MAKING SENSE OF TECHNOLOGY TRENDS IN THE IT LANDSCAPE:
A DESIGN SCIENCE APPROACH FOR DEVELOPING CONSTRUCTS
AND METHODOLOGIES IN IT ECOSYSTEMS ANALYSIS

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ABSTRACT

An important problem for firms making IT investment and development decisions is analyzing
the complex IT landscape to understand trends in IT development. The sheer number of avail-
able technologies and the complex set of relationships among them make IT landscape analysis
extremely challenging for innovators, senior managers, and policymakers. Most IT consuming
firms rely on third parties and suppliers for strategic recommendations on IT investments which
can lead to biased and generic advice. Based on the design science research paradigm, this arti-
cle defines a new set of constructs and methodologies by conceptualizing an ecosystem model of
technology evolution to help practitioners address this important business problem. The objec-
tive of these artifacts are: (1) to provide a formal problem representation for the analysis of tech-
nology development trends in the IT landscape, and (2) to suggest reusable structures which en-
sure that the complex technological environment is considered in the analysis of technology
trends. We adopt a process theory perspective and use a combination of visual mapping and
quantification strategies to develop a new empirical method to identify patterns of technology
evolution and a state diagram-based methodology to represent evolutionary transitions over time.
We illustrate the qualitative application of our proposed constructs and methodologies using the
example of digital music technologies. We also develop an associated quantitative empirical
methodology, which is illustrated with the example of wireless networking technologies. We
evaluate the utility of our proposed constructs by conducting in-depth interviews with several IT
industry experts and demonstrating the complementarities between our proposed approach and
existing techniques for technology forecasting.

Keywords: Design science, ecosystem model, evolutionary patterns, IT landscape analysis,
management of technology, paths of influence, technology ecosystem, technology evolution.
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1. INTRODUCTION

The landscape of information technology (IT) is in a constant state of change. There are an overwhelming number of technologies available for use by organizations and that set continuously grows at a steady pace. Additionally, the economic scope of IT investments is typically very large, which adds significant pressure in the IT investment and development decision-making process. Most IT managers indicate that it is difficult, if not impossible, to accurately forecast advances and trends in IT. Nevertheless, senior managers need to understand the nature of technological change and be able to accurately interpret the IT landscape\(^1\) to position their firms’ high-value technology investments and to achieve success with emerging market opportunities.

Through interviews with IT industry experts we have learned much about how firms analyze the IT landscape. We have found that this analysis and the IT strategic decision-making process itself are often outsourced to third parties.

“It’s kind of a funny thing. In IT it’s okay to outsource your future decision-making, but with the business you would never do that...[Companies] outsource their IT decision making just because it’s so complicated.” -- VP of Global IT Infrastructure at a Fortune 500 company.

The difficulty of making these decisions typically requires skills and expertise beyond the capabilities of most firms. As a result, many firms rely on reports produced by consulting companies such as Gartner, Forrester, and IDC, and advice provided by their existing IT partners and sup-

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\(^1\) Throughout the paper we use the terms IT landscape and IT ecosystem quite often. *IT landscape* is commonly used by practitioners to describe the overall IT environment. *IT ecosystem* is a term that we operationally define as the IT landscape centered around 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.
pliers. We recognize that such input can be helpful in the decision-making process; however, our in-depth discussions with experts, whom we interviewed, identified two key concerns. First, advice provided by existing partners and suppliers is often biased; existing suppliers have an incentive to encourage firms to continue their investment. Second, reports produced by third parties are usually too general and often lack formal analysis of the IT landscape, relying primarily on expert opinion and simple extrapolations to make recommendations.

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

To address these problems, we propose a new theory-based conceptual approach, a set of new constructs, and a novel methodology for formally analyzing the IT landscape and identifying trends in IT evolution. Adomavicius et al. (2007) proposed a new ecosystem model of technology evolution for understanding the dynamic and complex nature of technological evolution. Building on this model, we follow a technological determinism viewpoint (Smith and Marx 1994) and use a process theory approach (Mohr 1982, Langley 1999) to develop a new set of problem representation constructs and a novel methodology for identifying patterns of technology evolution in the IT landscape. We incorporate the temporal aspect of technology evolution and visually represent transitions between patterns of technology evolution over time. The goal of our new approach and methodology is to complement existing techniques and provide firms that make IT investment and development decisions with a more formal technique for analyzing specific IT ecosystems and the interdependent relationships among the technologies they contain.

In developing and evaluating this new set of constructs and methodology, we adhere to the principles of design science research, as outlined by Hevner et al. (2004) and March and Smith (1995). Design science involves the construction of new artifacts to solve important organiza-
tional IT problems. Hevner et al. (2004) note that the definition of the IT artifact, as it applies to
design science, is both broader and narrower than the definitions outlined in prior literature.
Specifically, they include constructs, models, and methods in their definition, but do not include
people or elements of organizations. We present a new set of constructs, a model for represent-
ing relationships between ITs, and a new methodology for identifying and representing patterns
of technology evolution. This set of artifacts constitutes a new process for evaluating the IT
landscape, which is aimed to address the key business problem described earlier. This research
aims to explain the structure of relationships among ITs in a technology ecosystem, and to help
practitioners analyze the changes that occur in this structure over time. Whinston and Geng
(2004) argue that research that clearly impacts the IT artifact is important for furthering the IS
research field. As noted by Benbasat and Zmud (2003), the IS discipline includes methodologi-
cal practices and capabilities involved in the planning, construction, and implementation of IT
artifacts. This research follows in that vein by providing a new set of tools for analysts involved
in the IT investment and development decision-making process.

An important aspect of design science is the evaluation of the proposed artifacts, i.e., the util-
ity of the proposed artifacts must be demonstrated. To perform this evaluation we conducted in-
depth semi-structured interviews with a set of knowledgeable IT industry experts. These inter-
views were conducted to provide: (1) further understanding and motivation for the business and
organizational IT problem we address; (2) an evaluation of the utility of our proposed approach
in real-world settings; and (3) suggestions for improvements and future work. We constructed
structured interviews for four groups of IT industry experts to provide robustness to our utility
evaluation and capture differences of opinion. These groups were: IT industry senior managers
and executives, IT industry consultants, IT industry research staff and analysts, and senior aca-
emic researchers with expertise in the IT industry. We further demonstrated the utility of our proposed approach by drawing insights from a qualitative example and quantitative empirical analysis on two real-world IT ecosystems. We also provide in-depth discussion on the complementarities between our proposed approach and existing techniques that firms employ for evaluating the IT landscape.

The remainder of the article proceeds as follows. Section 2 briefly reviews the foundations of the research, and discusses sense-making from process data and the ecosystem model of technology evolution. Section 3 defines our analytical constructs and outlines the new problem representation structure for exhibiting relationships among ITs within an ecosystem. Section 4 provides some examples of patterns of technology evolution, based on the constructs and model presented in Section 3. In Section 5, we illustrate the application of the constructs with a qualitative example on the digital music industry and present a state-diagram-based visualization approach. Section 6 presents a quantitative application of our constructs using a new empirical method for identifying temporal changes in an IT ecosystem. The empirical method is used to analyze a dataset containing over 3,000 new product certifications by the Wi-Fi Alliance (www.wi-fi.org). Section 7 provides an evaluation of the utility of our proposed approach using in-depth interviews with IT industry experts. It also offers a detailed discussion of the complementarities between our approach and existing techniques that are used by firms and their consultants for technology forecasting. Section 8 provides the summary of main contributions as well as discusses the limitations of our proposed approach and opportunities for future work.

2. CONCEPTUAL FOUNDATIONS

Decision-making and justification for IT investments is of strategic importance for modern firms and can be difficult for even the most-seasoned and knowledgeable managers in the presence of
technology, organizational, and market complexity (Clemons and Weber 1990, Bacon 1992). An important aspect of the IT investment decision-making process is analyzing the market landscape to identify trends in IT development, which is often helpful for investment planning and product development strategies. Formal analysis in this domain has traditionally been difficult primarily due to the sheer number of available technologies and the complex inter-relationships among them. Compounding this problem is the fact that practitioner knowledge of the historical drivers, relationships, and patterns of technology evolution is often limited, and rarely is it well-structured knowledge outside the realm of the IT forecasting and consulting firm ‘gurus.’ The objective of this research is to address this problem by providing industry practitioners with a new set of tools for analyzing the IT landscape. Our artifacts consist of a representation structure and a set of constructs for defining a technology ecosystem, and a new methodology for identifying trends within an ecosystem, consistent with the design science research paradigm outlined by Hevner et al. (2004). We build upon existing theory related to technology evolution and IT innovation, and use a process theory approach for defining the constructs upon which we formulate and develop our tools.

2.1. The Process Theory Perspective for Design Science Research

Process theory provides the ideal theoretical lens for developing tools to analyze the IT landscape. Understanding the complex IT landscape and changes that occur within it over time requires sensemaking (Weick 1979) of an environment that consists of many technologies and relationships. Process theories are concerned with explaining how outcomes evolve or develop over time (Mohr 1982, Markus and Robey 1988), and, therefore, the process theory approach is a proper base for developing tools for evaluating changes in the IT landscape.
The process theory approach has been used extensively in IS research, most notably as a base for *structuration analysis* (Orlikowski and Robey 1991, Orlikowski 1993), and for modeling sequences of events (Abbot 1990, Newman and Robey 1992). In each of these cases, the process theory approach was applied to inform the development of new techniques for analyzing complex process data. Process data are difficult to analyze and manipulate because they deal mainly with sequences of events, often involve multiple levels and units of analysis, vary in terms of temporal precision and duration, and tend to focus on eclectic phenomena such as changing relationships (Langley 1999). This description matches the type of data used to analyze trends in an IT landscape very well – event data (e.g., new technology introductions) consisting of multiple types of technologies with differing attributes and various temporal measures. Our objective, as noted earlier, is to develop tools that help practitioners understand how technologies evolve over time and why they evolve in a certain way, which is also a key objective of process-data-related research (Van de Ven and Huber 1990).

Langley (1999) outlines seven strategies for sensemaking and theorizing with process data, and our current research uses a combination of two of them – the *quantification strategy* and the *visual mapping strategy* – to develop its theoretical perspective and empirical methodology. The quantification strategy, as exemplified by the research of Van de Ven and Poole (1990), involves the systematic coding of events according to predetermined characteristics. It further involves gradually reducing the complexity of the process data to a set of quantitative time series that can be analyzed using empirical methods (e.g., Garud and Van de Ven 1992, Romanelli and Tushman 1994). The visual mapping strategy, which can be used for the development and verification of theoretical ideas, involves producing graphical representations of process data to present large quantities of data in relatively little space (Miles and Huberman 1994). Visual map-
1. Pings allow simultaneous representations of a large number of dimensions and can be easily used to show precedence, parallel processes, and the passage of time (Langley 1999). A diagram can provide an intermediate step between raw data and theory development, and the comparison of several diagrams can help researchers look for common sequences of events, patterns, and progressions in the data (Langley and Truax 1994). Both organization researchers (e.g., Meyer 1991, Meyer and Goes 1988) and decision researchers (e.g., Mintzberg et al. 1976, Pentland 1995) use the visual mapping strategy to develop process maps.

Our research combines the principles and sensemaking strategies of process theory with the formal guidelines of design science research (Hevner et al. 2004) to develop new tools for modeling and analyzing technology evolution. Our tools are designed to provide structure and a means of analyzing the complex IT landscape by producing graphical representations of patterns and trends. We use a quantification strategy to define a set of constructs for coding technology innovation types and a methodology for empirically identifying patterns of technology evolution. We also use a visual mapping strategy to represent these patterns over time, which is illustrated through two examples of IT evolution. The two strategies complement each other by providing theoretical and methodological underpinnings for the new artifacts that we present.

2.2 The Technology Ecosystem

A technology ecosystem view is a useful approach for representing the many technologies and relationships that make up the IT landscape. Following this analogy, an IT ecosystem is comprised of a set of technologies that interact with and impact the success of one another. Hannan and Freeman’s (1977 and 1989) seminal work on organizational ecology has sparked the increased use of an ecological analogy in business and organization research. The theoretical perspective of organizational ecology is used to examine: (1) the environment in which organiza-
tions compete, and (2) the birth and death processes of firms. Strategy researchers have also
adopted a biological ecosystem model in the analysis of business relationships and strategic deci-
sion-making (Iansiti and Levien 2002, 2004). Managers and academicians are recognizing the
value of the ecosystem metaphor for understanding the complex network of business relation-
ships within and across industries (Harte et al. 2001). Most recently, IS researchers have also
begun to adopt an ecosystem perspective: Quaadgras (2005) used network modeling techniques
to define the RFID business ecosystem and forecast firm participation, Nickerson and zur
Muehlen (2006) analyzed Internet standards creation using a population ecology model, and
Funk (2007) presented a hierarchy of relationships between technologies to determine the timing
of dominant technology designs.

Although the ecosystem view is proving to be important in business and research, in most
cases the ecosystem perspective has been used merely as means of starting discussion. There has
been a lack of development of analytical tools that provide real value to practitioners based on an
ecological perspective. Additionally, previous research incorporating the ecosystem analogy has
focused primarily on industrial ecosystems and relationships between firms and organizations.
The current research applies the ecosystem analogy to the task of understanding the relationships
among technologies in the IT landscape. Two recent papers provide insights for modeling trends
in technology evolution using an ecosystem view. Lyytinen and Rose (2003) developed a model
of disruptive IT innovation that considers the interrelationships between technological innova-
tions at the systems development, infrastructure, and IT service levels. Considering cross-level
impacts of innovation is a key step in understanding the relationships between technologies as an
ecosystem. Adomavicius et al. (2007) developed a formal ecosystem model of technology evolu-
tion for the purposes of representing relationships that occur with technology changes. We build
on this model to develop a new set of constructs and methods for identifying trends in techno-
logical changes within an IT ecosystem.

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

The ecosystem model of technology evolution (Adomavicius et al. 2007) integrates the
strengths of many modeling methods and theoretical frameworks in economics, engineering, and
organizational theory. Three key research streams are combined to provide a comprehensive
conceptual model of evolution within a technology ecosystem. First, the population perspective
(Saviotti and Metcalfe 1984, Saviotti 1996) proposes that multiple interrelated technologies
should be viewed as a system or population whose characteristics and members change over
time. This concept of viewing technologies as an interrelated system is also supported by Dosi’s
technology paradigms (1982), Nelson and Winter’s technology regimes (1982), Laudan’s tech-
ology complexes (1984), and Sood and Tellis’ platform of innovation (2005). Second, complex
systems of technologies can be organized in hierarchies (Clark 1985, Rosenkopf and Nerkar
1999), which leads to the definition of specific roles played by technologies in the ecosystem.
Three levels of the hierarchy are typically considered. In particular, component-level technolo-
gies combine to form product-level technologies, and products are then combined to form a sys-
tem of use. Co-evolution of technologies in this model occurs both within and across levels in
the hierarchy (Campbell 1990, Rosenkopf and Nerkar 1999). Finally, technologies tend to fol-
low specific trajectories (Dosi 1982) and patterns of innovation (Sahal 1981 and 1985) through
the process of technology evolution. Baldwin and Clark (1997 and 2000) argue that, in the “age
of modularity,” specific design rules govern the common patterns of technological innovation.
These include the combination of two technological modules into one, or the augmentation of an
existing module into a new module.

We next build on technology ecosystem theory and use a process theory approach to develop
our model and constructs. We develop a means of representing the IT landscape analysis prob-
lem in terms of an IT ecosystem. We then present a methodology for identifying and analyzing
trends in technological change within an IT ecosystem over time.

3. MODEL AND CONSTRUCTS

The core of our model is a set of roles and relationships that are used to code technology innova-
tions and represents patterns of technological change in an ecosystem. In this section, we discuss
our use of theory (Gregor 2006) in support of our effort to design artifacts and define constructs
that provide foundations for a new visual representation and empirical approach for modeling
technology evolution patterns over time.

3.1 Roles in the Technology Ecosystem

The hierarchical nature of technologies within a population leads to the identification of specific
roles that technologies can play within the ecosystem (Adomavicius et al. 2007). By acting
through these roles, classes of technologies can influence each other’s evolution and develop-
ment through common patterns of innovation. Specifically, the three roles that technologies play
within an ecosystem are: product and application, component, and support and infrastructure, as defined in Adomavicius et al. (2007).

The product and application role describes technologies that are built up from a set of components, and are designed to perform a specific set of functions or satisfy a specific set of needs. This role includes the focal technology and other technologies in direct competition with it in the given context and associated with a specific application or use. By focal technology, we mean the technology in which the analyst is most interested for the purpose of analysis. By a given context, we are referring to some capability, use or application of the focal technology. For example, in the digital music technology ecosystem, an MP3 player (a focal technology) plays a product role because it is composed of several components and is designed to provide a specific service to its user: storing and playing digital music files (a given context). Additionally, MP3 players can compete with related technologies, such as CD players and satellite radio devices.

The component role describes technologies that are used as components or subsystems in more complex technologies. Components are necessary for the product and application role technologies to perform their functions in the given context of use. For example, there are several technologies that act as components for the personal computer: microprocessors, RAM chips, hard disk drives, etc. Individually and in combination, these components provide different functionality to the product role technologies. This is an important relationship in the ecosystem because individual technologies can act as components in multiple technologies and contain components themselves. Consider the hard disk drive. It acts as a component in PCs, MP3 players, and many other devices. However, the hard disk drive also has a set of component technologies itself, including DC spindle motors, actuators, and platters. So, in our approach, the assignment of technology roles and the scope of an ecosystem are based on relevance to the focal
technology and the specific context of analysis.

The *support and infrastructure role* describes technologies that work in conjunction or collaboration with (or as a peripheral to) product and application role technologies. The distinction between the component role and the support and infrastructure role is that components are necessary for the design and are part of the physical structure of another more complex technology, while support and infrastructure technologies simply work in combination with other technologies. A key point about the support and infrastructure role is that technologies add value to the technologies they support. For example, a printer is not physically necessary for the design and use of a PC, but it supports the PC’s functionality, expands the PC’s system of use, and together they provide additional value and services to their users.

### 3.2 Paths of Influence in the Technology Ecosystem

The decision to invest in or develop a new technology often requires the manager to understand trends in technological change to capitalize on market opportunities. Since technologies change over time, any practical model of technological evolution must consider the *temporal aspects* of such change.

Technological determinism and social construction of technology are two competing theories that attempt to explain the change in technology over time. *Technological determinism* posits that technological development drives social and cultural changes (Smith and Marx 1994), while *social construction* argues the opposite: society and culture determine technological development (Bjiker et al. 1987). A related, yet slightly different debate exists in the economics and management literature. Demand-side forces, such as consumer and market needs, drive technological development (e.g., Adner and Levinthal 2001, Clark 1985, Malerba et al. 1999). Another perspective though is that supply-side forces, such as firm capabilities and R&D, are responsible
Below we model technological change as relationships between specific technologies over time, which closely relates to the supply-side and technology determinism perspectives. Our model is focused on the technical forces that drive technological change (Nelson 1995) and does not explicitly model external forces such as society, culture, and the demand environment. We recognize that society and culture impact the development and evolution of technology. However, our model is targeted towards domain experts that are aware of market forces and their target audience. In addition, in most firms that are consumers of IT, IT investment decisions are for internal purposes and social construction is less of a concern. While our long-term goal is to incorporate these forces and develop more comprehensive set of interactions, in this paper we focus on reducing technological complexity while increasing the understanding of the IT landscape for the purpose of technology forecasting. For this study, we conjecture that domain experts will be able to define their contexts with appropriate consideration for market and social forces – as demonstrated by the digital music example in Section 5.

Boland et al. (2003) argue that understanding the information technology adoption requires an integrated view of the innovation process. In particular, their work highlights the importance of history and the effects of time in understanding innovation (Arthur 1989) and viewing it as a continuous “path creation” process. Similarly, to represent the influence that current technologies have on future technologies, the technology ecosystem model of Adomavicius et al. (2007) defined paths of influence, which occur within or across the component, product and application, and support and infrastructure technology roles within the ecosystem.

Technological evolution and development is complex and can take many paths through the layers within a technology ecosystem. Therefore, paths of influence are possible from any of the current states to any of the future states of the technology roles within an ecosystem. For exam-
ple, the current component technologies can potentially influence the development of new prod-
uct technologies, representing a specific path of influence: Component Role (C) $\rightarrow$ Prod-
uct/Application Role* (P*). Here the asterisk (*) is used to indicate a future state of a technol-
ogy role in the ecosystem, and C, P, I are used as abbreviations for component role, product and
application role, and support and infrastructure role, respectively. Roles without an asterisk rep-
resent current states in the ecosystem.

Paths of influence represent the influence one technology role has on another in the evolution
of a set of technologies in the ecosystem. For example, the success of the DVD player has
helped drive the development of new DVD component technologies. These include recordable
DVD ROMs, multi-layer DVD ROMs, and new blue-ray and HD technologies ($P \rightarrow C*$). Simi-
larly, the evolution of infrastructure technologies can drive the development of new product
technologies. For example, the wide cellular phone network provides infrastructure for new
phone services and applications such as text messaging and picture mail ($I \rightarrow P*$). Paths of influ-
ence follow the design science paradigm (Hevner et al. 2004), as they are a set of constructs that
provide a problem representation structure for analyzing technological interdependencies in
technology evolution. Table 1 presents a 3 x 3 matrix that classifies possible paths of influence.

We have discussed the roles technologies can play in an ecosystem and the paths of influence
possible between technology roles. These constitute the constructs of our model, and in the next
section we discuss several examples of patterns of technology evolution using these constructs.
We derive these constructs directly from the theory developed in Adomavicius et al. (2007). We
develop new methodologies for analyzing technology evolution based on these constructs and
using strategies of sensemaking from process data. In Section 4, we use these constructs as the
basis for a visual mapping strategy that generates graphical representations of evolutionary pat-
terns, and in Section 5 we demonstrate this using a qualitative evaluation of the digital music
technology ecosystem. In Section 6, we demonstrate how these constructs can be used to de-
velop a quantification strategy that empirically identifies evolutionary patterns using a data set of
over 3,000 wireless networking technologies.

6. REPRESENTING PATTERNS OF TECHNOLOGY EVOLUTION

Sahal (1981 and 1985) defines an analytical framework for understanding patterns of technologi-
cal evolution. The author identifies several specific patterns, including invention, innovation,
and diffusion, and recognizes that technology development follows an evolutionary process.
Additionally, the author notes that the temporal evolution of any system that is subject to a col-
lection of random changes is characterized, in general, by prolonged oscillations. Therefore, the
existence of recurring fluctuations in innovation and technology evolution should be expected.
Worlton (1998) investigates the recent evolution of high-performance computing and identifies
patterns of technological change. He notes that technological change typically occurs in four
stages: invention, innovation, diffusion, and change of scale. Rosenberg (1994, p. 74) shows that
“technological forces exist which may lead to cyclical behavior in certain industries, where ma-
jor innovations come to substitute for one another sequentially in time.” Also, Baldwin and
Clark (1997 and 2000) argue that, due to increased modularity, specific design rules can lead to
predictable innovation patterns.

4.1 Coding and Representation

We next define a visual mapping strategy for representing patterns of technological change based
on the roles technologies can play and the paths of influence among them within an ecosystem.
Visual mapping strategies provide a means for simultaneously representing multiple dimensions
and can help researchers identify common patterns, sequences, and progressions in process data (Langley 1999, Langley and Truax 1994). For example, Nickerson and zur Muehlen (2006) demonstrate the use of a population ecology perspective to map out the complexities in Internet standards making. They use a visual mapping strategy to represent the “space-time network” of the migration of ideas generated during Web services standards development. Similarly, Lyytinen et al. (2003) use a visual mapping strategy to represent path creations in industries as a result of IT-led innovations.

As technologies evolve, some new technologies are introduced, and some existing technologies die out. An ecosystem’s form and content change as well as the patterns of evolution occurring within the ecosystem. The component, product, and infrastructure roles can be used to code technologies according to their position within an ecosystem. Within a specific time period, the quantity of technologies in each role determines the dominance of a role in the ecosystem. Transitions from one set of dominant roles in the ecosystem to another set can then be represented by paths of influence and over time evolutionary patterns can be represented as collections of the paths of influence occurring in the technology ecosystem. At any given point in time, any collection of paths of influence can be at work in the ecosystem. Table 1 provides a pattern template, and Figure 1 provides examples of several evolutionary patterns, each one represented by a collection of certain paths of influence occurring at the same time.

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

INSERT FIGURE 2 ABOUT HERE

An aspect of the power of coding technologies into the component, product, and infrastructure roles is the complexity that emerges from a seemingly simple model. Three roles may seem to offer a rather simple representation, however, nine possible paths of influence emerge from these roles and dozens of possible patterns of technology evolution emerge as various combinations of different paths of influence. The three technology roles provide a simple set of constructs that is strongly based on a synthesis of prior literature and provide a means for representing a large number of complex patterns of technological change.

4.2 Example Patterns of Technology Evolution

To demonstrate the mapping technique described above, we present five examples of technology evolution patterns. (See Figure 1.) They are based on observations of real-world instances of technology evolution and development, and some of these patterns can also be traced back to innovation theory outlined at the beginning of this section.

**Product Development.** The first example pattern of technology evolution describes the initial stages of the evolution of a particular product technology. In this pattern, the ecosystem may exhibit many different product and component technologies, as designs are being developed and accepted. We call this the *product development pattern* because the primary paths of influence at work in the ecosystem deal with the impacts of new technology components and products on each other. (See Figure 1a.) For example, in the personal computing ecosystem the introduction of the first personal digital assistants (PDAs), such as the Apple Newton and the Palm Pilot, required the simultaneous development of products, the PDAs themselves (P→P*), and components, microprocessors, micro hard disk drives, touch screens, etc. (C→C*). Component tech-
nologies are developed and refined to meet requirements of new products (P→C*) and, similarly, product designs are modified and refined based on the newly available components (C→P*).

**Product and Infrastructure Alignment.** A second pattern – *product and infrastructure alignment* – depicts a scenario where a set of infrastructure technologies already exists. (See Figure 1b.) Infrastructure technologies provide incentives for the ongoing use and adoption of product technologies in an ecosystem and enhance the utility of existing technologies. New products, in turn, leverage existing infrastructure to provide new services and functionality. For example, in the European mobile phone ecosystem there was a mutual development of 3G wireless networks and the mobile phones that would operate on them. New network capabilities drive innovations in mobile phones and the desire to provide more functionality in phones drives the development of the network. This demonstrates a collection of paths of influence, (e.g., P→I*, I*→P), working in parallel to ensure interoperability of products and infrastructure.

**Feed-Forward Evolution.** Two more patterns describe what Campbell (1990, 1994) calls *cross-level co-evolution*. The paths of influence in the upper right section of the 3 x 3 matrix are *feed-forward paths of influence*. In each case, evolution of current technologies impacts technologies at higher levels of the technology hierarchy in the future state. (See Figure 1c.) The introduction of an evolved component technology can drive evolution of the product technologies that will use this new component. When new components are combined to create a new product, this path of influence reflects the process of design and compilation. For example, in the digital camera ecosystem the development of color LCDs, high-capacity solid-state storage devices, and CMOS sensors for image capture provided the component technology enhancements to create a digital camera product technology (C→P*).

**Feed-Back Evolution.** The paths of influence in the lower left section of the 3 x 3 matrix re-
fer to *feed-back paths of influence* in technology evolution. (See Figure 1d.) Often the use of a technology impacts the development and evolution of the technologies on which it depends. For example, in the web programming ecosystem the development of many new Internet component technologies such as Dynamic HTML or Active Server Pages (ASP) resulted from the continuous growth of the World Wide Web (I→C*). Also, once a support or infrastructure technology is in place, it provides opportunities for a new product technology to leverage the services and facilities it provides. The widespread adoption of instant messaging (IM) paved the way for new products and applications, such as IM-based video conferencing, file transfer, and online game software, leveraging the existing infrastructure (I→P*).

**Incremental Evolution.** The last example pattern, "incremental evolution," represents within-level co-evolution and continuous development and refinement of technologies within each role. (See Figure 1e.) For example, Moore’s Law explains that processing power of integrated chips will double approximately every eighteen months, and ongoing research and development continues to uphold this law (C→C*). In the mobile phone ecosystem, camera phones are an example of the integration of two existing technologies, digital cameras and mobile phones, to create a new product (P→P*) and continuous expansion and refinement in the cellular network is an example of incremental infrastructure evolution (I→I*). Incremental evolution can be considered a type of steady-state evolution in which expected incremental technological progress occurs within a role.

Although the ability to identify single patterns of evolution in technology ecosystems provides additional insights for managers making technology-related decisions, a more significant contribution of the ecosystem model is its ability to provide a systematic approach for describing the temporal changes (transitions) in the ecosystem using these evolutionary patterns. In the next
section, we use an example to illustrate the utility of our approach by examining how a series of evolutionary transitions can be represented by connecting multiple patterns over time, which can lead to the identification of some intrinsic patterns (e.g., in certain cases representing evolutionary cycles) that can be utilized in technology forecasting.

5. QUALITATIVE APPLICATION: EVOLUTIONARY TRANSITIONS IN DIGITAL MUSIC TECHNOLOGIES

We next use the landscape of digital music technologies evolution to provide a demonstration of a qualitative approach for applying the constructs and patterns discussed in Sections 3 and 4. This example demonstrates the design and use of our constructs and communicates their relevance for both IS research and practice. We identify technology evolution patterns, and use the visual mapping strategy (Langley 1999) to create a state diagram to map the patterns of technological change and cycles of innovation that emerge from patterns of evolution discussed in Section 4.

5.1 Qualitative Analysis Approach

We use the evolution of digital music technologies to demonstrate the effectiveness of identifying transitions between common evolutionary patterns in technology ecosystems. The digital music technology ecosystem is an ideal setting for analysis. It includes many different component, product, and infrastructure technologies. Furthermore, most digital music technologies have only existed since the mid-1990s, yet there has been a significant amount of technological change in this ecosystem. Demand for these technologies has skyrocketed over the past several years, so we expect to see many new product introductions and new entrants in the market. Additionally, digital music technologies span the consumer electronics, entertainment, and computer industries, which suggest that there is an underlying complexity in their design and relationships within the ecosystem. Furthermore, digital music technologies have revolutionized the
consumption of music and other forms of media, and most people can relate to these technolo-
gies since they likely own or use them. We will show that, in its young life, the digital music
ecosystem has passed through at least two evolutionary cycles.

In developing this qualitative example, we follow the descriptive approach outlined by Hev-
nner et al. (2004) to demonstrate the application of our proposed constructs. We used LexisNexis
and Internet search tools to gather announcements, news stories, and historical records related to
technologies in the digital music ecosystem between 1989 and 2006. In total, we gathered in-
formation on approximately 100 related technologies (e.g., flash-based storage, LCD screens,
MP3 players, digital music services). These were coded into examples of new technologies in
the component, product and infrastructure roles. Using information on the timing of technology
releases, we developed a rich qualitative interpretation of technology trends in the ecosystem.

While we do provide insights on the nature of digital music technology evolution, the objective
of this analysis is to illustrate the use of our artifacts for analyzing an IT ecosystem qualitatively.

5.2 Technology Evolution in the Digital Music Ecosystem

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

INSERT TABLE 2 AND FIGURE 3 ABOUT HERE

The first cycle of digital music technology evolution started with the introduction of the MP3 compression format and software applications for playing MP3-encoded music files. The birth period of the digital music industry was characterized primarily by the initial product development pattern of technology evolution, where component technologies (such as the MP3 compression format) and product technologies (digital music software, such as WinAmp) were being refined as they gained more attention. Activities in this era included the refinement of the MP3 format by integrating it into MPEG-1 in 1992 and MPEG-2 in 1994. Once MP3 files reached a reasonable level of adoption, feed-forward patterns of technology evolution took over as new product and infrastructure technologies were introduced based on the MP3 encryption format. The first portable MP3 player, the 32MB MPMan device from Eiger Labs, was released in mid-1998 (Van Buskirk 2005), and P2P networks were introduced with Napster’s inception in May 1999. Both technologies emerged because of the popularity of the MP3 compression format.

As popularity increased for the technologies in the digital music ecosystem, additional infrastructure technologies were developed, including refinements to P2P networks and the introduction of new MP3 standards, such as Microsoft’s WMA and Apple’s AAC. As a result of the continued growth in popularity of digital music products and technologies, feed-back patterns of technology evolution took hold, and new components and products, such as higher capacity flash storage based players, were developed. At this point the majority of MP3 players were flash-storage-based and virtually all MP3 file distribution occurred over P2P networks.

A second evolutionary cycle began when innovations in components, such as high-capacity
micro hard disk drives, led to the initial product development of hard disk drive-based MP3
players, such as the Apple iPod and the Creative Nomad Jukebox. These new HDD-based play-
ers sparked a new feed-forward patterns of evolution that resulted in the introduction and adop-
tion of new online music services, such as iTunes and Napster 2.0, as well as a slew of accesso-
ries for portable MP3 players, such as FM transmitters and voice recorders. With the presence of
multiple online music providers and portable MP3 players, technology evolution became focused
on the alignment of infrastructure and product technologies. The wide adoption of the second-
generation digital music technologies led to feed-back patterns that included introduction of new
products using new components such as color LCD screens.

5.3 Mapping the Analysis Back to the Constructs

The events that occurred in the digital music technology ecosystem can be represented as pat-
terns of technological change using the roles and paths of influence defined in Section 4. Figure
4 provides a visual representation of the two evolutionary cycles that were described above. This
represents a series of evolutionary transitions that represents connections between multiple evo-
olutionary patterns over time. Coding the technologies into roles allowed us to identify paths of
influence, represented by the arrows in Figure 4, and multiple patterns of technology evolution,
represented by the collection of arrows in each time period. As the figure shows, we can then
depict the sequence of 3 x 3 matrices representing paths of influence as a state diagram. We be-
lieve that both qualitative and quantitative data can be used to develop these evolutionary paths
and cycles, enabling an analyst to understand and predict next generation of technologies in the
desired context. Our development is supported by prior research, which shows that innovation
typically occurs in specific patterns (Sahal 1981 and 1985, Baldwin and Clark 2000, Worlton
1998) and in some cases cycles (Rosenkopf and Nerkar 1999, Worlton 1998). It also shows that
new innovations typically replace existing ones (Rosenkopf and Nerkar 1999).

Based on the previous cycles, an analyst might forecast that the next cycle of technology evolution in the music industry will begin as new components are introduced that allow for even more advanced features in product technologies. For example, the evolution of components that are used across multiple ecosystems may result in the convergence of hand-held computing devices (e.g. PDAs, cellular phones, MP3 players, digital cameras). In fact, Motorola introduced one of the first MP3-enabled mobile phones (Shillingford 2005), and the Sony/Ericsson Walkman MP3 phone grew sales by 33% in the second quarter of 2006 (Ewing and Burrows 2006), as demand expanded in the presence of falling prices. Microsoft released a new multimedia-playing (audio, video, and software) hand-held device called a “Zune” in November 2006, and Apple released its “iPhone,” an iPod-Phone hybrid device, in mid-2007.

Currently, the ecosystem is rapidly evolving, with reconsideration being given to embedded digital rights management (DRM), extensions involving web services on hand-held devices, GPS built-in functionality for location-based shopping, and component innovations that will eventually support mobile TV. These all reflect digital convergence with technology components that have been developed outside the hand-held sphere of technological influence. The ecosystem view allows the manager to model these types of evolutionary patterns as well as track and analyze their progression over time (including the identification of transitions and cycles), which will provide a better understanding of the dynamic nature of technology evolution.

6. QUANTITATIVE APPLICATION: EVOLUTIONARY TRANSITIONS IN WI-FI TECHNOLOGIES

To further substantiate the application of our constructs and model, we developed a new empirical methodology to identify technology evolution patterns by combining a quantification strategy.
with the visual mapping state-diagram-based approach for sensemaking from process data (Langley 1999, Van de Ven and Poole 1990). A quantitative approach for analyzing the IT landscape provides a strong complement to the qualitative approach we demonstrated in Section 5. When sufficient data on the introduction of technologies are available, a quantitative approach provides additional rigor to the identification of evolutionary patterns. We follow guidelines in Hevner et al. (2004) and use an analysis of real data to demonstrate our empirical methodology.

6.1. Data

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

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

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

We collected data on over 3,000 certifications for new wireless networking (802.11) tech-
nologies awarded by the Wi-Fi Alliance. The member companies of the Wi-Fi Alliance include 3Com, Apple, Dell, Intel, Linksys, and many others. Certifications are awarded for ten different technology categories: access points, cellular convergence products, compact flash adapters, embedded clients, Ethernet client devices, external cards, internal cards, PDAs, USB client devices, and wireless printers. Technologies can be certified based on IEEE communication standard (802.11a, b, g, d, and h), security (e.g., WPA, and WPA2), authentication protocol (e.g., EAP, and PEAP), and quality of service (e.g., WMM).\(^2\)

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

We coded the Wi-Fi certification categories into the ecosystem roles (component, product, and infrastructure) based on our operationalization of the theory of the ecosystem model of technology evolution. Compact flash adapters, internal cards, external cards, and USB client devices were coded as component technologies, because each clearly acts as a component by providing wireless capabilities for product devices. We coded access points, Ethernet client devices, and wireless printers as infrastructure, because these technologies either form or extend the network.

\(^2\) WPA (Wi-Fi protected access) is a standard for wireless network security. For more information, see [en.wikipedia.org/wiki/WPA](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](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](en.wikipedia.org/wiki/WMM) offers details.
infrastructure necessary for wireless communication. Finally, we coded PDAs, embedded cli-
ents, and cellular convergence technologies as products, because each represents a product de-
vice that provides fully functioning wireless networking capabilities to the end user. Coding
the wireless technologies into appropriate roles will lead to the identification of dominant roles
and the paths of influence between roles. The collections of these paths of influence at different
time periods will represent patterns of technology evolution in the ecosystem.

6.2. Empirical Methodology

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

INSERT TABLE 3 ABOUT HERE

First, raw technology evolution data must be coded according to the component, product, and
infrastructure roles within a specific ecosystem (Step 1 in Table 3). As noted above, the wireless
networking data were coded based on the product category assigned to a technology in the Wi-Fi
Alliance certification. Technical specifications for wireless networking technologies exhibit a
natural progression over time. For example, the IEEE 802.11b standard was introduced prior to
the 802.11g standard and, therefore, new technology introductions are distributed accordingly,
based on their technical specifications. We use the technical specifications of IEEE communica-
tion standard (802.11b versus 802.11g) and the basic security standard (WPA1 versus WPA2) to
identify different generations of wireless technologies. We independently analyzed each 802.11

3  Cellular convergence certifications are awarded to cellular phones that are Wi-Fi enabled. Embedded clients are
certifications for PCs, laptops, and other end user devices that are certified with internal Wi-Fi capabilities.
and WPA generation (i.e., two generations in each category) and then made comparisons across
generations to identify cycles of technology evolution.

Next, to derive a baseline for the number of new technologies introduced over time, we esti-
mate a function of the frequency of all technologies introduced across all roles (Step 2 in Table
3). This function provides an approximation for the total innovative activity in the technology
ecosystem over time. A wide variety of approximation techniques may be used for this purpose.
For example, for the wireless network data we used a five-month moving average of the fre-
quency counts (i.e., to eliminate random monthly fluctuations and obtain the underlying trend)
and estimated the frequency curve using a polynomial approximation function. In this specific
case, a sixth-degree polynomial provided a good fit with $R^2$ values over 90%. Figure 5 depicts
the estimation for the frequency of technology introductions in the 802.11b generation.

We next derived threshold frequency functions for each role using the frequency function es-
timated for all technology introductions (Step 3 in Table 3). If we assume that the introductions
of new technologies are independent of the role to which they belong and there are no interde-
pendencies across roles, we would expect to see the number of technology introductions in each
role over time be proportional to the total number of technology introductions in the ecosystem.
With this in mind, we derive estimated frequency functions for each role based on the proportion
each role has of the total number of technology introductions. For reference, the set of technolo-
gies released in the 802.11b generation is 54.4% components, 10.4% products, and 35.2% infra-
structure, and the set released in the 802.11g generation is 45.9% components, 8.0% products,
and 46.1% infrastructure. In Figure 6, the top curve represents the estimated frequency function
for all technologies and the three curves below represent the proportional frequency estimates for
components, infrastructure, and products, respectively from the top.

Estimating the proportional frequency curves is necessary in order to take into account scale differences in the number of technologies introduced in each role. In the context of the wireless networking data, the total number of product certifications is significantly lower than the number of component and infrastructure certifications. There are several possible reasons for the lower number of product certifications. In particular, one certification for an embedded client or cellular convergence technology is often applied to multiple product models using the same technology. For example, Dell may certify one laptop-embedded client and then apply the certification to multiple laptops using the same client. Also, not all product technologies in this ecosystem need to be certified. For example, a laptop that uses a wireless adapter is a product technology in this ecosystem; however, the laptop itself is not certified; only the adapter is.

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

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

6.3. Mapping the Analysis Results Back to the Constructs

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

A state diagram for the WPA1 and WPA2 generations in the same wireless networking data is presented in Figure 10. In this case, it is also apparent that component technology innovations predate product and infrastructure technology innovations. In the WPA2 generation it is very clear that the progression of technological innovation was from components to infrastructures to products, while in the WPA1 case there is an initial component precedence followed by a dominance of infrastructure and products.

Using the information provided by these two cycles of technology evolution in the Wi-Fi ecosystem, an analyst may be able to forecast that the lag between component and infrastructure technology innovations and product technology innovations will continue to reduce, and eventually simultaneous innovation across all technology roles will occur. In 2006, Linksys demonstrated routers (infrastructure) and Internal cards (components) that operate on the emerging 802.11n standard (Garcia 2006) and Dell Computer shipped an 802.11n laptop client (product) using Broadcom chipsets (Corner 2006). As of mid-2007, there has not yet been widespread adoption of 802.11n-ready infrastructure capabilities and clients, and sentiments in the current marketplace suggest some lag in next-generation wireless product technologies, as infrastructure capabilities catch up and consumers become aware of the benefits (Thornycroft 2007).

6.4 Comparison of Digital Music and Wireless Networking Technologies

The qualitative example of digital music evolution and the quantitative analysis of the wireless network technologies demonstrated that different patterns of technological change can occur in
different ecosystems. The difference in the digital music and Wi-Fi evolutionary patterns might be explained in part by the influence of infrastructure technologies as either supporting or enabling other technologies within the ecosystem. Specifically, in the digital music ecosystem, infrastructure technologies typically play a supporting role— they are not required for the use of digital music products but provide additional value (e.g., online digital music stores, FM transmitters). In contrast, in the Wi-Fi ecosystem, infrastructure technologies had to be developed first simply to make wireless networking possible for product technologies. Then, as the ecosystem developed, new infrastructure technologies, such as wireless printers, supported the product technologies by providing additional value to their use. The existence of two different types of infrastructure roles— supporting and enabling—provides a possible explanation of different evolutionary cycles across different ecosystems.

There are also other possible explanations for the different patterns in these ecosystems. For example, digital music technologies are typically purchased by individuals while wireless networking technologies are purchased by both individuals and firms. The social construction of technology view would argue that different social and cultural environments around the use of each technology lead to different patterns of innovation. Similarly, demand-driven theories of innovation would argue that the consumer and market will demand different functionality from the technologies in each of these ecosystems, and therefore their evolution should be different.

7. UTILITY EVALUATION OF THE PROPOSED ARTIFACTS

The utility of a new artifact must be demonstrated using well-formulated and well-executed evaluation techniques. To demonstrate the utility of our proposed artifacts, we follow Hevner et al. (2004), who suggested seven evaluation methods, two of which are appropriate for the context we have studied. The first of these is the *observational approach*, which is exemplified by
case study and interviewing methods. We used this approach to evaluate the effectiveness of our proposed artifacts in the business environment. We accomplished this through a number of one-hour structured interviews with IT industry experts. The second is the descriptive approach. We employed the informed argument method, an instance of the descriptive approach, by using information from the knowledge base of our research domain to build arguments for the utility of our proposed artifacts. We accomplished this by assessing common techniques that are used in practice for analyzing the IT landscape, and pointing out how our artifacts complement these techniques to improve analysis capabilities and achieve utility.

7.1 Interviews with IT Industry Experts

Conducting interviews is a key technique for performing IS case study research (Benbasat et al. 1987, Eisenhardt 1989) and is one of the most important data gathering tools in qualitative research (Myers and Newman 2007). We chose to use interviews as our primary technique for evaluating the utility of our proposed artifacts for two reasons. First, our proposed artifacts are novel and not directly comparable to existing IT landscape analysis techniques on any specific quantitative performance measures, so we must rely on qualitative evaluation techniques. Second, interviews provide a means for capturing extremely rich data and, in this case, can be used to evaluate the potential utility of our proposed artifacts in a business setting by allowing us to capture the informed opinions of IT industry experts.

The Interview Process. Our interview approach was based on an interview script that was developed ahead of time and pre-tested to ensure that the questions we asked would be understood and properly interpreted, that they would yield the appropriate kinds of insights, and that they would be scoped to encourage open-ended input while they delivered answers that would help us to gauge the utility of the technological artifacts in our research. The interviewer en-
sured that all questions in the script were covered during the interview; however, related topics of discussion were permitted in order to increase the richness of the information we captured. The interview included an opening, introduction, key questions, and a closing (Myers and Newman 2007). The interview script and additional information about the development and implementation of interviews are provided in an appendix at the end of this paper. The opening was used as a means of introducing the interviewer and interviewee and capturing basic background demographic information about the interviewee. The introduction was used to explain the purpose of the interview.

The interviewee was then asked questions about: (1) the business and organizational problem of analyzing the IT landscape for technology investment and development decision-making; (2) the utility of our proposed artifacts, based on their strengths and weaknesses in a context of use; and (3) potential improvements that might be appropriate to our proposed artifacts. Between the first two sets of questions, the interviewee was given a three-page handout that summarized our proposed approach. This was the first time the interviewee was introduced to our proposed artifacts. The interviewer subsequently spent, on average, twenty to thirty minutes explaining and demonstrating the proposed approach, using the handout as a guide. The interviewer answered questions raised by the interviewee during this discussion. The closing of the interview was a simple debriefing and included a request for follow-up interviews, as needed. The interviews took a little less than one hour each.

**Interview Subjects.** We interviewed a set of IT industry experts with participants from four distinct populations: (1) IT industry senior managers and executives, (2) IT industry consultants, (3) IT industry research staff and analysts, and (4) senior academic researchers with expertise on the IT industry. We interviewed a total of twelve experts, three in each group. Each participant
had well over ten years of experience in the IT industry or academia, and over ten years of experience in a management or decision-making role. All participants evaluated themselves to have a high level of understanding of the landscape of current and past ITs, which validated our participant selection process. The participants hailed from Fortune 500 companies, technology research and government organizations, and well-known research universities.

**Question Coverage.** To evaluate our proposed approach, we created questions in our interview script to evoke discussion of the interviewee’s opinions about four key aspects of our artifacts for analyzing and understanding the IT landscape. (See Table 4.) First, we evaluated the *usefulness of the proposed constructs* in the ecosystem model. In particular, we asked if the use of the component, product, and infrastructure roles was a useful model for representing technologies within an ecosystem. We also queried their opinions about the use of paths of influence to classify temporal relationships. Second, we evaluated the *logic of the qualitative and quantitative methodologies* for identifying and visualizing trends in the IT landscape. Here our questions directed the discussion to the soundness of the methodologies and the insights produced by following them. Third, we evaluated the *utility of the information produced* by the proposed qualitative and quantitative methodologies. Here we directed the discussion to the interviewee’s opinions about the usefulness of the information about technology trends to practitioners and organizations involved in the IT investment or development decision-making process. We also captured opinions about the format and understandability of the output graphs and diagrams. Fourth, we captured the interviewee’s opinions about *how our methods complement existing approaches* for analyzing the IT landscape. The interviewees’ feedback regarding these four issues led us to identify several key dimensions of utility for our proposed artifacts, which we describe in the remainder of Section 7.
7.2. Results of the Interviews: Key Dimensions of Utility

Responses to the first set of interview questions provided motivation and shaping of the business and organizational problem our proposed artifacts address. Several key insights came out of this part of the interview. The majority of the participants noted that the staff and management of most IT-consuming companies do not have the time or expertise to perform the necessary analysis of the IT landscape, and so they must outsource this process to third parties. Additionally, every participant noted the reliance of IT organizations on reports produced by the companies like Gartner, Forrester, and IDC. Multiple participants also noted that current IT investments and partnerships play a significant role in future investments, and often IT investment decisions are outsourced to partners and suppliers. This yielded important information for us on the locus of likely value for our proposed artifacts – not necessarily through direct use by IT managers within a company, but instead through the consultants, partners, and agents with whom they work in the implementation of their strategic, operational, and product-related use of IT.

In general, all of the participants found value in our proposed artifacts for evaluating the IT landscape. Four key dimensions about the utility of our proposed artifacts consistently emerged in their opinions regarding the value of our research. In particular, these artifacts support complexity reduction, help to structure investment decisions, provide a formal method for quantifying technology ecosystem evolution, and support the identification of the locus of value for post-investment evaluation. We discuss each of these in succession, and provide our respondents’ reactions to illustrate our arguments about utility.

**Complexity Reduction.** The general consensus of the experts we interviewed was that the use of technology roles and the paths of influence provide a novel and useful way of reducing the
complexity of the IT landscape while maintaining the important relationships between technolo-
gies. Our interviewees’ commented:

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

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

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

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

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

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

Through the interviews we discovered evidence of a lack of structure in how firms go about ana-
lyzing the IT landscape. They typically rely on third-party reports and advice from suppliers and
partners, as we noted earlier, but this apparently is still not sufficient. Our proposed methodol-
ogy provides a means for generating representations of the IT landscape and associated technol-
ogy trends that are relevant to the firm’s interests and business contexts. A majority of the par-
ticipants also noted that the proposed approach is a useful tool for decision-makers across differ-
ent functional roles in the organization. The participants felt that senior managers and strategic
planners, as well as technical managers and engineers, could all benefit from understanding the IT landscape and technology trends in terms of the proposed technology ecosystem model. In general, the consensus of the participants was that the proposed methods should be useful in the IT investment and development decision-making process.

**Formal Method to Quantify Technological Change.** The proposed methods provide a formal technique for quantifying trends in technological change within the IT landscape. Our interviewees noted that the techniques most commonly used by firms to analyze the IT landscape are informal and *ad hoc*:

"Most work on this problem is informal and this is one of only a few formal approaches I have seen. Attempts to formally quantify things are a good thing. This is a formal methodology to add some quantification to the analysis by [companies like Gartner]." -- Senior Consultant at a Fortune 500 technology company

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

It turns out that only few firms – including those producing industry reports – use formal quantitative means to produce technology forecasts, aside from simple linear extrapolation. All interviewees found the quantification aspect of the proposed methods to be useful, and most also commented that our formal approach will complement existing techniques well and will provide firms with new and useful information for making IT investment and development decisions.

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

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

"For analysis purposes, this sort of model is very good and should definitely help analysts at Gartner or Forrester produce reports for managers." -- IT Manager at a Fortune 500 retail company
Based on interviews, an interesting finding for us was that, in terms of the locus of value, the interview participants differentiated between the utilities of different artifacts: (1) the utility of the proposed model, constructs, and the information produced by our methods (i.e., resulting graphs and diagrams of specific ecosystems), and (2) the utility of methodologies themselves for conducting IT landscape analysis and producing various patterns of technology evolution. The participants indicated that the information produced by our proposed methods would be useful to decision-makers in both IT-consuming and IT-producing firms. On the other hand, the majority of the interview participants felt that using the proposed approach to actually conduct the analysis of the IT landscape would be most beneficial to firms that either produce IT or produce the industry reports on trends in IT. Understanding the trends in technology evolution that led to the current state of the IT landscape should prove vital in determining what directions IT development initiatives should follow in the future. Furthermore, the reality of IT landscape analysis is that IS and corporate strategy staff members at most IT-consuming firms have neither the time, the resources, nor the technology and market knowledge to conduct formal analyses. So, even if the techniques for analyzing the landscape improve, IT-consuming firms will still likely rely on third parties to conduct their technology assessments and analyses for them. As a result, new formal approaches for analyzing the IT landscape, such as what we propose, should add value to both the firms producing the forecasts and the firms consuming them.

Through our interviews we also captured recommendations and suggestions for enhancing the proposed artifacts. We review the most important suggestions in Section 8, where we elaborate on the limitations and future directions for this research.

7.3. The Fifth Dimension: The Complementary Value of the Proposed Artifacts

“This [approach] should be very useful for helping educate analysts about the [IT] landscape. It is complementary to other existing approaches.” -- Senior Researcher at a Fortune 500 technology company.
An additional aspect of utility that was suggested by most of the interview participants was that our proposed methods will complement well existing techniques for analyzing the IT landscape. To delve deeper into the potential complementarities, we evaluated the strengths and weaknesses of many common approaches for technology forecasting and IT landscape analysis and discuss how our approach specifically complements each of them.

Table 5 provides an outline of common technology forecasting and planning techniques used in industry, including trend analysis, expert opinion, modeling and simulation, and scenario analysis. Although specific methods are most often proprietary, firms, such as Gartner, use some version and/or combination of these techniques to generate their IT forecasts and reports. The constructs and methods presented in this article are intended to complement firms’ proprietary approaches, and provide an additional means for viewing technology evolution. Our approach utilizes elements of trend analysis and modeling techniques, enables mapping of the historical relationships among technologies, and can provide useful insights regarding the next possible evolutionary steps within an ecosystem. In particular, at a given point in time, our approach may complement existing technology forecasting methods (as noted in the last row of Table 5) by providing structured input and formal analysis of the past and current states of the IT landscape.

Another relevant industry analysis approach is a technology roadmap. A technology roadmap is a tool that is typically used for planning purposes, such as in product, strategic, service/capability, and process planning (Kostoff and Schaller 2001, Rinne 2004, Phaal et al. 2004). Technology roadmaps provide a way to identify, evaluate, and select strategic alternatives by mapping structural and temporal relationships among R&D, technologies, potential products, and markets (Kostoff and Schaller 2001, Rinne 2004). The process of generating a technology
roadmap follows a visual mapping strategy not unlike we have presented. Our methods complement technology roadmaps by providing a problem representation vocabulary that extends current road-mapping techniques, and provides a more formal quantitative method for identifying trends in technological change. Technology roadmaps are designed to outline the set of possible future strategies for a specific firm (Kostoff and Schaller 2001), and our technique adds to this by providing a method for historically evaluating the evolution of an entire set of interrelated technologies (represented by technology roles within the ecosystem) using similar visual representation techniques.

As noted in Table 5, all technology forecasting methods have inherent assumptions, and the accuracy of these assumptions influences the predictive accuracy of the forecast. Most of these methods, with the exception of some regression and econometric approaches, are not predictive in the sense of classical variance theory (Mohr 1982), where a set of predictor variables is used to predict the level of some outcome variable. The basic assumption in all forecasting techniques, including the ones that a variance theory would suggest, is that the historical trends and patterns will continue into the future following the same dynamics. Our approach follows the same basic assumption: if technological change will continue to occur following the same patterns identified using our methods, then we can make reasonable forecasts about the future.

8. CONCLUSION, LIMITATIONS, AND FUTURE WORK

Following the design science research paradigm, the major contribution of this research is the development of a new set of artifacts for: (1) codifying technological innovations based on the role they play within an ecosystem of interrelated technologies, (2) identifying dominant technology types within an ecosystem using real-world data, and (3) visually representing patterns of technological change over time based on dominant technological roles. These artifacts comprise
a new technique for analyzing the IT landscape to inform the IT investment and development decision-making process. This article contributes to the IS research field in several additional ways. We provide a review of relevant IS and organizational science research on technology evolution and construct a theoretical perspective that integrates and builds upon previous ideas. We incorporate strategies for sensemaking of complex data (e.g., quantification and visual mapping) from process theory. In addition, we provide insightful analysis on the evolution of technologies in the digital music and wireless networking ecosystems. We employ interviews with senior technology managers, consultants, and industry researchers as a means to demonstrate utility of our proposed artifacts, and we also review existing technology forecasting methods and theoretical perspectives on technological change.

To develop the methodologies presented in this article, we used a combination of the visual mapping and quantitative strategies for sensemaking from process data (Langley 1999). These strategies do have their limitations. Process mapping and visual representations may exclude some dimensions of data ambiguity, and graphical forms may be biased toward the representation of certain types of information over others. The conclusions derived may sometimes have rather mechanical qualities since these representations deal more with the surface structure of activity sequences than the underlying forces (Langley 1999). On the other hand, since the goal of quantification strategies is to reduce complexity, their use may sometimes lead to a loss of richness in the process data (Langley 1999). A common criticism of the process theory in general is that, although it can produce enriched understanding and explanation, it often lacks predictive power (Van de Ven 1992).

To address the limitations of process theory, Langley (1999) suggests that both the quantitative and visual mapping strategies should be used in combination with other approaches. We
chose to use these two in combination because they complement each other well. Visual mapping provides additional contextual information that may be lost in quantification, while quantification provides an opportunity to apply empirical rigor that is missing in visualization. Furthermore, we demonstrated the use of our model’s constructs in both qualitative (digital music technologies) and quantitative (Wi-Fi technologies) investigations. The constructs were used successfully to identify evolutionary patterns in both scenarios thus suggesting their usefulness.

All models are abstractions of the real world and, therefore, depend on the assumptions used in their construction. In this research we relied on the assumption, based on our synthesis of prior literature and our observations of the real world, that the common roles technologies play in an ecosystem are components, products, and infrastructure. Another choice we make in this model is to follow the technological determinism approach (Smith and Marx 1994) and currently exclude the role of external forces such as market dynamics, the demand environment, society, and culture. Multiple interview participants recommended expanding our model in future research to include more external forces and context-specific factors. Excluding these factors may result in a loss of contextual richness; however, by limiting the number of factors considered in the model we gain control and specificity, and reduce complexity for the user of our methods.

An objective of our approach is to demonstrate that the patterns of technological change can be identified using a model based solely on relationships between technologies. We do recognize, however, the potential contribution of including these external factors in the analysis of the IT landscape. We plan to expand the current model and methodology to include more aspects of the external environment, such as market demand and social forces. Combining the technological determinism view with the social constructivism view will likely provide many new insights and opportunities for further improving techniques for analyzing the IT environment.
Although an important goal was to develop general constructs and methods for mapping out evolutionary patterns in technology ecosystems, our research provided insights about possible specific innovation and evolution drivers in specific technology ecosystems. We point to some of these in our quantitative and qualitative analyses in Sections 5 and 6 (e.g., the possible difference in evolutionary trends when you have supporting vs. enabling types of infrastructure). Using our ecosystem-based approach as a basis, in future research we will analyze ecosystem-specific drivers of innovation within several IT ecosystems and explore their similarities and differences.

The interview participants who evaluated our proposed artifacts provided three additional important recommendations and comments for expansions to the current research. First, there was a suggestion that exploring the directionality of paths of influence may provide interesting insights on technological development. In the current model, we looked primarily at positive relationships – an innovation of a technology in one role provides an opportunity for the development of a new technology in another role. There may be negative relationships between technologies though. For example, a new technology may make a series of existing technologies obsolete, thus effectively exterminating a portion of the ecosystem. Considering the directionality of the relationships between technologies also reinforces the ecological analogy in which both birth and death processes occur.

Second, the time scale may be used more effectively in the quantitative analysis to identify lags in transitions between patterns in technology trends. Quantifying such lags may provide a predictive tool for forecasting the occurrence of future trends. Third, two of the interview participants noted that they would expect data collection for performing the proposed analysis to be difficult for many firms. We recognize the importance of this comment and note that many
technology services companies are investing significantly in new business intelligence tools for extracting quantifiable data from the seas of information available on and off the Internet. As these tools evolve, rich data on the IT landscape should become more readily available, and we plan to investigate opportunities for integrating our proposed approach with these tools.

References


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Sahal, D. *Patterns of Technological Innovation*. Addison-Wesley, Reading, MA, 1981.


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

<table>
<thead>
<tr>
<th>COMPONENT PRESENT STATE (C)</th>
<th>COMPONENT FUTURE STATE (C*)</th>
<th>PRODUCT PRESENT STATE (P)</th>
<th>PRODUCT FUTURE STATE (P*)</th>
<th>INFRASTRUCTURE PRESENT STATE (I)</th>
<th>INFRASTRUCTURE FUTURE STATE (I*)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>COMPONENT</strong></td>
<td><strong>PRODUCT</strong></td>
<td><strong>INFRASTRUCTURE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Component Evolution</td>
<td>Design and Compilation</td>
<td>Standards and Infrastructure Development</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Examples: microprocessors and Moore's Law, digital camera mega-pixels.</td>
<td>Examples: digital camera, MP3 players, PCs</td>
<td>Examples: XML, RFID</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PRODUCT</strong></td>
<td><strong>PRODUCT</strong></td>
<td><strong>INFRASTRUCTURE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Present State</td>
<td>Present State</td>
<td>Present State</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Component Evolution</td>
<td>Design and Compilation</td>
<td>Standards and Infrastructure Development</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Examples: microprocessors and Moore's Law, digital camera mega-pixels.</td>
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<td>Examples: XML, RFID</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>INFRASTRUCTURE</strong></td>
<td><strong>INFRASTRUCTURE</strong></td>
<td><strong>INFRASTRUCTURE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Present State</td>
<td>Present State</td>
<td>Present State</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infrastructure-Driven</td>
<td>Infrastructure-Leveraging</td>
<td>Support Evolution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Component Development</td>
<td>Product Development</td>
<td>Examples: mobile cellular phone network, Internet 2.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Examples: Internet technologies, 802.11g Wi-Fi equipment</td>
<td>Examples: instant messaging services, picture mail</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

### Table 2. Timeline of Digital Music Technologies

<table>
<thead>
<tr>
<th>YEAR</th>
<th>EVENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td>German MP3 patent</td>
</tr>
<tr>
<td>1996</td>
<td>US MP3 patent</td>
</tr>
<tr>
<td>1998</td>
<td>First portable MP3 player (32 MB)</td>
</tr>
<tr>
<td>Feb 1999</td>
<td>Sub Pop distributes MP3 music</td>
</tr>
<tr>
<td>May 1999</td>
<td>Napster founded</td>
</tr>
<tr>
<td>May 2000</td>
<td>Transactional watermarking developed</td>
</tr>
<tr>
<td>Jan 2001</td>
<td>Apple iTunes music applications released</td>
</tr>
<tr>
<td>Jul 2001</td>
<td>Napster injunction</td>
</tr>
<tr>
<td>Oct 2001</td>
<td>10 GB Apple iPod introduced</td>
</tr>
<tr>
<td>Mar 2002</td>
<td>20 GB iPod for PC introduced</td>
</tr>
<tr>
<td>Apr 2003</td>
<td>40 GB iPod introduced</td>
</tr>
<tr>
<td>Oct 2003</td>
<td>Dell DJ introduced</td>
</tr>
<tr>
<td>Sep 2004</td>
<td>iTunes online music store opens</td>
</tr>
<tr>
<td>May 2005</td>
<td>Yahoo online music store opens</td>
</tr>
<tr>
<td>Oct 2005</td>
<td>First iPod with video capabilities</td>
</tr>
<tr>
<td>Sep 2006</td>
<td>iTunes starts selling full length movies</td>
</tr>
<tr>
<td>Aug 2006</td>
<td>160 GB 1.8 inch HDD introduced</td>
</tr>
<tr>
<td>July 2007</td>
<td>iPhone (MP3 player/phone) introduced</td>
</tr>
<tr>
<td>Sep 2007</td>
<td>160 GB Video iPod introduced</td>
</tr>
</tbody>
</table>
Table 3. Empirical Methodology Overview

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

Table 4. Coverage of Interview Questions: Key Issues for Evaluation

<table>
<thead>
<tr>
<th>ISSUE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constructs</td>
<td>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?</td>
</tr>
<tr>
<td>Logic of Methodology</td>
<td>Are the qualitative and quantitative methodologies we propose for identifying trends in technology evolution sound? Do they produce new insights?</td>
</tr>
<tr>
<td>Information Produced</td>
<td>Is the information produced by the proposed artifacts useful to practitioners? Does it aid in IT investment and development decision-making?</td>
</tr>
<tr>
<td>Relationship to Existing Techniques</td>
<td>Do the proposed artifacts complement existing techniques to provide new insights and improved analysis of IT evolution?</td>
</tr>
</tbody>
</table>
Table 5. Overview of the Traditional Technology Forecasting/Modeling Methods and How Our Approach Complements Them

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

Note: Based on the technology forecasting methods discussed in Porter et al. (1991) and Millet and Honton (1991).
Figure 1. Example Patterns of Technological Change

a) Product Development
b) Product and Infra. Alignment
c) Feed-forward
d) Feedback
e) Incremental

Figure 2. Transformation between Different State Diagram Representations
**Figure 3. Digital Music Technology Evolution Cycles**

Initial MP3 format, files and applications

MP3 becomes standard and P2P networks introduced

P2P networks continue to evolve and grow in popularity

Flash based MP3 players evolve and grow in popularity

High capacity HDD based digital music players introduced

Digital music players become mainstream and new services introduced

Continued evolution and adoption of online music services

HDD MP3 players evolve with color screens and additional features

Next Cycle?

**Figure 4. Digital Music Technology Graph-Based State Diagram**
Figure 5. Estimating the Monthly Frequency of 802.11b Technology Certifications Using a Polynomial Approximation Function

Figure 6. Proportional Frequency Functions for the Total Number of Certifications and Each Technology Role
Figure 7. Actual Frequencies of 802.11b Technologies Plotted against Threshold Functions
Figure 8. Actual Frequencies of 802.11g Technologies Plotted against Threshold Functions
Figure 9. State Diagram for 802.11b and 802.11g Generations
(6-month periods, starting March 2000)

Figure 10. State Diagram for the WPA 1 and WPA 2 Generations
(6-month periods, starting March 2000)
APPENDIX: INTERVIEW SCRIPT

Participant name ________________________________
Participant organization ___________________________
Participant title ________________________________

1) Present introductory paragraph (Handout 1) to participant.
   a. Provide a summary of the introductory paragraph
   b. Ask permission to record the interview (audio) and mark that you asked them

2) Gather demographic information (2 minutes)
   a. Years of general experience
      Less than 5  5-10  More than 10
   b. Years of experience in IT industry or research
      Less than 5  5-10  More than 10
   c. Years of experience making IT related decisions (tech acquisitions, investments, etc.)
      Less than 5  5-10  More than 10
   d. How would you rate your knowledge of the IT landscape
      low  medium  high
   e. Education _____________________________________________

3) Gather information on experience with technology forecasting, IT landscape analysis, etc. (10 -15 Minutes)

   Based on your experience, how are technologies chosen in the information technology (IT) investment and development decision processes? i.e., How do organizations typically go about analyzing the IT landscape to discover potential technologies to invest in?

   ASK ALL OF THESE TOGETHER UPFRONT (HISTORICAL, CURRENT, FORECASTING)

   How important do you think historical technology analysis of is for making decisions about IT investment/development? (Rate 1-5 and then explain)

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Unimportant</td>
<td>Somewhat Unimportant</td>
<td>Neither important or unimportant</td>
<td>Somewhat important</td>
<td>Very important</td>
</tr>
</tbody>
</table>

   Please explain

   How important do you think evaluating the current landscape of IT is for making investment/development decisions? (Rate 1-5 and then explain)

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Unimportant</td>
<td>Somewhat Unimportant</td>
<td>Neither important or unimportant</td>
<td>Somewhat important</td>
<td>Very important</td>
</tr>
</tbody>
</table>

   Please explain
How important do you think predicting the future landscape of IT (technology forecasting) is for making decisions about IT investment/development?

Please Rate

1  2  3  4  5
Very Unimportant  Somewhat Unimportant  Neither important or unimportant  Somewhat important  Very important

Please explain

What types of techniques, methods, or tools have you or your company/organization used (or are familiar with) to analyze the past, current and future landscape of information technology?

Based on your experience, what are common challenges in IT landscape analysis, forecasting and the IT investment/development decision making process? In what ways, if any, do you think existing tools/methods/techniques could be improved?

How effective do you feel existing tools/methods/techniques are for analyzing the technology landscape and performing technology forecasting?

Please explain

4) Provide handouts H2-1, H2-2, and H2-3 and discuss our proposed theory and method (10-15 minutes)
   a. Discuss the objective/motivation for the proposed technique
   b. Go over constructs (with specific examples)
   c. Go over paths of influence (with specific examples)
   d. Discuss the Music case study
   e. Discuss the method of identifying trends
   f. Discuss the Wi-Fi example case study

5) Gather reactions to methodology (10-15 minutes)
   a. Goal of methodology
   How effective do you feel the proposed methodology is in providing a new technique for identifying and analyzing patterns in technology evolution?

Please explain
b. Roles
   Do you feel the use of the component, product, and infrastructure roles help in
   understanding the nature of technology evolution? If so, how do you think they
   create value?

   Are there any missing or unnecessary roles? Please Explain

c. Relationships
   Do you feel the method for identifying relationships between technology roles is
   provides better understanding about the evolution of focal technology? Please
   Explain

   Do you feel the classification of paths of influence is complete? Please Explain

   What do you think are the strengths and weaknesses of the technology roles and
   paths of influence?

d. Logic of the method
   Do you feel the method (qualitative and quantitative) for identifying patterns of
   technology evolution is sound? Please Explain

   Are there any assumptions or steps in the method that seem unreasonable? Please
   Explain

e. Information output
   Do you feel the information generated using the proposed methodology is useful?
   Please Explain

   Do you feel the graphical representation of trends is useful? Please Explain

   What do you think are the strengths and weaknesses of the information generated
   by the proposed methodology?

f. Overall utility of the approach
   What is your general reaction to the proposed methodology and its utility for ana-
   lyzing technology trends?
If you feel the proposed methodology and approach is useful, how is it useful for organizations?

Do you feel the proposed conceptual approach and methodology would benefit organizations making IT forecasts? Please Explain

Do you feel the proposed conceptual approach and methodology would aid in the IT investment/development decision making process? Please Explain

Overall, what do you feel are the strengths and weaknesses of the proposed conceptual approach and methodology?

Who do you think is the most appropriate user of the proposed conceptual approach and methodology, if any? Please Explain

6) Debriefing
   a. Provide the participant with the debriefing handout.
   b. Give the participant a summary of the debriefing handout
   c. Ask if they have any questions or additional comments
   d. Point out the contact information
   e. Discuss possibility of a follow up
   f. Thank them and give them a thank you gift
Handout 1: Description of Study and Purpose of Interview

We are a group of information systems researchers from XXXXXXXXXXX XXXXXXXXX XXXXXXXXX. We are currently developing new methods for analyzing the evolution of information technology (IT) with the goal of providing useful tools to IT professionals to aid in the IT investment decision making process. We are conducting interviews with IT industry managers, IT industry consultants, IT industry researchers, and academic researchers to gather impressions and evaluations of our proposed conceptual approach and methods. This interview will take approximately 45 minutes and will consist of four parts. First, we will ask for some background information about you, your organization, and your experience and understanding of information technology landscape analysis and forecasting. Second, we will present you with a brief document outlining our proposed conceptual approach and methodology. We will explain our conceptual approach and methodology using the document as a supplement; we will allow time for any questions you might have. Third, we will ask for your reactions and evaluation of the proposed theory and methodology. Fourth, we will perform a short debriefing. Thank you for your participation. You may quit the interview at any time. Your personal information will not be shared or published. The input of industry experts and academics is necessary to produce new tools that are useful, practical, and accessible to our intended users and we highly value your input.

Do you give us permission to record the audio of this interview?

Yes _________ No _________
Handout 2-1: Overview of theory and constructs

Motivation
- The IT landscape is complex with many technologies and interdependencies.
- This makes the information technology investment decision making process difficult.
- Can we create a methodology that systematically identifies patterns in technology evolution to help inform managers making these decisions?

Technology Ecosystem
- A theoretical construct that is used to represent multiple associated ITs and the interdependent relationships among them over time.
- A technology ecosystem is centered on a focal technology in a certain context and consists of a set of technologies acting in specific roles and influencing each other through paths of influence.

Focal Technology and Context
- The focal technology and its context are the center of the technology ecosystem. Example: mobile phone in the context of wireless entertainment.
- A technology ecosystem representation is flexible, choosing a different focal technology and/or context changes the representation.

Technology Roles
- Components are the elemental pieces or subsystems that make up complex technologies. Examples: RAM chip, microprocessor, CMOS sensor.
- Products are built up from a set of components, and are designed to interact with a user to perform a specific set of functions. Examples, MP3 player, digital camera, personal computer.
- Infrastructure technologies work in conjunction or collaboration with (or as a peripheral to) products to add value to users. Examples: laser printer, Ethernet, network attached storage.

Technology Relationships
- There are clear relationships between the components, products and infrastructure (e.g., digital camera ecosystem
- Over time, technologies in each role change and evolve which impacts related technologies.
- The Paths of Influence matrix classifies these interactions.
- An evolutionary pattern is identified from multiple paths of influence over time.

<table>
<thead>
<tr>
<th>COMPONENT PRESENT STATE (C)</th>
<th>COMPONENT FUTURE STATE (C*)</th>
<th>PRODUCT FUTURE STATE (P*)</th>
<th>INFRASTRUCTURE FUTURE STATE (I*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component Evolution</td>
<td>Design and Compilation</td>
<td>Standards and Infrastructure Development</td>
<td></td>
</tr>
<tr>
<td>Product Present State (P)</td>
<td>Product-Driven Component Development</td>
<td>Product Integration and Evolution</td>
<td>Diffusion and Adoption</td>
</tr>
<tr>
<td>Infrastructure Present State (I)</td>
<td>Infrastructure-Driven Component Development</td>
<td>Infrastructure-Leveraging Product Development</td>
<td>Support Evolution</td>
</tr>
<tr>
<td>YEAR</td>
<td>EVENT</td>
<td></td>
<td></td>
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<tr>
<td>------</td>
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<td></td>
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<tr>
<td>1989</td>
<td>German MP3 patent</td>
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<tr>
<td>1996</td>
<td>US MP3 patent</td>
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<tr>
<td>1998</td>
<td>First portable MP3 player (32 MB)</td>
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<tr>
<td>Feb 1999</td>
<td>Sub Pop distributes MP3 music</td>
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<tr>
<td>May 1999</td>
<td>Napster founded</td>
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<tr>
<td>May 2000</td>
<td>Transactional watermarking developed</td>
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<tr>
<td>Jan 2001</td>
<td>Apple iTunes music applications released</td>
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<tr>
<td>Jul 2001</td>
<td>Napster injunction</td>
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<tr>
<td>Oct 2001</td>
<td>10 GB Apple iPod introduced</td>
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<tr>
<td>Mar 2002</td>
<td>20 GB iPod for PC introduced</td>
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<tr>
<td>Apr 2003</td>
<td>40 GB iPod introduced</td>
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<tr>
<td>Oct 2003</td>
<td>Dell DJ introduced</td>
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<tr>
<td>Sep 2004</td>
<td>iTunes online music store opens</td>
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<tr>
<td>May 2005</td>
<td>Yahoo online music store opens</td>
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</tr>
</tbody>
</table>

Initial MP3 format, files and applications

- MP3 becomes standard and P2P networks introduced
- P2P networks continue to evolve and grow in popularity
- Flash based MP3 players evolve and grow in popularity

High capacity HDD based digital music players introduced

- Digital music players become mainstream and new services introduced
- Continued evolution and adoption of online music services
- HDD MP3 players evolve with color screens and additional features

Next Cycle?

Initial MP3 format, files and applications

- MP3 becomes standard and P2P networks introduced
- P2P networks continue to evolve and grow in popularity
- Flash based MP3 players evolve and grow in popularity

High capacity HDD based digital music players introduced

- Digital music players become mainstream and new services introduced
- Continued evolution and adoption of online music services
- HDD MP3 players evolve with color screens and additional features
## Handout 2-3: Overview of quantitative methodology and example

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

### Threshold Plots

**802.11b Components**

![Threshold Plots](image)

**802.11b Products**

**802.11b Infrastructure**

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### Pattern Identification

- **802.11b**
  - Period: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13

- **802.11g**
  - Period: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13
Handout 3: Debriefing

Interviewer: XXXXXXXXXXXXXXXXXXXX
Date/Time of Interview ___________________________

Research Team: XXXXXXXXXXX
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
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If you wish to follow up with our research team for any reason please contact:

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