9 demonstrated by both organization researchers (e.g., Meyer 1991, Meyer and Goes 1988) and
10 decision researchers (e.g., Mintzberg et al. 1976, Pentland 1995).

11 Our research combines the principles and sensemaking strategies of process theory with the
12 formal guidelines of design science research (Hevner et al. 2004) to develop new tools for mod-
13 eling, visualizing, analyzing and predicting trends in the IT landscape. The quantification strat-
14 egy is used for coding IT innovations and developing a methodology for empirically identifying
15 patterns of technology evolution. The visual mapping strategy is used to represent these patterns
16 over time.

17 **2.2 The Technology Ecosystem**

18 An *ecosystem view* is a useful approach for representing the many technologies and relationships
19 that make up the IT landscape. Hannan and Freeman's (1977 and 1989) seminal work on *organi-*
20 *zational ecology* has sparked the increased use of an ecological analogy in business and organi-
21 zation research. The theoretical perspective of organizational ecology is used to examine the en-
22 vironment in which organizations compete as well as the birth and death processes of firms.
23 Strategy researchers have also adopted an ecosystem model in the analysis of business relation-
24 ships and strategic decision-making (Iansiti and Levien 2002, 2004). Managers and academi-

1 cians are recognizing the value of the ecosystem metaphor for understanding the complex net-
2 work of business relationships within and across industries (Harte et al. 2001). Most recently, IS
3 researchers have also begun to adopt an ecosystem perspective: Quaadgras (2005) used network
4 modeling techniques to define the RFID business ecosystem and forecast firm participation,
5 Nickerson and zur Muehlen (2006) analyzed Internet standards creation using a population ecol-
6 ogy model, and Funk (2007) presented a hierarchy of relationships between technologies to de-
7 termine the timing of dominant technology designs.

8 Although the ecosystem view is proving to be important in business and research, in most
9 cases the ecosystem perspective has been used merely as means of starting discussion. There has
10 been a lack of development of analytical tools that provide real value to practitioners based on an
11 ecological perspective. Additionally, previous research incorporating the ecosystem analogy has
12 focused primarily on industrial ecosystems and relationships between firms and organizations.
13 Our research goes beyond this existing literature in an effort to formalize the ecosystem analogy
14 in the context of IT and apply it to the task of forecasting IT trends.

15 Two recent papers on IT innovation and technological change provide insights for develop-
16 ing an IT ecosystem model. Lyytinen and Rose's (2003) model of disruptive IT innovation con-
17 siders the *interrelationships* among technological innovations at the systems development, IT
18 base, and IT service levels. They argue that existing IT innovation theory must be expanded
19 upon, and modeling cross-level impacts of innovation is one of the key steps in understanding
20 the relationships among different technologies over time. In their analysis, they take a primarily
21 organizational innovation view, which demonstrates the effects of disruptive IT innovation on
22 firm's adoption and acceptance of new technologies. Our research differs by focusing on the
23 technology level of analysis and considering relationships between technologies and technologi-
24 cal innovation independent of specific firms. Adomavicius et al. (2007) explored an *ecosystem*

1 approach to technology evolution for the purposes of representing temporal relationships among
2 technologies. Although both of these papers provide useful frameworks for viewing relation-
3 ships among technologies the IT landscape, they both stop short of providing useful tools for
4 practitioners. We attempt to address this gap by using the insights from this prior research to in-
5 form the design of our formal modeling constructs and methods, with the goal of producing use-
6 ful tools to aid IT decision makers in identifying, analyzing, and predicting trends in the IT land-
7 scape.

8 The term *technology ecosystem* emphasizes the organic nature of technology development
9 and innovation that is often absent in standard forecasting and analytical methods. The tradi-
10 tional notion of an “ecosystem” in biological sciences describes a habitat for a variety of differ-
11 ent species that co-exist, influence each other, and are affected by various external forces. In the
12 ecosystem, the evolution of one species affects and is affected by the evolution of other species.
13 By considering the technology ecosystem as an interrelated set of technologies, a manager can
14 more successfully identify factors that may impact innovation, development, and adoption of
15 new technologies—and ultimately the success of the business activities that use the innovations.

16 The *ecosystem model of technology evolution* (Adomavicius et al. 2007) integrates the
17 strengths of many modeling methods and theoretical frameworks in economics, engineering, and
18 organizational theory. Three key research streams are combined to provide a comprehensive
19 conceptual model of evolution within a technology ecosystem. First, the *population perspective*
20 (Saviotti and Metcalfe 1984, Saviotti 1996) proposes that multiple interrelated technologies
21 should be viewed as a system or population whose characteristics and members change over
22 time. This concept of viewing technologies as an interrelated system is also supported by Dosi’s
23 *technology paradigms* (1982), Nelson and Winter’s *technology regimes* (1982), Laudan’s *tech-*
24 *nology complexes* (1984), and Sood and Tellis’ *platform of innovation* (2005). Second, complex

1 systems of technologies can be organized in *hierarchies* (Clark 1985, Rosenkopf and Nerkar
2 1999), which leads to the definition of specific roles played by technologies in the ecosystem.
3 Three levels of the hierarchy are typically considered: *component-level technologies* combine to
4 form *product-level technologies*, and products are then grouped to form a *system of use*. Co-
5 evolution of technologies in this model occurs both within and across levels in the hierarchy
6 (Campbell 1990, Rosenkopf and Nerkar 1999). Finally, technologies tend to follow specific *tra-*
7 *jectories* (Dosi 1982) and *patterns of innovation* (Sahal 1981 and 1985) through the process of
8 technology evolution. Baldwin and Clark (1997 and 2000) argue that, in the “age of modular-
9 ity,” specific design rules govern the common patterns of technological innovation. This sug-
10 gests that patterns and trends in IT innovation can be identified.

11 Each of the aforementioned research streams (i.e., technology populations, technology hier-
12 archies, and technology trajectories) provides a different (and perhaps complementary) perspec-
13 tive to understanding technological change and has its advantages and limitations. Thus, one of
14 the major contributions of our work is the synthesis of these different research perspectives to
15 develop constructs and methods leading towards a more comprehensive understanding of tech-
16 nology evolution.

17 **3. MODEL AND CONSTRUCTS**

18 The core of our model is the concept of an IT ecosystem and a set of roles and relationships that
19 are used to code technology innovations and represent patterns of technological change in an
20 ecosystem. In this section, we discuss our use of theory in support of our effort to design arti-
21 facts (Gregor 2006) and define constructs that provide foundations for a new visual representa-
22 tion and empirical approach for modeling technology evolution patterns over time.

1 **3.1 IT Ecosystem**

2 The size and complexity of the IT landscape contributes to the difficulty of predicting future IT
3 developments. To reduce this complexity, we introduce the concept of an *IT ecosystem*. Follow-
4 ing the notions of *systems of use* (Rosenkopf and Nerkar 1999) and *technology ecosystem* (Ado-
5 mavicius et al. 2007), we define an IT ecosystem as a subset of information technologies in the
6 IT landscape that are related to one another in a specific context of use. There can be many dif-
7 ferent IT ecosystems, which can also possibly overlap. A specific context of use is necessary to
8 be able to define the most relevant set of technologies that make up an IT ecosystem. For exam-
9 ple, an IT ecosystem could be defined by an analyst working for a mobile phone manufacturer
10 interested in the context of providing mobile entertainment to users. This ecosystem would in-
11 clude the technologies involved in the delivery and consumption of mobile-phone-based enter-
12 tainment. By limiting the scope of an ecosystem through the context of use, the complexity of
13 the IT landscape is greatly reduced, and trends relevant to the analysis at hand can be more easily
14 identified.

15 **3.2 Roles in the IT Ecosystem**

16 The hierarchical nature of technologies within a population leads to the identification of specific
17 *roles* that technologies can play within an IT ecosystem. By acting through these roles, classes
18 of technologies can influence each other's evolution and development through common patterns
19 of innovation. Due to the systemic nature of IT, information technologies can act as *products*
20 *and applications, components, or infrastructure* (Adomavicius et al. 2007).

21 The *product and application role* describes technologies that interact with a user in the given
22 context of use and are built up from component technologies. They are designed to perform a
23 specific set of functions in the specific context of use. For example, in an IT ecosystem centered
24 on the digital music playback, an MP3 player would act in a product role because it interacts di-

1 rectly with the user in the given context: storing and playing digital music files. Other technolo-
2 gies that would be considered products in this context include CD players, mobile phones, lap-
3 tops, and satellite radio devices.

4 The *component role* represents technologies that are sub-units or subsystems of other tech-
5 nologies in an IT ecosystem. For example, in a personal computing IT ecosystem, there are sev-
6 eral technologies that act as components: microprocessors, RAM chips, hard disk drives, etc.
7 Individually and in combination, these components provide functionality to products (such as
8 laptops, desktops, PDAs, and smart phones) in this IT ecosystem. To differentiate between com-
9 ponents and products, the latter are typically defined by designers and emerge by combining
10 components into products that solve users' problems or needs. For example, a recent report on
11 emerging economies notes that combining existing components to create new products is becom-
12 ing a common mode of technological innovation (Economist 2007). Individual component tech-
13 nologies can be sub-units of multiple products in the same ecosystem and contain components
14 themselves. For example, the hard disk drive is a standard component in many of the products
15 mentioned above. However, the hard disk drive also has a set of component technologies itself,
16 including DC spindle motors, actuators, and platters. This emphasizes the importance of defin-
17 ing the scope of the IT ecosystem around a context of use relevant to a specific analytical task.

18 The *infrastructure role* describes technologies that enable or work in conjunction with (or as
19 a peripheral to) product and application role technologies in an IT ecosystem. Note that the term
20 "infrastructure" has multiple connotations in the research literature. For example, Star and
21 Ruhleder (1996) define infrastructure as a constellation of products that are in use by multiple
22 communities (over time and space). In this paper, however, we define infrastructure as tech-
23 nologies that add value to the use of the product technologies they support in the given context of
24 use. Therefore, technologies in the infrastructure role are, by definition, differentiated from

1 product technologies. For example, in the personal computing IT ecosystem a printer is not
2 physically necessary for the design and use of a PC, but it extends the PC's functionality, ex-
3 pands the PC's system of use, and provides additional value and services to their users.

4 **3.3 Paths of Influence in the Technology Ecosystem**

5 Technological evolution and development is complex and can take many paths within a technol-
6 ogy ecosystem. Boland et al. (2003) argue that understanding the changes of information tech-
7 nology over time requires an integrated view of the innovation process. In particular, their work
8 highlights the importance of history and the effects of time in understanding innovation (Arthur
9 1989) and viewing it as a continuous path creation process. To capture the types of temporal in-
10 fluences technologies have on one another, we define *paths of influence* to represent the impacts
11 of innovation across technology roles within an IT ecosystem. Innovations in any one of the
12 technology roles within an ecosystem can cascade through the other roles resulting in subsequent
13 innovations. We are essentially adopting a *path-dependent* view, in which change in an IT eco-
14 system follows “a dynamic process whose evolution is governed by its own history” (David
15 2007, p. 1). For example, the introduction of a new component technology can influence the de-
16 velopment of new product technologies in the future, representing a specific path of influence:
17 Component role \rightarrow Product/application role* (or $C \rightarrow P^*$). Here the asterisk (*) is used to indicate
18 a future state of a technology role in the ecosystem, and C, P, I are used as abbreviations for
19 component role, product and application role, and infrastructure role.

20 Paths of influence represent the impact one technology role has on another in the evolution of
21 a set of technologies in the ecosystem. For example, the success of the DVD player has helped
22 drive the development of new DVD component technologies. These include recordable DVD
23 ROMs, multi-layer DVD ROMs, and new blue-ray and HD technologies ($P \rightarrow C^*$). Similarly, the
24 evolution of infrastructure technologies can drive the development of new product technologies.

1 For example, a 3G cellular phone network provides infrastructure for new phone services and
2 applications such as streaming video and rich applications (I→P*). Paths of influence provide a
3 problem representation structure for analyzing technological interdependencies in an IT ecosys-
4 tem over time. Specifically, they provide a way to reduce the complexity of relationships among
5 technologies within an ecosystem and identify trends in technological change. Table 1 presents a
6 3 x 3 matrix that classifies the nine possible paths of influence based on the three information
7 technology roles. The examples in Table 1 are potential paths of influence in a personal comput-
8 ing IT ecosystem.

9 INSERT TABLE 1 ABOUT HERE

10 There are many theories of what drives technological change. *Technological determinism*
11 posits that technological development drives social and cultural changes (Smith and Marx 1994),
12 while *social construction of technology* argues the opposite: society and culture determine tech-
13 nological development (Bijker et al. 1987). A related, yet slightly different debate exists in the
14 economics and management literature. Demand-side forces, such as consumer and market
15 needs, drive technological development (e.g., Adner and Levinthal 2001, Clark 1985, Malerba et
16 al. 1999). The opposing perspective is that supply-side forces, such as firm capabilities and
17 R&D, are responsible (e.g., Dosi 1982, Sahal 1985). Our current model is focused on the techni-
18 cal drivers of technological change (Nelson 1995) and does not explicitly model external forces
19 such as society, culture, and the supply or demand environment. We recognize that society and
20 culture impact the development and evolution of technology. However, we refrain from explic-
21 itly aligning our model with any of the aforementioned theoretical perspectives. Instead, in an
22 effort to develop a parsimonious model and usable artifacts that reduce the complexity of the IT
23 landscape, our current model is focused only on technology roles and relationships in an IT eco-
24 system. Although our long-term goal is to incorporate these forces and develop a comprehensive

1 set of interactions, in this paper we demonstrate that reducing technological complexity while
2 increasing the understanding of the IT landscape can be accomplished by focusing strictly on re-
3 lationships among information technologies. Thus, since our model is targeted for use by do-
4 main experts, for this study we assume that domain experts are aware of market and social forces
5 and will be able to define their ecosystems with appropriate consideration.

6 **3.4 Representing Patterns of Technology Evolution**

7 Identifying patterns of technological change within an IT ecosystem is necessary for predicting
8 future trends. Sahal (1981 and 1985) identifies several specific patterns of technological change,
9 including invention, innovation, and diffusion, and recognizes that technology development fol-
10 lows an evolutionary process. Other researchers have made similar observations. Worlton
11 (1998) observes that patterns of technological change typically follow four stages: invention, in-
12 novation, diffusion, and change of scale, and Baldwin and Clark (1997 and 2000) argue that, due
13 to increased modularity, specific design rules can lead to predictable innovation patterns. The
14 constructs defined in the previous section can be used to identify patterns of technological
15 change within an IT ecosystem.

16 Visual mapping strategies provide a means for simultaneously representing multiple dimen-
17 sions and can help researchers identify common patterns, sequences, and progressions in process
18 data (Langley 1999, Langley and Truax 1994). For example, Nickerson and zur Muehlen (2006)
19 demonstrated the use of a population ecology perspective to map out the complexities in Internet
20 standards making. They use a visual mapping strategy to represent the “space-time network” of
21 the migration of ideas generated during Web services standards development. Similarly, Boland
22 et al. (2003) used a visual mapping strategy to represent path creations in industries as a result of
23 IT-led innovations. We present a method for visually mapping patterns of technological change
24 in an IT ecosystem to help IT practitioners identify, analyze, and predict IT trends using the con-

1 cepts of technology roles and paths of influence.

2 As technologies evolve, some new technologies are introduced, and some existing technolo-
3 gies die out. An ecosystem's form and content change as well as the patterns of evolution occur-
4 ring within the ecosystem. Technologies in an ecosystem can be coded into component, product,
5 and infrastructure roles and, within a specific time period, the quantity of technologies in each
6 role determines the dominance of a role in the ecosystem. Transitions from one set of dominant
7 roles in the ecosystem to another set can then be represented by paths of influence and, over
8 time, evolutionary patterns can be identified as *collections* of the paths of influence occurring in
9 the IT ecosystem. Table 1 provided a pattern template, and Figure 1 provides examples of sev-
10 eral patterns of technological change, each one represented by a collection of paths of influence
11 occurring in an ecosystem at the same time.

12 INSERT FIGURE 1 ABOUT HERE

13 An alternative representation of the patterns can be achieved using a graph-based approach.
14 The nodes in Figure 2 represent the collection of component (C), product (P), and infrastructure
15 (I) technologies at each time in the evolutionary process. The edges between nodes represent the
16 individual paths of influence, and the evolutionary patterns are represented by the set of edges in
17 each time period.

18 INSERT FIGURE 2 ABOUT HERE

19 Three roles may seem to offer a rather simple representation, however, nine possible paths of
20 influence emerge from these roles, and dozens of possible patterns of technology evolution
21 emerge as various combinations of different paths of influence. The three technology roles pro-
22 vide a simple set of constructs that enable representation a large number of complex patterns of
23 technological change.

24 Although the ability to identify single patterns of evolution in technology ecosystems pro-

1 vides insights for managers making technology-related decisions, a more significant contribution
2 of the ecosystem model is its ability to provide a systematic approach for describing the temporal
3 changes (transitions) in the ecosystem using these patterns. In the next section, we demonstrate
4 the use of our approach by examining how a series of evolutionary transitions can be represented
5 by connecting multiple patterns over time, which can lead to the identification of some intrinsic
6 patterns that can be utilized in technology forecasting.

7 **4. QUALITATIVE APPLICATION: EVOLUTIONARY TRANSITIONS IN** 8 **DIGITAL MUSIC TECHNOLOGIES**

9
10 We use the digital music technology ecosystem to provide a demonstration of a qualitative ap-
11 proach for applying the constructs and identifying patterns of technological change. This exam-
12 ple demonstrates the design and use of our constructs and communicates their relevance for both
13 IS research and practice. We use our visual mapping strategy to create a state diagram to map
14 the patterns of technological change and innovation that emerge.

15 **4.1 Qualitative Analysis Approach**

16 The digital music technology ecosystem is an ideal setting for analysis. It includes many differ-
17 ent component, product, and infrastructure technologies and, although most digital music tech-
18 nologies have only existed since the mid-1990s, there has been a significant amount of techno-
19 logical change in this ecosystem. Demand for these technologies has skyrocketed over the past
20 several years, so we expect to see many new product introductions in the market. Additionally,
21 digital music technologies span the consumer electronics, entertainment, and computer indus-
22 tries, which suggest that there is an underlying complexity in their design and relationships
23 within the ecosystem. Furthermore, digital music technologies have revolutionized the con-
24 sumption of music and other forms of media, and most people can relate to these technologies
25 since they likely own or use them.

1 In developing this qualitative example, we follow the descriptive approach outlined by Hev-
2 ner et al. (2004) to demonstrate the application of our proposed constructs. We used LexisNexis
3 and Internet search tools to gather announcements, news stories, and historical records related to
4 technologies in the digital music ecosystem between 1989 and 2006. In total, we gathered in-
5 formation on approximately 100 related technologies (e.g., flash-based storage, LCD screens,
6 MP3 players, digital music services). These announcements were coded into examples of new
7 technologies in the component, product, and infrastructure roles. Using information on the tim-
8 ing of technology releases, we developed a rich qualitative interpretation of technology trends in
9 the ecosystem. We provide insights on the nature of digital music technology evolution and il-
10 lustrate the use of our artifacts for qualitative analysis of an IT ecosystem.

11 **4.2 Technology Evolution in the Digital Music Ecosystem**

12 The demand for digitally-formatted music files, players, and services has grown steadily over the
13 past five years. In fact, a new digital music market has developed with many technological in-
14 novations and rapid consumer adoption. Since it was originally patented in Germany in 1989,
15 the MP3 audio compression format has had a significant impact on the traditional music indus-
16 try. In 1999, peer-to-peer (P2P) file sharing networks gained rapid acceptance, sparking legal
17 battles and the development of new encryption and file-tracking technologies. In February 1999,
18 Sub Pop Records became one of the first labels to begin releasing music in the MP3 format
19 (*Wired News* 1999). Since then, the introduction of mass storage digital music players and on-
20 line digital music retailers has transformed the music business. Table 2 and Figure 3 provide
21 multiple illustrations of the timeline and the evolution of digital music technologies.

22 INSERT TABLE 2 AND FIGURE 3 ABOUT HERE

23 Digital music technology evolution started with the introduction of the MP3 compression
24 format and software applications for playing MP3-encoded music files. The birth period of the

1 digital music industry was characterized primarily by the initial product development pattern of
2 technology evolution (Figure 1a), where component technologies (such as the MP3 compression
3 format) and product technologies (digital music software, such as WinAmp) were being refined
4 as they gained more attention. Activities in this era included the refinement of the MP3 format
5 by integrating it into MPEG-1 in 1992 and MPEG-2 in 1994. Once MP3 files reached a reason-
6 able level of adoption, a *feed-forward* pattern of technology evolution (Figure 1c) took over as
7 new product and infrastructure technologies were introduced based on the MP3 encryption for-
8 mat. The first portable MP3 player, the 32MB MPMAN device from Eiger Labs, was released in
9 mid-1998 (Van Buskirk 2005), and P2P networks were introduced with Napster's inception in
10 May 1999. Both technologies emerged because of the popularity of the MP3 compression for-
11 mat.

12 As popularity increased for the technologies in the digital music ecosystem, additional infra-
13 structure technologies were developed to align with existing product offerings (Figure 1b), in-
14 cluding refinements to P2P networks and the introduction of new digital music encoding stan-
15 dards, such as Microsoft's WMA and Apple's AAC. As a result of the continued growth in pop-
16 ularity of digital music products and technologies, a *feed-back* pattern of technology evolution
17 (Figure 1d) took hold, and new components and products, such as higher capacity flash storage
18 based players, were developed. At this point, the majority of MP3 players were flash-storage-
19 based and virtually all MP3 file distribution occurred over P2P networks.

20 These patterns of technological change repeat themselves with the next generation of digital
21 music technologies. Innovations in components, such as high-capacity micro hard disk drives,
22 led to the initial product development of hard disk drive-based MP3 players, such as the Apple
23 iPod and the Creative Nomad Jukebox. These new HDD-based players sparked a new *feed-*
24 *forward* pattern of evolution that resulted in the introduction and adoption of new online music

1 services, such as iTunes and Napster 2.0, as well as a slew of accessories for portable MP3 play-
2 ers, such as FM transmitters and voice recorders. With the presence of multiple online music
3 providers and portable MP3 players, technology evolution became focused on the alignment of
4 infrastructure and product technologies. The wide adoption of the second-generation digital mu-
5 sic technologies led to feed-back patterns that included introduction of new products using new
6 components such as color LCD screens.

7 **4.3 Mapping the Analysis Back to the Constructs**

8 The events that occurred in the digital music technology ecosystem can be represented as pat-
9 terns of technological change using the roles and paths of influence. Figure 4 provides a visual
10 representation of transitions between multiple evolutionary patterns over time. Coding the tech-
11 nologies into roles allowed us to identify paths of influence, represented by the arrows in Figure
12 4, and multiple patterns of technology evolution, represented by the collection of arrows in each
13 time period. Figures 3 and 4 represent two different ways in which we can visually depict the
14 sequence of 3 x 3 matrices representing paths of influence as a state diagram. Both qualitative
15 and quantitative analysis can be used to develop these representations of evolutionary patterns,
16 enabling an analyst to understand and predict the next generation of technologies in the desired
17 context. Our development is supported by prior research, which shows that innovation typically
18 occurs in specific patterns (Sahal 1981 and 1985, Baldwin and Clark 2000, Worlton 1998), in
19 some cases cycles (Rosenkopf and Nerkar 1999, Worlton 1998), and that new innovations typi-
20 cally replace existing ones (Rosenkopf and Nerkar 1999).

21 **INSERT FIGURE 4 ABOUT HERE**

22 Based on this visual mapping, an analyst could forecast that the next generation of digital
23 music technologies will begin as new components are introduced that allow for even more ad-
24 vanced features in product technologies. For example, the evolution of components that are used

1 across multiple ecosystems may result in the convergence of hand-held computing devices (e.g.,
2 PDAs, cellular phones, MP3 players, digital cameras). In fact, Motorola introduced one of the
3 first MP3-enabled mobile phones (Shillingford 2005), and the Sony/Ericsson Walkman MP3
4 phone grew sales by 33% in the second quarter of 2006 (Ewing and Burrows 2006), as demand
5 expanded in the presence of falling prices. Microsoft released a new multimedia-playing (audio,
6 video, and software) hand-held device called Zune in November 2006, and Apple released its
7 “iPhone,” an iPod-phone hybrid device, in mid-2007.

8 Currently the ecosystem is rapidly evolving to include many new technological possibilities,
9 such as embedded digital rights management (DRM), web services on hand-held devices, GPS
10 built-in functionality for location-based shopping, and component innovations that will eventu-
11 ally support mobile TV. The ecosystem view allows the manager to model these types of evolu-
12 tionary patterns as well as track and analyze their progression over time, which provides better
13 understanding of the dynamic nature of technological change in a given context.

14 **5. QUANTITATIVE APPLICATION: EVOLUTIONARY TRANSITIONS** 15 **IN WI-FI TECHNOLOGIES**

16
17 To further substantiate the application of our constructs and model, we developed a new empiri-
18 cal methodology to identify technology evolution patterns by combining a quantification strategy
19 with the visual mapping state-diagram-based approach for sensemaking from process data
20 (Langley 1999, Van de Ven and Poole 1990). A quantitative approach for analyzing the IT land-
21 scape provides a strong complement to the qualitative approach we demonstrated in Section 4.
22 When sufficient data on the introduction of technologies are available, a quantitative approach
23 provides additional rigor to the identification of evolutionary patterns. We follow guidelines in
24 Hevner et al. (2004) and use an analysis of real data to demonstrate our methodology.

1 **5.1. Data**

2 The wireless networking ecosystem provides an appropriate context for applying our empirical
3 methodology for several reasons. Similar to the digital music technology ecosystem example,
4 wireless networking technologies are relatively young but have experienced a large amount of
5 technological change; in addition, these technologies also fit into the computer and consumer
6 electronics industries, so complexity is high. However, unlike digital music technologies, wire-
7 less networking technologies have had clearly-defined generations based on IEEE standards.
8 The existence of these standards suggests that recognizable patterns may exist, and our empirical
9 methodology can be validated by identifying those patterns. Furthermore, wireless networking
10 technologies are used not just by individuals but also by firms and organizations. They are also
11 typically certified by the Wi-Fi Alliance (www.wi-fi.org), which maintains a database of product
12 certifications and makes the data publicly available:

13 *“The Wi-Fi Alliance is a global, non-profit industry trade association with more than 200 member compa-*
14 *nies devoted to promoting the growth of wireless local area networks (WLAN). Our certification programs*
15 *ensure the interoperability of WLAN products from different manufacturers, with the objective of enhanc-*
16 *ing the wireless user experience.”*

17 This provides an opportunity to compare and contrast different ecosystems, and to evaluate our
18 constructs and visual mapping strategy with both qualitative and quantitative analyses.

19 We collected data on over 3,000 certifications for new wireless networking (802.11) tech-
20 nologies awarded by the Wi-Fi Alliance. The member companies of the Wi-Fi Alliance include
21 3Com, Apple, Dell, Intel, Linksys, and many others. Certifications are awarded for ten different
22 technology categories: access points, cellular convergence products, compact flash adapters, em-
23 bedded clients, Ethernet client devices, external cards, internal cards, PDAs, USB client devices,
24 and wireless printers. Technologies can be certified based on IEEE communication standard
25 (802.11a, b, g, d, and h), security (e.g., WPA, and WPA2), authentication protocol (e.g., EAP,

1 and PEAP), and quality of service (e.g., WMM).²

2 Generally, historical product data that includes comprehensive technical specifications and
3 dates of release is difficult to obtain. However, the Wi-Fi Alliance certifications have been
4 awarded to a substantial number of technologies, with most certified prior to their commercial
5 release. For this reason, we have used the date of certification as a proxy for the date of innova-
6 tion for a new technology, and the type of certification as a proxy for the technical specifications
7 of the product. Both are readily observed, and the former is likely to occur close to the date of
8 innovation, and so they represent acceptable empirical proxies.

9 We coded the Wi-Fi certification categories into the ecosystem roles (component, product,
10 and infrastructure) based on our operationalization the IT ecosystem model. Compact flash
11 adapters, internal cards, external cards, and USB client devices were coded as component tech-
12 nologies, because each clearly acts as a component by providing wireless capabilities for product
13 devices. We coded access points, Ethernet client devices, and wireless printers as infrastructure,
14 because these technologies either form or extend the network infrastructure necessary for wire-
15 less communication. Finally, we coded PDAs, embedded clients (PCs and laptops), and cellular
16 convergence technologies (Wi-Fi enabled cell phones) as products, because each represents a
17 product device that provides fully functioning wireless networking capabilities to the end user.
18 Coding the wireless technologies into appropriate roles leads to the identification of dominant
19 roles and the paths of influence between roles. The collections of these paths of influence at dif-
20 ferent time periods represent patterns of technology evolution in the ecosystem.

² WPA (Wi-Fi protected access) is a standard for wireless network security. For more information, see en.wikipedia.org/wiki/WPA. EAP (extensible authentication protocol) is a universal authentication framework frequently used in wireless networks, and PEAP is an open-standard authentication framework based on EAP proposed by Cisco, Microsoft, and RSA Security. See en.wikipedia.org/wiki/Extensible_Authentication_Protocol for additional information. WMM (Wi-Fi multimedia, also known as WME – wireless multimedia extensions) is a standard that provides basic quality of service (QoS) for wireless networks by prioritizing traffic according to the following access categories: voice, video, best effort, and background. en.wikipedia.org/wiki/WMM offers details.

1 **5.2. Empirical Methodology**

2 Following a quantification strategy similar to Van de Ven and Poole (1990), we present a meth-
3 odology for reducing the complexity of technology evolution process data to a set of time-based
4 quantitative data that can be used to empirically identify patterns. Table 3 provides a high-level
5 description of the steps in the methodology.

6 INSERT TABLE 3 ABOUT HERE

7 First, raw technology evolution data were coded according to the component, product, and
8 infrastructure roles within a specific ecosystem (Step 1 in Table 3). As noted above, the wireless
9 networking data were coded based on the product category assigned to a technology in the Wi-Fi
10 Alliance certification. Technical specifications for wireless networking technologies exhibit a
11 natural progression over time. For example, the IEEE 802.11b standard was introduced prior to
12 the 802.11g standard and, therefore, new technology introductions are distributed accordingly,
13 based on their technical specifications. We use the technical specifications of IEEE communica-
14 tion standard (802.11b versus 802.11g) and the basic security standard (WPA1 versus WPA2) to
15 identify different generations of wireless technologies. We independently analyzed each 802.11
16 and WPA generation (i.e., two generations in each category) and then made comparisons across
17 generations to identify patterns of technology evolution.

18 Next, to derive a baseline for the number of new technologies introduced over time, we esti-
19 mated a function of the frequency of all technologies introduced across all roles (Step 2 in Table
20 3). This function provides an approximation for the total innovation activity in the technology
21 ecosystem over time. A wide variety of approximation techniques may be used for this purpose.
22 For example, for the wireless network data we used a five-month moving average of the fre-
23 quency counts (i.e., to eliminate random monthly fluctuations and obtain the underlying trend)
24 and estimated the frequency curve using a polynomial approximation function. In this specific

1 case, a sixth-degree polynomial provided a good fit with R^2 values over 90%. Figure 5 depicts
2 the estimation for the frequency of technology introductions in the 802.11b generation.

3 INSERT FIGURE 5 ABOUT HERE

4 We next derived *threshold frequency functions* for each role using the frequency function es-
5 timated for all technology introductions (Step 3 in Table 3). If we assume that the technology
6 roles do not have an effect on the timing of new technology introductions and there are no inter-
7 dependencies across roles, we would expect to see the number of technology introductions in
8 each role over time be proportional to the total number of technology introductions in the ecosys-
9 tem. With this in mind, we derive estimated frequency functions for each role based on the pro-
10 portion each role has of the total number of technology introductions. For reference, the set of
11 technologies released in the 802.11b generation is 54.4% components, 10.4% products, and
12 35.2% infrastructure, and the set released in the 802.11g generation is 45.9% components, 8.0%
13 products, and 46.1% infrastructure. In Figure 6, the top curve represents the estimated frequency
14 function for all technologies and the three curves below represent the proportional frequency es-
15 timates for components, infrastructure, and products, respectively from the top.

16 INSERT FIGURE 6 ABOUT HERE

17 Estimating the proportional frequency curves is necessary in order to take into account scale
18 differences in the number of technologies introduced in each role. In the context of the wireless
19 networking data, the total number of product certifications is significantly lower than the number
20 of component and infrastructure certifications. There are several possible reasons for the lower
21 number of product certifications. In particular, one certification for an embedded client or cellu-
22 lar convergence technology is often applied to multiple product models using the same technol-
23 ogy. For example, Dell may certify one laptop-embedded client and then apply the certification
24 to multiple laptops using the same client. Also, not all product technologies in this ecosystem

1 need to be certified. For example, a laptop that uses a wireless adapter is a product technology in
2 this ecosystem; however, the laptop itself is not certified; only the adapter is.

3 The proportional frequency functions are used as thresholds for determining the dominant
4 technology roles over time (see Step 4 in Table 3). If the number of actual technologies released
5 for a certain role is above (below) the threshold, then one can argue that there is proportionally
6 more (less) innovation activity occurring in that role than expected under the assumption of in-
7 dependent technology introductions and no interdependencies among roles. Using error bars, in
8 this case exogenously set at $\pm 5\%$ of the threshold curve value, actual frequencies of technology
9 introductions in each role are compared to the threshold (plus or minus error) to determine which
10 roles are dominant at what times. Figures 7 and 8 present this comparison for the 802.11b and
11 802.11g wireless technology generations. In the figures, the solid line with error bars is the
12 threshold curve, the dotted line represents the actual frequency counts per month, and the
13 smoothed line represents a five-month moving average of the frequency counts. From these
14 plots it is apparent that over time the dominant technology roles vary. For example, for the
15 802.11b generation it is clear that component and infrastructure technologies either trace the
16 threshold or surpass it for the first half of the generation, but they begin to lag in the second half
17 as product technologies begin to dominate. Similar patterns are apparent in the 802.11g figure.

18 INSERT FIGURES 7 AND 8 ABOUT HERE

19 The results of the threshold comparisons discussed above can be represented using the visual
20 mapping strategy discussed previously. By identifying the dominant technology roles in each
21 time period, a state diagram can be created to represent the transitions across technology evolu-
22 tion patterns (see Step 5 in Table 3). The next section provides the examples of state diagrams
23 obtained from the Wi-Fi certification data using the proposed methodology.

1 **5.3. Mapping the Analysis Results Back to the Constructs**

2 Based on the analysis presented in Figures 7 and 8 for the 802.11b and 802.11g wireless tech-
3 nologies, the state diagram in Figure 9 was generated, which allows several general trends to be
4 observed. The empirical method described above identifies the dominant technology type within
5 each time period (represented as nodes in Figure 9), and the expert can then define the transitions
6 from one time period to the next (represented as arrows in Figure 9) using contextual information
7 from the domain. In particular, it is apparent that innovations in product technologies clearly lag
8 the introduction of new component and infrastructure technologies. As 802.11b component and
9 infrastructure innovation intensity begins to drop off, an increase in 802.11b product certifica-
10 tions develops as well as the initial certifications for 802.11g components and infrastructure (i.e.,
11 the next innovation cycle begins). In addition, product innovations initially lag component and
12 infrastructure innovations, but for the second generation this lag is shorter, likely because
13 802.11g products are backwards-compatible with 802.11b components and infrastructure.
14 Manufacturers are able introduce the next generation (802.11g) of wireless product technologies
15 more quickly without having to wait for the widespread development of 802.11g components
16 and infrastructure.

17 **INSERT FIGURES 9 AND 10 ABOUT HERE**

18 A state diagram for the WPA1 and WPA2 generations in the same wireless networking data
19 is presented in Figure 10. In this case, it is also apparent that component technology innovations
20 predate product and infrastructure technology innovations. In the WPA2 generation the progres-
21 sion of technological innovation was from components to infrastructure to products, while in the
22 WPA1 case there is an initial component precedence followed by a dominance of infrastructure
23 and products.

24 Using the information provided by these two cycles of technology evolution in the Wi-Fi

1 ecosystem, an analyst may be able to forecast that the lag between component and infrastructure
2 technology innovations and product technology innovations will continue to reduce, and eventu-
3 ally simultaneous innovation across all technology roles will occur. In 2006, Linksys demon-
4 strated routers (infrastructure) and Internal cards (components) that operate on the emerging
5 802.11n standard (Garcia 2006) and Dell Computer shipped an 802.11n laptop client (product)
6 using Broadcom chipsets (Corner 2006). As of mid-2007, there has not yet been widespread
7 adoption of 802.11n-ready infrastructure capabilities and clients, and sentiments in the current
8 marketplace suggest some lag in next-generation wireless product technologies, as infrastructure
9 capabilities catch up and consumers become aware of the benefits (Thornycroft 2007).

10 **5.4 Comparison of Digital Music and Wireless Networking Technologies**

11 The qualitative example of digital music evolution and the quantitative analysis of the wireless
12 network technologies demonstrated that different patterns of technological change can occur in
13 different ecosystems. The difference in the digital music and Wi-Fi evolutionary patterns might
14 be explained in part by the influence of infrastructure technologies as either *supporting* or *ena-*
15 *bling* other technologies within the ecosystem. Specifically, in the digital music ecosystem, in-
16 frastructure technologies typically play a supporting role – they are not required for the use of
17 digital music products but provide additional value (e.g., online digital music stores, FM trans-
18 mitters, P2P networks). In contrast, in the Wi-Fi ecosystem, infrastructure technologies had to
19 be developed first simply to make wireless networking possible for product technologies. Then,
20 as the ecosystem developed, new infrastructure technologies, such as wireless printers, supported
21 the product technologies by providing additional value to their use. The existence of two differ-
22 ent types of infrastructure roles – supporting and enabling – provides a possible explanation of
23 different evolutionary cycles across different ecosystems.

24 There are also other possible explanations for the different patterns in these ecosystems. For

1 example, the types of consumers that purchase digital music technology products versus wireless
2 networking technology products could be fundamentally different. The social construction of
3 technology view (Bijker et al. 1987) would argue that different social and cultural environments
4 around the use of each technology lead to different patterns of innovation. Similarly, demand-
5 driven theories of innovation (e.g., Adner and Levinthal 2001) would argue that the consumer
6 and market will demand different functionality from the technologies in each of these ecosys-
7 tems, and therefore their evolution should be different. As mentioned earlier, we plan to explore
8 this issue in more detail in our future work.

9 **6. UTILITY EVALUATION OF THE PROPOSED ARTIFACTS**

10 To demonstrate the utility of our proposed artifacts, we follow Hevner et al. (2004), who sug-
11 gested seven evaluation methods, two of which are appropriate for the context we have studied.
12 The first of these is the *observational approach*, which is exemplified by *case study* and *inter-*
13 *viewing* methods. In the previous two sections, we used two case studies to establish face valid-
14 ity of our proposed artifacts and demonstrate their application using both quantitative and quali-
15 tative approaches. In this section we report the results of a number of one-hour semi-structured
16 interviews with IT industry experts who assessed the use of the proposed artifacts by practitio-
17 ners for analysis of the IT landscape. We also use the *descriptive approach* of artifact evaluation
18 by employing the *informed argument method* using information from the knowledge base of our
19 research domain to build arguments for the utility of our proposed artifacts. We accomplished
20 this by assessing common techniques that are used in practice for technology forecasting, and
21 discussing how our artifacts complement these techniques to improve IT landscape analysis ca-
22 pabilities.

23 Our proposed artifacts provide a novel approach to IT landscape analysis. This approach is

1 not directly comparable to existing technology forecasting techniques on any specific quantita-
2 tive performance measures because of its fundamentally different focus on technological change
3 within an IT *ecosystem* (as opposed to other forecasting techniques that typically focus on evolu-
4 tion of either individual technologies or entire industry sectors). Therefore, we must rely on
5 qualitative evaluation techniques. In an ideal evaluation scenario, a prediction of IT evolution
6 would be made using the proposed techniques followed by a wait and then an assessment of the
7 accuracy of the prediction. Since the ideal evaluation scenario is not possible in this context,
8 combining case studies with interviews and comparative analysis provides the next best evalua-
9 tion approach.

10 **6.1 Interviews with IT Industry Experts**

11
12 Conducting interviews is a key technique for performing IS case study research (Benbasat et al.
13 1987, Eisenhardt 1989) and is one of the most important data gathering tools in qualitative re-
14 search (Myers and Newman 2007). Interviews provide a means for capturing extremely rich da-
15 ta and, in this case, can be used to evaluate the potential utility of our proposed artifacts in a
16 business setting by allowing the informed opinions of IT industry experts to be captured.

17 **The Interview Process.** Our interview approach was based on an interview script that was
18 pre-tested to ensure questions would be understood and properly interpreted, would yield the ap-
19 propriate kinds of insights, and would be scoped to encourage open-ended input while they de-
20 livered answers that would help us to gauge the utility of the technological artifacts in our re-
21 search. The interviewer ensured that all questions in the script were covered during the inter-
22 view; however, related topics of discussion were permitted in order to increase the richness of
23 the information captured. The interview included an opening for capturing basic background
24 information, an introduction to explain the purpose of the interview, key questions, and a closing
25 to provide a debriefing (Myers and Newman 2007). The interview script and additional informa-

1 tion about the development and implementation of interviews are provided in the appendix.

2 Each interview participant was asked questions about: (1) the business and organizational
3 problem of analyzing the IT landscape for technology investment and development decision-
4 making; (2) the utility of our proposed artifacts, based on their strengths and weaknesses in a
5 context of use; and (3) potential improvements that might be appropriate to our proposed arti-
6 facts. Between the first two sets of questions, the participant was given a three-page handout that
7 summarized our proposed approach for the first time. The interviewer subsequently spent, on
8 average, 25 minutes explaining and demonstrating the proposed approach and answering clarifi-
9 cation questions, using the handout as a guide. The interviews took, on average, one hour each.

10 **Interview Subjects.** We interviewed a set of IT industry experts with participants from four
11 distinct populations: (1) IT industry senior executives, (2) IT industry consultants, (3) IT industry
12 research staff and analysts, and (4) senior academic researchers with expertise on the IT industry.
13 We chose these groups to represent the comprehensive set of perspectives of experts typically
14 involved in the problem of IT landscape analysis. Using local industry and national academic
15 contacts, we invited up to eight people in each group to participate in the interview process and
16 selected a subset of participants to have a balanced sample based on availability and given time
17 constraints. We interviewed a total of twelve experts, three in each group. Each participant had
18 well over ten years of IT industry experience, and over ten years of experience in a management
19 or senior decision-making role. All participants evaluated themselves to have a high level of un-
20 derstanding of the landscape of current and past information technologies. The participants
21 hailed from Fortune 500 companies, technology research and government organizations, and
22 well-known research universities. A summary description of the interview participants appears
23 in Table 4.

24 **Question Coverage.** We asked questions to evoke the participants' opinions about four key

1 aspects of using our artifacts for analyzing the IT landscape. (See Table 5.) First, we evaluated
2 the *usefulness of the proposed constructs* in the ecosystem model. In particular, we asked
3 whether the component, product, and infrastructure roles provided a useful model for represent-
4 ing technologies within an ecosystem. We also queried their opinions about the use of paths of
5 influence to classify temporal relationships. Second, we evaluated the *logic of the qualitative*
6 *and quantitative methodologies* for identifying and visualizing trends in the IT landscape. Here
7 our questions directed the discussion to the soundness of the methodologies and the insights pro-
8 duced by following them. Third, we evaluated the *utility of the information produced* by the
9 proposed qualitative and quantitative methodologies. Here we directed the discussion to the par-
10 ticipant’s opinions about the usefulness of the information about technology trends to practitio-
11 ners and organizations involved in the IT investment or development decision-making process.
12 We also captured opinions about the format and understandability of the output graphs and dia-
13 grams. Fourth, we captured the interviewee’s opinions about *how our methods complement ex-*
14 *isting approaches* for analyzing the IT landscape. The participants’ feedback regarding these
15 four issues led us to identify several key dimensions of utility for our proposed artifacts.

16 INSERT TABLES 4 AND 5 ABOUT HERE

17 **6.2. Results of the Interviews: Key Dimensions of Utility**

18 Responses to the first set of interview questions provided motivation and shaping of the business
19 and organizational problem our proposed artifacts address. Several key insights came out of this
20 part of the interview. On average, the participants indicated that the importance of historical,
21 current, and future IT landscape analysis to IT investment decision making as 3.7, 4.6, and 4.5
22 (on a scale 1 to 5), respectively. (Table 6a provides summary statistics of numeric questions we
23 asked in the interview.) The majority of participants (nine of twelve) independently noted that
24 the staff and management of most IT-consuming companies do not have the time or expertise to

1 perform the necessary analysis of the IT landscape, and so they must outsource this process to
2 third parties. Additionally, every participant independently noted the reliance of IT organiza-
3 tions on reports produced by the companies like Gartner, Forrester, and IDC. Multiple partici-
4 pants (six of twelve) also noted that current IT investments and partnerships play a significant
5 role in future investments, and often IT investment decisions are outsourced to partners and sup-
6 pliers. These insights reinforced the importance of providing new techniques to aid practitioners
7 in evaluating trends in the IT landscape.

8 In general, all of the participants found value in our proposed artifacts for evaluating the IT
9 landscape and providing aid in predicting future technology trends, rating the potential effective-
10 ness of using our proposed artifacts as 4.2 (on a scale 1 to 5), as shown in Figure 6a. Four key
11 dimensions about the utility of our proposed artifacts consistently emerged in their opinions re-
12 garding the value of our research. These dimensions were identified from the interpretation of
13 points independently made by several interview participants. In particular, we found that the
14 proposed artifacts support complexity reduction, help to structure investment decisions, provide
15 a formal method for quantifying technology ecosystem evolution, and support the identification
16 of the locus of value for post-investment evaluation. We discuss each of these in succession, and
17 provide our respondents' reactions to illustrate our arguments about utility. Table 6b provides a
18 summary of our interview findings with respect to the different dimensions of utility.

19 INSERT TABLES 6A AND 6B ABOUT HERE

20 **Complexity Reduction.** The general consensus of the experts we interviewed was that the
21 use of technology roles and the paths of influence provide a novel and useful way of reducing the
22 complexity of the IT landscape while maintaining the important relationships between technolo-
23 gies. Ten of the twelve respondents independently made comments to this effect, for example:

1 “[The roles and model] are very clever because you compress the universe of possibilities and make the
2 ecosystem understandable.” -- Senior Technology Analyst at a Fortune 500 transportation company

3 “This is a very good way to think about the problem ... it explains the technology ecosystem very well and is
4 nice way of trying to break up very complex phenomena.” -- Managing Director of a Government IT Or-
5 ganization

6 The exercise of defining the technology ecosystem provides two useful insights to the user of
7 the proposed constructs from the points of view of our respondents. First, it forces the analyst to
8 consider *interdependencies* among technologies and realize the *complexity* of the technology
9 ecosystem. Second, it provides structure (based on the concepts of technology roles and paths of
10 influence) to reduce this complexity using a system view of the IT landscape and captures the
11 technology ecosystem from the analyst’s point of view. Each of these aspects enhances the
12 user’s ability to understand the nature of relationships in the IT landscape.

13 **Structure for IT Investment Decision-Making.** The interviewees also reported:

14 “*This approach provides structure to the conversation and decision-making process for IT investment.*” --
15 Director of Business Development at a major university IT-related research center

16 “*This [approach] brings the ability to work on [the IT investment decision-making problem] interdiscipli-
17 narily within an organization. You could present this to the CEO, engineering guys, marketing guys, and
18 they would all know what you were talking about. They may ask different questions, but they would all find
19 it useful.*” -- Former VP of a Fortune 500 technology company, current IT industry private consultant

20 Through the interviews we discovered evidence of a lack of structure in how firms go about ana-
21 lyzing the IT landscape. They typically rely on third-party reports and advice from suppliers and
22 partners, as we noted earlier, but this apparently is still not sufficient. Ten of the twelve respon-
23 dents noted that our proposed methodology provides a means for generating representations of
24 the IT landscape and associated technology trends that are relevant to the firm’s interests and
25 business contexts. Six of the twelve participants also noted that the proposed approach is a use-
26 ful tool for decision-makers across different functional roles in the organization. The partici-
27 pants felt that senior managers and strategic planners, as well as technical managers and engi-
28 neers, could all benefit from understanding the IT landscape and technology trends in terms of

1 the proposed technology ecosystem model. In general, the consensus of the participants was that
2 the proposed methods should be useful in the IT investment and development decision-making
3 process.

4 **Formal Method to Quantify Technological Change.** Seven of the twelve respondents made
5 comments that the proposed methods provide a much needed formal technique for quantifying
6 trends in technological change within the IT landscape. Our interviewees noted that the tech-
7 niques most commonly used by firms to analyze the IT landscape are informal and *ad hoc*:

8 *"Most work on this problem is informal and this is one of only a few formal approaches I have seen. At-*
9 *tempts to formally quantify things are a good thing. This is a formal methodology to add some quantifica-*
10 *tion to the analysis by [companies like Gartner]." -- Senior Consultant at a Fortune 500 technology com-*
11 *pany*

12 *"The systematic approach this provides is useful. [...] Most strategic IT decisions are made using less for-*
13 *mal types of analysis." -- Senior Technology Analyst at a Fortune 500 transportation company*

14 We gathered from our interviews that only a few firms – including those producing industry
15 reports – use formal quantitative means to produce technology forecasts, aside from simple linear
16 extrapolation. All participants found the quantification aspect of the proposed methods to be
17 useful, and nine out of twelve also commented that our formal approach will complement exist-
18 ing techniques well and will provide firms with new and useful information for making IT in-
19 vestment and development decisions.

20 **Locus of Value for the Artifacts.** We also learned where the value of our proposed artifacts
21 will be the highest, which is another important aspect of their utility. This is similar to the *locus*
22 *of value* construct (Kauffman and Weill, 1989), which describes where value flows are most like-
23 ly to occur. A consultant and a senior manager offered the following comments:

24 *"Companies that can benefit most from this are the technology producers, like for example IBM, Microsoft,*
25 *and Sun. These are the ones defining the future technologies. By looking at a systematic way of how tech-*
26 *nology got to where it is today it may help [technology producers] determine what types of technologies*
27 *are needed." -- Senior Consultant at a Fortune 500 technology company*

28 *"For analysis purposes, this sort of model is very good and should definitely help analysts at Gartner or*
29 *Forrester produce reports for managers." -- IT Manager at a Fortune 500 retail company*

1 Based on interviews, an interesting finding for us was that, in terms of the locus of value, the
2 interview participants differentiated between the utilities of different artifacts: (1) the utility of
3 the proposed model, constructs, and the information produced by our methods (i.e., resulting
4 graphs and diagrams of specific ecosystems), and (2) the utility of methodologies themselves for
5 conducting IT landscape analysis and producing various patterns of technology evolution. The
6 participants indicated that the *information produced by our proposed methods* would be useful to
7 decision-makers in both IT-consuming and IT-producing firms. On the other hand, the majority
8 of the interview participants (seven of twelve) felt that *using the proposed approach to actually*
9 *conduct the analysis of the IT landscape* would be most beneficial to firms that either produce IT
10 or produce the industry reports on trends in IT. Understanding the trends in technology evolu-
11 tion that led to the current state of the IT landscape should prove vital in determining what direc-
12 tions IT development initiatives should follow in the future. Furthermore, the reality of IT land-
13 scape analysis is that IS and corporate strategy staff members at most IT-consuming firms have
14 neither the time, the resources, nor the technology and market knowledge to conduct formal ana-
15 lyses. So, even if the techniques for analyzing the landscape improve, IT-consuming firms will
16 still likely rely on third parties to conduct their technology assessments and analyses for them.
17 As a result, new formal approaches for analyzing the IT landscape, such as what we propose,
18 should add value to both the firms producing the forecasts and the firms consuming them.

19 **6.3. The Fifth Dimension: The Complementary Value of the Proposed Artifacts**

20 *“This [approach] should be very useful for helping educate analysts about the [IT] landscape. It is com-*
21 *plementary to other existing approaches.”* -- Senior Researcher at a Fortune 500 technology company.

22 An additional aspect of utility suggested by most of the interview participants (ten of twelve)
23 was that our proposed methods will complement well existing techniques for analyzing the IT
24 landscape. To delve deeper into the potential complementarities, we evaluated the strengths and

1 weaknesses of many common approaches for technology forecasting and IT landscape analysis
2 and discuss how our approach specifically complements each of them.

3 Table 7 provides an outline of common technology forecasting and planning techniques used
4 in industry, including trend analysis, expert opinion, modeling and simulation, and scenario
5 analysis. Although specific methods are most often proprietary, firms, such as Gartner, Forres-
6 ter, and IDC, use some version and/or combination of these techniques to generate their IT fore-
7 casts and reports. These reports typically are narrative summaries of entire industry sectors
8 based on market and financial information as well as expert opinions that are obtained in a se-
9 quential Delphi-type approach. These reports often focus on trajectories of diffusion, cost fore-
10 casts, and impact of current technologies. In contrast, our approach utilizes elements of trend
11 analysis and modeling techniques, enables mapping of the historical relationships among specific
12 technologies, and can provide useful insights regarding the next possible evolutionary steps
13 within a specific ecosystem. In particular, our approach may complement existing technology
14 forecasting methods (as noted in the last row of Table 7) by providing structured input and for-
15 mal analysis of the past and current states of the IT landscape.

16 INSERT TABLE 7 ABOUT HERE

17 Another relevant industry analysis approach is a technology roadmap. A *technology road-*
18 *map* is a tool that is typically used for planning purposes, such as in product, strategic, ser-
19 vice/capability, and process planning (Kostoff and Schaller 2001, Rinne 2004, Phaal et al. 2004).
20 Technology roadmaps provide a way to identify, evaluate, and select strategic alternatives by
21 mapping structural and temporal relationships among R&D, technologies, potential products, and
22 markets. The process of generating a technology roadmap follows a visual mapping strategy not
23 unlike we have presented. Our methods complement technology roadmaps by providing a prob-
24 lem representation vocabulary that extends current road-mapping techniques, and provides a

1 more formal quantitative method for identifying trends in technological change. Technology
2 roadmaps are designed to outline the set of possible future strategies for a specific firm, and our
3 technique adds to this by providing a method for historically evaluating the evolution of an entire
4 set of interrelated technologies (represented by technology roles within the ecosystem) using
5 similar visual representation techniques.

6 As noted in Table 7, all technology forecasting methods have inherent assumptions, and the
7 accuracy of these assumptions influences the predictive accuracy of the forecast. Most of these
8 methods, with the exception of some regression and econometric approaches, are not predictive
9 in the sense of classical variance theory (Mohr 1982), where a set of predictor variables is used
10 to predict the level of some outcome variable. The basic assumption in all forecasting tech-
11 niques, including the ones that a variance theory would suggest, is that the historical trends and
12 patterns will continue into the future following the same dynamics. Our approach follows the
13 same basic assumption: if technological change will continue to occur following the same pat-
14 terns identified using our methods, then we can make reasonable forecasts about the future.

15 **7. CONCLUSIONS, LIMITATIONS, AND FUTURE WORK**

16 Following the design science research paradigm, the major contribution of this research is the
17 development of a new set of artifacts designed to help IT practitioners and researchers make
18 sense of the IT landscape and identify, analyze, and predict technological trends. Specifically,
19 the artifacts provide tools for: (1) codifying technological innovations based on the role they play
20 within an ecosystem of interrelated technologies, (2) identifying dominant technology roles
21 within an ecosystem using real-world data, and (3) visually representing patterns of technologi-
22 cal change over time based on dominant technological roles. We evaluated the proposed arti-
23 facts in several ways. First, we used a qualitative case study of digital music technologies and a

1 quantitative case study of wireless networking technologies to demonstrate the face validity of
2 the proposed artifacts and their applicability to real-world business problems. Second, we con-
3 ducted in-depth interviews with several IT industry experts to assess the use of the proposed arti-
4 facts by practitioners for analyzing the IT landscape. Finally, we provided a comparison of the
5 proposed artifacts to existing technology forecasting techniques to highlight complementarities.

6 This work contributes to the IS research field in several additional ways. We provide a re-
7 view of relevant IS and organizational science research on technology evolution and construct a
8 theoretical perspective that integrates and builds upon previous ideas. We demonstrate strategies
9 for sensemaking of complex data (e.g., quantification and visual mapping) from process theory.
10 In addition, we provide insightful analysis on the evolution in two contemporary and important
11 IT ecosystems: digital music and wireless networking technologies. We also review and com-
12 pare existing technology forecasting methods.

13 The visual mapping and quantitative strategies for sensemaking from process data that we
14 used to develop our proposed artifacts do have their limitations. Process mapping and visual rep-
15 resentations may exclude some dimensions of data ambiguity, and graphical forms may be bi-
16 ased toward the representation of certain types of information over others. The conclusions de-
17 rived may sometimes have rather mechanical qualities since these representations deal more with
18 the surface structure of activity sequences than the underlying forces. On the other hand, since
19 the goal of quantification strategies is to reduce complexity, their use may sometimes lead to a
20 loss of richness in the process data (Langley 1999). To address the limitations of process theory,
21 Langley (1999) and Van de Ven (1992) suggest that both the quantitative and visual mapping
22 strategies should be used in combination with other approaches, as we have done in this work by
23 using the two together. Visual mapping provides additional contextual information that may be

1 lost in quantification, while quantification provides an opportunity to apply empirical rigor that is
2 missing in visualization.

3 All models are abstractions of the real world and, therefore, depend on the assumptions used
4 in their construction. In this research we relied on the assumption, based on our synthesis of
5 prior literature and our observations of the real world, that the common roles technologies play in
6 an ecosystem are components, products, and infrastructure. Another choice we make in this
7 model is to currently exclude the role of external forces, such as market dynamics, the demand
8 environment, society, and culture. Although an objective of our approach is to demonstrate that
9 the patterns of technological change can be identified using a model based solely on relationships
10 between technologies, multiple interview participants recommended expanding our model in fu-
11 ture research to include external forces and context-specific factors. Excluding these factors may
12 result in a loss of contextual richness; however, by limiting the number of factors considered in
13 the model we gain control and specificity, and reduce complexity for the user of our methods.

14 The interview participants who evaluated our proposed artifacts provided three additional
15 important recommendations and comments for expansions to the current research. First, there
16 was a suggestion that exploring the directionality of paths of influence may provide interesting
17 insights on technological development. In the current model, we looked primarily at positive
18 relationships – an innovation of a technology in one role provides an opportunity for the devel-
19 opment of a new technology in another role. The negative relationships between technologies
20 may also provide important insights. For example, a new technology may make a series of exist-
21 ing technologies obsolete, thus effectively exterminating a portion of the ecosystem. Consider-
22 ing the directionality of the relationships between technologies also reinforces the ecological
23 analogy in which both birth and death processes occur. Second, the time scale may be used more
24 effectively in quantitative analysis to identify lags in transitions between patterns in technology

1 trends. Quantifying such lags may provide a predictive tool for forecasting the occurrence of
2 future trends. Third, two of the interview participants noted that they would expect data collec-
3 tion for performing the proposed analysis to be difficult for many firms. We recognize the im-
4 portance of this comment and note that many technology services companies are investing sig-
5 nificantly in new business intelligence tools for extracting quantifiable data from the seas of in-
6 formation available on and off the Internet. As these tools evolve, rich data on the IT landscape
7 should become more readily available, and we plan to investigate opportunities for integrating
8 our proposed approach with these tools.

9 Modeling the IT landscape is a difficult, complex, and important problem and there are many
10 potential extensions to the current work. The notion of path dependence (i.e., that a dynamic
11 process is governed by its own history) aligns well with our proposed methodology and provides
12 interesting avenues for extensions to our research. As noted by David (2007, p. 1), path depend-
13 ence figures especially prominently in “the analytical consciousness of all who are concerned to
14 study the evolution of technologies.” The idea of path dependence emphasizes a broader and
15 more influential role of history, which is in contrast to many traditional approaches of economic
16 and social science analyses that focus on finding stable unique equilibrium of a system. Path de-
17 pendence also emphasizes the effect of initial conditions and historic events that can have influ-
18 ential impact on future outcomes. Additionally, the role of agents, such as engineers and policy
19 makers, and the decisions that they make based on current system conditions can have a substan-
20 tial impact on the future system dynamics. Applying the formal definitions and modeling tech-
21 niques of path dependence in stochastic processes and dynamical systems to the IT ecosystem
22 model is a promising extension to our research that we plan to explore.

23 Simulation provides an advantageous approach for modeling the system dynamics of an IT
24 ecosystem and would allow us to extend the current research and include the role of agents, ex-

1 ternal forces (e.g., demand and social environment), and the formalisms of path dependence. In
2 addition, the current lack of structured data and the general complexity of the IT landscape pro-
3 vide further reasons for exploring simulation techniques. Simulation can be used to explore the
4 emergent behavior of IT ecosystems and incorporate additional structures into the system, such
5 as firms and consumers.

6 Finally, to continue to provide useful tools to practitioners and researchers who are analyzing
7 the IT landscape, we plan to explore combining design science with action research to extend
8 this work with research methods that have a more proactive orientation (Cole et al. 2005). Ac-
9 tion research is an iterative problem-solving process that involves researcher and practitioner act-
10 ing together to conduct relevant IS research (Avison et al. 1999). Combining the action and de-
11 sign science research approaches will inform the refinement and extension of our IT ecosystem
12 model and improve the utility of the resulting artifacts for analyzing the IT landscape.

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1 **Table 1. Paths of Influence in a Technology Ecosystem**

	COMPONENT FUTURE STATE (C*)	PRODUCT FUTURE STATE (P*)	INFRASTRUCTURE FUTURE STATE (I*)
COMPONENT PRESENT STATE (C)	Component Evolution Examples: Moore’s law and the continual improvement of microprocessor performance.	Design and Compilation Examples: Combining of new touch screen components and hand writing recognition software to create tablet PCs.	Standards and Infrastructure Development Examples: The development of IEEE 802.11 standards for wireless components.
PRODUCT PRESENT STATE (P)	Product-Driven Component Development Examples: New designs for smart phones and PDAs driving development of higher capacity flash-based storage components.	Product Integration and Evolution Examples: Integration of PDA and mobile phone to create the smart phone for personal computing.	Diffusion and Adoption Examples: Widespread adoption of personal computers helps drive high-speed internet service development.
INFRASTRUCTURE PRESENT STATE (I)	Infrastructure-Driven Component Development Examples: Internet and broadband infrastructure helps drive development of wireless chipsets and multi-media optimized processors.	Infrastructure-Leveraging Product Development Examples: Internet-optimized PC designs and smart phones designed to utilize the broadband wireless services.	Support Evolution Examples: Continual improvement of networking infrastructure, such as gigabit Ethernet and fiber optics.

2

3 **Table 2. Timeline of Digital Music Technologies**

YEAR	EVENT
1989	German MP3 patent
1996	US MP3 patent
1998	First portable MP3 player (32 MB)
Feb 1999	Sub Pop distributes MP3 music
May 1999	Napster founded
May 2000	Transactional watermarking developed
Jan 2001	Apple iTunes music applications released
Jul 2001	Napster injunction
Oct 2001	10 GB Apple iPod introduced
Mar 2002	20 GB iPod for PC introduced
Apr 2003	40 GB iPod introduced
Oct 2003	Dell DJ introduced iTunes online music store opens
Sep 2004	MSN online music store opens
May 2005	Yahoo online music store opens
Oct 2005	First iPod with video capabilities
Sep 2006	iTunes starts selling full length movies
Aug 2006	160 GB 1.8 inch HDD introduced
July 2007	iPhone (MP3 player/phone) introduced
Sep 2007	160 GB Video iPod introduced

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1 **Table 3. Empirical Methodology Overview**

STEP	DESCRIPTION
1. Coding	Raw data on technology introductions is coded into the component, product, and infrastructure roles.
2. Frequency Estimation	A function of the frequency of all technology introductions over time is estimated.
3. Threshold Determination	Based on the proportion of technologies of each role within the overall number of technology introductions, a threshold function is derived for each role.
4. Dominant Role Identification	Actual frequency of technology introductions is compared to threshold function for each role to determine dominant roles in each time period.
5. Pattern Identification	Transitions between dominant roles in adjacent time periods are mapped out.

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3 **Table 4. Descriptive Summary of Interview Participants**

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CHARACTERISTIC	DESCRIPTION
Years IT of Experience	All but one participant had more than 10 years work experience in IT or IT related fields. The one exception had greater than 5 years of experience.
Self-Reported Expertise on IT Landscape	All but one of the participants self-rated as having “high” level of expertise on the IT landscape (out of three choices: low, medium, high). The one exception selected “medium.”
Participant Professions Represented	Senior IT executives (4), senior IT consultants (4), senior IT analysts or industry researchers (4), senior IT-related academic researchers (4)
Industries Represented	IT services and consulting, IT hardware manufacturing, software, medical device manufacturing, materials/general manufacturing, retail, transportation, government IT office, government research lab, university research lab, university business school

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6 **Table 5. Coverage of Interview Questions: Key Issues for Evaluation**

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ISSUE	DESCRIPTION
Constructs	Is the ecosystem model, with its technology roles and paths of influence, a useful approach for representing the evolution of ITs? Does this representation improve managerial capabilities for analysis? Does it aid the processes of IT investment and development decision-making?
Logic of Methodology	Are the qualitative and quantitative methodologies we propose for identifying trends in technology evolution sound? Do they produce new insights?
Information Produced	Is the information produced by the proposed artifacts useful to practitioners? Does it aid in IT investment and development decision-making?
Relationship to Existing Techniques	Do the proposed artifacts complement existing techniques to provide new insights and improved analysis of IT evolution?

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Table 6a. Interview Findings: Summary Statistics of Numerical Questions

QUESTION	MEAN	STD. DEV.
Importance of historical technology analysis in IT investment decision making. (1=very unimportant, 5 = very important)	3.7	1.15
Importance of evaluating current IT landscape for IT investment decision making. (1=very unimportant, 5 = very important)	4.6	0.67
Importance of predicting future IT landscape for IT investment decision making. (1=very unimportant, 5 = very important)	4.5	0.67
Effectiveness of existing methods and techniques for analyzing IT landscape. (1 = very ineffective, 5 = very effective)	2.9	0.52
Effectiveness of the proposed methodology for analyzing IT landscape. (1 = very ineffective, 5 = very effective)	4.2	0.39

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Note: N=12 for all questions.

Table 6b. Interview Findings: Dimensions of Utility

DIMENSION	DESCRIPTION	REPRESENTATIVE QUOTE	COUNT
Complexity Reduction	Technology roles and paths of influence provide a novel and useful way of reducing IT landscape complexity.	<i>"[The roles and model] are very clever because you compress the universe of possibilities and make the ecosystem understandable."</i> - Senior technology analyst at a Fortune 500 transportation company	10
Structuring IT Investment Decision Making	The IT ecosystem methodology provides a means for identifying IT trends that are relevant to a specific firm's interests and business contexts.	<i>"This approach provides structure to the conversation and decision-making process for IT investment."</i> – Director of business development at a major university IT related research center	10
Formal Method	The IT ecosystem model and methodology provide a much needed formal technique for quantifying complex trends in the IT landscape.	<i>"The systematic approach this [methodology] provides is useful. [...] Most strategic IT decisions are made using less formal types of analysis."</i> – Senior technology analyst at a Fortune 500 transportation company	7
Multiple Loci of Value	The IT ecosystem model provides value to both decision makers that use the information produced by using the methodology and analysts that employ the methodology in their technology forecasts.	<i>"For analysis purposes, this sort of model is very good and should definitely help analysts at Gartner or Forrester produce reports for managers."</i> – IT manager at a Fortune 500 retail company	7
Methodological Complementarities	The IT ecosystem model and methodology complement well existing techniques for forecasting technological development.	<i>"This [approach] should be very useful for helping educate analysts about the [IT] landscape. It is complementary to other existing approaches."</i> –Senior researcher at a Fortune 500 technology company	10

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Note: "Count" column refers to the number of interview participants (out of 12) that independently made comments that agree with the corresponding utility dimension.

1 **Table 7. Overview of the Traditional Technology Forecasting/Modeling Methods and How**
 2 **Our Approach Complements Them**

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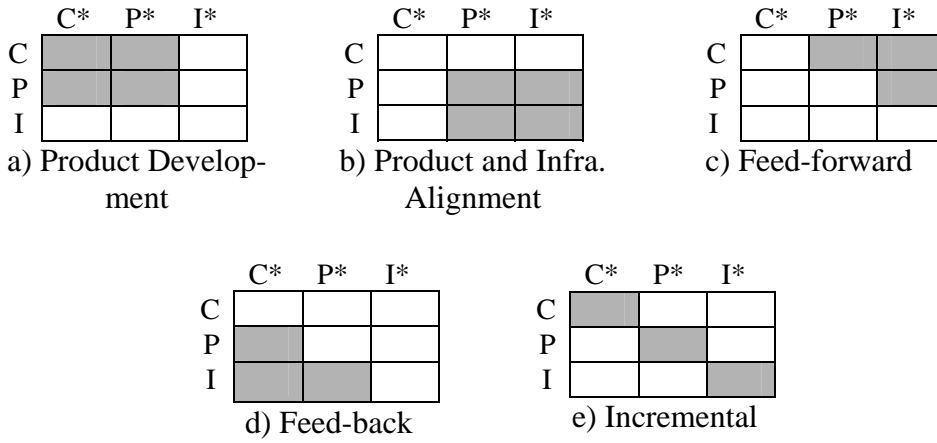
	TREND ANALYSIS	EXPERT OPINION	MODELING AND SIMULATION	SCENARIOS
Description	Historical trends are extended into the future using mathematical and statistical techniques.	Domain expert opinions are collected and analyzed.	Simplified representation of structure and dynamics of real world created to forecast or simulate future outcomes.	Plausible set of outcomes for some aspect of future is created and analyzed.
Examples	Extrapolation, time series estimation, regression and econometrics, S-curve estimation	Delphi method, interviews, questionnaires, idea generation	Cross-impact analysis, system dynamics analysis, path and tree analysis	Descriptive vs. normative scenarios, baseline vs. optimistic vs. pessimistic scenarios
Assumptions	Past trends will continue into future.	Experts know significantly more about a domain than others. Group opinions are better than individual opinions.	Complex structures and processes can be captured effectively by simplified models.	Imaginative descriptions can reasonably capture the full set of future possibilities.
Strengths	Quantifiable and data-based forecasts, short-term accuracy	Experts typically possess detailed knowledge of subject matter that produces high-quality forecasts.	Models reduce complexity and highlight the most important factors. Process of building a model can provide insights.	Effective way to communicate forecasts. Incorporate a wide range of qualitative and quantitative data.
Weaknesses	Requires a significant amount of data, which can be difficult to obtain. Can be inaccurate for long time horizons.	Difficult to identify experts. Knowledge is typically implicit (internalized). Group forecasts may be affected by social and psychological factors.	Models often ignore qualitative and contextual factors.	Can be highly speculative and not firmly based in reality.
Our Approach Complements This by Method Providing:	A view of relationships between multiple technologies that complements and informs in-depth analysis of a single technology attribute.	A formal quantitative approach and a representation of the past and current IT landscape that can structure discussion among experts.	A representation of the structure of the IT landscape that can inform the development of a more realistic simulation.	A formal representation of the past and present ecosystem which can be used as quantifiable input for generating scenarios.

Note: Based on the technology forecasting methods discussed in Porter et al. (1991) and Millet and Honton (1991).

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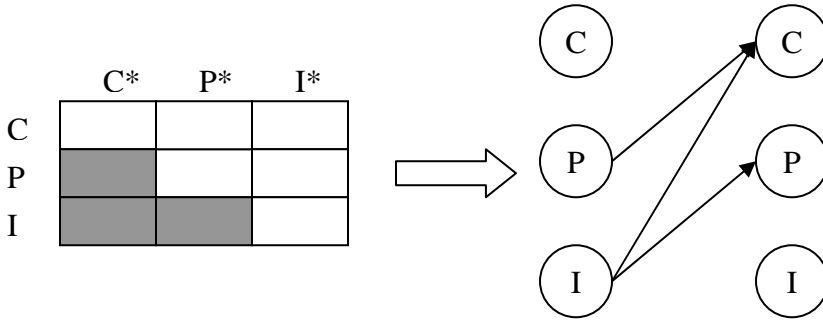
1 **Figure 1. Example Patterns of Technological Change**



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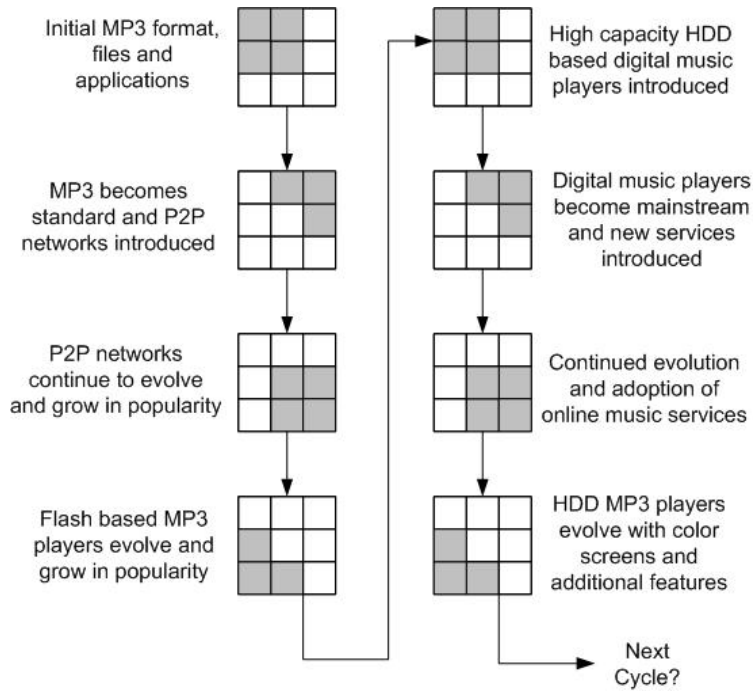
4 **Figure 2. Transformation between Different Pattern Representations**



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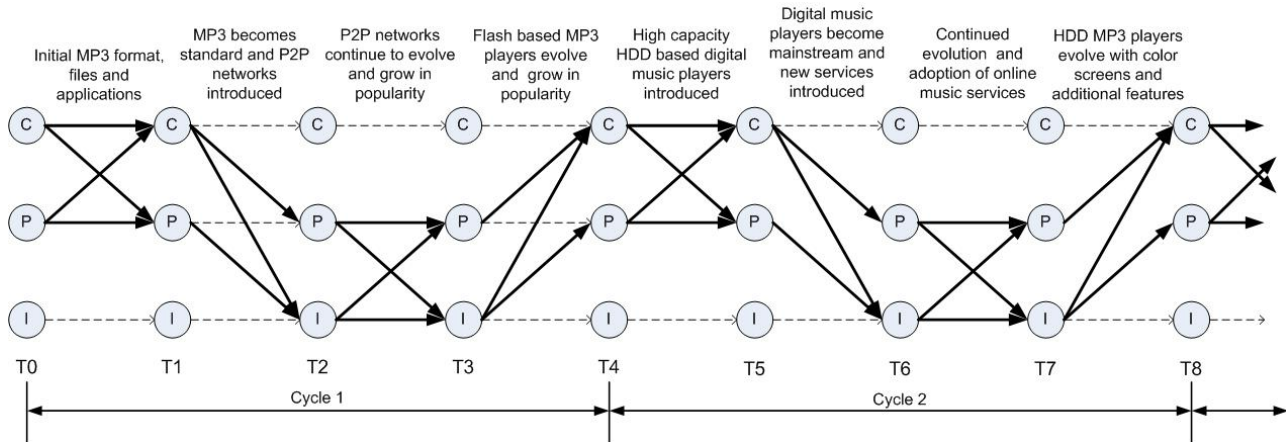
2 **Figure 3. Patterns of Digital Music Technology Evolution**



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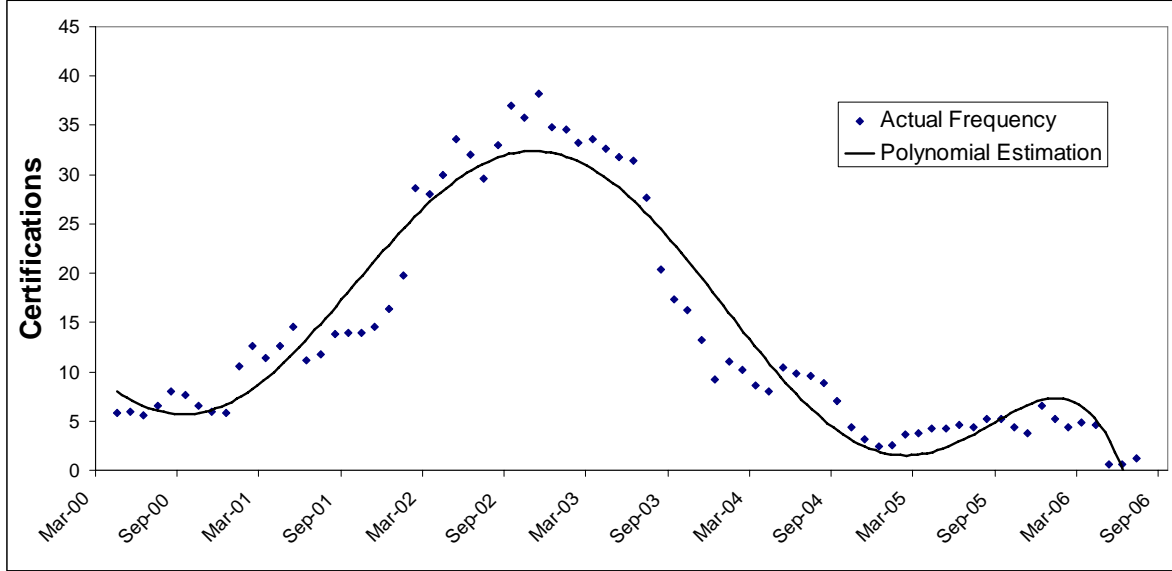
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5 **Figure 4. Digital Music Technology Graph-Based State Diagram**

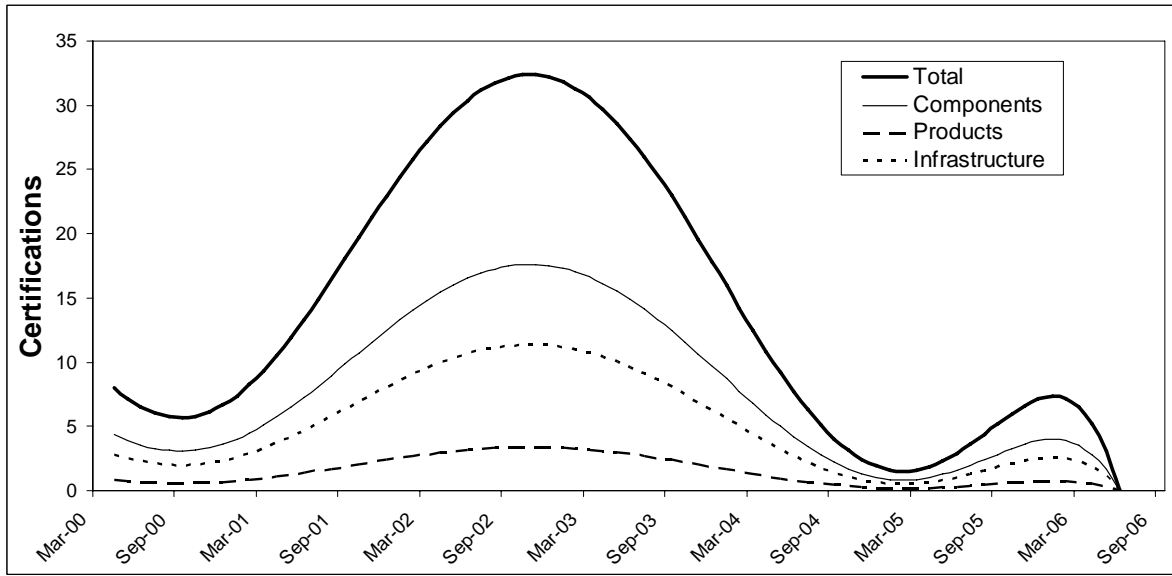


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1 **Figure 5. Estimating the Monthly Frequency of 802.11b Technology Certifications Using a**
 2 **Polynomial Approximation Function**



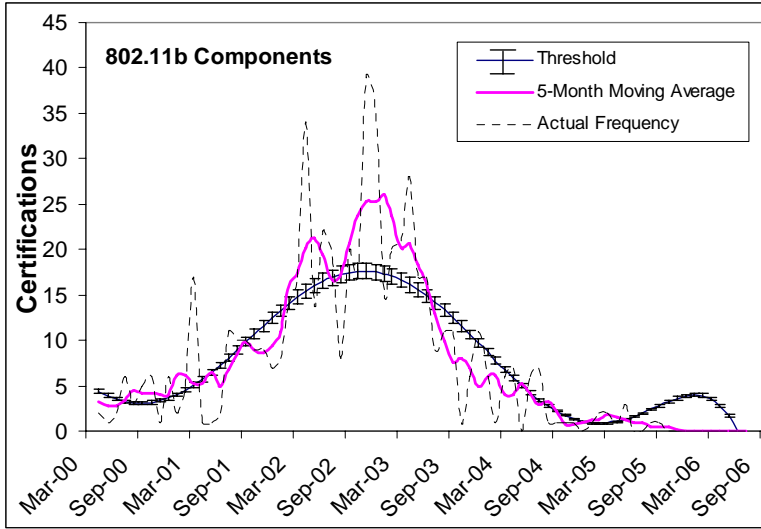
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 5 **Figure 6. Proportional Frequency Functions for the Total Number of 802.11b**
 6 **Certifications and Each Technology Role**



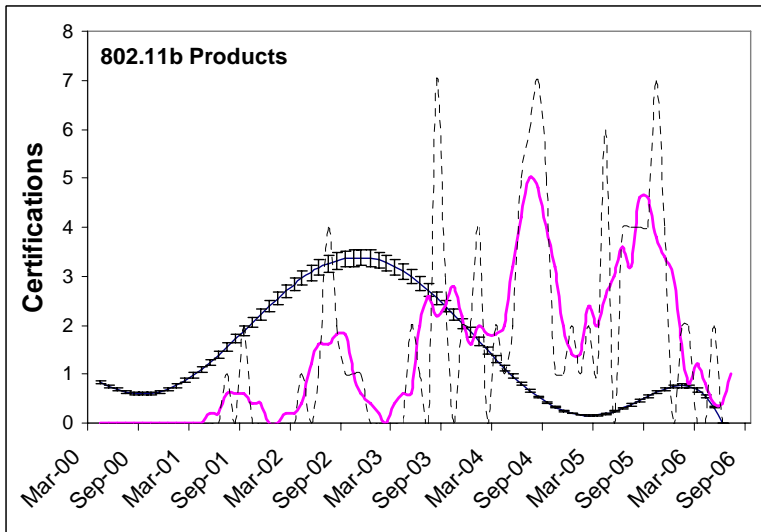
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1 **Figure 7. Actual Frequencies of 802.11b Technologies Plotted against Threshold Functions**

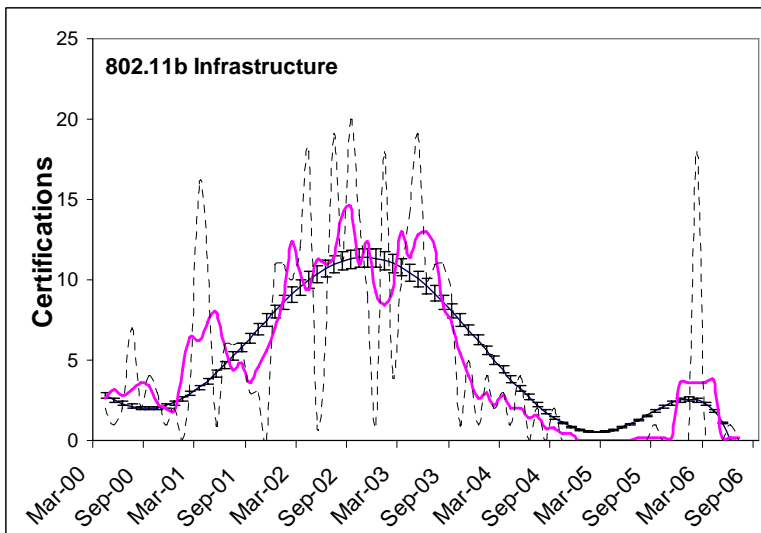
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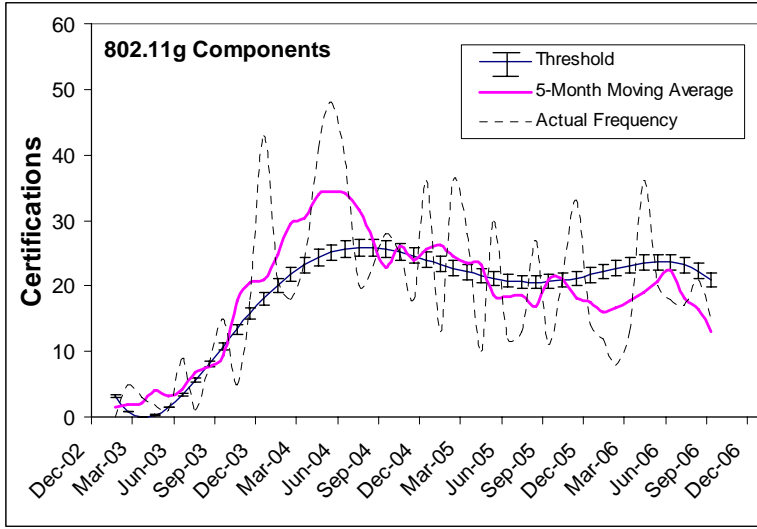
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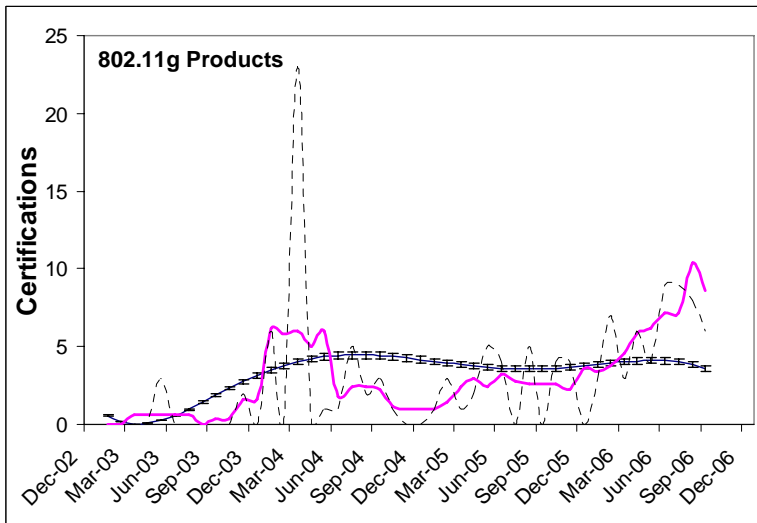
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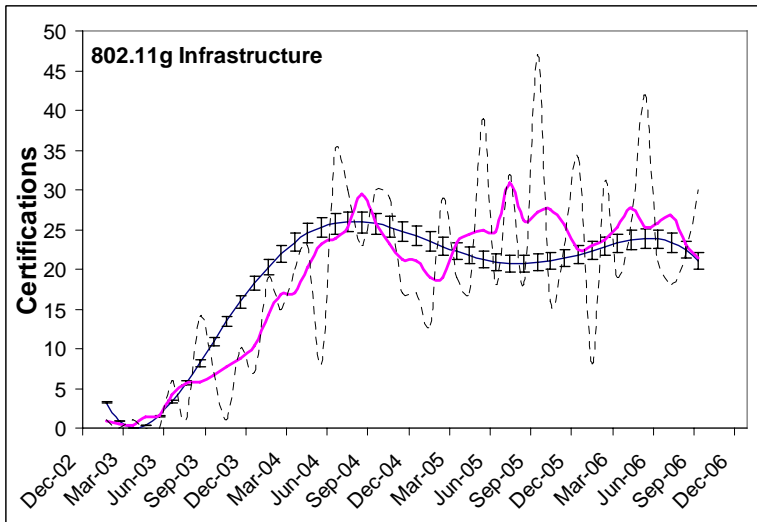
1 **Figure 8. Actual Frequencies of 802.11g Technologies Plotted against Threshold Functions**



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