Digital Technology and the Variation in Design Routines: A Sequence Analysis of Four Design Processes[1]

Completed Research Paper

James Gaskin
Case Western Reserve University
Cleveland, OH
james.eric.gaskin@gmail.com

B. Veeresh Thummadi
Case Western Reserve University
Cleveland, OH
vthummadi@gmail.com

Kalle Lyytinen
Case Western Reserve University
Cleveland, OH
kalle@case.edu

Youngjin Yoo
Temple University
Philadelphia, PA
youngjin.yoo@temple.edu

Abstract

We advance a theory of design process variation across organizational types and the effects of digitalization on these processes. We argue that design routines are subject to greater variation within and between organizations as organizations embed increasingly rich repertoires of digital capabilities in their design activities. Using a sequence analysis method we compare design process variation in four organizations to examine how design routines vary due to differences in embedded digital capabilities and organization of the design process. Our analysis reveals new insights on the effects organizational context and digitalization have on design routine composition.

Keywords: Design processes, organizational routines, sequence analysis, digitalization

Introduction

> "Do different environments and organizations tend to produce the same patterns, or are there systematic differences? Do different organizations given similar environments, produce similar patterns? Are there characteristics of the persons or team responsible for the [routines] that may predict variation in patterns of actions? In other words, are routines shaped more by the external environment or by internal features of the organization? *…answers to these questions seem a long way off at the moment…*" (Pentland et al. 2009).

In this paper we ponder: perhaps we are not too far off! As we endeavor to address some of the questions posed by Pentland et al. we argue, in particular, that advances in methods for analyzing socio-technical process data (Gaskin et al. 2010a; Gaskin et al. 2010b) enable us to attack these questions from a new angle with greater precision and ease.

[1] This paper is based on work supported, in part, by the National Science Foundation under grants *VOSS-0943157* and *VOSS-0943010*. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. We would like to thank Nicholas Berente, Rob Kulanthinal, Zhewei Zhang, Yohan Choi, and Omri Shiv for their contributions to the project.

We base our analysis on a view that an organization is fundamentally a nexus of routines (Nelson 2009) which vary over time (Pentland et al. 2010). Hence the same functional routine may take different forms (Berente 2008; Nelson and Winter 1982; Pentland and Feldman 2005) in different contexts, whilst different organizations may employ functionally equivalent routines, though their appearances might differ. Henceforth, understanding 'evolving' varieties in organizational routines can offer new insights into organizational change or performance. Within the Information Systems (IS) literature it is a common wisdom that vastly different organizational consequences follow the use of a similar technology (Lacity and Willcocks 1998; Orlikowski 2007; Orlikowski and Baroudi 1991). We argue that greater insights can be gained *why* and *how* such differences emerge by studying, in detail, variation in organizational routines that follow digitalization (Pentland et al. 2010). Yet, extant literature offers only few insights on *why* and *how* functionally similar organizational routines vary across contexts (both within and across organizations) as organizations digitize their work processes, with regards to how digitalization of routines takes place.

In this study, we examine variations in routines that serve a specific functional goal – that of generating design artifacts. Accordingly, we define a *design routine* as a sequence of (design) tasks, which transform some representational inputs into a set of material and representational outputs, leading ultimately to a generation of a design artifact that offers a set of functions for a community of users (Gaskin et al. 2010b). Unlike other routines, such as payroll, that perform highly standardized tasks with clearly defined inputs, outputs and transformation rules, design routines are fluid. They often deal with unknown inputs and outputs due to changing requirements that result from learning and environmental volatility (Cross et al. 1996; March and Smith 1995). Hence, design routines must deal with novel transformation challenges with unknown goals and constraints (Cross 2001). Recently, organizations have increasingly started to use a rich array of varying and powerful digital tools to support their design routines (Boland et al. 2007), often denoted as PLM tools, CAD/CAM tools and so on. Routines are also increasingly enacted in a distributed way, enabled by modular designs that decentralize some design decisions (Baldwin and Clark 1997; Schilling 2000) and provide greater discretion for local designers (Yoo et al. 2010).

We are fascinated with how the increased embedding of digital capabilities into design tasks can become an important source of routine variation. To this end, we next explore the influence of organizational and environmental contexts in the observed range of variations in four digitally supported functionally similar design routines. We apply a genetic model of design routines to analyze this variation (Gaskin et al. 2010a; Gaskin et al. 2010b) with the aim to develop a theory of design routine variation associated with organizational characteristics of the design task. To this end we analyze the variability of design routines across four design contexts which vary along two organizational dimensions: (1) *environmental volatility* (frequency of product and market fluctuations) and (2) *power structure* (hierarchical versus networked). Overall, we then analyze 623 design routines which are sampled from the four design contexts constituted by different values of these two organizational dimensions (2 x 2 research design). In each context we, in particular, examine how digitalization of design routines has taken place and how it affects design routine variation under these organizational contingencies.

The remainder of the paper is organized as follows. First, we review research on organizational routines, design and digitalization. Then we formulate a theory of routine variation based on organizational contingencies and the level of digital embedding. We then outline our research design and provide detail of the analysis method to validate the theory. We conclude by providing a critical summary of our findings and discussing future research.

Organizational Routines Defined

An "organizational routine" is a "general term for all regular and predictive behavioral patterns of firms" (Nelson and Winter 1982). The construct informs us "how organizations accomplish their tasks, how they change, and how organizational capabilities are accumulated, transferred and applied" (Becker and Lazaric 2009). In a sense, routines can be thought of as "technologies" or a set of techniques for doing something (Nelson 2009). These "technologies" are not the machinery of innovation, but rather embedded physical and social mechanisms that underlie all work. Here, *physical* technologies refer to the apparatus, inputs and outputs, and procedures employing these to control how and what gets done in organizations. *Social* technologies refer to the human side of work: social organization and collaboration (Nelson 2009). Finally, organizational routines can be viewed as accumulated capabilities garnered through repeated behaviors, which reflect an organization's strengths to employ its physical and social technologies. Overall, routines can be viewed as replicable 'modules' that knowledge workers mobilize to accomplish tasks without having to "reinvent the wheel" each time they engage in work (Hodgson 2009). In this sense, routines exhibit the organizational analog of individual habit. However, as Hodgson (2009) notes, organizational routines should not be constrained to apply only to organizational level analyses, as individual habit forms a key component of repeatable organizational behaviors – i.e. routines. Rather, routines are generative and dynamic systems, continuously emerging with internal structures and dynamics (Pentland and Feldman 2005).

Routines also have a recursive relationship with organizational memory. On one hand, routines are enabled by, transfer, and manifest organizational memory (Becker and Lazaric 2009). On the other hand, routines—as repeatable modules—could not exist without the persistence of organizational memory. Without organizational memory, organizational processes would exhibit a similar structure only by coincidence. Routines also enhance organizational memory by modularizing (chunking) organizational techniques for "getting things done" (Nelson 2009; Nelson and Winter 1982). Lastly, organizational routines evince the presence of a successful organizational memory: a routine—especially an evolving one—provides evidence that the organization is not only remembering how work is done, but learning how to do it better (Hodgson 2009).

Most studies around routines have been conducted in the context of standardized administrative processes (Pentland et al. 2010) or highly structured ERP systems (Berente 2008; Volkoff et al. 2007). These studies show a tight connection between generative models as a way to represent the capability of routines to vary as organizational processes unfold (Pentland 1995; Pentland and Reuter 1994). Some studies have also examined interactions between organizational memory and routine change as a result of selection and retention (Miller et al. 2010a; Miller et al. 2010b). Recently, Pentland and Feldman (2007) have suggested that combinations of routines, and their material contexts and artifacts, can be described as "narrative networks". This interpretation gives primacy neither to the technical nor to human dimensions but their joint dynamics in the analysis of routines (Pentland and Feldman 2008).

Organizational routines are particularly difficult to analyze for three reasons. First, the concept of 'organizational routine' has, until recently, remained rather obscure and nebulously defined (Hodgson 2009). Second, the correct granularity and appropriate way to classify routines and their elements has been lacking (Pentland et al. 2009) making it difficult to analyze organizational routines and theorize around them. Hence the two issues—granularity and taxonomy—form a 'catch 22'. Settling on a specific level of granularity is difficult without advancing taxonomy of organizational routines. But developing taxonomies requires a decision on granularity. Should organizational routines be captured at the activity level or just include specific types of activities? Or, should we also capture information about the actors, their roles, the tools they use, the methods they use for collaborating, etc.? Or should we capture more granular information about data flow, design objects, and even algorithmic processes? No definitive solution to this question has been derived, although recent research (Gaskin et al. 2011) emphasizes multi-level granularity and the need to capture more detailed contextual information on how routines and their elements are composed.

The third barrier deals with methods of analyzing routines and their change. Until recently, the primary methods for collecting data and analyzing routines was qualitative observations and narratives (Becker and Lazaric 2009). These rich micro-level ethnographic accounts of organizational routines (Henderson 1991; Majchrzak et al. 2000) neither detect the varying patterns of routines across multiple contexts nor help to understand the long-term effects, which seemingly innocent changes—such as employing a new digital tool—have on shaping routines. Similarly, the dominant variance-based approaches are inadequate because they fail to account for process change, and they offer a limited perceptual window to tap into process variation, i.e., how routines are composed and how these compositions vary over time and space (Mohr 1982). Consequently, variance-based approaches cannot capture and compare sequential variety of categorical values of routine elements across several cases. Recent advances in sequence analytic techniques, however, combined with advances in digital tracing techniques (computer logs) can provide one means for increasingly rigorous and extensive styles of quantitative analyses of routines and their variation (Gaskin et al. 2010a; Pentland et al. 2009; Salvato 2009a; Salvato 2009b). For example, Pentland et al. (2009) recently analyzed structure and variation of workflows associated with over 2000 invoicing processes in a single organization. This analysis covers descriptive statistics, formal network analysis of flow structure, and sequence analysis to detect variation in sequences. Sequence analysis, in particular, offers novel insights into routine variation and composition including the detection of patterns of similarity or difference between multiple sequences, and comparisons of the sequential ordering of sub-tasks.

Understanding Design Routine Variation Using a Lens of Biological Variation

As noted, design processes are knowledge-based activities performed by engineering or design professions to construct material artifacts. Hence we view design organizations as conglomerates of routines that simultaneously afford the benefit of stability in design behaviors and the capability to adapt design novelty by 'mutating' routines through new variations of performing the same or a new design task.

Design routines mobilize heterogeneous bodies of practical and abstract knowledge. While enacting the routines, designers must satisfy performance and quality standards by operating within time and budgetary constraints while confronting significant novelty and complexity due to evolving and ambiguous design tasks (Clarkson and Eckert 2005). In general, design routines involve a series of translations from ideas to alternative forms of representations, and eventually to the intended design artifacts (Maher and Tang 2003). In this process, designers also draw upon a variety of physical and digital tools, where each tool supports or enables some aspect of the design task (Gaskin et al. 2010b). At each step, tools can support the creation or modification of design representations such as drawings, sketches, diagrams, models, requirements and detailed design specifications. Design routines also mobilize heterogeneous actors: like different design professionals, users, managers and so on. Additionally, multiple representations need to traverse across and touch different actors while designers and other stakeholders deploy physical and digital artifacts to communicate and coordinate design knowledge (Rosenman and Gero 1996). Overall, representations are highly important to, and for, design routines, which, while being enacted, trigger constant iterations across and within representations – both individually and socially (Berente et al. 2009). This makes design routines enormously complex.

Design routines also involve argumentation around different logical modalities that characterize design knowledge (Buchanan 1992). Accordingly, design processes are interactively complex and demand significant task and knowledge-based coordination, creating the potential for significant variation on how design tasks are carried out (Gaskin et al. 2011). Hence, one perennial challenge in managing design organizations is how to leverage these local project-specific idiosyncrasies in work practices, while preserving globally the integrity of the routines (Cusumano and Nobeoka 1998; Yoo et al. 2006). Because each design task forms important occasions to learn due to their novelty we see generativity as one source of variation in design routines. At the same time routines need to enforce stability which is needed to create predictability and lower outcome variation in critical design dimensions. This raises the question: how stability and variability are both enabled and sustained through design routines and what factors affect these processes?

In this paper, drawing on the metaphorical lens adopted from biological variation, we conjecture that the emergence and evolution of organizational routines can be best understood by examining the sequences of design tasks as changing variations of their 'genetic elements'. After Pentland and Feldman (2008), we propose that a design routine can be metaphorically understood as a sequence of (genetic) elements.

More specifically, we interpret a design routine as a sequence of essential elements to carry out a design task. These elements are essential in the sense that without them, engaging in design would be impossible. We view them in genetic terms in the sense that they may vary over time due to changes triggered by environment or internal learning (such as new digital tools, new design tasks, skills etc.). Overall, such routines as sequences of elements of design tasks form "design DNA". In this "DNA" each design task is performed by some actors who consume and generate design artifacts by mobilizing some tools (Kock 2008). These tools—both physical and digital—are used to extend designer's cognition and to generate alternatives (Boland and Tenkasi 1995; Simon 1996) or to communicate and coordinate activities (Malone and Crowston 1994), often as boundary objects (Carlile 2002). The tools accomplish this by enabling sets of affordances that are enacted in support of the design routine. Actors can be either individuals or groups, and they can be either collocated or distributed. These are the dimensions in which design task genes can vary.

Using this metaphor of variation and change, one can characterize design routines with a set of generative elements that give birth to routine variation. Here, we can structurally delineate the extent of variation in the low-level design elements across instances of design routines. By doing so, we can show how alternative combinations of low-level design elements can generate a wide range of variations in design routines. This allows us to detect the organizational DNA of each design routine by showing how an organization's design routines are the outcomes of combining and recombining, *in situ*, a limited set of 'genetic' elements into a concatenated sequence. Likewise, different design routines—characterized by different sequences of the same genetic elements—can be compared using computational techniques appropriate for sequential data analysis. The evolutionary idea of organizational routines provides the theoretical backdrop to our inquiry that seeks to detect evolution and variation in design routines across different design contexts. Using this type of variation model, we can explore whether the embedding of digital tools creates new variations in design routines, and how different organizational contexts influence that process.

Four Different Design Contexts and Variations of Design Routines

Design organizations do not digitalize or mutate their design routines out of "thin air." Instead, design routines are enabled and constrained not only by the digital artifacts at hand, but also by path dependent institutional and environmental factors. Therefore, in this paper we consider *power centrality* and *environmental volatility* as two organizational dimensions that are likely to influence the way design routines vary. We use power centrality to refer to the extent to which the organizational control of the design process is managed by a central body as opposed to a distributed authority. For example, are decisions made top down by a project manager, or are they made by consensus through a distributed network of minds? Hence, the study of design control involves a broad understanding of the impacts of organizational structure, norms, and micro-level power in organizational behavior like design work (Clegg et al. 2006). Organizations are generally thought to operate somewhere along a continuum, with centralized hierarchical organizational forms at the one extreme, and egalitarian networks at the other (Clegg et al. 2006). Due to the use of IT, firms can also act increasingly in combinations of the two forms of control, centralized and decentralized (what Clegg (2006) refers to as "polyarchies") (King 1983; Yoo et al. 2008). We use environmental volatility to refer to industry and market volatility, and the level of uncertainty that is associated with design decisions and their consequences. For example, an organization that designs mobile phones operates in a more volatile environment than an organization that designs bicycles. Phone features and components change constantly and rapidly, whereas bike features and components remain relatively constant. Similarly, the size, shape, and capabilities of the bike change far less frequently than in a mobile phone[2]. These two dimensions of design contingencies are found in varying combinations in every design organization.

We focus on power centrality and environmental volatility for the following two reasons. First, we surmise that the structures and norms related to design processes are conditioned by the volatility of a given industry – a classic contingency factor in organizational research (Galbraith 1973; Lawrence and Lorsch 1967; Thompson 1967). In the case of design organizations, this involves the volatility of the design parameters, architectural principles and the level of uncertainty related to design decisions and market forces. Second, any investigation into the impacts of design routines should address the issues related to design control; i.e., the allocation and exercise of rights to make decisions about the structure or features of the design artifact, or the process of the design. Such design control has traditionally been conceived to be synonymous with managerial prerogative (Yates and Project 1989), but will bear a markedly different character depending upon where the control is located along the continuum of power centralization. This control may also change from time to time, or from project to project. Thus a single organization may exhibit both networked and hierarchical structures, depending upon the project in question. Additionally, there exists a relationship between structure and volatility; namely, more volatile environments tend to encourage less centralized structures due to information overload (Casson 1994).

Overall, the interplay of the digital and physical capabilities with these polarized regimes of change and control is critical in understanding how design processes change. Thus, by looking at both the centralization as well as the volatility of design tasks, we can identify four 'Weberian' ideal forms of design

---

[2] This is also likely due to the difference in maturity of the two industries. Bikes are centuries old, whereas mobile phones are young.

contexts: 1) stable networked, 2) stable hierarchical, 3) dynamic networked, and 4) dynamic hierarchical. These classifications form continuums and any given instance of an organization may find itself crossing into different forms at different times. Figure 1 describes the framework.

		Power Structure	
		Less Centralized	**More Centralized**
Environmental Volatility	**Less Volatile**	Stable Networked Organization	Stable Hierarchical Organization
	More Volatile	Dynamic Networked Organization	Dynamic Hierarchical Organization

Figure 1. Forms of Design Contexts

In *stable network organizations*, design decisions are distributed among heterogeneous actors who represent different disciplines. Not all of these domains, however, face rapid change. Teams in the Architecture, Construction and Engineering (AEC) industry, for example, may operate in stable networked design organizations. In a typical AEC project, an architect only provides "design intent" while design decisions are distributed as contractors and subcontractors decide how to "build" the building based on the design intent as represented in the initial design documents (Boland et al. 2007).

In *dynamic networked organizations*, design decisions are distributed among heterogeneous actors as diverse groups bring their own unique disciplinary knowledge to bear on a design and new and changing knowledge resources are continually brought to bear in the design (Berente et al. 2010). Yet, each of these diverse actors faces rapid and unevenly distributed changes in their own disciplines (Yoo et al. 2008). Open-source communities are good examples of such dynamic networked design organizations.

In *stable hierarchical organizations*, design decisions are centrally made by a key design architect. Typically, these organizations execute well-developed design routines as they face relatively stable environments. We see this type of stable hierarchical design organization in manufacturing firms who design products for stable markets using in-house resources, often based on a unique market niche or capability. Design teams that make tooling such as dies and molds might reflect stable hierarchical organizations. In these cases design engineers interact with customers in a limited set of ways and provide support for local manufacturing.

Finally, in *dynamic hierarchical organizations*, design decisions remain centrally controlled. These organizations, however, face much unpredictability. Design organizations in the IT industry (such as microprocessor manufacturers or mobile phone manufacturers) fall into this category. In order to execute the centrally made design decisions rapidly, these firms retain a repertoire of design routines and templates (Yoo et al. 2006) and constantly enroll new knowledge resources while innovative requirements emerge and change unpredictably (Berente et al. 2007).

Towards a Theory of Routine Variation

How do these different design contexts influence variation in design routines? Do design routines within an organization share a more similar pattern than across organizations? We argue that design routines within an organization will share a more similar pattern when compared with routines from a different organization. Routines within an organization operate with the same organizational memory, culture, and environmental pressures (Becker and Lazaric 2009; Miller et al. 2010a; Miller et al. 2010b), thus reducing routine variety and promoting stability (Pentland 1995). Based on path dependency we argue that organizations which operate in more similar design contexts have more similarities in their design routines than those operating in differing design contexts. Thus we propose:

> *H1. Design routines vary less within an organization than between organizations in different design contexts.*

Next we ask how digitalization influences design process variety. Do activities which are more digitally driven show more or less variety than activities that employ more physical tools? Digital tools are particularly well-suited to perform multiple types of tasks through a multiplicity of functionality and interpretive flexibility which may even be extended through improvisation (McGann and Lyytinen 2008). Digital innovations are also often solutions to streamline processes and consolidate design work (Henfridsson et al. 2009). Compare this to the use of physical tools which are often well-suited to a single type of functionality and are functionally "rigid". Given these differences, when digital tools become the primary instrument for, and bearer of, design work, variety within the routine is likely to be low, given that a single tool can perform multiple functions, and thus fewer tools will be needed to accomplish the work. Conversely, when physical tools supplement the use of digital tools, the design process variety is likely to increase because more tools will be required to perform the same amount of functionality. At the same time, a counterargument can also be made that digitalization actually increases variety due to the combinatorial and expansive nature of digital tools (Sun et al. 2008). Because digital tools can be used in many different ways, the larger potential of affordances available through the use of digital tools would be a source of variety, rather than stability. The measured level of variety then depends a great deal on the sensitivity and granular level of the analytic approach. Given the two plausible influences of digital tools on design routine variations, we put forward two competing hypotheses:

> *H2a. Design routines vary less when performed with digital tools.*
>
> *H2b. Design routines vary more when performed with digital tools.*

The impact of design contexts on the variations of design routines can be directly assessed by comparing the patterns of design routines along the two dimensions of volatility and power centrality. Specifically, how do design routines within organizations operating in volatile environments compare to the patterns of routines within organizations operating in stable environments? Similarly, how do patterns within hierarchical organizations compare to routine patterns within networked organizations? Environmental stability should be conducive to less experimentation and less frequent variation of design routines, because a predictable market requires little changes in processes which are not risky (Damanpour and Gopalakrishnan 1998; Galbraith 1973; Peet and Watts 1996). Conversely, volatility in the environment will prevent organizations from sticking to what apparently works. Their change is compelled by external forces (Galbraith 1973; Hannan and Freeman 1977; Truex et al. 1999). Experimenting and making changes to routines is a risky move, but it is pursued because the market changes rapidly. Thus we hypothesize:

> *H3a. Design routines among organizations in volatile environments vary more than design routines among organizations in more stable environments.*

Along these same lines we can hypothesize about the similarity of design routines based on power structure. Variation in routines is often conceptualized as organizational innovation (Nelson and Winter 1982; Nelson and Winter 2002; Pentland and Reuter 1994). Process innovations are changes to the way work is done, i.e., changes in design routine (Carlo et al. 2005; Lyytinen and Rose 2003). In a meta-analysis of 23 studies of organizational innovation, Greenhalgh et al. (2004) found centralization to have a consistent negative effect on innovation—in other words, centralized organizations innovate less when it comes to processes. Decentralized, or networked, organizations are more likely to innovate because they draw upon a network of minds, each empowered to make decisions (Clegg et al. 2006). Therefore, their design routines are likely to vary more; whereas in centralized organizations, the design routines are more likely to follow 'ostensive' top-down guidelines, and thus, vary little from the espoused institutional rule. Additionally, centralized hierarchies enable task decomposition with limited access to information and autonomy (Radner 1992) which can reduce variation in routines. Thus we propose:

> *H3b. Design routines among centralized organizations vary less than design routines among decentralized organizations.*

Research Design

Selected Organizations and Projects

We collected process data from four large organization denoted here as Alpha, Beta, Gamma and Delta. A total of 43 interviews (of at least an hour each) were conducted to collect and validate design process data. All interviews were transcribed and then diagramed as design process models. Archival data and observations were also utilized to triangulate the rendered process models. All models were validated with team leads at the respective organizations. We selected several different projects in our sites that reflected their typical design routines. Even though these projects may appear different in nature, they all have a common theme; i.e., they embed significant digital technologies while representing essential and typical design tasks in their respective domains. Per Sydow et al. (2009), in terms of routine composition, each of the projects is in their formative stage, which means their routines exhibit great variation while new digital capabilities are embedded into the design processes. All these projects extensively used digital tools and artifacts, and involved large numbers of actors in the enactment of the design routines. Of the 623 design activities we captured during our data collection, 79% employed digital tools exclusively. Next we offer a brief description of the organizations and studied design projects.

Alpha

Alpha is a large American OEM car manufacturer. Its operations are global and carried out in several parts of the world. We collected data from a large software development unit within Alpha. This unit focuses on developing and integrating the software that organizes product information and the associated processes for design and manufacturing. The Bill of Material (BOM) search project followed a traditional waterfall structure as dictated by Alpha's life cycle development methodology that is founded on object oriented data modeling, use cases, and derivation of a software design architecture using object oriented design. The project was initiated in the first quarter of 2009 to enhance search in the Bill-Of-Material (BOM) database and it lasted for about two years. It is relatively large in size (over 20 man years) and involved 24 people working in two locations (U.S. and India). The BOM project followed the phases of the prescribed in waterfall methodology enforced by the OEM that involved gathering requirements, creating designs, coding and debugging, and testing the product sequentially with gate decisions in between. The project also involved iterations within development and testing phases (Thummadi et al. 2011). The software development unit in Alpha represents a dynamic hierarchical organization.

Beta

Beta Corporation is a leading semiconductor manufacturer. It uses a sequential design cycle model for scaling up to the requirements of chip miniaturization. One step in the process involves shrinking of process technology of the previous micro architecture (process change). A second design step involves a design of new micro architecture (big functional change) involving 60-70% change in the functional logic. We collected data from one of the latter types of designs. The studied chip design consists of several cores which all include memory, central processor, caching, instruction fetching, and optimization. The chip design process consists broadly of phases for 1) partitioning of the microprocessor 2) design process for changing functionality and control 3) implementation and 4) integration. Two different types of design strategies and related tools support were analyzed: structured data path (SDP) and functional logic representation (FLR). The latter involves nearly a full automation of the digital logic onto a chip. Beta represents a dynamic networked organization.

Gamma

Gamma Construction Company is a large, U.S.-based firm that designs and builds structures and facilities for the advancement of modern society. We selected an MEP coordination (Mechanical, Electrical, and Plumbing) project as the design process of interest. MEP often forms a critical path in complex construction projects, and is one common design challenge that virtual design has been able to simplify by using new digital capabilities. The MEP process is highly complex and potentially expensive (at roughly 30-35% of construction costs), because each subcontractor working on one technical subsystem (e.g. HVAC systems) must coordinate their work with other contractors, fitting the various MEP components together like one would fit together a three dimensional jigsaw puzzle. The MEP coordination process at Gamma has continuously changed over the past five years as new capabilities have been added, and old capabilities have been removed and replaced. Gamma is still exploring within this process, adding and dropping tools and activities in order to find the best way to do virtual MEP coordination. Thus, we feel that MEP coordination at Gamma is a prime candidate to examine for variation in design processes—it was an explorative process innovation enabled by digital capabilities which is being constantly re-designed based on learning-by-trying. Gamma represents a stable networked organization.

Delta

Delta Corp is a hydraulic design and manufacturing company, which recently finished designing a new and innovative hose system. This solution is thinner, stronger, and cheaper. The project began back in 2007 as an idea for a new product. A database was set up and devoted to this project to record testing information (like system output information during testing cycles). Prototype hoses were made according to the specifications of the sketches and specification documents, then assembled and prepared for testing. In order to reduce the number of prototypes, Finite Elements Analysis was employed to eliminate infeasible prototype designs before actual physical testing. The FEA was able to discover flawed designs that would certainly not pass testing, and thus shouldn't be submitted to it. The use of new digital capabilities in this project led to a product with characteristics (durability, thinness, cost) never before achievable. These new digital capabilities have become a fundamental component of future design routines at Delta. Delta represents a stable hierarchical organization.

Method

To test our hypotheses, we employed the method developed by Gaskin et al. (2010a), using their updated taxonomy of design process elements (Gaskin et al. 2011). The method treats design process models as sequences of design "DNA", and therefore uses multiple alignment sequence analysis through optimal matching with a gene sequencing software, ClustalG (Wilson 2001; Wilson 2006). The Gaskin et al. (2010a) sequencing method is based on a taxonomy for defining and classifying the elements that make up design routines. It offers a notation for specifying how these elements relate to each other and specifies seven 'genetic' elements of design routines: (1) a value for the type of activity that needs to be carried out for the task, (2) a value for the configuration of actors, (3) a value for the design tool materiality used for the task, (4) a value for the design tool affordance enacted for the task, (5) a value for the task location, (6) a value for the design object type used and/or produced by the task, and (7) a value for the flow of the data/information being used or produced during the task. Providing values for each of these seven elements is necessary to represent a design task. One or more such design tasks comprise a design activity. A design activity is thus defined as a set of design tasks that serve a single functional purpose. Each activity is an instance of a design routine. For example, a team can meet to review model specifications. During this activity, multiple tools can be used for multiple purposes (each being a task), and actors may use these tools to manipulate, utilize or produce multiple design objects. This particular activity, a review meeting of model specification, is an instance of a "review" routine. Furthermore, there may be many different instances of review routines in the organization, as team members might use different tools and perform different tasks to review model specifications in different contexts.

Once activities are structured into visual task sequences, in MetaEdit+ (Andersen et al. 1991; Tolvanen and Rossi 2003) (http://www.metacase.com/mep/), the process data can be next structured into comparable sequences, much like in traditional (biological) DNA analysis. These sequences can then be analyzed in ClustalG (Wilson 2006; Wilson et al. 2005; Winter and Szulanski 2001), a derivative of ClustalX and ClustalW (Larkin et al. 2007), both widely used biological sequence analysis to detect protein and nucleotide molecules (Aiyar 2000; Thompson et al. 2002). ClustalG is an expanded version that enables the analysis of multiple types of event sequences found in social sciences with varying base elements. For example, Wilson (2001) has used ClustalG to cluster behavioral (career) patterns among Canadian women. The reliability of sequence analyses using ClustalG has also been demonstrated by Wilson (2006).

ClustalG helps find patterns in sequences and also identifies the sample members for each pattern. To this end, ClustalG performs a pairwise alignment of the sequences in order to construct a similarity matrix that is then converted into distance scores. Next, it compiles multiple alignments based on the branching pattern of a tree calculated from pairwise distances and other conventions that affect alignment scores (Wilson 2001), including a user-specified weight matrix[3]. It is from this similarity matrix that we draw conclusions regarding our hypotheses. Additional analyses are conducted through simple descriptive statistics calculated using pivot tables describing the frequency of elements for the design process activity data for each studied organization.

Findings

With H1, we hypothesized that design routines vary less within an organization than between organizations in different design contexts. The similarity scores for each routine were calculated by taking the average multiple alignment score between sequences within an organization (for diagonal values), and the average score between sequences from each pair of organizations (for non-diagonal values). Our results largely **support H1** as shown in Figure 2, which shows the percent similarity of design routine patterns within and across organizations. Our results show that organizations tend to produce more similar patterns within organization than when compared to other organizations in different contexts, with the exception of the similarity between Beta and Alpha. We observe that in all other cases, the percent similarity is greater within the organization (on the diagonal) than the percent similarity shared with any other organization. The reason for the high degree of similarity between Beta and Alpha may be due to the amount of iterations that occurred during Beta's design process (which would also explain the abnormally high within-organization percent similarity). This high number of iterations could have also worked against the similarity if those activities within the iterated process were highly dissimilar. It just so happens that in this case, the iterations inflated, rather than deflated, the percent similarity.

	Alpha	Beta	Gamma	Delta
Alpha	**47%**			
Beta	48%	**71%**		
Gamma	42%	42%	**47%**	
Delta	43%	43%	40%	**48%**

Figure 2. Similarity of Design Routine Patterns Within and Across Organizations

Guided by the Pentland et al. (2009) quote, we further looked into what "characteristics of the persons or team" might be associated with variation in the design routines. Although we did not put forward formal hypotheses, we would expect that in centralized organizations, work is more likely to be done locally and in teams because centralized organizations typically have a designated workplace (office space) where tasks are to be performed. And, as actors are within close proximity to each other, they are more likely to work in teams because the cost and effort of coordination for rich interactions is low (Daft and Lengel 1986; Dennis et al. 2008). However, contrary to our expectations, we found that (on average) design work in centralized organizations was performed by <u>individuals</u> (rather than teams) to a <u>greater</u> extent than in decentralized organizations (see Figure 3).

[3] The weight matrix is used to specify scores for aligning two values. Weights specified in our matrix include a zero score for aligning values from different elements, a five score for aligning different value from the same element, and a ten score for aligning identical values. However, the results were robust to using/not using the weight matrix. i.e., the alignment scores did not change a great deal whether the weight matrix was used or not.

		Power Structure	
		Less Centralized	More Centralized
Environmental Volatility	Less Volatile	20% (Gamma)	73% (Delta)
	More Volatile	79% (Alpha)	93% (Beta)
Average		**49.5%**	**83%**

Figure 3. Percent of work done by individuals (rather than teams)

This unexpected finding may be due to the very low value reported for Gamma, which brings down the average considerably. If more companies and projects were being analyzed, we may find a more predictable result. Additionally, and as expected, more centralized organizations did coordinate their work locally to a greater extent than in decentralized organizations (see Figure 4).

		Power Structure	
		Less Centralized	More Centralized
Environmental Volatility	Less Volatile	54% (Gamma)	75% (Delta)
	More Volatile	50% (Alpha)	100% (Beta)
Average		**52%**	**87.5%**

Figure 4. Percent of work done locally (rather than distributed)

In H2a and H2b, we explored if the use of digital tools increases or decreases design routine variety. As shown in Figure 5, the difference between similarity of design routines driven by physical tools versus digital tools is not practically meaningful. Thus, **H2a** and **H2b were rejected**[4]. This is not surprising, as there are arguments for and against each hypothesis. These findings seem to indicate that additional variables might be necessary to explain the relationship between tool modality and activity variation.

	Physical	**Digital**
Physical	53%	
Digital	42%	52%

Figure 5. Similarity of Design Routines Driven by Physical or Digital Tools

We further explored, through descriptive statistics, what each type of tool was used for. Table 1 shows for each affordance, how often is the design work performed using digital or physical tools.

[4] Despite the large difference in the number of physically-enabled versus digitally-enabled activities, the alignment scores within and between each type of materially-enabled activity demonstrated equivalent variance and normality, and therefore the difference in sample sizes does not appear to bias our results.

Table 1. Percent Affordance Enacted through Physical or Digital Materiality

Materiality	Analysis	Control	Cooperative	Infrastructure	Representation	Storage	Transform	Total
Digital	85%	100%	88%	100%	53%	98%	94%	86%
Physical	15%	0%	12%	0%	47%	2%	6%	14%
Total	100%	100%	100%	100%	100%	100%	100%	100%

We next explored the use of digital and physical tools at each organization. Figure 6 reveals the dominance of digital tools used in the design work at each organization and for each factor in our 2 x 2 matrix. On average, more centralized organizations rely more on digital tools, although the difference is very small. A slightly larger difference is exhibited between stable and volatile environments. This is probably because volatility requires dynamic flexibility, which is more easily afforded by digital tools than physical tools. Digital tools often are inbuilt with multiple afforded functionality, and can be (relatively) easily adapted and adjusted to extend that functionality to meet changing requirements. Thus digital tools are a must in volatile design environments.

		Power Structure		Average
		Less Centralized	More Centralized	
Environmental Volatility	Less Volatile	85% (Gamma)	77% (Delta)	**81%**
	More Volatile	81% (Alpha)	95% (Beta)	**88%**
Average		**83%**	**86%**	

Figure 6. Percent Work Accomplished Using Digital Tools at each Organization

Finally, we explored the impact on design contexts on design routine varieties. Specifically, we hypothesized that volatility would increase the variety in design routines (H3a), while the power centrality would decrease it (H3b). Our results **support H3b**, but not H3a. We found that design routines do not vary more for organizations in more volatile environments (46% similarity) than for organizations in more stable environments (40%), but actually *display less variety*. However, we did find that design routines do vary less among centralized organizations (47%) than among networked organizations (42%).

In our results we have not included any "p-values" for tests of statistical significance. At first we were concerned with this, because we are in a field that has become madly accustomed to variance models and concerns for "statistical significance". However, after consulting with a biologist, we decided not to pursue statistical significance at this early stage of research. Biologists typically are not concerned with finding "statistically significant" alignments between gene sequences because alignments reveal similarity but obscure evolutionary processes (the key story). Whether species A is closer to species B or species C by a given alignment is only the first step in a biologists' understanding of species relatedness and variation. By itself, it is not of particular interest given that the history of each of those species is different. Nevertheless, future research in the area of organizational routines (rather than biology) may pursue statistical validation of these methods, possibly through bootstrapping or jackknifing of sequence data.

Discussion

We advance research focused on organizational routines by shedding new light on enacted design processes through a sequence analysis that explores the effects organizational context has on design routine variation. We offer thereby some initial answers to the questions posed by Pentland et al. (2009). Having answered these questions through a cycle of theory development and validation we feel that we are better positioned to advance understanding of the variation of organizational routines and how digitalization affects this. To begin, we can ask: (1) What are other contextual factors that affect routine variation (aside from power structure and environmental volatility)? (2) What role does time play in the routine variation? (3) Can certain patterns of action be attributed to desirable outcomes (efficiency, quality, low risk, decreased effort, etc.)? and, (4) Can variation of routines be explored, or even predicted, through simulations (such as Markov chains)? Given the advancements in methods and knowledge in this field as of late, answers to these questions might not be "a long way off". The real challenge lies in good and large enough data sets, which are hard to come by.

Managers in design organizations can benefit from our findings in multiple ways. Individuals in organizations often refuse to change their behaviors as new routines are implemented. The introduction of new digital tools is often seen as a major source of such changes. However, our analyses of design routines in organizations reveal that the digital tools can possibly lead to the reduction in variety of design routines. This suggests that although digital tools can be a major source of disruption initially, once it is embedded in design routines, organizations might need to spend less time in adjusting to the new design routines as more design tools are deployed.

The next thing that managers have struggled with is the power structure of the organization, especially at the team level; i.e., whether it would be better to have decision making power be centralized or decentralized. Our analysis of the design routines in centralized and decentralized organizations reveal that routines in centralized organizations vary less than in decentralized organizations, and thus the question of power structure for mangers then boils down to the extent to which they expect the design routines to vary. For instance, an organization focusing on innovation should seek greater variations in design routines in order to foster an innovative backdrop, and thus, decentralization might be a simple route to achieve this goal. Similarly, if the organization is seeking organizational efficiency then variations in design routines should be minimized, and thus, a centralized power structure is more favorable (Shane 2009).

To summarize, Pentland et al. (2009) pose a question which we have sought to address: Do different environments and organizations tend to produce the same patterns, or are there systematic differences, and, do organizations in these environments use digital tools differently to shape their routines? In this paper we have addressed these questions by exploring how environmental variation and power structures shape routine variation. We have also examined how alternative configurations of actors, and the way they coordinate design, is carried out differently across different contexts due to digitalization. Lastly, we have explored the effects of digitalization on routine variation, and found that design routines executed primarily through digital tools exhibit less variation than when supplemented by physical tools, confirming the hypothesis of organizational standardization that is associated with the use of digital capabilities. We have moved a little forward our understanding of organizational routines by developing and validating a small theory of organizational routine variation, and by highlighting how digital capabilities affect design routine variation.

References

Aiyar, A. 2000. "The Use of Clustal W and Clustal X for Multiple Sequence Alignment," *Methods Mol. Biol* (132), pp. 221-241.

Andersen, R., Bubenko, J., Sølvberg, A., Smolander, K., Lyytinen, K., Tahvanainen, V.-P., and Marttiin, P. 1991. "Metaedit— a Flexible Graphical Environment for Methodology Modelling," in *Advanced Information Systems Engineering*. Springer Berlin / Heidelberg, pp. 168-193.

Baldwin, C.Y., and Clark, K.B. 1997. "Managing in the Age of Modularity " *Harvard Business Review* (75:5), pp. 84-93.

Becker, M., and Lazaric, N. 2009. *Organizational Routines: Advancing Empirical Research*. Northampton, Massachusetts: Edward Elgar Publishing.

Berente, N. 2008. "Institutional Logics and Loosely Coupled Practices: The Case of Nasa's Enterprise Information System Implementation," in: *Information Systems*. Cleveland, Ohio: Case Western Reserve University, p. 21.

Berente, N., Baxter, R., and Lyytinen, K. 2010. "Dynamics of Inter-Organizational Knowledge Creation and Information Technology Use across Object Worlds: The Case of an Innovative Construction Project," *Construction Management and Economics* (28:6), pp. 569-588.

Berente, N., Hansen, S., and Lyytinen, K. 2009. "High Impact Design Requirements-Key Design Challenges for the Next Decade," *Design Requirements Engineering: A Ten-Year Perspective*), pp. 1-10.

Berente, N., Srinivasan, N., Yoo, Y., Boland, R., and Lyytinen, K. 2007. "Binate Diversity and the Rolling Edge of Design Networks," *28th International Conference on Information Systems (ICIS)*, Montreal, Canada.
Boland, R.J., Jr, and Tenkasi, R.V. 1995. "Perspective Making and Perspective Taking in Communities of Knowing," *Organization Science* (6:4), pp. 350-372.
Boland, R.J., Lyytinen, K., and Yoo, Y. 2007. "Wakes of Innovation in Project Networks: The Case of Digital 3-D Representations in Architecture, Engineering, and Construction," *Organization Science* (18:4), pp. 631-647.
Buchanan, R. 1992. "Wicked Problems in Design Thinking," *Design Issues* (8:2), pp. 5-21.
Carlile, P.R. 2002. "A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development," *Organization Science* (13:4), pp. 442-455.
Carlo, J.L., Lyytinen, K., and Rose, G.M. 2005. "Not All Innovations Are Created Equal: A Survey of Internet Computing as Disruptive Innovation in Systems Development Organizations," *International Conference on Information Systems (ICIS)*, Las Vegas, USA.
Casson, M. 1994. "Why Are Firms Hierarchical?," *Journal of the Economics of Business* (1:1), pp. 47-76.
Clarkson, J., and Eckert, C. 2005. *Design Process Improvement: A Review of Current Practice*. London, England: Springer.
Clegg, S., Courpasson, D., and Phillips, N. 2006. *Power and Organizations*. Sage Publications Ltd.
Cross, N. 2001. "Designerly Ways of Knowing: Design Discipline Versus Design Science," *Design Issues* (17:3), pp. 49-55.
Cross, N., Christianns, H., and Dorst, K. (eds.). 1996. *Analyzing Design Activity*. Chichester, UK: John Wiley & Sons.
Cusumano, M.A., and Nobeoka, K. 1998. *Thinking Beyond Lean*. New York, New York: The Free Press.
Daft, R., and Lengel, R. 1986. "Organizational Information Requirements, Media Richness, and Structural Design," *Management Science* (32:5), pp. 554-571.
Damanpour, F., and Gopalakrishnan, S. 1998. "Theories of Organizational Structure and Innovation Adoption: The Role of Environmental Change," *Journal of Engineering and Technology Management* (15:1), pp. 1-24.
Dennis, A.R., Fuller, R.M., and Valacich, J.S. 2008. "Media, Tasks, and Communication Processes: A Theory of Media Synchronicity," *MIS Quarterly* (32:3), pp. 575-600.
Feldman, M.S., and Pentland, B.T. 2003. "Reconceptualizing Organizational Routines as a Source of Flexibility and Change," *Administrative Science Quarterly* (48:1), pp. 94-118.
Galbraith, J.R. 1973. *Designing Complex Organizations*. Boston, Massachusetts: Addison-Wesley Longman Publishing.
Gaskin, J., Lyytinen, K., Thummadi, V., Schutz, D., Yoo, Y., Weiss, A., and Berente, N. 2010a. "Design DNA Sequencing: A Set of Methodological Artifacts for Sequencing Socio-Technical Design Routines," in: *International Conference on Information Systems*. St. Louis, Missourri.
Gaskin, J., Schutz, D., Berente, N., Lyytinen, K., and Yoo, Y. 2010b. "The DNA of Design Work: Physical and Digital Materiality in Project-Based Design Organizations," in: *Academy of Management Best Paper Proceedings*. Montreal, Canada.
Gaskin, J.E., Lyytinen, K., Yoo, Y., Shiv, O., and Zhang, Z. 2011. "Evolution of Digitally-Enabled Design Processes: The Case of a Large Design and Construction Firm," in: *Academy of Management*. San Antonio, Texas.
Greenhalgh, T., Robert, G., Macfarlane, F., Bate, P., and Kyriakidou, O. 2004. "Diffusion of Innovations in Service Organizations: Systematic Review and Recommendations," *Milbank Quarterly* (82:4), pp. 581-629.
Hannan, M., and Freeman, J. 1977. "The Population Ecology of Organizations," *American journal of Sociology* (82:5), pp. 929-964.
Henderson, K. 1991. "Flexible Sketches and Inflexible Data Bases: Visual Communication, Conscription Devices, and Boundary Objects in Design Engineering," *Science, Technology & Human Values* (16:4), p. 448.
Henfridsson, O., Yoo, Y., and Svahn, F. 2009. "Path Creation in Digital Innovation: A Multi-Layered Dialectics Perspective," *Sprouts: Working Papers on Informatin Systems* (9:20).
Hodgson, G.M. 2009. "The Nature and Replication of Routines," in *Organizational Routines: Advancing Empirical Research,* M. Becker and N. Lazaric (eds.). Northampton, Massachusetts: Edward Elgar Publishing, pp. 26-44.
King, J.L. 1983. "Centralized Versus Decentralized Computing: Organizational Considerations and Management Options," *ACM Computing Surveys (CSUR)* (15:4), pp. 319-349.
Kock, N. 2008. "E-Collaboration and E-Commerce in Virtual Worlds," *International Journal of e-Collaboration* (4:3), pp. 1-13.

Lacity, M.C., and Willcocks, L.P. 1998. "An Empirical Investigation of Information Technology Sourcing Practices: Lessons from Experience," *MIS Quarterly* (22:3), pp. 363-408.

Larkin, M., Blackshields, G., Brown, N., Chenna, R., McGettigan, P., McWilliam, H., Valentin, F., Wallace, I., Wilm, A., and Lopez, R. 2007. "Clustal W and Clustal X Version 2.0," *Bioinformatics* (23:21), p. 2947.

Lawrence, P.R., and Lorsch, J.W. 1967. "Differentiation and Integration in Complex Organizations," *Administrative Science Quarterly* (12:1), pp. 1-47.

Lyytinen, K., and Rose, G.M. 2003. "The Disruptive Nature of Information Technology Innovations: The Case of Internet Computing in Systems Development Organizations," *MIS Quarterly* (27:4), December, pp. 557-595.

Maher, M., and Tang, H.-H. 2003. "Co-Evolution as a Computational and Cognitive Model of Design," *Research in Engineering Design* (14:1), pp. 47-64.

Majchrzak, A., Rice, R.E., Malhotra, A., King, N., and Ba, S. 2000. "Technology Adaptation: The Case of a Computer-Supported Inter-Organizational Virtual Team," *MIS Quarterly* (24:4), pp. 569-600.

Malone, T.W., and Crowston, K. 1994. "The Interdisciplinary Study of Coordination," *ACM Computing Surveys (CSUR)* (26:1), p. 119.

March, S.T., and Smith, G.F. 1995. "Design and Natural Science Research on Information Technology," *Decision Support Systems* (15:4), pp. 251-266.

McGann, S., and Lyytinen, K. 2008. "The Improvisation Effect: A Case Study of User Improvisation and Its Effects on Information System Evolution," *International Conference on Information Systems*, Paris, France.

Miller, K.D., Choi, S.H., and Pentland, B.T. 2010a. "Social Networks in Organizational Routines," in: *Under review at Organization Science*. Ann Arbor, Michigan: Michigan State University.

Miller, K.D., Pentland, B.T., and Choi, S.H. 2010b. "Dynamics of Performing and Remembering Organizational Routines," in: *Conditional acceptance at: Journal of Management Studies Special issue on "Micro-level origins of organizational routines and capabilities"* Ann Arbor, Michigan: Michigan State University.

Mohr, L.B. 1982. "Approaches to Explanation: Variance Theory and Process Theory," in *Explaining Organizational Behavior,* L.B. Mohr (ed.). Ann Arbor, Michigan: Jossey-Bass, pp. 35–70.

Nelson, R. 2009. "Routines as Technologies and as Organizational Capabilities," in *Organizational Routines: Advancing Empirical Research,* M. Becker and N. Lazaric (eds.). Northampton, Massachusetts: Edward Elgar Publishing, pp. 11-25.

Nelson, R.R., and Winter, S.G. 1982. *An Evolutionary Theory of Economic Change*. Belknap Press/Harvard University Press: Cambridge.

Nelson, R.R., and Winter, S.G. 2002. "Evolutionary Theorizing in Economics," *Journal of Economic Perspectives* (16:2), pp. 23-46.

Orlikowski, W.J. 2007. "Sociomaterial Practices: Exploring Technology at Work," *Organization Studies* (28:9), pp. 1435-1448.

Orlikowski, W.J., and Baroudi, J.J. 1991. "Studying Information Technology in Organizations: Research Approaches and Assumptions," *Information systems research* (2:1), pp. 1-28.

Peet, R., and Watts, M. 1996. *Liberation Ecology: Development, Sustainability, and Environment in an Age of Market Triumphalism*. London, UK: Routledge.

Pentland, B.T. 1995. "Grammatical Models of Organizational Processes," *Organization Science* (6:5), pp. 541-556.

Pentland, B.T., and Feldman, M.S. 2005. "Organizational Routines as a Unit of Analysis," *Industrial and Corporate Change* (14:5), pp. 793-815.

Pentland, B.T., and Feldman, M.S. 2007. "Narrative Networks: Patterns of Technology and Organization," *Organization Science* (18:5), pp. 781-795.

Pentland, B.T., and Feldman, M.S. 2008. "Designing Routines: On the Folly of Designing Artifacts, While Hoping for Patterns of Action," *Information and Organization* (18:4), pp. 235-250.

Pentland, B.T., Hærem, T., and Hillison, D. 2010. "Comparing Organizational Routines as Recurrent Patterns of Action," *Organization Studies* (31:7), pp. 917-940.

Pentland, B.T., Haerem, T., and Hillison, D.W. 2009. "Using Workflow Data to Explore the Structure of an Organizational Routine," in *Organizational Routines: Advancing Empirical Research,* M. Becker and N. Lazaric (eds.). Northampton, Massachusetts: Edward Elgar Publishing, pp. 47-67.

Pentland, B.T., and Reuter, H.H. 1994. "Organizational Routines as Grammars of Action," *Administrative Science Quarterly* (39:3).

Radner, R. 1992. "Hierarchy: The Economics of Managing," *Journal of economic literature* (30:3), pp. 1382-1415.

Rosenman, M.A., and Gero, J.S. 1996. "Modelling Multiple Views of Design Objects in a Collaborative Environment," *Computer-Aided Design* (28:3), pp. 193-205.

Salvato, C. 2009a. "Capabilities Unveiled: The Role of Ordinary Activities in the Evolution of Product Development Processes," *Organization Science* (20:2), pp. 384-409.

Salvato, C. 2009b. "The Contribution of Event-Sequence Analysis to the Study of Organizational Routines," in *Organizational Routines: Advancing Empirical Research,* M.C. Becker and N. Lazaric (eds.). Northampton, Massachusetts: Edward Elgar Publishing, pp. 68-102.

Schilling, M.A. 2000. "Toward a General Modular Systems Theory and Its Application to Interfirm Product Modularity," *The Academy of Management Review* (25:2), pp. 312-334.

Shane, S.A. 2009. *Technology Strategy for Managers and Entrepreneurs*. Upper Saddle River, NJ: Pearson/Prentice Hall.

Simon, H.A. 1996. *The Sciences of the Artificial*. Cambridge, Massachusettes: MIT Press.

Sun, H., Zhang, P., and Hall, H. 2008. "Adaptive System Use: An Investigation at the System Feature Level," in: *International Conference on Information Systems (ICIS)*. Paris, France: pp. 14-17.

Sydow, J., Schreyögg, G., and Koch, J. 2009. "Organizational Path Dependence: Opening the Black Box," *The Academy of Management Review ARCHIVE* (34:4), pp. 689-709.

Thompson, J.D. 1967. *Organizations in Action*. New York, New York: McGraw-Hill.

Thompson, J.D., Gibson, T.J., and Higgins, D.G. 2002. *Multiple Sequence Alignment Using Clustalw and Clustalx*. Hoboken, New Jersey: John Wiley & Sons, Inc.

Thummadi, B.V., Shiv, O., Lyytinen, K., and Berente, N. 2011. "Enacted Software Development Routines Based on Watefall and Agile Methods: A Socio-Technical Event Sequence Study," in: *DESRIST*.

Tolvanen, J.-P., and Rossi, M. 2003. "Metaedit+: Defining and Using Domain-Specific Modeling Languages and Code Generators," in: *Companion of the 18th annual ACM SIGPLAN conference on Object-oriented programming, systems, languages, and applications*. Anaheim, CA, USA: ACM.

Truex, D.P., Baskerville, R., and Klein, H. 1999. "Growing Systems in Emergent Organizations," *Communications of the ACM* (42:8), pp. 117-123.

Volkoff, O., Strong, D.M., and Elmes, M.B. 2007. "Technological Embeddedness and Organizational Change," *Organization Science* (18:5), pp. 832-848.

Wilson, C. 2001. "Activity Patterns of Canadian Women: Application of Clustalg Sequence Alignment Software," *Transportation Research Record: Journal of the Transportation Research Board* (1777:-1), pp. 55-67.

Wilson, C. 2006. "Reliability of Sequence-Alignment Analysis of Social Processes: Monte Carlo Tests of Clustalg Software," *Environment and Planning A* (38:1), p. 187.

Wilson, C., Harvey, A., and Thompson, J. 2005. "Clustalg: Software for Analysis of Activities and Sequential Events, Paper Presented at the Workshop on Sequence Alignment Methods, Halifax." October.

Winter, S.G., and Szulanski, G. 2001. "Replication as Strategy," *Organization Science* (12:6), pp. 730-743.

Yates, J.A., and Project, H.E.-B. 1989. *Control through Communication: The Rise of System in American Management*. Johns Hopkins University Press Baltimore, MD.

Yoo, Y., Boland Jr, R., and Lyytinen, K. 2006. "From Organization Design to Organization Designing," *Organization Science* (17:2), p. 215.

Yoo, Y., Henfridsson, O., and Lyytinen, K. 2010. "Research Commentary--the New Organizing Logic of Digital Innovation: An Agenda for Information Systems Research," *Information Systems Research* (21:4), pp. 724-735.

Yoo, Y., Lyytinen, K., and Boland, R. 2008. "Innovation in the Digital Era: Digitization and Four Classes of Innovation Networks," *Hawaii International Conference on System Sciences*, Waikoloa, Hawaii.