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A Modular Systems Perspective of IT Infrastructure Configurations and Productivity

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Abstract

Research on IT infrastructure investments and organizational productivity has been marked with ambiguity, evidenced by the much debated productivity paradox. *Part of the ambiguity arises from a paradigmatic* aggregated *treatment of IT infrastructure and productivity constructs along with a disregard for contingencies and time lags. The focus in this paper is to extend the component based view to understand IT infrastructure productivity. Using a modular systems perspective, revisiting the constructs in an attempt to disaggregate them for a more detailed examination is proposed. This study adds to the body of knowledge through a holistic examination of the relationship between IT infrastructure configurations, contingencies, and organizational productivity.*

"*The object of all science…is to co-ordinate our experiences into a logical system*"
Einstein (1922)

1 INTRODUCTION

Tracing the locus of information technology (IT) productivity in organizations has come a long way. With the onslaught of time and the proliferating evidence of newer and more innovative information technologies promising efficiency and effectiveness, organizations have fervently acclimatized themselves to invest in such technologies to develop a discernible edge over the competition. Increasing organizational expectations of veritable returns from IT investments, especially with the growth of electronic commerce, have implicated a bandwagon effect of consistent and considerable IT investments. Despite a relative reduction in IT spending (Gartner Group 2002), figures still show a rising trend evidencing bandwagon adoption. IT spending by U.S. and European firms is projected to grow at 5 percent and 6.5 percent in 2002 and 10 percent and 8 percent in 2003, respectively (International Data Corporation 2002). Abounding speculations of achieving competitive advantage from the scale of IT investments has indubitably explicated the issue to be one of the dominant IT research themes for the past two decades (Bender 1986; Harris and Katz 1991; Lichtenberg 1993; Markus and Soh 1993; Strassman 1990; Turner 1985; Weill 1992).

Fueled by speculation, research on the relationship between IT infrastructure investments and organizational productivity has been prolific, albeit equivocal, evidenced by the much debated "productivity paradox" (Brynjolfsson 1993). The debate has been accentuated with large capital outlays by firms for creating an effective IT infrastructure in anticipation of swift and venerable returns. These firms face a lingering paradox. While there seems to be an apparent need for IT infrastructure replenishment to maintain competitiveness, an ambiguity concerning the timeliness and amplitude of returns from IT infrastructure investments remains.

[1]I wish to thank the reviewers and the editorial board for their helpful and constructive comments.

The ambiguity arises mainly from a paradigmatic *aggregated* perspective of IT infrastructure and productivity constructs accentuated by factors identified by such as a disregard for possible time lags between IT investments and productivity, skewed productivity measurements, and lack of effective management of IT (Brynjolfsson 1993). Prior studies (Brynjolfsson and Yang 1996; Devaraj and Kohli 2000; Sircar et al. 1998) have researched IT infrastructure and productivity as aggregated constructs, ignoring the essential impact that their components, configurations, and time lags might have on evaluating IT productivity. In a call for research, Sambamurthy and Zmud (2000, p. 107) present the need for a research direction for an "organizing logic" for IT activities in response to an "enterprise's environmental and strategic imperatives." Robey (1977), too, has long voiced a need for a distinctive categorical and component-based approach for discerning the specific nature of IT. Yet not much has been done in terms of research beyond Huber's (1990) "computer-assisted communication technologies" and Keen's (1991) "IT architecture" categorizations. Using propositions and corollaries, Huber (1990) revealed that as technology progressed, so did the integration and configuration of individual IT components. For example, the integration of once-independent IT components of computing and communication technologies into computer-assisted communication is found to be both efficacious and efficient at multiple organizational levels, encompassing both subunit and organizational structures and processes (Huber 1990). Keen further explicated organizational IT by using the architecture metaphor, a formal classification and decomposition of the generic "IT infrastructure" construct. The decomposition of what Keen calls "corporate master architecture" into components that can be integrated not only provides a compatibility index but also initializes a discussion and examination into the issue of how to allocate IT investments toward the acquisition and use of IT components that support the organizational architecture.

The focus in this paper is to support and extend this component-based view of organizational IT to understand the organizing logic behind IT infrastructure activities leading to productivity. Establishing this focus requires an epistemological shift, one that focuses on facilitating the situation by privileging a decomposition and configuration of constructs over aggregation. Using a modular systems perspective, we disaggregate the constructs of IT infrastructure and productivity into configurable and collectively exhaustive components. We then proceed to examine the implications of IT infrastructure configurations upon productivity while considering necessary time lags and recursive causalities. This study adds to the body of knowledge through a holistic examination of the relationship between IT infrastructure configurations, contingencies, and organizational productivity.

The study described in this paper is designed to trace the locus of IT productivity from four perspectives: (1) What is the locus of IT investments that leads to organizational productivity? (2) What are the components of IT infrastructure and how can they be configured? (3) What is the role and impact of IT management in achieving productivity? (4) What is the impact of the business environment upon IT productivity?

The constitution of this paper is as follows: Section 2 reviews the underlying theoretical perspective for explicating IT infrastructure productivity. Section 3 describes the subsystems constituting IT infrastructure productivity followed by an integrative relational model. Section 4 discusses the contributions of and provides future research directions from the study.

2 SYSTEMS THEORY AND THE MODULAR SYSTEMS PERSPECTIVE

Systems theory, as proposed by von Bertalanffy (1968, p. 32), "is the investigation of organized wholes...and requires new categories of interaction, transaction." In his famous treatise on cybernetics, Ashby (1956, p. 55) considers systems as an observer's preferred description of a set of interrelated elements where elements are connected by an organized stream of information, maintaining "independence within a whole." Furthermore, elements within a system can structurally intersect with one or more elements simultaneously (Maturana and Varela 1987). It is through the *transaction, interaction,* and *interrelation* that a system and its elements dynamically transform inputs into outputs.

Systems theory provides a relevant degree of abstraction from evidence gathered from reality, divulging both components and functions at multiple levels and dimensions. Morel and Ramanujam (1999) indicate that the efficacy of systems theory comes from being able to reduce systems into smaller components, looking at their interaction and then integrating them together for a more holistic perspective. In overcoming inertia, Schilling (2000) revealed that disaggregation of organizational systems was a prospective candidate for understanding causality. We pose IT infrastructure productivity as a unique and dynamic system that can be decomposed into subsystems for the purpose of analysis. Because a system and its context coevolve over time (Gell-Mann 1995), there is an inherent recursive or circular causality among some systems through feedback.

Among the vast array of attributes propounded by the systems approach, the basis for our analysis is the property of modularity, a concept that describes the degree by which a system's components can be separated and recombined, thereby "exponentially increasing the number of possible configurations achievable from a given set of inputs" (Schilling 2000, p. 4). Furthermore, it provides a context within which a system exists, thus generating relevance for multilevel elements that place demands on a system (Alexander 1964). Modularity also provides the premise for coupling and recombination of systems or subsystems. An organizational system benefits from combination and recombination of its components to achieve optimal configuration (Schilling 2000).

Incorporating the potential and relevance offered by the attributes of systems theory supported by precedent research, the next section describes extends the systems perspective to the domain of IT infrastructure productivity.

3 IT INFRASTRUCTURE PRODUCTIVITY

IT infrastructure productivity, as a modular organizational system, typically comprises of subsystems or components. We view an IT infrastructure productivity to comprise of a *holistic* view of *interrelated modular subsystems connected through an organized stream of information transforming inputs into outputs*. This perspective not only *creates a detailed and disaggregated view of the constructs* but also *provides latitude to attest a numerical value to each component for greater measurement benefits*. We attest our view with precedent research.

In explicating the considerations necessary for systems, Churchman (1968 1971) asserted the need to include the system performance objectives (outcome), system resources and components, system management, and the system's environment. In presenting their IT interaction model, Silver et al. (1995) similarly maintain "the consequences of information systems in organizations follow largely from the interaction of the technology with the organization and its environment" (p. 361). This provides an integrated and "stylized view of the dynamics of information systems in organizations" (p. 384); something that can be used by firms either proactively or reactively to anticipate or to analyze and reorganize. This study forwards the research perspectives of Churchman (1968) and if Silver et al. as a basis for our modular systems perspective of organizational IT.

Figure 1 depicts an aggregated view of the IT infrastructure productivity model from a systems perspective. The model consists of four constituent subsystems, namely: (1) the IT infrastructure subsystem and its components; (2) the IT management subsystem; (3) the environmental subsystem; and (4) the productivity outcome subsystem. The figure also illustrates the interrelationships among the four subsystems.

3.1 IT Infrastructure Subsystem

The construct of IT infrastructure, albeit having undergone prolific research, has remained esoteric and in the realm of "conjecture and anecdote" (Duncan 1995, p. 39). The esoteric quality of the construct has made it difficult to correctly assess its significance, creating conjectural evidence concerning its efficacy.

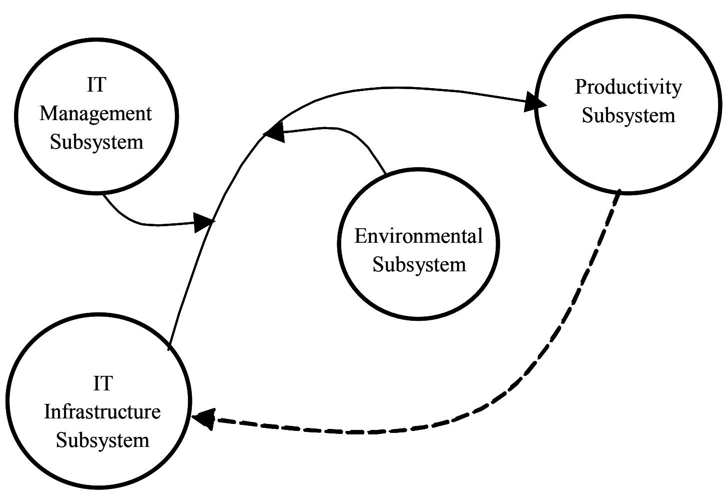


Figure 1. The IT Infrastructure Productivity Model

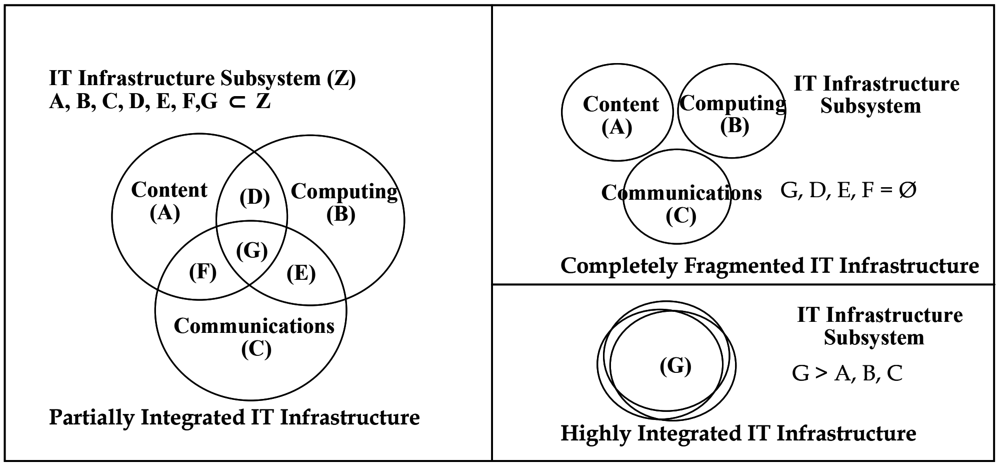


Figure 2. IT Infrastructure Configurations

Weill and Broadbent (1998, p. 332) refer to IT infrastructure as "the enabling base for shared IT capabilities," encompassing technical and human elements across multiple technological components. Robey's (1977) call for a component-based approach for discerning the nature of IT was answered by Huber's (1984) "C^2 –technology" that comprised only of computing and communications components. With the growing importance of content in terms of data and information, Silver et al. included databases as an additional "leverageable" component of the IT infrastructure. The component perspective was further adopted by Tapscott (1997), categorizing *data and information* as content, *IT systems* as computing, and *networks* as communication.

Tapscott's categorization alleges the convergence of three distinct and basic IT domains, namely communications (network-based resources), computing (system-based resources), and content (information-based resources). Both Tapscott and Sambamurthy and Zmud (2000) posit that these domains, once heralded as fragmented, are slowly converging in the face of the digital economy. Even Zachman's (1987) framework for enterprise architecture had highlighted its technological components as consisting of databases (data), process specifications (system processes and functions), and configurations (networks).

The choice of a component-based IT infrastructure design is implicated and reified by referent literature. In providing a conceptual and clarified framework for IT infrastructure, Kayworth et al. (1997) posit that IT infrastructure consists of system platforms (computing), databases (content), and telecommunications (communications), referring to them as physical artifacts. We utilize and adopt Keen's (1991) and Tapscott's categorization schemas and incorporate them in our study to derive and decompose our construct of IT infrastructure into resource-oriented components of communications, content, and computing and their configurations. Basic infrastructure resources are provided for by distinct technologies pertaining to content (A), computing (B), and communications (C); shared infrastructure pertains to resources provided for by the convergence of computing and content (D), computing and communications (E), and content and communications (F); integrated infrastructure resources pertain to the convergence of content, computing, and communications (G). Each of these sections includes physical or operation-level and/or application-level technologies. The collectively exhaustive IT infrastructure subsystem (Z) is shown in Figure 2 where $A, B, C, D, E, F, G \subset Z$.

- **Content (information-based resources) (A):** The content component includes all of the data and information under organizational governance. It includes data and information in multiple formats of text, graphics, audio, video, etc. Keen defines data architecture as resources needed to organize data for the purposes of cross-referencing and retrieval, through the creation of information or data repositories as content for organizational accessibility. Most of the organizational content is managed by relational or object-oriented databases acting as repositories of information. Content technologies involve both operation-level and application-level assets dedicated to managing data and "pure" information. The content component involves technological assets focused on the acquisition, allocation, and development of the data/content infrastructure. Operation-level assets include magnetic-media storage (disk drives, external/removable storage devices, virtual tape), optical-media storage (CD, DVD, holographic storage, magneto-optical, optical jukeboxes, optical library); application-level assets include applications focused on data creation and manipulation (spreadsheets, text/graphic editors, statistical software).

- **Computing (processing system-based resources) (B)**: The computing component involves system or processor-based resources focused on input-output, control, and processing. Keen defines the processing systems architecture as comprising of operating systems environments, applications software, and technical standards for the hardware for operation and multi-vendor compatibility. Content technologies involve both operation-level and application-level assets dedicated to operating and managing systems. The computing component involves technological assets focused on the acquisition, allocation, and development of the computing infrastructure. Operation-level assets include hardware such as processors (Intel, AMD, Motorola), processor-based systems (Sun, Unix, PC, Apple), mobile-devices (PDAs/pocket PCs, PalmOS, cellular phones, pagers), input devices (keyboards, mice), output devices (monitors, printers), theft prevention devices, operating systems (Windows 9x, Linux, Unix, Apple OS); application-level assets include developmental software (compilers, debuggers, programming tools), system administration software (backup/recover, emulators, disk/file access, system monitoring, user management) and other general applications providing system operation and support.

- **Communications (telecommunications and network-based resources) (C)**: The communication component involves network-oriented resources that support organizational communications. Keen refers to the telecommunications/network architecture as resources that provide organizational connectivity using networking standards over which voice and data are is transported within and across organizations. Content technologies involve both operation-level and application-level assets dedicated to optimizing and managing communication networks. The network component involves technological assets focused on the acquisition, allocation, and development of the networking infrastructure. Operation-level assets include physical hardware technologies (telephones, faxes, backbone, routers, switches, bridges, gateways, hubs, cabling modems [wired and wireless], etc), directory services (ADSI, DEN, X.500/LDAP, NDS), connectivity technologies (ATM. T1/T3/E1, DSL, ISDN, gigabit ethernet, token-ring, digital audio/video, VPN, optical networking), network architecture (MAN, WAN, LAN, client/server, peer-to-peer); application-level assets include applications pertaining to network administration (network solutions, traffic management, remote/automated administration, print/fax, domain controllers, clustering/load balancing), network protocols (VoIP, DHCP, HTTP, PPP/SLIP, DNS, SMTP, TCP/IP, IMAP, POP3, SNMP), and network troubleshooting.

- **Content and Computing (information and system-based resources) ($D = A \cap B$)**: The convergence of content and computing gains significance especially in light of the complexity of information and data stored within organization. Convergent content and computing technologies involve both operation-level and application-level assets dedicated to developing, operating, and managing content-oriented systems. This component refers to technologies that address and help integrate content (data and information) and computing (system processing) and involves technological assets focused on the acquisition, allocation, and development of the common integrated infrastructure. Operation-level assets would primarily include computing (system) hardware resources that provide access to stored content such as storage access devices (tape/JAZ/ZIP drives, CDR/CDRW/DVD drives, storage media adaptors); application-level assets include applications pertaining to cottent administration (OODBMS, RDBMS, compression, data-vaulting, user access, file sharing, hierarchical storage management, file sharing, resource virtualization, archiving, backup/recovery, hard disk management), heterogeneous storage integration (storage domain managers, data migration and synchronization), file service optimization (data ONTAP software), and content processing (data warehousing, data mining, data query processing). There is a significant shift data to multiprocessor workstation computers or dedicated content providing workstations with dedicated processor resources for database management.

- **Computing and Communications (system and network-based resources) ($E = B \cap C$):** The convergence of system and network resources is gradually becoming evident as systems resources are being linked over popular network protocols. Convergent computing and communication technologies involve both operation-level and application-level assets dedicated to developing, operating, and managing content and computing-oriented convergent systems. This component refers to technologies that address and help integrate computing (system processing) and communications (networks) and involves technological assets focused on the acquisition, allocation, and development of the common integrated infrastructure. These are found in high end computing systems forming computing clusters by connecting processors and workstations over networks based on load distribution to optimize processes and resources such as the massive parallel LINUX clusters or Sun UltraSPARC III based computing clusters. Operation-level assets include technologies pertaining to secure systems-access (biometrics, token and smart card technology, firewall server hardware), thin clients and terminals, network operating systems, distributed processing (parallel processing, distributed computing, shared memory multiprocessors, grid computing); application-level assets include distributed application performance monitoring, collaborative computing, heterogeneous system connectivity protocols and software (CORBA, COM+/DCOM, Java RMI, middleware interoperability, Samba, Tivoli NetView, Tanit IRIS, Compaq TIP).

- **Content and Communications (information and network-based resources) ($F = A \cap C$)**: As information sources become distributed over networked environments, the need for information integration has grown steadily (Rudensteiner et al. 2000). Distributed and networked databases remain at the heart of the convergence of content and communications. This has led to increasing reviews on the efficacy of multiple information integration techniques such as on-demand approach to integration or tailored information repository construction (Rudensteiner et al. 2000). Convergent content and computing technologies involve both operation-level and application-level assets dedicated to developing, operating, and managing content and computing-oriented convergent systems. Technologies supporting the convergence of content and communications pertain to distributed data/information and content delivery and management. This component refers to technologies that address and help integrate content (data and information) and communications (networks) and involves technological assets focused on the acquisition, allocation, and development of the common integrated infrastructure that focuses on preparation, deployment, and management of content over large networks (for example, Cisco's content delivery networks). In this section, most technologies are application-level. It includes applications pertaining to networked content protection (virus protection, access protection), network-attached storage (NAS), storage-area networks (SAN) (SAN managers, SAN/NAS convergence), extract, transform, load (ETL) (metadata repositories, data cleansers), interfaces and standards (CGI, fiber channel, ESCON, SCSI, HIPPI, iFCP, iSCSI, FCIP).

- **Content, Computing, and Communications (information, system, and network-based resources) ($G = A \cap B \cap C$):** The convergence of content, computing, and communications by merging information, system, and network-based resources has been a growing trend, especially with the proliferation of enterprise-wide systems and applications. The component refers to technologies that address and help integrate content (data and information), computing (system processing), and communications (networks), and involves technological assets focused on the acquisition, allocation, and development of the common integrated infrastructure, supporting enterprise systems. Enterprise application integration is an example of that combination of processes, software, standards, and hardware resulting in the seamless integration of two or more enterprise systems allowing them to operate as one, such as building CRM systems, business-to-business integration, or leveraging legacy systems. Convergent content, computing, and communication technologies involve both operation-level and application-level assets dedicated to developing, managing, and integrating content, computing, and communication-oriented systems. This component entails integrated technologies that are regarded as converging other component technologies by linking functional distributed databases in a parallel processing environment connected using network protocols. Operation-level assets include network servers (application servers, Web servers, wireless servers, mail servers, proxy servers), electronic server clusters (using distributed processor and system resources to provide content across wide networks), distributed databases; application-level assets include integration security (Hitachi TPBroker, Veracity, FreeVeracity, Gradient DCE, UniCenter, Tivoli SecureWay), bsiness pocess itegration (wokflow, pocess management, pocess modeling), goupware and collaborative communication (Lotus Notes, document exchange), distributed data management (SQL server, Oracle 9i), application integration development (XML, ASP, LDAP, Panther for IBM WebSphere), application integration standards (UML, EDI), application integration adaptors/wrappers (bTalk adaptor for SAP, BEA eLink for PeopleSoft, OpenAdaptor), enterprise resource planning suites (Baan, Microsoft Great Plains, Oracle, SAP R/3).

Each of the components (communication, computing, and content) comprises of two distinct infrastructure dimensions: technical and human. Following researchers such as McKay and Brockway (1989), infrastructure is regarded as a fusion of technical and human assets. The shift in perspective could be attributed to the socio-technical dimension first offered by Kling and Scacchi (1982). Those researchers introduced the importance of people "behind the terminal" representing the mortar that binds all technical IT components (McKay and Brockway 1989). It is this human infrastructure that enhances the technical infrastructure in terms of increasing the scope of the technical infrastructure by optimizing and innovating work processes through efficient use of technology. Kayworth et al. substantiate the notion by pointing out that technical artifacts along with human assets can provide differentiated value by enhancing IT performance. Both assets have to work in unison to augment their individual resource potential within each IT infrastructure subsystem component (Figure 3). It is through interaction between the technical and human infrastructure that "value-innovation" procedures emerge (Sambamurthy and Zmud 2000).

3.2 IT Management Subsystem

The importance of managing the IT infrastructure to achieve productivity cannot be overstated. Researchers such as Broadbent and Weill (1997) and Davenport and Linder (1994) realize that the IT infrastructure investments need effective management. Weill and Broadbent (1998) refer to IT management as a scarce resource that organizations can use for productivity.

Sambamurthy and Zmud (1992) conceptualize IT management as a process of *aligning* business and IT infrastructure domains to achieve competitive advantage. IT management complements the IT infrastructure by initiating effective management measures to *enhance* existing infrastructure resources. According to Sambamurthy and Zmud (2000), IT management positions the enterprise to exploit business opportunities by *aligning* competencies for value innovation and solutions delivery. IT alignment thus becomes a core constituent in IT management by effectively linking "business and technology in light of dynamic business strategies and continuously evolving technologies" (Luftman and Brier 1999, p. 110). We review IT management in terms of IT alignment and view it as a moderating construct in our proposed model.

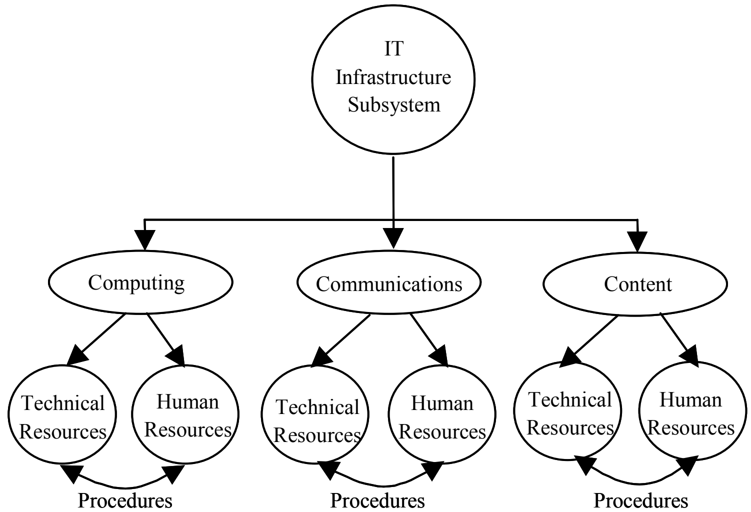


Figure 3. IT Infrastrucure Subsystem Components

According to Reich and Benbasat (2000), IT alignment has a *strategic* and a *social* research dimension. While strategic research concentrates on organizational structure and planning, the social research dimension concentrates on the actions, communications, and commitment of management executives.

The strategic research dimension of IT alignment indicates the need to properly match business level strategic orientation to IT resources (Chan and Huff 1993). Upon reviewing both manufacturing and service firms, a significantly positive influence of IT alignment on firm performance is found.

The social research dimension of IT alignment is defined by Reich and Benbasat as a state where management executives understand and are committed to both IT and business plans and objectives. Reich and Benbasat forge a robust defense for understanding IT alignment by looking beyond the strategic artifacts of plans and structures to investigate the executives' understanding of IT and business objectives.

While each of the research dimensions offer an understanding of IT alignment, we believe that the dimensions are interwoven and socio-strategic. IT alignment has a normative aspect (planning and structure) and also a social aspect (understanding, communication of IT and business objectives). However, none of them are independent and each relies upon the other for IT alignment. The high degree of intertwining between the two dimensions offers a rich ground for contending that it is the interaction of the two dimensions that constitute the IT alignment construct.

3.3 Environmental Subsystem

The external environment also plays a key role as a contingent factor in achieving IT infrastructure productivity. Productivity depends upon a firm's ability to adapt to and learn from the influences exerted by its environment. Two dimensions bring about the significance of the environment as a moderating subsystem variable. First, every firm faces and dynamically interacts with its environment (Aldrich 1979). Second, organizations face varying degrees of uncertainty. This implies that firms in different environments will reveal varying degrees of IT infrastructure productivity, *ceteris paribus*.

We refer to the study by Lee and Grover (1999) in framing our moderating variable of environmental subsystem. Duncan (1972) described the external environment in terms of environmental uncertainty. Salmela et al., (2000) reveal that environmental uncertainty considerably increases the risk of IT investment failure. Lee and Grover use Duncan's definition to define environmental uncertainty in terms of *environmental dynamism* and *environmental complexity*.

According to Dess and Beard (1984), environmental dynamism refers to the rate of unpredictable change within environmental elements. Dynamism refers to unpredictable volatility in technologies, demand, and other industry and economic characteristics. Unpredictable change contributes to uncertainty because organizations do not know on what assumptions they should organize their IT infrastructure.

Environmental complexity describes the heterogeneity in and range of environmental factors that a firm faces (Duncan 1972). Complexity is determined by the number of heterogeneous external entities about which firms require information in order to be responsive and adaptive.

For the purposes of this study, we assume that the moderating variable of environmental uncertainty comprises of two components: environmental dynamism and environmental complexity.

3.4 Productivity Subsystem

Previous research examining the impact of information technology investments on organizational performance has employed a wide range of productivity measures. Chan (2000) and Devaraj and Kohli (2000) have conducted comprehensive reviews of existing productivity literature. We borrow their research to disaggregate and classify the productivity construct based on dimensions of standardization and functional focus.[2]

As Figure 4 indicates, productivity can be classified as being either standardized or non-standardized, depending on whether such variables are commonly used to measure other aspects of an organization's productivity. *Standardized* measures comprise of tactical-level metrics commonly used to quantify productivity in terms of accounting and operational/process efficiency. *Non-standardized* measures comprise of strategic-level metrics that focus on productivity in terms of operational/process quality and competitiveness/sustainability.

Accounting and strategic measures of productivity represent the bipolarities in productivity assessment. While strategic measures are completely non-standardized and vary by competitive landscapes, accounting measures are completely standardized and compiled using protocols prescribed by GAAP. Operational measures are quasi-standardized in terms of their usage. For example, measures based on process and human resources efficiency are standardized (e.g., throughput, sales per employee) while measures based on process and human resources quality are non-standardized (e.g., quality improvements, employee satisfaction).

Accounting-based measures include return on assets (Rai et al. 1997; Tam 1998), return on investment (Jelassi and Figon 1994), and return on sales (Mahmood and Mann 1993).

Standardized operational-level measures used to gauge the efficiency of key business processes include inventory turnover (Mukhopadhyay et al. 1995), labor productivity (Brynjolfsson 1993) and capacity utilization (Barua et al. 1995).

Non-standardized operational measures include measures of the quality of business processes and human resources. Examples of such measures include service quality improvements (Myers et al. 1997), work environment improvements (Teo and Wong 1998) and improvements in information exchange (Sheffield and Gallupe 1993).

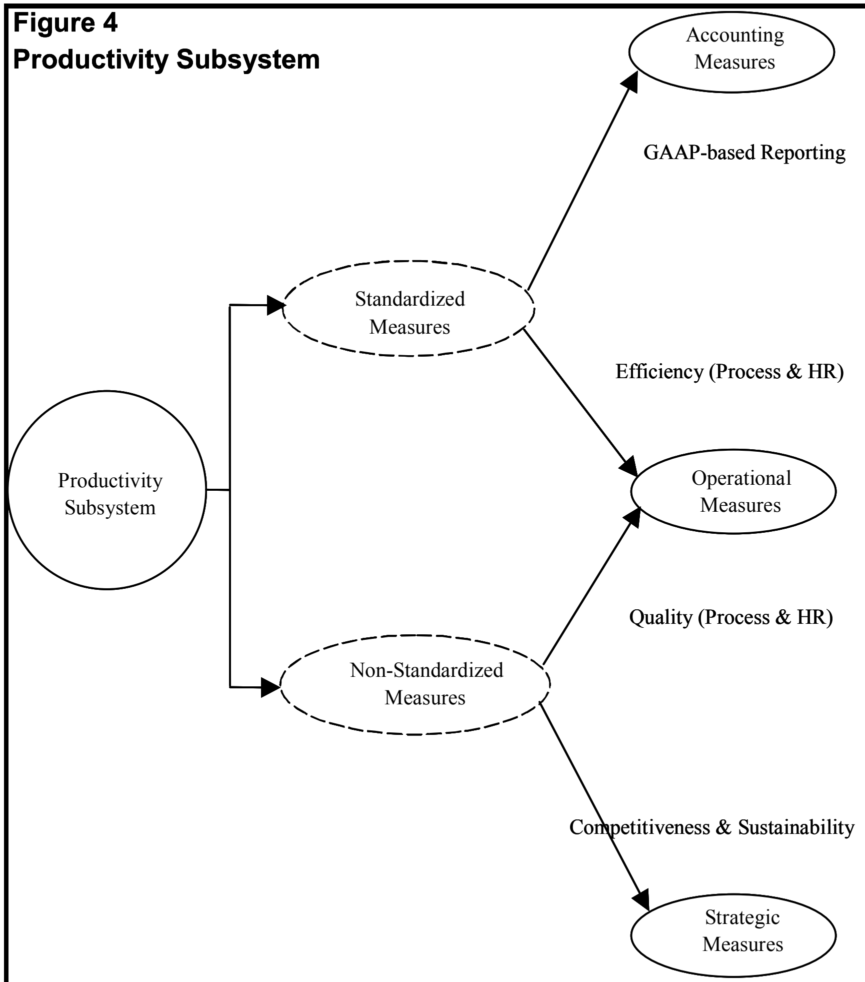
Strategic-level measures include quality of new products (Barua et al. 1995), customer satisfaction levels (Anderson et al. 1997), improvements in performance (Vandenbosch and Huff 1997), development of new markets (Hess and Kemerer 1994), and improved customer convenience (Nault and Dexter 1995).

The classification schema is presented in Figure 4.

Disaggregating of the productivity construct into a modular metric-based classification scheme not only illuminates how productivity can be measured as distinct components but also provides insight on how productivity is both perceivable and traceable across multiple levels of orientation within an enterprise. Furthermore, the classification schema can help ascertain how a specific infrastructure category (A, B, …G) can be related to a specific type of productivity. A disaggregated, component-based treatment of infrastructure and productivity provides potential of tracing the loci between specific IT infrastructure components and their corresponding impact on specific productivity categories. For example, it would be easier for a firm to trace whether infrastructure pertaining to the convergence of communications and content specifically impacts operational productivity in terms

[2]Grateful acknowledgement to Harold Lagroue for tabulating the metrics and literature from Chan (2000) and Devaraj and Kohli (2000).

Figure 4
Productivity Subsystem



Matrices	Reference Literature
Return on assets	Rai et al. 1997; Tam 1998
Return on investment	Jelassi and Figon, 1994
Return on sales	Tam, 1998; Mahmood and Mann, 1993
Operating costs	Desmaris et al. 1997
Profitability	Hitt and Brynjolfsson 1996
Book value of assets	Tam, 1998
Labor expense, no. of employees	Dewan and Min 1997
Labor productivity	Brynjolfsson 1993
Total documents processed	Teo et al. Wei 1997
Administrative productivity	Rai et al. 1997
Capacity utilization	Barua et al. 1995
Inventory turnover	Mukhopadhyay et al.1995
Inventory and stockout levels	Lee et al. 1999
Premium income per employee	Francalanci and Gala, 1998
Reduction in training time	Desmaris et al. 1997
Improved information exchange	Sheffield and Gallupe 1994
Quality improvement	Wilcocks and Lester 1997
Service quality	Myers et al. 1997
Improved work environment	Teo and Wong 1998
User satisfaction with IT systems	Yoon et al. 1995
Improved operating effectiveness	Henderson and Lentz 1995-96
Quality of new products	Barua et al. 1995
Decision-making improvements	Belcher and Watson 1993
Customer satisfaction	Anderson et al. 1997
Changes in organizational structure	Lucas et al. 1996
Relative market share	Kettinger et al. 1994
Improvements in performance	Vandenbosch and Huff, 1997
Development of new markets	Hess and Kemerer 1994
Improved customer convenience	Nault and Dexter 1995

Figure 4. Classification Schema

of increased process and human resource quality. Similarly, firms can realize and distinguish productivity impacts, both in scale and scope, of specific infrastructure configurations. Understanding the impetus of each infrastructure component on each productivity component is likely to lead to a more efficient and effective procedure aimed at alleviating a particularly ailing productivity component by tweaking the *ad hoc* infrastructure component. Referencing the aforesaid example, decreases in operational quality can be remedied by enhancing assets pertaining to the convergence of content and communications. While this paper seeks to *confirm* a relationship between IT infrastructure and productivity, tracing the "locus of value" of each productivity category to a corresponding IT infrastructure component is largely *exploratory*. The development of a distinguishing locus of value connecting a specific infrastructure component to a specific productivity category can, therefore, be immensely beneficial for both practitioners and researchers desperately trying to understand the economic impact of a specific IT infrastructure.

IT infrastructure productivity is not temporally encapsulated. In order to reveal the dynamics of a system, it becomes necessary to employ the element of time. The essence of time is incorporated using two dimensions: *time lags* and *feedback loops*.

The paper asserts that there is a *time lag* between infrastructure and productivity. Brynjolfsson bemoaned the fact that a disregard of inherent time lags between IT infrastructure investments and productivity contributed to and reinforced the productivity paradox. Both Mahmood and Mann (1997) and Brynjolfsson and Hitt (1998) suggest that the accrual of productivity could be better traced if firms could take into consideration the effects of an inherent time lag required to match organizational factors and IT investments. While the presence of time lags between IT infrastructure investments and productivity is well evidenced, the magnitude of the time lag is seen to vary by industry and maturity of the IT infrastructure within an organization (Devaraj and Kohli 2000).

The second dimension concerns *feedback loops*. According to Stacey (1996), dynamics involves the circular causality that flows via *feedback loops* across mutually interdependent systems or subsystems. An organization is "a dynamic system with feedback loops" where "approaches designed with static, closed systems in mind…may be inadequate" (Chan 2000, p. 231). Based on the productivity outcome, feedback loops help determine *ex post* IT infrastructure configurations. For example, a partially integrated IT configuration may generate a level of productivity that may provide feedback for a need for a more integrated configuration. Conversely, productivity levels may generate feedback entailing more flexibility or customization of IT infrastructure configurations.

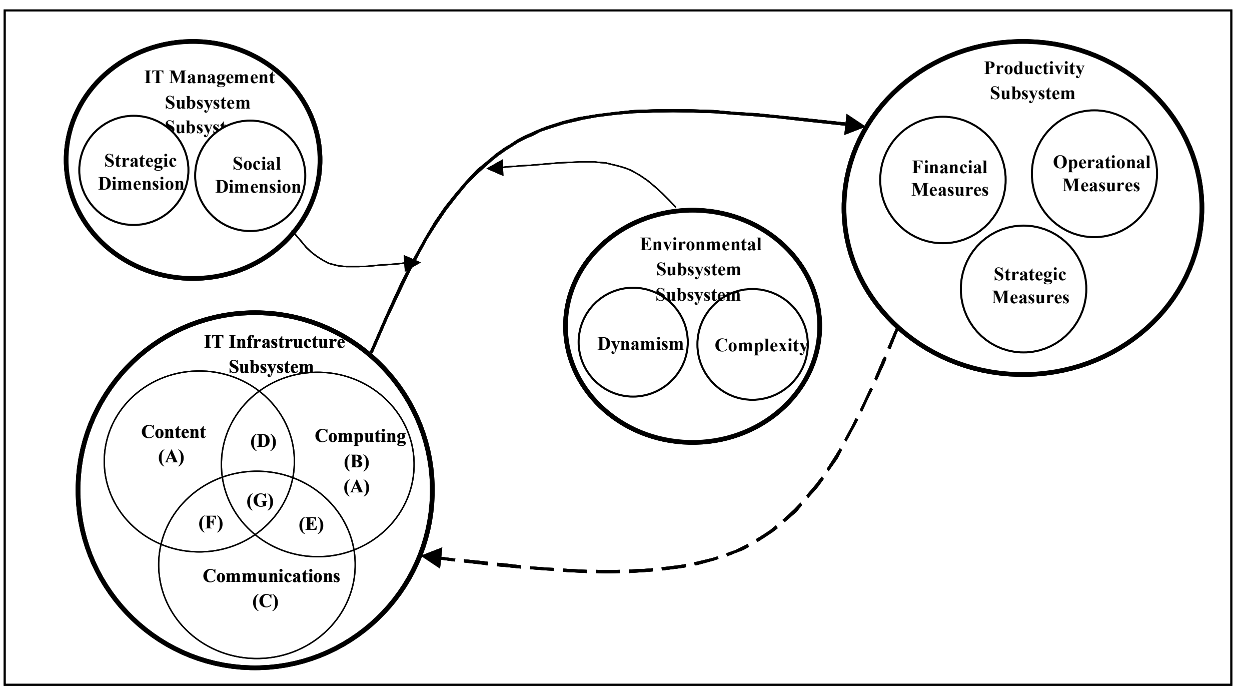


Figure 5. Comprehensive Model of IT Infrastructure Productivity

4 DISCUSSION AND FUTURE RESEARCH DIRECTIONS

IT infrastructure productivity research has been a frequent research topic. However, past research has paradigmatically treated the constructs at an aggregated level. The present study advances the current body of knowledge by providing an epistemological shift in understanding and linking the constructs. The study set out to create a *disaggregated integrative model based on the relationships among the constructs constituting IT infrastructure productivity*. The IT infrastructure was disaggregated into configurable components of content, computing, and communications, each involving a human and technical infrastructure. Productivity subsystem as an outcome was disaggregated into three components based on financial measures, operational measures, and strategic measures. Furthermore, the moderating influence of the IT management subsystem and the environmental subsystem on productivity was traced. In addition to providing a more detailed understanding of the constructs, this study provides avenues to identify and distinctly quantify the components.

This study extends the prior prolific literature in five ways. First, it moves away from aggregation to a more disaggregated and detailed view of each variable, especially the much debated constructs of IT infrastructure and productivity. Second, the component-based view alleviates the measurement impediments by decomposing variables into components that are more manageable in term of measurements. Third, the moderating effects of IT management and the environment provide a rich texture of understanding influences of the moderators on productivity. Fourth, the incorporation of time lags mirrors reality to a greater degree. Finally, none of the constructs are temporally encapsulated and it is posited that productivity does not constitute in the culmination of a system but reflects the feedback provided by productivity on the reconfiguration of the IT infrastructure components.

The proposed model in this study provides the underlying conceptual framework that can guide empirical research concerning IT infrastructure and productivity while considering the identified contingencies, temporal lags, and organizational dynamics. Because this framework identifies, disaggregates, and holistically integrates core constructs, future studies can be designed to empirically examine the relationships between the disaggregated components and the constructs from both a process or variance theoretical perspective. The modular systems perspective provides enough latitude to incorporate either or both of the theoretical perspectives, albeit our depiction of the IT infrastructure productivity system as a developmental sequence of events. Recognizing the temporal lags and the dynamics associated with the core constructs is consistent with viewing IT infrastructure productivity as a relationship of factors in a sequence of events that unfold over time. Moreover, the identification of meso and macro level contingencies provides further avenues to study and control for managerial level and environmental level factors. The framework modeled in this study can be utilized by researchers either as a general nomothetic *event-based process* perspective or as an idiographic perspective to identify the *unique* and *non-current*. In particular, researchers can, either qualitatively or quantitatively, (1) use the model to empirically trace the relationship between IT infrastructure and productivity unfolding through time, and (2) develop, understand, and provide a finer understanding of the working of IT infrastructure and productivity. Our framework allows researchers to capture the intricacy and complexity of IT infrastructure productivity, while providing the practitioner a relevant and congruous model for use in and across industries.

In summary, this study provides an initial design for a model that is comprehensive, disaggregated, relational, and integrative. It reveals the dynamics if IT infrastructure in terms of its coupling and the configurability of its components. It understands that productivity is not bounded by a single categorical measure and tries to ascertain productivity gains across exhaustive components. Feedback loops ascertain the existence of a temporal dimension. After all, infrastructure design and investment should be more reflective of organizational needs denoted by temporal feedbacks rather than a simple bandwagon effect. Supported by systems theory, the overall model reveals a more information-rich "beyond the box" recipe for understanding IT infrastructure productivity.

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