ESSAYS ON IMPACT OF INFORMATION TECHNOLOGY

by
Sumit Milap Bhansali

M.B.A. Management
Massachusetts Institute of Technology, 2007

M.S. Computer Science
Stanford University, 2001

B.S. Electrical Engineering
Georgia Institute of Technology, 1999

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Signature of Author:____

MIT Sloan School of Management
July 10, 2007

Certified by:____

Erik Brynjolfsson
Professor of Management
Thesis Supervisor

Accepted by:____

Birger Wernerfelt
Professor of Management Science
Chair, Doctoral Program Committee

Essays on the Impact of Information Technology

By
Sumit Milap Bhansali

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ABSTRACT

The five essays in this dissertation look at how specific information technologies (such as Electronic Document Management (EDM), Semantic Web and RuleML) and IT in general can be used to automate and standardize data and processes, enable faster and more accurate information flow, and improve individual as well as firm performance.

The first essay is an analytical review-type study in which we provide a comprehensive survey of research literature about different complementary organizational assets that when coupled with IT can lead to higher firm performance.

In the second essay, we study the causal effects of digitizing work on information workers' time-use and performance at a large insurance firm. We make causal inferences and obtain unbiased estimates by exploiting a quasi-experiment: the phased introduction of Electronic Document Management (EDM) across multiple offices at different dates. In addition to large changes in time-use and performance, we find that digitization leads to a decline in the substitutable routine labor input and an increase in complementary non-routine cognitive labor input at the information worker level. We also uncover a new micro-level mechanism, "IT-enabled slack", that explains how exactly IT can lead to payoff in terms of information worker productivity.

In the third essay, we examine the IT productivity relationship using a large primary source firm-level dataset about IT investments that spans the 2003-2005 period. Given results from previous studies, we present evidence of an inverted U-shaped returns curve, with returns now close to what they were in pre-Internet era.

The fourth essay explores what high-performing firms specifically do to gain the greatest benefits from their IT investments. Through a set of matched interviews with multiple respondents at 138 firms, we find that data/process standardization and systems integration, level of application integration and several IT-specific cultural elements are positively correlated with IT impact on customer satisfaction.

The fifth essay shows the first detailed realistic e-business application scenario that exploits capabilities of the SweetRules V2.1 toolset for e-contracting using the SweetDeal approach. SweetRules is a powerful integrated set of tools for semantic web rules and ontologies. SweetDeal is a rule-based approach to representation of business contracts.

Thesis Supervisor: Erik Brynjolfsson
Title: Professor of Management

Dedicated to my Parents
Milap and Sushila Bhansali

I owe all I have and my successes to them.

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All mistakes are my own.

SUMMARY

The five essays in this dissertation look at how specific information technologies (such as Electronic Document Management (EDM), Semantic Web and RuleML) and IT in general can be used to automate and standardize data and processes, enable faster and more accurate information flow, and improve individual as well as firm performance. Through a set of essays (one analytical review-type essay, three empirical studies, and one demonstration), we assess how, when, where and what impact IT can produce at the individual information worker level and at the firm level.

The first essay is an analytical review-type study which explores how just investing in IT may not be enough when it comes to extracting maximum value from those investments. Value derived from IT in terms of its impact on performance is contingent on the presence of many other synergistic factors, such as business processes appropriately re-designed or re-engineered to fit the new technology. We provide a comprehensive analytical survey of research literature about different complementary organizational assets that when coupled with IT can lead to higher firm performance. The six primary organizational variables identified are human capital measured in terms of worker skills, education and training; worker composition and workplace organization measured in terms of the degree of decentralization; business process redesign or redesign of tasks; CEO or senior management attitude/practices; organizational culture and organizational learning. We not only describe the state of research in the important area of IT-related intangible assets but also provide analytical reasoning and insights to explain the various findings and to help researchers and practitioners attain a comprehensive understanding of the topic expeditiously.

In the second essay (the first of three empirical studies), we study the causal effects of digitizing work on information workers' time-use and performance at a large insurance firm. We make causal inferences and obtain unbiased estimates by exploiting a quasi-experiment: the phased introduction of Electronic Document Management (EDM) across multiple offices at different dates. We apply a difference-in-differences methodology to econometrically measure changes in a suite of performance metrics. We further triangulate on the effects of digitizing work via three complementary research techniques: extensive onsite interviews before, during and after implementation; detailed time use diaries and observation; and a series of surveys. In addition to large changes in time-use and performance, we find that digitization leads to a decline in the substitutable routine labor input and an increase in complementary non-routine cognitive labor input at the information worker level. We also uncover a new micro-level mechanism, "IT-enabled slack", that explains how exactly IT can lead to payoff in terms of information worker productivity.

In the third essay, we examine the IT productivity relationship after the dot-com boom or post 2001-02 economic recession. We gather and analyze a large primary source firm-level dataset about IT investments that spans the 2003-2005 period. To the best of our knowledge, this is the first analysis of a large sample firm-level IT investments dataset from the post Internet-boom era. Importantly, in contrast to previous studies, most of our data captures actual IT expenditures versus IT budgets. Further, the coverage of industries in our dataset is more balanced than that in prior research. Using a variety of econometric analyses, we show that the contribution of IT to firm-level performance measures such as value-added has not dramatically changed in the most recent time period from what was observed in the first firm-level IT productivity studies which analyzed data from the 1988- 1992 period. Given results from previous studies, we present evidence of an inverted U-shaped returns curve, with returns now close to what they were in pre-Internet era.

The fourth essay explores what high-performing firms specifically do to gain the greatest benefits from their IT investments. It identifies several IT-specific factors such as Data/Process Standardization, Systems Integration and Application Integration as practices that are correlated with significant IT impact on a key business performance metric: customer satisfaction. The firms interviewed in this study represent large companies that invest significantly in enterprise software applications such as customer relationship management, sales force automation, enterprise resource planning and knowledge management. Through a set of matched interviews with multiple respondents at 138 firms, we identify several concrete practices as well as cultural variables that are associated with positive IT impact on customer satisfaction, and perhaps equally importantly, several practices where the effects are not positive. Specifically, we find that in our cross-sectional sample of firms: Data/process standardization and systems integration, level of application integration and cultural elements such as policy that "IT funding occurs only after a business need has been demonstrated" and perception that "network and e-business foundation provides firm with a competitive advantage in the market" are positively correlated with IT impact on customer satisfaction. On the other hand, level of access to internal data and systems for external entities such as customers, partners, and suppliers is negatively correlated with IT impact on customer satisfaction.

The fifth essay (a demonstration of a specific IT application) shows the first detailed realistic e-business application scenario that uses and exploits capabilities of the SweetRules V2.1 toolset for e-contracting using the SweetDeal approach. SweetRules is a uniquely powerful integrated set of tools for semantic web rules and ontologies. SweetDeal is a rule-based approach to representation of business contracts that enables software agents to create, evaluate, negotiate and execute contacts with substantial automation and modularity. The scenario that we implement is of electronic procurement of computers, with request-response iterated B2B supply-chain management communications using RuleML as content of the contracting discovery/negotiation messages. The demonstration of use of standards such as RuleML and IT applications such as SweetRules that leverage those standards is an important step in the reduction of transaction costs incurred in negotiating contractual agreements. Specifically, these transaction costs are the costs incurred in specifying nature of goods and services to be exchanged, specifying contingencies and other contract terms, and monitoring and enforcing terms of the contract[*]. The reduction in these costs represent the elimination of the "business co-invention" bottleneck, which is expected to greatly impact the speed of creation of social value in inter-organizational computing[*].

Overall, the dissertation looks at the relationship of IT in general and specifically new information technologies that enable data standardization and process automation by leveraging standards to overall productivity, performance and customer satisfaction. The key points and contributions of each essay are mentioned on the following pages.

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[*] See Bresnahan (2002) "Prospects for an Information-Technology-Led Productivity Surge", *Innovation Policy and the Economy*

ESSAY 1

IT AND INTANGIBLE ASSETS: AN ANALYTICAL SURVEY OF ORGANIZATIONAL COMPLEMENTARY ASSETS THAT IMPACT FIRM PERFORMANCE

Summary and Contributions:

- Value derived from IT in terms of its impact on performance is contingent on the presence of many other synergistic factors. This paper provides a comprehensive analytical survey of research literature about different complementary organizational assets that when coupled with IT can lead to higher firm performance.
- It attempts to provide a useful list of organizational variables that should be considered by IS researchers who are interested in investigating whether interactions between IT and different organizational assets/factors can explain more precisely the relationship between IT investments and firm performance. The six primary organizational variables identified are human capital measured in terms of worker skills, education and training; worker composition and workplace organization measured in terms of the degree of decentralization; business process redesign or redesign of tasks; CEO or senior management attitude/practices; organizational culture and organizational learning
- We not only describe the state of research in the important area of IT-related intangible assets but also provide analytical reasoning and insights to explain the various findings and to help researchers and practitioners attain a comprehensive understanding of the topic expeditiously.

- For each organizational factor that we point out, we suggest various avenues of future academic research to further improve our understanding of how investments in that factor complement IT investments.

ESSAY 2

DIGITIZING WORK: DRIVING AND MEASURING CHANGES IN INFORMATION WORKER TIME USE AND PERFORMANCE VIA A LONGITUDINAL QUASI-EXPERIMENT

Summary

- We use a four-pronged research study to holistically assess the causal impact of an enterprise IT (EDM) on the workers compensation division of a large insurance firm. Through pre- and post-EDM interviews, time use studies, surveys and importantly analysis of office-level objective performance data, we have qualitatively and quantitatively documented the causal impact of EDM.
- We demonstrate how EDM changed task composition at the individual level. EDM led to a significant decline in the substitutable routine labor input and an increase in non-routine cognitive labor input at the information worker level.
- EDM directly impacted the supply of routine labor input, which was substituted away by the technology. In reducing the time to complete various routine tasks, EDM made time available to do other value-adding tasks that involved interaction and higher-order cognitive and analytic skills.
- With the deployment of IT, some "slack" developed, which allowed the information workers to "pack" in more units of value-adding tasks. This "IT-enabled slack" led to productivity enhancements in two distinct ways: first, as described above, the slack allowed information workers to spend more time on value-adding communication activities, which directly led to

productivity and performance improvements. Secondly, "IT-enabled slack" allowed for more personal time relaxing/resting at work or at home (less overtime), which in turn led to less stressed-out, happier and more productive employees.

- EDM also brought about an outward shift in the supply of routine informational inputs which complemented the non-routine cognitive labor input (such as interactions and communications) in the sense that they increased the productivity of workers performing nonroutine tasks that demanded those inputs. Post-EDM, both the quantity and quality of routine informational inputs significantly increased.
- The improvement in both the quantity and quality of the routine informational inputs increased the productivity and performance of workers performing non-routine tasks that demanded those inputs. We demonstrated the impact of shift in task composition of the workers on productivity and performance metrics at the office level.

Contributions

- First, our research contributes to the IT impact literature by documenting the significant impact of a specific IT application, electronic document management, not yet examined empirically in the economics of information systems literature despite its salience in the context of information management.
- Second, we demonstrate using a detailed empirical study how computerization changes task composition at the individual information worker level. We also show, at the information worker level, that computerization leads to a decline in the substitutable routine labor input and an increase in non-routine cognitive labor input, and that this non-routine cognitive labor input is an economic complement to computerization.

- Third, we unpack the black box of IT impacting performance and uncover a new micro-level mechanism as to how exactly IT can lead to significant payoff, especially in terms of information worker productivity. We show how with the deployment of IT, some "slack" may develop; this "IT-enabled slack" would allow the information worker to "pack" in more units of value-adding tasks such as communication activities.
- Fourth, we contribute methodologically to the process perspective in the IS literature by using time use studies and differences-in-differences econometric analyses to assess the impact of EDM at the activity and process level. Given the spectacular variety of IT applications and the great need to document the precise causal impact of IT at a micro-level, there is a pressing need for application-specific, differences-in-differences quasi-experimental empirical studies. Our research study addresses that need by assessing the impact of EDM using a quasi-experiment.
- Fifth, given the diversity of IT applications and the lack of application-specific studies that use primary longitudinal data to look at the lagged effect of IT, we contribute to the IT impact literature by collecting panel data and analyzing the lagged effects of EDM technology on various performance metrics.

ESSAY 3

IT AND PRODUCTIVITY: NEW LARGE SAMPLE EVIDENCE FROM POST-RECESSION 2003-2005 PERIOD

Summary and Contributions:

- Given the fundamental nature of the IT-productivity link in our discipline, the diversity of sources of firm-level data analyzed in prior research has not been very encouraging.
- Though the IT productivity paradox has been laid to rest on the basis of prior firm-level and industry-level studies, the nature of the relationship needs continuous investigation especially after periods of significant economic activity or inactivity.
- Given the importance of understanding the potentially evolving nature of the IT-productivity relationship and the need to validate prior results from a variety of sources (secondary as well as primary) more firm-level research is called for. The difficulties of gathering a large sample of data required to conduct this type of research may explain why papers based on more recent data and diverse sources have not been forthcoming.
- We have gathered and analyzed a large primary source firm-level dataset about IT investments that spans the 2003-2005 period, which is post 2001-2002 economic recession in the US. In doing so we have extended previous firm-level work done by Brynjolfsson and Hitt (1995, 1996), Lichtenberg (1995) and Kudyba and Diwan (2002). To the best of our knowledge, this is the first large sample firm-level IT investments dataset from the post Internet-boom era.

- Importantly, in contrast to previous studies, most of our data captures actual IT expenditures versus IT budgets. Since IT budgets are forecasted IT expenditures, they can certainly overestimate or underestimate actual IT expenditures, and hence the distinction is an important one. Further, the coverage of industries in our dataset is more balanced than that in prior research.
- Using a variety of econometric analyses, we have confirmed the positive and highly statistically significant relationship between IT and gross output or value-added for the most recent time period. Further, we have shown that the contribution of IT to firm-level performance measures such as value-added has not dramatically changed from what was observed in the first firm-level IT productivity studies which analyzed data from the 1988-1992 period.
- In contrast to Kudyba and Diwan's observation about increasing returns to IT based on their analysis of the 1995-1997 Internet boom era dataset, we present evidence of an inverted U-shaped returns curve, with returns now close to what they were in pre-Internet era.
- We have shown that our results are generally robust to a variety of specifications and estimation techniques.
- We have also shown that use of IT flow (a measure of actual IT expenditure or IT budget) versus IT stock (a capitalized measure of IT that includes hardware capital and IT labor) does not produce a significant change in the magnitude of the estimated IT elasticities.
- We have also documented the lagged effects of IT investments on firm-level productivity measures. Though the magnitude of estimated IT elasticities declines with the increase in the number of lags of the IT stock independent variable in our regressions, the decline is marginal and the elasticity coefficient remains positive and highly statistically significant.

ESSAY 4

IT PRACTICES AND CUSTOMER SATISFACTION AT 138 LARGE FIRMS

Summary and Contributions:

- This empirical research study tries to fill an important gap in the IT business value literature: identification of IT-specific intangible investments such as investments in IT practices and organizational culture that allow firms to achieve favorable IT investment outcomes especially at the process-level.
- Specifically, in this study we address the following research question: what are some effective IT practices and IT-specific cultural elements that help explain performance improvement differentials on a process-level performance metric such as customer satisfaction?
- We identify, via an econometric analysis of 138 firms (which completed a pair of telephonically-administered structured questionnaires in 2005 about IT operations as well as customer service & support operations), several IT practices and cultural variables that allow firms investing significantly in IT to achieve superior improvements in customer satisfaction. The results are based on analysis of data on firms that invest significantly in enterprise software applications such as customer relationship management (CRM) and enterprise resource planning (ERP). We expect that these firms that are heavy-users of IT would also tend to have the most effective IT practices and cultural variables that would allow them to achieve significant improvements in performance.
- Specifically, we find that in our cross-sectional sample of firms:
    - Data/process standardization and systems integration are positively correlated with IT impact on customer satisfaction.

- Level of application integration is positively correlated with IT impact on customer satisfaction.
- Cultural elements such as policy that "IT funding occurs only after a business need has been demonstrated" and perception that "network and e-business foundation provides firm with a competitive advantage in the market" are positively correlated with IT impact on customer satisfaction.
- The level of access to internal data and systems for external entities such as customers, partners, and suppliers is negatively correlated with IT impact on customer satisfaction.

ESSAY 5

EXTENDING THE SWEETDEAL APPROACH FOR E-PROCUREMENT USING SWEETRULES AND RULEML

Summary and Contributions:

- We show the first detailed realistic e-business application scenario that uses and exploits capabilities of the SweetRules V2.1 toolset for e-contracting using the SweetDeal approach.
- SweetRules is a uniquely powerful integrated set of tools for semantic web rules and ontologies. SweetDeal is a rule-based approach to representation of business contracts that enables software agents to create, evaluate, negotiate and execute contacts with substantial automation and modularity.
- The scenario that we implement is of electronic procurement of computers, with request-response iterated B2B supply-chain management communications using RuleML as content of the contracting discovery/negotiation messages.
- In particular, the capabilities newly exploited include: SweetJess or SweetXSB to do inferencing in addition to the option of SweetCR inferencing, SweetOnto to incorporate/merge-in OWL-DLP ontologies, and effectors to launch real-world actions.
- We identify desirable additional aspects of query and message management to incorporate into RuleML and give the design of experimental extensions to the RuleML schema/model, motivated by those, that include specifically: fact queries and answers to them.
- We present first scenario of using SCLP RuleML for rebates and financing options, in particular exploiting the courteous prioritized conflict handling feature.

- We give a new SweetDeal architecture for the business messaging aspect of contracting, in particular exploiting the situated feature to exchange rulesets, that obviates the need to write new (non-rule-based) agents as in the previous SweetDeal V1 prototype. We finally analyze how the above techniques, and SweetDeal, RuleML and SweetRules overall, can combine powerfully with other e-business technologies such as RosettaNet and ebXML.

ESSAY 1

IT AND INTANGIBLE ASSETS: AN ANALYTICAL SURVEY OF ORGANIZATIONAL COMPLEMENTARY ASSETS THAT IMPACT FIRM PERFORMANCE

Abstract

Value derived from IT in terms of its impact on performance is contingent on the presence of many other synergistic factors. This paper provides a comprehensive analytical survey of research literature about different complementary organizational assets that when coupled with IT can lead to higher firm performance. It attempts to provide a useful list of organizational variables that should be considered by IS researchers who are interested in investigating whether interactions between IT and different organizational assets/factors can explain more precisely the relationship between IT investments and firm performance. We not only describe the state of research in the important area of IT-related intangible assets but also provide analytical reasoning and insights to explain the various findings and to help researchers and practitioners attain a comprehensive understanding of the topic expeditiously. For each organizational factor that we point out, we suggest various avenues of future academic research to further improve our understanding of how investments in that factor complement IT investments.

Keywords: Intangible assets, IT investments, IT payoff, firm performance

1 Introduction

There is much case-related evidence that shows that investing in technology alone may not translate to desired or expected gains in performance. Consider a few examples from (Brynjolfsson et al 1997): In the 1980s, General Motors invested $650 million dollars on technology at one plant but since it failed to simultaneously change the labor management practices at the plant, no significant improvements in performance levels were realized (Osterman 1991). Similarly, Jaikumar (1986) found that US companies adopting flexible technology did not see same gains as their Japanese counterparts because operating procedures were not changed with the introduction of the technology. The popular press is rife with many such examples of companies that exhibit diverse performance results despite investments in similar technologies. In a survey of 659 CEOs by the London School of Economics (Compass Group 1999), only 25% of the executives were satisfied with the performance outcomes of IT investments made by their firms. Though executive perceptions of the impact of IT investments may be a noisy indicator of actual impact, the result does seem to suggest that there are considerable differences in performance results firms obtain from their IT investments. It is now well accepted that investments in technology alone cannot lead to guaranteed enhancements in firm performance.

Using evidence from the IT payoff literature, Devaraj and Kohli (2000) point out that the relationship between IT investments and payoff is far from conclusive. They point to several possible reasons behind the heterogeneity of results in the literature including diversity of variables used in the different studies, the level of analysis (for example: industry level versus firm level) as well as the research design employed (for example: cross-sectional versus longitudinal). Several more recent review and meta-analysis type studies have pointed out a host of reasons behind the observed variance in the results on the IT investments-payoff link (Kohli and Devaraj, 2003; Melville et al., 2004; Piccoli and Ives, 2005). For example, industry sector or context, sample size, characteristics of data source (primary or secondary), type of dependent variable (profitability-based or productivity-based) can have an impact on IT payoff reported in the literature (Kohli and Devaraj, 2003). Not discounting the importance of methodological issues, we feel that an important reason why some studies may fail to show a positive correlation between IT and performance may in fact be because many firms truly fail to improve their performance from just investing in IT. There seems to be significant heterogeneity in the abilities of different firms to invest in important complementary organizational assets (or factors) that can be crucial to extracting value from IT.

The "IT performance paradox" at companies which invest large amounts in IT but fail to see correspondingly significant increases in performance levels may in fact be attributable to the lack of investment in other complementary organizational factors such as human and business resources. Achieving performance gains out of using IT is dependent on coupling IT with other company-specific, inimitable, and intangible organizational, human, and business resources (Miller and Rice 1967; Walton 1989; Benjamin and Levinson 1993; Keen 1993; Powell and Dent-Micallef 1997). Complementary intangible assets play an important role in explaining heterogeneity in firm performance when similar investments in IT are made.

1.1 Contingency Theory, Resource-Based View and Complementary Organizational Investments

The main theoretical lens that has been used to analyze the role of intangible assets in the IT and firm performance relationship is that of contingency theory, which claims that optimal firm performance can be obtained by using resources that are congruent or that "fit" well with each other. Thus, when IT is combined with complementary (or in one sense "congruent") organizational resources, better performance can be realized. Specifically, the role of these other resources is that of a mediator (in the sense of "fit as mediation", see Venkatraman (1989)) and they can be viewed as a significant intervening mechanism that mediate the link between IT and performance.

Much research has been done recently to study the complementarities between organizational investments and IT investments and their impact on the performance of a firm. It has been hypothesized that having IT resources combined with certain intangible organizational assets is more productive than having just those IT resources or just those organizational assets. In other words, the presence of specific intangible assets increases the marginal returns associated with IT assets or in the mathematical framework developed by Milgrom and Roberts (1990), IT investments and investments in specific intangible assets are "complements." Brynjolfsson, Hitt & Yang (2002) show that "the combination of computers and organizational structures creates more value than the simple sum of their separate contributions." (page 176). This again implies that investments in information technology and investments in specific organizational assets are complements.

Davern and Kauffman (2000) further underscore the importance of complementary assets in creation of potential value from IT and in impacting what they call “value-conversion contingencies.” According to them, conversion from “potential IT value” to “realized IT value” is dependent on the satisfaction of several “value-conversion contingencies” that include investments in various complementary assets. They present several examples of generalized value conversion contingencies across multiple levels of analysis (2000, Table 1). For example, to realize maximum value from new software applications being introduced, firms need also to invest in a complementary asset, the infrastructure, which is needed to leverage and integrate the applications. Extraction of full value from an ERP (Enterprise-Resource Planning) application deployment is contingent on the redesign of current business processes to take full advantage of the application.

The second main theoretical lens that has been used to analyze the role of IT intangible assets in impacting firm performance is that of the resource-based view (RBV). According to RBV, differences in firm performance arise out of the heterogeneous distribution of resources among firms (Barney 1991, Tippins and Sohi 2003). Firms that have unique or relatively scarce, inimitable resources have a performance-advantage over firms that do not. In line with RBV, the mere presence of IT does not guarantee improvements in firm performance, as IT can be easily acquired by rival firms (Clemons and Row 1991; Powell and Dent-Micallef 1997); however, when IT is coupled with other complementary organization-specific intangible resources, optimal performance gains can be realized. One possible way to make IT give a sustainable performance-related advantage is to embed it in the organization in such a way that maximally leverages the complementarities between IT and different organizational resources (Powell and

Dent-Micallef 1997). Co-specialization of complementary resources (such that the resources have little or no value without the others) can also lead to a performance advantage that can be hard to achieve otherwise (Powell and Dent-Micallef 1997).

The idea of coupling technology with the human or intangible dimensions of an organization can be traced to the "socio-technical" framework developed over 40 years ago (Trist and Bamforth 1951; Rice 1958; Emery and Trist 1965; Powell and Dent-Micallef 1997). Thus, the concept that performance will be maximized when the technology and related organizational resources are jointly optimized is not new (Miller and Rice 1967; Powell and Dent-Micallef 1997). Notwithstanding this knowledge, firms continue to differ in their capacities to extract the maximum value from IT in terms of performance improvements.

1.2 Contributions

Though there is some empirical research that explores what intangible assets could potentially be coupled with IT to produce higher performance, the research on the topic is distributed. This paper provides a comprehensive analytical survey of academic literature about such complementary organizational assets. It attempts to provide a useful list of organizational variables that should be considered by IS researchers who are interested in investigating whether interactions between IT and different organizational assets/factors can explain more precisely the relationship between IT investments and firm performance. The factors identified can be used to assess the true impact of IT on performance by looking at the relative marginal impact of the interactions between IT and these other factors. They represent the "unobserved" or omitted variables in the regression that attempts to assess the contribution of IT assets to performance. These omitted variables lead to unusually high (or unrealistic) coefficients on computer assets in the regression relating those assets to firm market value, and including specific interaction terms to take into account the coupling of IT and complementary organizational variables lowers the coefficients to more reasonable values (Brynjolfsson and Yang 2002).

We delve deeply into the “complementary resources barrier”, pointed out by Piccoli and Ives (2005, see pp. 757-759) in their review-type study as one of the barriers to erosion of IT-dependent competitive advantage. We hope that the survey is also useful for practitioners who in our opinion are looking for a list (hopefully a prioritized list) of factors that they need to think about if they want to maximize the performance impact of IT investments within their organizations. Making similar IT investments as their competitors but not obtaining similar performance improvements can be frustrating to firms. What can be even more frustrating is not knowing where to focus their energies to allow them to match or even outperform their competitors. Much academic research exists that addresses the specific questions of practitioners about IT intangible assets but is not accessible to them in one place and in an easy-to-digest presentation. Our hope is that this survey will fulfill that need.

What makes the survey useful (we hope) is that we not only describe the state of research in the important area of IT intangible assets but also provide analytical reasoning and insights to explain the various findings and to help researchers and practitioners attain a comprehensive understanding of the topic. For each organizational factor that we point out, we suggest various avenues of future academic research to further improve our understanding of how investments in that factor complement IT investments.

We hope that our paper will encourage further empirical research to answer important questions such as – What organizational variables complement IT? What organizational variables coupled with IT have the highest impact on firm performance? What theories help explain the link between the intangible organizational factors and IT?

1.3 Structure

The paper is divided into four sections, including this introductory section, which presented the theoretical underpinnings of the research on IT intangible assets. The section on IT and its organizational complements provides an analytical survey of the theoretical and empirical research that links IT investments to investments in specific complementary organizational assets. The summary section provides a useful summary in the form of two tables that researchers working in this area could use as a quick and easy reference. The conclusions section provides some final thoughts. For the survey, peer-reviewed scholarly journals and highly-reputed practitioner journals were consulted. Both empirical and theoretical articles on IT and its organizational complements were reviewed. There was no specific time period chosen for the journal searches. Examples include *Administrative Science Quarterly, American Economic Review, Bell Journal of Economics, Harvard Business Review, Journal of Management Information Systems, Journal of Production Economics, Management Science, MIS Quarterly, Organization Science, Sloan Management Review, Strategic Management Journal, Quarterly Journal of Economics, Rand Journal of Economics, Review of Economics and Statistics.*

2 IT and its Organizational Complements

This section reviews the research on the impact of IT coupled with different organizational assets on firm performance. We provide an extensive survey and analysis of the organizational variables identified in the literature. The six primary organizational variables identified are human capital measured in terms of worker skills, education and training; worker composition and workplace organization measured in terms of the degree of decentralization; business process redesign or redesign of tasks; CEO or senior management attitude/practices; organizational culture, and organizational learning.

2.1 Coupling IT with Human Capital (Skills, Education, Training)

Bresnahan et al (2002) find that IT and human capital interactions (but not levels of these variables individually) positively predict firm performance. Specifically, they find that IT combined with a more skilled or a more highly-educated work force leads to higher performance. Their work thus presents evidence for the complementarities between IT and human capital measured in terms of skills and education. As investments in new technology are made, it is important for the firm to make investments in employees who are educated, skilled and comfortable enough to be able to use the new technology effectively. For example, simply investing in a new technology without adequately training existing staff in the use of that technology or without investing sufficiently in the screening and acquisition of employees that would thrive in the new environment would be counter-productive. Skilled human resources would be needed not only to properly administer the technology and take care of technology-specific issues but also to effectively use it and manage it.

As new IT is deployed, it is also important for the firm to seek out employees who are highly skilled at doing non-routine information processing or exception handling, which becomes especially key in a work environment where most of the routine information processing has been substituted away by IT. As IT reduces the amount of time spent on routine information processing, the extra time made available to employees can be more productively used by them in high-level cognitive processing, leading to higher employee value creation. Employees capable of high-level cognitive processing become especially valuable resources in firms that are heavy IT users. Investments in human resource practices that focus on the hiring, development and retention of employees skilled at more demanding cognitive work can be key to recouping the full benefits of IT investments. IT typically also increases the total volume of data that is recorded and the total amount of information available for consumption in the organization. Skilled employees who can critically analyze and effectively synthesize vast amounts of information can potentially add tremendous value to the organization that invests heavily in IT. Though human capital investments in terms of skills and education levels have been explored in the context of IT-related intangible assets, the importance of investments in adequate and relevant training when new information technologies are introduced in the workplace has not been explored much. Previous research has shown that past training raises current performance (Black and Lynch 1996, 2001). The lagged effect of training on performance is consistent with the analysis that as new skills are introduced into the workplace, there are initial adjustment costs, but after some time, the newly learned skills lead to higher performance. In a separate study, Koch and McGrath (1996) find a positive relationship between investments in training and development of workers to organizational performance. These studies point to the importance of investments in training in improving performance. It would be useful to empirically demonstrate the importance of coupling IT investments and relevant IT training in impacting firm performance.

2.2 Coupling IT with Worker Composition and Workplace Organization

Francalanci and Galal (1998) present evidence of the impact of the combined effect of IT and worker composition on performance. They define worker composition as the percentage distribution of managers who perform supervisory tasks, professional workers who perform specialized production-related tasks, and clerical workers, who perform administrative tasks. They find that increases in IT coupled with increases in the proportion of managers lead to higher performance and that decreases in fraction of professional workers and clericals combined with increases in IT lead to higher performance.

The above results are consistent with theoretical predictions. Information processing theory provides support for decentralized decision-making as a way to increase the information processing capacity of an organization. As information processing requirements of an organization increase, firms tend to decentralize decision-making by increasing the number of self-contained, functional units (Galbraith 1973, 1977). This decentralization in response to increased requirements to do quick and unstructured decision-making leads to an increase in the managerial component of work or higher percentage of managers in the organization. At the same time, transaction economics theory tells us that decentralized decision-making makes it costlier to coordinate between units and agency theory tells us that decentralization increases the probability of opportunistic behavior that cannot be directly observed by the principal (Jensen and Meckling 1992). In other words, decentralized decision-making increases both transaction and agency costs. This is where IT can be extremely useful. It can support and extend management control by increasing the monitoring that can be done and thereby help lower agency costs (Francalanci and Galal 1998). It can also enable easier coordination between groups and independent units and thereby help lower transaction costs. Thus, it is expected that as the managerial component of the organization increases, higher use of IT can reduce both transaction costs and agency costs, and improve overall firm performance. At the same time, IT has a deskilling effect on professional workers, in the sense that some of the routine tasks performed by them can be substituted away by IT. Clerical workers performing mainly administrative roles face the greatest threat of substitution from IT. Consequently, it would be expected that increases in IT resources combined with decreases in professional workers and in clerical staff would lead to improvements in performance levels.

Bresnahan et al (2002) find that IT coupled with a more decentralized work organization and team-oriented production leads to higher performance. The link between organizational structure and IT can be understood in a similar way to that between worker composition and IT. As IT can potentially make available voluminous amounts of information, it can be easy for the decision-makers who must act on that information to get overwhelmed. To effectively leverage the information captured by IT, the firm should make investments in organizational structure or workplace organization to increase the information processing capacity of the organization. A decentralized workplace, where even lower-level employees have the authority to act upon the information to which they have access, can overcome the problem of managers becoming bottlenecks in terms of the total amount of information processed. Decentralization of decision-making rights can successfully incent employees to exert effort to process vast amounts of complex information. Similarly, team-based work can alleviate information processing bottlenecks at the managerial level that might be observed in traditional hierarchical organizations. Collective decision-making may help organizations alleviate the problem of bounded rationality and allow for better decisions to be reached in an environment of an abundance of data and information made available through information technology.

As mentioned previously, there is some empirical work that captures the performance-enhancing complementarity between IT investments, human capital and work organization; however more work is needed to flush out the mechanisms that are responsible for the observed relationship. Empirical evidence regarding the mechanisms can help researchers gain more confidence in the firm-level finding that human capital and workplace organization are important IT complements. It is important to note that researching the mechanisms will potentially require individual-level research that is currently not available. Much of the existing research is at the firm level and while this research is useful in pointing out that human capital and organizational structure are IT complements, exploring exactly how these intangible assets interact with IT to produce superior performance will probably require deeper exploration by going into organizations and conducting research at the individual employee level.

2.3 Coupling IT with Business Process Reengineering (BPR)

Value derived from IT in terms of its impact on performance is contingent on the presence of many other synergistic factors. Another such factor is BPR (Business-Process Re-engineering) implementation, which is defined by Hammer and Champy (1993) as the redesign of a process according to some performance measure such as cost, quality, service and speed. Devaraj and Kohli (2000) find that investments in IT when combined with BPR initiatives have a positive impact on firm performance. They find that impact of technology is higher when there is a higher degree of BPR activity and lower when there is a lower degree of BPR activity. In other words, BPR implementation and IT investment activity are complements, and higher BPR investments increase the returns associated with information technology investments. Specifically, they present evidence that BPR initiatives coupled with IT capital investments improves profitability of firms. This finding is in line with the theory of "business value complementarity" presented by Barua et al (1996), which implies that investments in IT and reengineering achieve higher performance when they are coupled and not when they are pursued in isolation.

Successful BPR initiatives can themselves be viewed as initiatives that require consideration of other complementary aspects, such as social, human, and technical aspects of process change. As Roy et. al argue (1998), it is important not to lose sight of the human and social aspects in BPR initiatives, if true gains in performance are to be realized. To maximize chances of re-engineering success in improving firm performance in some dimension, they argue that it is important to jointly optimize two classes of interdependent variables – "organizational adequacy" variables, which are related to the social and human aspects of the organization and "technical adequacy" variables, which are related to technical aspects such as the efficiency of the production processes. For example, use of IT to redesign a process should be combined with redesign of human tasks to fully exploit individual worker potential and with techniques to minimize worker resistance to process change by carefully managing anxieties and expectations. Only joint optimization of these complementary variables can ensure the success of BPR in increasing performance.

The implementation of a specific information technology, such as enterprise resource planning (ERP), can be used to understand the importance of BPR activity to extract the maximum value out of IT (Scheer and Habermann 2000). Successful implementation of ERP systems requires analysis of "as-is" business processes or existing business processes and then reengineering those processes to fit into the capabilities of the software that often captures the best-of-breed processes available. Reengineering business processes may involve minor changes to existing processes or replacing current processes with new ones. The scope of BPR activity may also vary from being local or limited to a few groups/regions to being global (Parr and Shanks 2000). Further, the timing of BPR activity may vary; BPR might be done before implementation of IT, after implementation of IT or in conjunction with implementation of IT. Though the associated BPR activities can often be painful, without thoughtful analysis and reengineering of existing business processes, the true power of the ERP software cannot be leveraged to improve firm performance.

Consider yet another example: the implementation of electronic document management technology (EDM) in a firm where the technology considerably frees up time of employees that was previously tied up in electronically documenting incoming paper documents. Without carefully reengineering the work processes used by employees that allows them to productively use the extra time now made available thanks to EDM, the firm would not be able to realize superior performance gains from using the technology.

Though the importance of the link between BPR activity and IT implementation has been explored somewhat in the academic literature, the coverage is very sparse. There have been few attempts to quantitatively capture the level of BPR activity in conjunction with the introduction of technology. A cross-industry, firm-level empirical study that looks at the complementarity between investments in BPR activity and IT investments is lacking. In addition, there are very few in-depth research articles that explore qualitatively what is the degree, scope and timing of BPR activity associated with successful IT implementation. Even in the most obvious example of ERP software, where some empirical evidence of the positive impact of the technology on firm performance has been published (Hitt et al 2002) and where BPR activity is suspected to play a crucial role in the successful implementation of the software, the mechanisms and activities employed by successful firms have not been explored.

2.4 Coupling IT with Specific Management Practices

Both Davern and Kauffman (2000) and Tallon et al (2000) underscore the importance of management practices in realizing higher IT value. The involvement of senior management in making sure that adequate resources are allocated to the implementation of a new business application can be a key contingency in realizing value from the IT investment. Management practices that focus on aligning the IT investment strategy with the business strategy of the company (Henderson and Venkatraman, 1993; Woolfe 1993; Tallon et al 2000) and that encourage extensive IT investment evaluation will lead to higher values of perceived IT payoffs (Tallon et al 2000). Management practices can thus be viewed as a crucial complementary asset that can impact the realization of maximum value from IT.

The CEO, in particular, can play a significant role in determining whether maximum performance gain can be obtained from IT. For example, CEO commitment to IT will enhance the effectiveness of implementation and use of IT (Henderson and Venkatraman, 1993), as adequate resources will be devoted to the adoption of IT and to its proper alignment with the business strategy (Kettinger et al., 1994). Neo (1988) similarly concludes that the organizational leadership of the firm can be a crucial factor that separates companies that successfully leverage

IT from companies that fail at obtaining IT performance improvements. Keen (1993) also acknowledges that “management differences” can explain why some firms perform better than others, since some managers are better than others in “fitting” or coupling IT with the different complementary organizational and business resources.

The importance of the role of the human agency in extracting superior performance from IT can be justified in light of the organizational imperative perspective (Markus and Robey 1988) in which improved organizational performance or organizational change is seen to be the result of managerial actions and choices and not technology. Specific IT management practices employed by able CEOs can help explain why some organizations succeed while others fail even when the same level of IT investments are made and identical technologies are employed. For example, senior management may institute new incentives to encourage use of IT within the organization. In addition, new monitoring and reporting mechanisms may be put in place by the management to make sure that there are no abuses and that the incentives have the desired effect. Investments in IT have to be coupled with actual use of IT to produce positive improvements in performance (Mukhopadhyay et al 1997; Devaraj and Kohli 2000). Given that actual use of IT is important, it seems reasonable to conclude that incentive systems that encourage the use of IT would be important as well.

Though there is some evidence in the research literature that senior management can play an important role in extracting value from IT, a comprehensive description of the attitudes and activities of executives of high-performing firms that also invest significantly in IT is missing. Many research questions arise that represent fruitful avenues of future research: Are some senior management activities more important than others when it comes to enabling high IT value extraction? What are the key CEO attributes or personality traits that are correlated with high IT performance? Does the presence of an executive in charge of information needs of the organization (or the CIO) distinguish high-performing firms from low-performing ones? What is the nature of relationships between the CEO and the CIO in firms that are top-performers?

2.5 Coupling IT with Organizational Culture

Organizational culture has been recognized as an important multi-dimensional variable in the determination of organizational performance. Organizational culture consists of three main dimensions: "a socio-cultural system of the perceived functioning of the organization's strategies and practices, an organizational value system, and the collective beliefs of the individuals working within the organization" (Marcoulides and Heck 1993, pp. 212). In a paper investigating the relationship between organizational culture and successful IT implementation, Harper and Utley (2001) identify five cultural variables that show a significantly positive correlation with successful IT implementation and five cultural variables that hinder successful IT implementation. Autonomy, trust, team-oriented work, flexibility, and free flow of information are shown to support success while cultural variables such as rigid rules, compliance, carefulness, preciseness, predictability are shown to be negatively correlated with success. Sutherland and Morieux (1988) also imply that the right "fit" between the use of IT and organizational culture can be a determinant of the effectiveness and efficiency of firms. They argue that organizational culture can promote or hinder the adoption of new technology and consequently impact the value that can be extracted from the technology. For example, an "IT phobic" culture can negatively impact firm performance because new technology is either not deployed or its correct use not properly understood and adopted. Employee attitudes can play an important role in how readily or widely new technology is accepted within the organization.

Powell and Dent-Micallef (1997) also show that the presence of cultural variables like open organization, open communications, and organizational flexibility that are complementary to IT lead to higher performance levels. They show that heterogeneity in firm performance can be traced to how well firms use IT resources to leverage complementary, though intangible, human and business resources. They identify six complementary human resources: open organization, open communications, organizational flexibility, organizational consensus, CEO commitment, and IT-strategy integration. The complementary business resources identified are supplier relationships, IT training, business process design, team orientation, benchmarking, and IT planning. They find that the complementary human resources explain the performance differentials to a greater degree than do the complementary business resources. Information processing theory predicts increasing decentralization of work, as the information processing requirements of organizations increase. Higher decentralization leads to higher transaction costs in communicating and coordinating across groups and also higher agency costs in terms of increased monitoring costs. The higher transaction and agency costs can however be circumvented by increased use of IT coupled with presence of organizational cultural attributes that promote open communication and free flow of information. Merely deploying some IT application that enables sharing of information may not produce the desired performance outcomes unless the organizational culture promotes information sharing by employees.

Though as described above there are a few studies that have explored the link between IT and organizational culture, a comprehensive analysis about the different cultural variables that might complement IT investments is currently missing. It would be useful for example to analyze using the highly detailed organizational cultural profile (OCP) developed by O'Reilly et. al (1991) what 54 attributes of the OCP should be coupled with IT investments to improve performance impact. Further, explaining how the cultural traits translate to higher IT payoffs would be key. Pointing out cultural variables and theoretically grounding those findings or clearly explaining how the cultural traits help improve IT performance would be highly useful to both practitioners as well as academics.

2.6 Coupling IT with Organizational Learning

Organizational learning is defined as a process via which new organizational knowledge gets created (Slater and Narver, 1995). It can be viewed as consisting of four main parts: information acquisition, information dissemination, shared interpretation, and development of organizational memory (Tippins and Sohi, 2003). Much research has been done to show the positive relationship between organizational learning and firm performance (Day 1994; Slater and Narver 1995). In the context of information systems, Tippins and Sohi (2003) show that the relationship between IT competency and firm performance is mediated by "organizational learning." In other words, they show that IT affects firm performance not directly but indirectly through its effects on how an organization learns. When IT investments are made such that they aid in the four organizational learning processes, superior performance may be obtained. For example, firms that effectively use IT to learn more about their customers, suppliers and competitors can achieve better performance. Firms are increasingly geographically distributed and so mechanisms to ensure that information generated by use of IT is not only effectively captured but disseminated or shared among the employees in various geographic locations can be key to ensuring that all the information is powerfully leveraged. Processes to ensure that different groups in an organization develop a shared understanding of the information captured by IT systems can help in reducing transaction costs incurred in resolution of misunderstandings or semantic conflicts. Ray et al (2005) show that shared knowledge between IT and customer service units moderates the effect of investment in generic information technologies on customer service process performance. This shared knowledge can be crucial as to how IT investments in skills and other resources are used to drive customer service process performance.

Ichniowski et al (2003) relate higher levels of a form of organizational capital called "connective capital," to higher performance. Connective capital is defined as the stock of human capital that employees can access through their connections to other workers. Trust can play an important role in the process of building new worker relationships that can lead to higher connective capital, and this can in turn increase the ease of sharing information among workers (Ichniowski et al 2003). Processes to help develop trust can be critical to organizational learning. Without trust, employees would be unwilling to share information with other employees within the organization or with suppliers or partners outside the organization. Potentially useful information generated by various IT systems under control of different groups or functions would not be aggregated or integrated and acted upon without a level of understanding and trust between the different groups.

There are few studies that describe in detail what kinds of specific processes and mechanisms, that enable organizational learning, can allow firms to maximize the performance impact they see from their IT investments. How important are the various organizational learning processes in extracting maximum value from IT? Are some processes more important than others?

3 Summary

Tables 1 and 2 usefully summarize the literature survey on IT intangible assets. Table 1 shows the different organizational factors that have been theorized or empirically shown to have a complementary relationship to IT in terms of their impact on firm performance. We discussed six primary organizational factors that when coupled with IT can lead to better firm performance: human capital measured in terms of education, skills and training; worker composition measured in terms of percentage distribution of managers, who perform supervisory tasks, professional workers, who perform specialized production-related tasks, and clerical workers, who perform administrative tasks; organizational structure or work organization that is closely related to worker composition; business process reengineering (BPR); specific senior management practices including incentive systems; organizational culture and organizational learning.

Table 2 shows the dependent and independent variables used in the different empirical studies on the topic. Table 2 is quite revealing in terms of the diversity of dependent variables used in the empirical studies in the area of IT intangible assets. Also, even though in sum there is a fair amount of theoretical and empirical research on the topic, the number of empirical research studies investigating each of the organizational factors hypothesized to be complementary to IT investments is small. Thus the table suggests that there is still a wide opportunity to do further research in each of the six sub-topics under IT intangible assets and augment current state of understanding in those areas. In future research studies, it would be useful to use the same or similar dependent variables so that we can definitively confirm the mediating effect of the various organizational variables on IT-led performance.

4 Conclusion

We have attempted to provide a comprehensive, analytical survey of the state of research on the topic of IT intangible assets, a topic that we believe is of great importance not just to the IS academic community but also to IT practitioners and executive decision-makers within organizations. As organizations struggle to extract performance gains from their IT investments, managers are looking for various factors that they need to think about if they want to maximize the performance impact of their IT investments. Making similar IT investments as their competitors but not obtaining similar performance improvements can be frustrating to firms. What can be even more frustrating is not knowing where to focus their energies to allow them to match or even outperform their competitors. Much academic research exists that addresses the specific questions of practitioners about IT intangible assets but is not accessible to them in one place and in an easy-to-digest presentation. Our hope is that this survey will fulfill that need.

Our survey provides a hopefully useful list of organizational variables for IS researchers who are interested in investigating whether interactions between IT and different organizational assets/factors can explain more precisely the relationship between IT investments and firm performance. The factors identified can be used to assess the true impact of IT on performance by looking at the relative marginal impact of the interactions between IT and these other factors. Though the task would be daunting and would in all likelihood involve collaboration of multiple institutions and researchers, it would be highly worthwhile to construct a detailed empirical study that includes all the various organizational factors that we have identified and then tries to assess which of these factors have the highest mediating effect on IT-led performance.

As we have pointed out at various points throughout this paper, more research is needed to exactly understand the mechanisms that underlie the observed complementary relationship between the various organizational factors and IT. To help achieve this goal, detailed case studies that examine firms that have succeeded and firms that have failed at using their IT investments to improve their performance would be highly useful. Empirical studies at the individual-level that try to investigate how individual performance is impacted by the presence of IT and complementary organizational factors would also help uncover fundamental mechanisms that explain the relationship between superior IT-led performance and investments in IT-related intangible assets.

Table 1. Summary of studies that relate IT and different intangible organizational assets to firm performance

IT and Human Capital (Education, Skills, and Training)	Bresnahan, Brynjolfsson, and Hitt (2002)
IT and Worker Composition, Work Organization	Francalanci and Galal (1998) Bresnahan, Brynjolfsson, and Hitt (2002) Brynjolfsson, Hitt, Yang (2002)
IT and Business Process Reengineering (BPR)	Roy, Roy, and Bouchard (1998) Devaraj and Kohli (2000)
IT and Management Practices	Neo (1988) Henderson and Venkatraman (1993) Keen (1993) Kettinger, Grover, Guha and Segars (1994) Davern and Kauffman (2000) Tallon, Kraemer, and Gurbaxani (2000)
IT and Organizational Culture	Sutherland and Morieux (1988) Powell and Dent-Micallef (1997) Harper and Utley (2001)
IT and Organizational Learning	Tippins and Sohi (2003)

Table 2. Dependent and Independent Variables in Empirical Research on IT Intangible Assets

	Study	**Dependent Variables**	**Independent Variables**
IT and Human Capital as well as Work Organization	Bresnahan, Brynjolfsson and Hitt (2002)	value added (as sales minus materials bill)	education levels, occupation mix, value of total capital stock of IT hardware
IT and Worker Composition, Work Organization	Francalanci and Galal (1998)	premium income per employee, ratio of operating expenses to premium income	managerial intensity (or fraction of managers), professional intensity, clerical intensity, IT expense
IT and Worker Composition, Work Organization	Brynjolfsson, Hitt and Yang (2002)	value added in constant dollars (as sales minus materials bill), market value of firm	structural decentralization, individual decentralization, team incentives, skill acquisition, total IT investment
IT and Business Process Reengineering (BPR)	Devaraj and Kohli (2000)	net patient revenue per day, net patient revenue per admission	anticipated total cost savings of all BPR projects under way, total IT expense (including labor, support, capital)
IT and Management Practices	Tallon, Kraemer and Gurbaxani (2000)	perceived IT business value in terms of realized impact on six critical business activities within the value chain.	alignment between IT strategy and business strategy, processes used by senior managers to evaluate major IT investments
IT and Organizational Culture	Powell and Dent-Micallef (1997)	IT performance, financial performance	organizational culture (including open organization, open communications, CEO commitment to IT, flexibility)
IT and Organizational Culture	Harper and Utley (2001)	overall IT payoff	organization culture (using 54 attributes based on OCP developed by O'Reilly et al, 1991)
IT and Organizational Learning	Tippins and Sohi (2003)	profitability, ROI, customer retention, sales growth	IT competency (including IT knowledge, IT operations, IT objects), organization learning (including information acquisition, information dissemination, shared interpretation, declarative memory, procedural memory)

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ESSAY 2

DIGITIZING WORK: DRIVING AND MEASURING CHANGES IN INFORMATION WORKER TIME USE AND PERFORMANCE VIA A LONGITUDINAL QUASI-EXPERIMENT *

Abstract

We study the causal effects of digitizing work on information workers' time-use and performance at a large insurance firm. We make causal inferences and obtain unbiased estimates by exploiting a quasi-experiment: the phased introduction of Electronic Document Management (EDM) across multiple offices at different dates. We apply a difference-in-differences methodology to econometrically measure changes in a suite of performance metrics. We further triangulate on the effects of digitizing work via three complementary research techniques: extensive onsite interviews before, during and after implementation; detailed time use diaries and observation; and a series of surveys. In addition to large changes in time-use and performance, we find that digitization leads to a decline in the substitutable routine labor input and an increase in complementary non-routine cognitive labor input. We uncover a new micro-level mechanism, "IT-enabled slack", that explains how exactly IT can lead to payoff in terms of information worker productivity.

Keywords: EDM, electronic document management, time use studies, differences-in-differences, productivity, IT payoff

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1 Introduction

Causal effects in fields such as medicine are often estimated using controlled experiments. This is less common in the social sciences because it is often difficult or extremely expensive to control the setting (often organizations) and treatment (often major technology investments and business process changes). In addition to obscuring causality, it is also difficult to estimate an unbiased return to the random adoption of new technologies (or the "average treatment effect") without experimental data (Bartel et al 2004, p. 221). The ideal to strive for would be a randomized controlled experiment in which the treatment is given to individuals or entities selected at random from a population. True randomized controlled experiment however can be difficult to achieve in reality. In this paper, we are able to report on results from a large "quasi-experiment", in which the time of application of the technology and process intervention (in our case electronic document management technology or EDM) to various entities (in our case the offices) is "as if" it was randomly determined i.e. in which randomness is introduced by variations in specific office circumstances such as timing of the implementation of the technology that makes it appear as if the technological treatment was randomly assigned to the offices. The quasi-experiment allows us to get very close to what would be ideal, a randomized controlled experiment, in which the causal effect could be measured by randomly selecting a sample of individuals from a population and then randomly giving the treatment to some of the individuals in the sample.

In the context of a quasi-experiment, we use a four-pronged research study to holistically assess the causal impact of an enterprise IT (EDM) on the workers compensation division of a large insurance firm. Through pre- and post-EDM interviews, time use studies, surveys and importantly analysis of office-level objective performance and cost data, we qualitatively and quantitatively document the causal impact of EDM. The interviews allow us to understand the behavioral impact of EDM on the employees. The time use studies help us to assess the impact of EDM on the allocation of time by employees to various activities. The surveys help us to assess quantitatively and qualitatively the perceived impact of EDM on various dimensions or measures such as individual case load, new cases, closure rates, amount of paper, communication patterns and time spent doing various activities. Finally, econometric analyses on the objective performance and cost data at the office level allow us to isolate the causal impact of EDM on various bottom line metrics. We combine the results of the econometric analyses with the results from interviews, time-use studies and surveys to understand the true impact of EDM. Our research study is an example of an "insider econometrics" study (Bartel et al, 2004) in which we focus on the operations of a single firm. Insider insights obtained through direct contact with the managers and information workers are key in this type of study, as they reduce concern about endogeneity bias and omitted-variable bias in the results (Bartel et al, 2004). Interviews and direct observations can help the researchers figure out what are the "right data" that need to be collected and also whether other confounding factors that could explain the observed results exist. Further, insider econometrics studies are useful in that they allow the researchers to gather primary data to estimate productivity/performance models in which the independent variables of interest can be expected to have direct effects that can be interpreted meaningfully (Bartel et al 2004, p. 221).

EDM technology is used to manage documents and is often categorized as an information management tool. EDM has been defined as the "application of technology to save paper, speed up communications, and increase the productivity of business processes" (Sprague 1995, p.29). EDM implementation is literally one of the most visible manifestations of the ongoing move from analog to digital organizations, as paper document and manual routing are replaced by digital documents that are managed electronically. Its salience derives from two facts: valuable information in organizations is stored in the form of documents such as reports, forms, memos, letters etc. and business processes are often driven by document flows (Sprague 1995). Despite its salience, EDM has not received much attention from IS researchers. To the best of our knowledge, few systematic empirical studies exist that assess the business value of EDM. In their review of published and unpublished cases on electronic records management systems (ERMS), Johnston and Bowen (2005) point out that benefits of such systems have rarely been measured and documented carefully (page 139) and most case studies do not report both the full costs and the detailed quantitative benefits (page 137). Many of the case studies are non-academic, where details are lacking, and where it is not clear whether rigorous standards of academic research were used to measure the benefits/costs of electronic document and records management systems (EDRMS). Some of the case studies mentioned in the review include the following: Orange County, California, reporting savings of over $1M per annum from their EDRMS, with additional savings of office space of over 800 square meters (Winton, 2003); Transport Canada reporting an ROI of 86% and 1.17 year payback for their EDRMS project (Nucleus Research, 2004); Salford City Council in UK reporting 15%-20% improvement in productivity in Council Tax and Benefits processing, 75% reduction in absence due to sickness and improved employee satisfaction and motivation after rolling out electronic records and enabling workers to work from home (Salford City Council, 2005).

One of the most famous examples of strategic information systems, Economost, is an example of an electronic order entry system, whose benefits for McKesson, a drug wholesaler, have been documented in prominent academic literature (Clemons and Row, 1988). Though Economost was not an EDMS or even ERMS, it was similar to EDMS in the sense that it reduced/eliminated hand-written paper orders. It is credited with at least playing a role in the following: reduction in order entry or transaction costs, reduction in prices for the customer, reduced order entry errors, improvement in operations such as: reduction in number of telephone order-taking clerks from 700 to 15, reduction in number of sales personnel by 50%, and strategic landscape effects such as drug wholesaler industry consolidation and reduction in the number of direct sales of drug manufacturers to drugstores.

Another technology namely CAD (Computer-Aided Design) also represents a significant technological achievement responsible in large part in helping the architectural community transition from the paper-based world to the electronic age (and in that respect similar to EDM). The case study of Dyer/Brown (Sviokla and Keil, 1991) demonstrates how the use of CAD by the firm led to significant improvement in productivity and to opening of strategic business opportunities to enter new areas (Fichman, 2003). In their study of the business value of EDI (Electronic Data Interchange), Mukhopadhyay et al (1995) assess the additional savings from electronic document preparation and transmission of $40 per vehicle, resulting in millions of dollars of total savings. Despite the above body of research, the amount of high-quality empirical research that uses primary longitudinal data and controls for other confounding factors remains low specifically in the context of electronic document management. This particular research attempts to fill that void by empirically assessing the impact of EDM using four complementary methods: 1) extensive on-site observation and interviews, 2) detailed time use records, 3) office-wide surveys, and 4) accounting data on multiple intermediate and final performance metrics. We are able to address the following questions: what are the net time savings, if any, that are attributable to EDM? What is the task level impact of EDM? How does that task-level impact translate to performance gains? More generally, we try to answer the following questions: What is the impact of digitizing work on tasks at the information worker level? How does the task-level impact of IT translate to productivity gains? What are the micro-mechanisms that lead to IT payoff?

In clarifying the scope of this IT impact research study, the answers to three basic questions addressed by business value of IT studies – *what* is measured, *how* is it measured, and *where* is it measured (Kohli and Devaraj, 2003) – are as follows: *what*: we focus on the productivity and cost impact of IT, *how*: we gather longitudinal cross-sectional or panel data to assess the causal impact of IT, *where*: we do our analysis at the level of an individual and at the office-level within a single firm. We focus on the efficiency (vs. effectiveness) formulation of performance (Melville et al, 2004) i.e. we focus on an internal perspective that emphasizes metrics such as cost- and time-related efficiency. In other words, we look at the *efficiency* impacts and not the *competitive* impacts of the technology (Melville et al, 2004). Ours is an empirical study (vs. conceptual, theoretical or analytical) (Melville et al, 2004) that combines both qualitative and quantitative research to assess the business value of a specific application at the process and business unit level. Given the importance of the difference between intermediate-level performance measures such as inventory turnover and organizational measures such as market share (Barua et al, 1995), it is important to clarify that we focus on intermediate process-level performance measures.

Kohli and Devaraj (2003) do a meta-analysis of several firm-level IT impact empirical studies and make several recommendations for future IT payoff studies, including use of primary data and use of larger samples of panel data to assess lagged effects of IT. Though their recommendations are made in the context of firm-level studies, we believe that the suggestions would apply well to even single-firm in-depth field research studies. In an effort to improve our understanding of the true impact of IT, we gather detailed primary data from eight offices in a large insurance company that rolled out the enterprise technology during the course of the study. Our data is also cross-sectional time series that allows us to assess the lagged effects of the new technology. Longitudinal data analysis had been recommended by many researchers to deepen our understanding of the impact of technology (Lucas, 1993; Brynjolfsson and Hitt, 1996; Dewan and Min 1997). There is some longitudinal research that looks at the impact of IT on performance (see examples in McAfee (2002): impact of automatic call planning system on salesperson performance (Fudge and Lodish, 1977), impact of novel point-of-sale systems on amount of material waste in fast-food restaurants (Banker et al, 1990) and impact of access to central information system of insurance carrier on insurance agent performance (Venkatraman and Zaheer, 1994)). However, as McAfee (2002) points out, the body of this research is small, and the magnitude of positive effects of IT shown in it is not substantially large. Further, much of this research is unable to say definitively whether either business process changes or information technology implementation caused the demonstrated effects (McAfee, 2002). Since we have access to a quasi-experiment in this study, our analysis of longitudinal data here is able to isolate unbiased estimates of the causal effects of information technology. Lack of consideration of lag effects has been pointed as a potential reason for the observed productivity paradox (Brynjolfsson and Hitt, 1996). Though there are a few studies that have analyzed primary longitudinal data and looked at the effects of specific IT applications over time (see for example, Peffers and Santos 1996; Devaraj and Kohli, 2000), given the diversity of IT applications, more research that uses primary longitudinal data to assess the trend of IT payoff or the lagged effects of IT is highly desirable. It is in this vein that our field research study contributes in one of many ways to the IT impact literature.

In accordance with the tool view of technology (Orlikowski and Iacono, 2001), the IT artifact in the IT impact literature is often assumed to lead to the consequences intended by the designers and the managers. This can often limit understanding of unintended consequences of the technology (Markus and Robey 2004). Our four-pronged research study allows us to assess the holistic impact of IT, including some of the unintended consequences of the new technology.

The impact of IT at the enterprise level can be measured more accurately by examining its contributions at the intermediate or process level (Barua et al 1995; Mukhopadhyay et al 1997b; Tallon et al 2000) where first-order effects may be observed since IT is often implemented in support of specific activities and processes (Ray, Muhanna, Barney 2005). Further, a deeper understanding of IT impact can be obtained by looking at the impact of individual IT applications on specific processes and tasks (Mukhopadhyay 1997b, Athey and Stern (2002)). At the firm level, the real impact of IT may be obscured because of aggregation problems: some applications may have a positive impact on certain tasks and processes, while others may have negative impact on those tasks and processes (Kauffman and Weill 1989; Mukhopadhyay 1997b). The aggregation issues at the firm level combined with the fact that most investment decisions are made at the application level, it becomes important to look at the impact of individual IT applications (Mukhopadhyay 1997b). Our research contributes to the IT impact literature by looking at the impact of a specific IT application, EDM, not yet sufficiently examined in the existing economics of information systems literature and an application particularly important for information workers. Further, we contribute methodologically to the process perspective in the IS literature by using time use studies and differences-in-differences econometric analyses to assess the micro-level impact of EDM at the activity and process level. There are several research studies that analyze pre- and post-introduction of IT data to quantify the impact of IT. For example, McAfee (2002) and Cotteleer and Bendoly (2006) use pre vs. post analysis to look at the impact of ERP (Enterprise Resource Planning) application on process output or operational variables such as lead time. Mukhopadhyay et al (1997a) use pre vs. post analysis to look at the impact of IT on labor productivity in toll collection (or specifically labor hours to complete different types of toll transactions). Athey and Stern (2002) present a differences-in-differences analysis of the impact of IT (in their case enhanced 911 technology) on the timeliness of emergency responses. Given the spectacular variety of IT applications and the great need to document the precise causal impact of IT at a micro-level, there is a dearth of application-specific differences-in-differences empirical studies. Our research study contributes to the IT impact literature by doing a rigorous differences-in-differences econometric analysis of the impact of EDM. Further, in documenting the impact of digitization of work, we uncover a micro-level mechanism as to how IT can lead to payoff in terms of higher performance.

2 Theory and Hypotheses

The motivation and theoretical basis of our work stems from the explanation offered by Autor et al (2003) for the observed skill-biased technical change or the "computer-skills" complementarity, which is the strong correlation between computerization and demand for higher-educated or college-educated labor. The theoretical task model (Autor et al, 2003) is at the core of this research. According to the model, computerization has differential impact on different types of tasks. There are two types of tasks: routine and non-routine tasks. Routine tasks are those tasks that can be specified using a programmable set of instructions. Non-routine tasks on the other hand cannot be explicitly coded as a set of logical instructions, as the rules for performing these tasks are not clear. Routine and non-routine tasks are further classified as manual and analytic tasks. Examples of routine manual tasks include sorting and repetitive assembly, whereas routine analytic tasks include repetitive information-processing tasks such as calculations and record-keeping. Examples of non-routine manual tasks include driving a vehicle, cleaning, and mopping whereas non-routine analytic tasks include problem-solving and complex communications (Autor et al, 2003). Autor et al (2002) describe the kind of tasks that computers can do well: computers can perform tasks that can be fully described using procedural or rules-based logic i.e. "If-Then-Do" type of logic, which specifies the sequence in which tasks should be performed and what tasks need to be performed at different contingencies. Computers can however solve only "known problems"; they are not very good at responding to unexpected contingencies and they still do not have the capacity to do higher-order analytical and cognitive tasks that humans are good at (Autor et al 2002). The above-described task categorization is similar to the classification of decision types in an organization described by Simon (1960).

According to Simon, three are two types of decisions: programmed and nonprogrammed. Programmed decisions are decisions that are routine and repetitive and hence automatable by computers and nonprogrammed decisions conversely are non-routine and often not previously encountered and hence not easily automatable by computers. In leveraging Simon's classification to create a useful framework for information systems, Gorry and Morton (1971) use the terms "structured" and "unstructured" decisions for "programmed" and "nonprogrammed" decisions respectively. We choose to use the task framework as the theoretical grounding for our work here for the following reasons: it classifies tasks versus decisions and we study impact of EDM technology on task input; the Autor classification is a newer and more fine-grained classification of tasks than the decisions categorization: the further classification of routine and non-routine tasks into manual and analytic tasks is a useful one for our purposes here.

Given the task framework and a description of the tasks that computers can do well, computerization and in our case digitizing work would have substantial substitution impact on routine tasks, both manual and analytic (Autor et al 2003). Computerization also "informates" (Zuboff, 1988) or in other words provides vast amounts of rich informational inputs, which can be very useful to information workers who typically have to employ higher-order cognitive skills to process the available information and make sense out of it. In this sense, computers complement information workers in their non-routine analytic tasks and can help them improve their productivity. As a concrete example, consider the availability of comprehensive online bibliographic searches for legal research: though this facility has greatly increased the information available for consumption, it has undoubtedly also positively impacted the quality of the research (Autor et al 2003).

With falling prices of computer technology and the strong substitutability of programmable tasks, there are economic pressures to substitute computers for humans in those routine tasks (Autor et al 2002). In their study of impact of digital check imaging on check processing at a bank, Autor et al (2002) demonstrate the loss of programmable or "routine" jobs held by high-school graduates when the new technology is introduced. At the same time, due to the strong complementarities between computerization and non-routine analytic tasks, increasing digitization of work should lead to higher demand for non-routine analytic labor input. Autor et al (2003) demonstrate at the *industry level, occupation level and education group level* that computerization is associated with reduced labor input of routine tasks (both manual and cognitive) and increased labor input of nonroutine cognitive (or analytic) tasks. We demonstrate in this research the same effect at the *individual information worker level* i.e. we demonstrate using a detailed empirical study how digitizing work changes task composition at the individual level. We test the hypothesis that digitization of work would lead to a decline in the substitutable routine labor input and an increase in non-routine cognitive labor input at the information worker level. Thus, we test whether non-routine cognitive labor input is a complement to digitization of work at the information worker level. From the production function standpoint, we test at the *individual* level whether "outward shifts in the supply of routine informational inputs [made available thanks to computerization], both in quantity and quality, increase the marginal productivity of workers performing nonroutine tasks that demand these inputs" (Autor et al 2003, p. 1285).

In our field research setting, we examine the impact of introduction of EDM on the task composition at the individual level. Prior to EDM, the information workers in our setting would need to supply a significant amount of routine labor input for their work. Pre-EDM, the information workers would need to type verbatim large sections of documents such as medical reports that were available only in paper form. Post-EDM, the paper documents were all scanned and made available in the electronic form. This obviated the need for the information workers to transcribe the paper documents. Thus, EDM directly impacted the supply of routine labor input, which was substituted away by the document management technology. Further, pre-EDM information workers would transcribe only certain sections of the documents that they deemed salient for their work purposes i.e. information in the paper documents was not completely captured. Information workers exercised significant discretion in deciding which pieces of information to type in verbatim into the information capture system, simply because there was not enough time in the day to transcribe complete copies of the documents. Information workers would apply different lenses to look at the same document. Thus, pieces of information interpreted to be important by one information worker may not be captured by another worker, who interpreted them to be less important. The incomplete information entered into the system was thus of a lower quality. Post-EDM, complete copies of the documents were available in electronic form. No information was lost. In other words, post-EDM, both the *quantity* and *quality* of routine informational inputs significantly increased. Since we hypothesize that increased supply of routine informational inputs should improve the marginal productivity of the information workers who demand these inputs for their non-routine cognitive tasks (Autor et al 2003), we test the impact of shift in task composition of the workers on productivity and performance metrics. Viewed slightly differently through the framework of managerial activities presented by Anthony (1965), we demonstrate how “operational control activities” (that are concerned with carrying out specific tasks such as verbatim transcription of medical reports effectively and efficiently) are substituted away by EDM technology and more time is made available for “management control activities” (that are concerned with making sure that appropriate resources are obtained and used effectively and efficiently to achieve organization’s objectives). Importantly, as mentioned by Gorry and Morton (1971), management control activities often involve interpersonal interaction and calls upon judgment of people, whereas operational control activities involve much less judgment of people. This difference leads operational control activities to be more likely to be automated than management control activities or in other words to their higher inherent substitutability.

In demonstrating a task shift at the information worker level, we also unpack the black box of IT impacting productivity and performance. We uncover a new mechanism as to how exactly IT can lead to significant payoff, especially in terms of information worker productivity. A prominent model of IT payoff that tries to explain the mechanisms that lead to payoff from IT investments from a process point-of-view is the one proposed by Soh and Markus (1995). According to this model, investments in IT applications, skills, and projects represent creation of IT assets, which in turn if successfully deployed lead to IT impacts such as improved coordination and decision-making, and IT impacts at strategic points in the organization lead to higher organizational effectiveness (Soh and Markus, 1995; Devaraj and Kohli, 2000). It is well known that IT can help reduce cost, improve quality, or increase revenues; however, the micro-level mechanisms as to how IT helps achieve those impacts are often unclear. We show how IT can reduce time spent on certain activities and in reducing the time to complete those tasks, how it makes time available to do other value-adding tasks that involve interaction and higher-order cognitive and analytic skills. Without the introduction of IT, there would not be sufficient time to "pack" in many value-adding tasks in the workday. The routine labor tasks may often be necessary to do the non-routine labor tasks i.e. the routine labor tasks may not be ignored to make time for additional non-routine labor tasks. However, with the deployment of IT, some "slack" may develop, which would allow the information worker to "pack" in more units of value-adding tasks. This "IT-enabled slack" is the new construct that we propose to add to the literature. "IT-enabled slack" can lead to productivity enhancements in two distinct ways: first, as described above, the slack allows information workers to spend more time on value-adding activities. These activities directly lead to productivity and performance improvements. Secondly, "IT-enabled slack" may allow for more personal time relaxing/resting at work or at home (less overtime), which in turn may lead to improvements in productivity (Hamermesh, 1990). Just as Hamermesh (1990, p. 132-S) claims, "additional time spent in on-the-job leisure at least partly represents unproductive shirking rather than productive schmoozing," it is unlikely that all of the "on-the-job leisure" is productively used. That claim notwithstanding, from our interviews and econometric analyses, it does seem that the additional on-the-job leisure time leads to less stressed-out, happier and more productive employees.

We present below a couple of mathematical models to capture the essence of the insider econometric study. The models are simple adaptations of the standard consumer choice model in economics.

In our case, the information worker must choose from a set of activities {1, 2,…, n} available to him at work. Each activity has a 'time price' associated with it i.e. the information worker needs time to complete the activity. Activity 1 requires time t_1, activity 2 requires t_2 and so on and so forth. Let t_1, t_2, …, t_n represent the time required to complete one unit of activity 1, 2, …, n respectively. Let x_1, x_2, …, x_n represent the number of units of activity 1, 2, …, n respectively chosen by the information worker. Assume x_i is single-valued i.e. assume x_i is a function of vector **t** and scalar T, where $\mathbf{t}=(t_1,t_2, \ldots, t_n)$ and T is the total time at work available to the information worker. Also assume that x_i is differentiable in each of its arguments.

Let the activities be divided into two sets of activities: routine activities substitutable by computers, and non-routine cognitive activities that are not easily substitutable by computers. EDM affects the routine activities {1, 2, …, m} where m < n. For those activities, EDM reduces the time associated with those activities i.e. EDM reduces t_1, t_2, … t_m. On the other hand, EDM does not impact the non-routine cognitive activities {m+1, ….n} i.e. EDM does not impact t_{m+1}, …t_n. For simplicity, we will assume that EDM does not introduce any new activities for the information worker.

We impose the natural restriction that information workers use up all their time doing their activities (note that we have at-work leisure activities as part of the set of work activities) i.e. we have the following equality (analogous to Walras' Law in Cosumer Choice Theory):

$$\mathbf{t}\,\mathbf{x}(\mathbf{t}, T) = T$$

i.e. $t_1x_1(\mathbf{t},T) + t_2x_2(\mathbf{t}, T) + \ldots + t_nx_n(\mathbf{t}, T) = T$

EDM produces a change in $t_1, t_2, \ldots t_m$; hence, differentiate the above equality w.r.t. t_j where j = 1, 2, …, m:

$$\frac{\partial}{\partial t_j}[t_1\, x_1(\mathbf{t}, T) + t_2\, x_2(\mathbf{t}, T) + \ldots + t_j\, x_j(\mathbf{t}, T) + \ldots + t_m\, x_m(\mathbf{t}, T) + t_{m+1}\, x_{m+1}(\mathbf{t}, T) + \ldots + t_n\, x_n\, (\mathbf{t}, T)] = 0$$

i.e. $x_j(\mathbf{t}, T) + \sum_{i=1}^{n} t_i \frac{\partial}{\partial t_j} x_i(\mathbf{t}, T) = 0 \;\ldots (1)$

With EDM, the information worker consumes fewer or same number of units of routine activities {1, 2, …, m} (assume here *no change* in number of units of routine activities, so $\frac{\partial}{\partial t_j} x_j(\mathbf{t}, T) = 0$) and re-arranges the 'consumption' bundle of other activities to consume more of those activities.

Multiplying every term on the LHS and RHS of (1) by $(\frac{t_j}{T})$ and the second term on the LHS by $(\frac{x_i}{x_i})$, we have the following:

$$(\frac{t_j}{T})\, x_j(\mathbf{t}, T) + \sum_{i=m+1}^{n} t_i(\frac{x_i}{T})(\frac{t_j}{x_i})\frac{\partial}{\partial t_j}\, x_i(\mathbf{t}, T) = 0 \;\ldots (2)$$

(2) can be written as follows:

$$(\frac{t_j}{T})\, x_j(\mathbf{t}, T) + \sum_{i=m+1}^{n} t_i(\frac{x_i}{T})(\frac{t_j}{x_i})\frac{\partial}{\partial t_j}\, x_i(\mathbf{t}, T) = 0$$

i.e.

$$b_j(t, T) + \sum_{i=m+1}^{n} b_i(t, T)\; \varepsilon_{ij} = 0 \;\ldots (3)$$

where $b_j(t, T)$ is the share of total time spent on activity j, and ε_{ij} is the 'cross-time-price elasticity' of activity i w.r.t. time required to do activity j. If EDM reduces t_j and assuming x_j stays unchanged, then the first term in (3) captures the 'IT-slackening effect' (analogous to the 'wealth effect' in consumer choice theory). In one sense, EDM makes the information worker 'richer' in terms of time available to do non-routine cognitive activities. The second term in (3) represents the substitution effect, as the information worker rearranges the activities in the consumption bundle to consume higher units of non-routine cognitive activities.

In the terms of the utility-maximizing information worker, we assume that the non-routine cognitive labor activities offer higher utility than routine labor activities. Let L_R represent the units of routine labor input and L_C represent the units of non-routine cognitive labor input (assume no other activities; at-work leisure activities may be considered to be part of L_C without affecting model/results). Assume, the utility function of the information worker is a Cobb-Douglas utility function represented by $U(L_R, L_C)$.

$U(L_R, L_C) = L_R^{\alpha} \, L_C^{\beta}$, where $\beta > \alpha$

Further, let T_R and T_C be the total time taken on 1 unit of routine labor activity and 1 unit of non-routine cognitive labor activity respectively. The information worker's problem is to maximize his utility function subject to the following constraints: total time spent on routine and non-routine cognitive labor activities should be less than or equal to the total time available at work (T), and he should do a minimum number (η) of routine activities i.e. the information worker cannot simply ignore routine labor activities. The information worker's problem can be represented simply as the following constrained optimization problem with two constraints:

$$\max_{L_R, L_C} U(L_R, L_C)$$

s.t. $L_R T_R + L_C T_C \leq T$

and $L_R \geq \eta$

Taking natural logs of the utility function, we have the Lagrangian (L) for the above problem.

L: $\alpha \ln L_R + \beta \ln L_C + \lambda_1(T - L_R T_R + L_C T_C) + \lambda_2(L_R - \eta)$

We have the following Kuhn-Tucker conditions:

$$\frac{\partial L}{\partial L_R} = 0 \; \text{->} \; \frac{\alpha}{L_R} + \lambda_1 (- T_R) + \lambda_2 = 0$$

$$\frac{\partial L}{\partial L_c} = 0 \; \text{->} \; \frac{\beta}{L_c} + \lambda_1 (- T_C) = 0$$

$$\lambda_1 \frac{\partial L}{\partial \lambda_1} = 0 \text{ and } \lambda_1 \geq 0 \text{ and } \frac{\partial L}{\partial \lambda_1} \geq 0$$

$$\lambda_2 \frac{\partial L}{\partial \lambda_2} = 0 \text{ and } \lambda_2 \geq 0 \text{ and } \frac{\partial L}{\partial \lambda_2} \geq 0$$

Intuitively, we know that both constraints will be binding. Therefore complementary slackness implies $\lambda_1 > 0$ and $\lambda_2 > 0$. We simply have the following expressions for L_R and L_C:

$$L_R = \eta \text{ and } L_C = \frac{T - \eta T_R}{T_C}$$

With EDM, T_R declines and L_C increases i.e. with EDM, time to do routine activities declines, resulting in slack, which in turn allows the worker to focus on the utility-enhancing (as well as productive) non-routine cognitive activities.

3 Research Methodology

We used a four-pronged research study to holistically assess the impact of EDM technology: pre- and post-EDM unstructured interviews, time use studies, structured questionnaires and importantly analysis of office-level objective performance and cost data.

We got access to a large workers compensation insurance company that rolled out EDM technology at different offices at different points in time. Although we conducted informational interviews at several offices of the company, our primary research site was a single large office, where we focused most of our energies. At that location, we conducted unstructured interviews to understand qualitatively the impact of EDM. The face-to-face interviews were conducted both pre- and post- introduction of EDM. They not only helped us to generate questions for the structured surveys and to ensure that we had a reasonably complete list of activities for the time use studies, but they also allowed us to understand the behavioral impact of EDM on the employees in the office. Quantitative analysis of data obtained from time use studies, surveys as well as other sources is highly useful, but it needs to be balanced with qualitative insights obtained from interviews. Many of the benefits/costs of EDM can be perceived immediately by the information workers and the interviews can be a highly useful instrument to understand from the individual employee perspective what are the perceived benefits/costs of using EDM.

Next, we performed two time use studies each done at three different points in time (one pre-EDM and two post-EDM): one at the office level in which the entire office participated and one at a much smaller scale, in which all case managers working on claims related to a single corporate customer were observed by a single researcher. These time use studies helped us to assess the impact of EDM on the time allocated by employees to various work and non-work activities during the work day. Importantly, this micro-level time use data helps us to evaluate the impact of EDM on efficiency captured in terms of net time savings i.e. it helps us to answer the question: what are the net time savings attributable to EDM? The justification for doing both a larger and a smaller, more focused time use study was the following: The office-wide time use study provides a reasonably large sample of activity profiles pre- and post-EDM for comparison purposes. However, the observations in this larger time use study are self-observations i.e. they are taken by the information workers themselves. It is quite possible that all the employees that participated in the office time-use study did not use the same standard to record the activities. This can introduce a degree of error or inaccuracy in the results. Also, self-reported time use data relies on understanding, diligence and honesty of the workers (Donahue et al, 2001) and this makes the approach somewhat disadvantageous. Further, it is important to gather qualitative, personal insights into how EDM impacts the allocation of time at the individual employee level. To achieve this objective, we did a much smaller time-use study for a group of information workers that was observed personally by the same researcher. Since the observations are taken by one individual, calibration (i.e. measuring against a standard) errors should be minimized. Further, qualitative insights into how EDM impacts work can be obtained through this process. However, there are some disadvantages to doing direct monitoring, including the significant expense to monitor a large sample and high level of intrusiveness as another party is observing the workers (Donahue et al, 2001).

We also administered a structured questionnaires pre- and post-introduction of the technology. The data collected through the survey instrument helped us to assess quantitatively and qualitatively the *perceived* impact of EDM on various dimensions of importance such as amount of paper, time spent on various activities and communication patterns. We sought to validate results from time-use studies and interviews by asking the consumers of the technology what their experience has been with the technology.

Though survey results are subject to response bias or "social desirability bias" (Stinson, 1999) (i.e. when the respondents answer the questions according to how they think they should respond rather than according to their true experience/beliefs), our survey questions are worded in a way such that they are not leading in a significant way. So, probability of response bias is minimized.

We are cognizant of the fact that employees may perceive things differently from reality. However, survey data of this form is still useful in assessing the direction of impact, if not the magnitude of the impact, of the technology. Also, large number of responses should help improve the statistical reliability of any averages that we compute in the analysis of the survey data.

Finally, differences-in-differences econometric analyses on the objective performance and cost data at the office level allowed us to isolate the causal impact of EDM on various bottom line performance and cost metrics. Time use studies help us to assess how EDM impacts the distribution of work activities at the individual level. The survey instrument helps us to look at the perceived impact of EDM on various metrics from the point of view of the individual employee. How does the impact on distribution of activities translate to an impact on objective metrics used by the firm to assess the performance of the offices? If we can isolate the impact of EDM on those metrics that is consistent with observed impact on individual work (seen through the time use studies) and with perceived impact on various measures and communication patterns (available through the survey instrument), then the results from the time use studies and surveys assume increased significance. Combining the results of the econometric analyses with results from analysis of data collected from interviews, time-use studies and questionnaires allows us to understand the true impact of EDM on productivity and performance.

4 Data Collection

Since we were interested in the impact of EDM on information work, we focused our energies in our data collection and analysis efforts on the main information workers in the workers compensation division of the insurance company (whose name is withheld for confidentiality purposes). These information workers are called *case adjusters* or *case managers* and they handle insurance claims related to injuries suffered by employees on the job. The case managers refer to the injured employee as the *claimant* and the company in which the injured employee (IE) works and which has a service contract with the insurance company as the *customer*.

4.1 Interviews

We conducted 17 unstructured interviews pre-EDM and 20 interviews post-EDM at various organizational levels (Operations Manager, Claims Manager, Team Manager, Case Manager, Nurses) in the office. Pre-EDM interviews were conducted in the last week of March (2006) and post-EDM interviews were conducted in the fourth week of August (2006) and the first week of February (2007). During the interviews, we focused on obtaining qualitative insights about the impact of EDM. Specifically, we wanted to know how case managers perceived personal and company benefits/costs of EDM, behavioral effects of EDM and EDM-related process changes, and how any time anticipated to be saved by EDM was re-allocated.

4.2 Office-Wide Time Use Study

The office-wide *self-reported* time use studies were conducted at three different time points (one pre-EDM and two post-EDM) to give us a longitudinal sample of self-captured activity profiles of case managers. Pre-EDM time use study was conducted in the last week of March (2006) and post-EDM time use studies were performed in fourth week of August (2006) and in the first week of February (2007), approximately 4 and 10 months after EDM was implemented in the office (implementation period: April 20-24, 2006).

With assistance from an internal team at the firm, we prepared a complete list of activities (or tasks) that would be performed by the case managers throughout the day. We invited a few managers and case managers to verify that the activity list was reasonably exhaustive. Given that the time use study would be quite disruptive to the office, we did not seek additional time to train the case managers on the activity codes and also did not perform several consecutive days of recording (as suggested by Stinson ,1999). We were actually pleasantly surprised that we had gotten unprecedented access to conduct an office-wide time use study. Our initial plans included doing only a small four case manager time use study.

The individual activity profiles were not anonymous as employees were requested to note their names on the observation sheets. A sample observation sheet is available in the appendix. Details of administration of the office-wide time use study are as follows: first, a meeting of the team managers was called and the details of the time use study were explained. Team managers were assured by the regional office manager as well as the researchers that the time use study was only meant to help assess the impact of the technology on the workplace. Team managers were encouraged in turn to explain the procedure and rationale to the case managers. Next, an excel file detailing the exact observation recording procedure as well as the activity code list was distributed electronically to the team managers, who in turn distributed it to the constituents of their teams, the individual contributors or case managers. On the day of the study, case managers were requested to record their activities every 10 minutes throughout their workday. Ideally we would have recorded every single activity along with start and stop time for each activity (Stinson , 1999); however, that would have been extremely disruptive to the case managers and in our efforts to minimize the distraction that our recording activity would cause, we decided to request recording of activities only every 10 minutes.

Case managers were asked to record four pieces of information for each observation: approximate time of observation, category code (9 category codes capture main categories of activities), activity code (each category contains several activities) and claim step code (17 codes capture the claim step associated with each activity). Ideally, we would have had a small army of researchers observing the case managers in the office throughout the day; however, this was not feasible given finite resources for the research project. Since it is quite possible that despite clear instructions and reasonably accurate descriptions of activities on the coding sheet case managers may have used different codes to record same/similar activities, we requested them to also record for each observation, descriptive details on the activity in the Notes column. This would allow us to correct any miscoded activities, provided the notes column was filled out accurately and with sufficient detail. For missed observations, employees were requested to record MO in the Notes column for that observation. We did not make provision for recording of parallel activities (Kitterod, 2001), which could happen if case managers were multi-tasking at the recording time. To make data collection easier for the case managers, we only asked them to record exactly what they were doing at the time of recording. From the comments that workers wrote in the Notes column, we did not see much evidence of parallel activities. The complete set of category and activity codes for the pre- and post-EDM observations is available in the Appendix.

53 case managers yielded 'usable' activity data in the pre-EDM time use study. Case managers were excluded from the data set unless they had at least 40 'valid' observations recorded

throughout the day. ‘Valid’ observations are those that have both activity code and category code specified. 46 and 56 case managers yielded ‘usable’ activity data in the post-EDM (t=1) and post-EDM (t=2) study, respectively. However, because of absenteeism or non-availability of case managers due to job training on the day or inability to record at least 40 valid observations, there can be case managers that are not common across the pre-EDM and post-EDM time use datasets. For more usable comparison, we constructed a matched data set that included pre- and post-EDM data from case managers common to the three time use datasets. The matched data set contains 26 case managers. Note that the data was scrubbed where possible to reduce coding mistakes. Since many case managers did not record descriptive details in the Notes column, a coding check was not possible to do on all the recorded activities.

4.3 Four Case Managers/Single Customer Time Use Study

We performed a much smaller *direct observations* time-use study for a group of 4 case managers, all residing in a physical ‘pod’ configuration and all handling a single customer’s account at the office. All four case managers in this time use study were observed personally by one of the researchers. The pre-EDM time use study was conducted in the last week of March (2006) and post-EDM time use studies were performed in the last week of August (2006) and first week of February (2007), approximately 4 months and 10 months after EDM was implemented in the office (April 20-24, 2006). The individual activity profiles were not anonymous. The observation and coding sheets used in this study were identical to those used in the office-wide time use study. The observations here were recorded every 12 minutes instead of every 10 minutes as in the office-wide time use study because only a single researcher was recording observations for all the four case managers in the pod. The time use study yielded a matched data set for 4 case managers at three points in time: pre-EDM, post-EDM(t=1) and post-EDM(t=2). There are two males and two females in the dataset.

Since case managers are expected to create what is called a ‘journal entry’ or an electronic record in an IT application called “ExPRS” after completing any significant activity, the journal entries are an electronic trail of their activities and analysis of the journal entry data can yield useful insights into distribution of activities of case managers Specifically, the journal entry data allows us to see the *types* of journal entries recorded by each of the case managers throughout the day. To validate our observations with objectively recorded data, we obtained journal entry data for the four case managers pre-EDM and post-EDM (t=1). This data allows us to cross-check the observational data against hard, objective data recorded by the IT systems at the company. Although we present the results of the analysis of this objective data, it is not to discount the value of the direct observations. In the context of measuring system usage, Rice (1990) mentioned that “while computer-monitored data are empirically more *reliable* measures of system usage than are self-reported data, diaries and observations, they are not necessarily more valid” (p. 641).

4.4 Surveys

We administered to case managers two structured questionnaires (one pre-EDM survey and the other post-EDM survey) consisting of five sections, each containing several questions. The first four sections contained questions for which quantitative data or choice answers were requested. The last section contained open-ended questions written to gather qualitative data. Copies of the surveys are available in the Appendix. The surveys were on the longer side (30 minutes to answer the survey) and were anonymous. The respondents were informed of the goal of the survey (to understand the impact of EDM on the work practices, communication patterns and performance of employees) and of their rights on page 1 of the survey.

42 case managers responded to the pre-EDM survey. 66 case managers responded to the post-EDM survey. Thus, the pre-EDM survey and the post-EDM survey represented response rates of 57.5% (42/73) and 91.7% (66/72) respectively. The missing survey responses can be attributed to the length of the survey as well as to absenteeism. To increase the response rates for the post-EDM survey, the researchers asked the respondents to certify on a detachable first sheet of the survey that they were completing the survey. The certification page with the name and signature of the employee was detached from the rest of the survey, which stayed anonymous.

4.5 Objective Process Output/Performance and Cost Metrics

We collected cross-sectional monthly data for the performance metrics for eight offices of the insurance company for the time period (Jan 2005 through Dec 2006) i.e. we have for most metrics, 24 months of data for the eight offices, in which EDM was rolled out at several points in time from Oct 2005 through Apr 2006. The specific dates for rollout of the EDM technology in the different offices were:

Office Code: 390 – October, 2005

Office Code: 205 – February 2006

Office Code: 555 – February 2006

Office Code: 471 – March 2006

Office Code: 413 – March 2006

Office Code: 648 – March 2006

Office Code: 608 – April 2006

Office Code: 949 – May 2006

We looked at the following performance metrics:

Current Year Closure Rate: This measures the percentage of claims closed that were opened in the current calendar year.

Previous Year Closure Rate: This measures the percentage of claims closed that were opened in years prior to the current calendar year.

YTD Average Physical Therapy Paid Amount Per Claim: This measures the amount spent per claim on physical therapy costs.

YTD Average Chiropractor Paid Amount Per Claim: This measures the amount spent per claim on chiropractor care costs.

Retention Rate: This measures the case manager retention rate.

YTD Loss Leakage: This measures the total loss payout on the claims. Losses are defined as additional expenses that should not have been incurred on claims if best practices associated with medical management and disability management processes had been properly followed by the case managers.

Rolling12-months TTD Days: This measures the number of days of temporary total disability or number of days that a claimant is absent from work due to a work-related injury and is paid disability benefits.

We also collected cross-sectional monthly data for several cost metrics for the eight offices for the time period (Jan 2005 through December 2006) i.e. we have for most metrics, 24 months of data for the eight offices.

Next-day Air Shipping Costs: Costs associated with shipping of documents via next-day air courier service

Outside Services Fees: Costs associated with claims-related processing services such as claim mail sorting, filing, indexing, and photocopying provided by an on-site vendor

Mailing Services Costs: Costs for mail room operations (covers all departments including claims)

Offsite Storage Costs: Costs associated with off-site storage and maintenance of hard copy records

Incoming 800 number calls costs: Costs associated with incoming 800 number calls

Telephone usage costs: Costs associated with telephone usage at the office

EDM would also be expected to have an impact on overall printing costs; however reliable data on printing costs is unavailable for the various offices, hence we are unable to determine that impact.

5 Data Analysis and Results

5.1 EDM Impact on Time Use: Four Case Managers/Single Customer Time Use Data Analysis

The four case manager time use study yielded a matched dataset of 149 observations pre-EDM, 153 observations post-EDM (t=1) and 175 observations post-EDM (t=2). A detailed pre- and post-EDM activity comparison for the UPS case managers is presented in Table 1. Each of the activities in the table is labeled as part of one of 10 activity groups in column 6: DOC PAPER, ACTIONPLAN, OTH DOC, OTH CASEMGMT, COMM, MEETING, OTH PAPER, EDM, OTH FILEWORK, PERSONAL. These activity groups described below are very useful in the analyses below. Note all % reported in Table 1 are arithmetic means or averages. The total time spent on each activity group is reported in column 7 (pre-EDM) and column 9 (average of post-EDM (t=1) and post-EDM (t=2)).

From the pre-EDM time-use data, we observe that on average 21.3% of the time of the case managers was spent documenting paper mail and paper faxes (a form of *routine labor input*) (see DOC PAPER activity group in table). Assuming that the case managers work for 8hrs and 15 minutes, this translates to approximately 1hr and 48 minutes or 108 minutes spent daily documenting paper mail & paper faxes. This form of documentation activity disappeared post-EDM as paper documents previously required for the most part to be typed in verbatim were now scanned in and available electronically i.e. 0% of the time post-EDM was spent documenting paper mail & paper faxes. Paper-related activity (excluding documenting paper mail & paper faxes) went down dramatically from 9.1% to 2.1% (see OTH PAPER activity group).

As seen from Table 1, the key result is that the level of documentation activity went down dramatically and time spent documenting seems to have been re-allocated towards significantly higher communication activity (a *non-routine cognitive labor input*). The documentation activity (composed of 'DOC PAPER' and 'OTH DOC' activity groups or specifically, documenting paper mail and paper faxes, writing journal entries, documenting claim screen/details) went down from 31% to 9% (a reduction of 71%), whereas communication activity ('COMM' activity group or specifically phone/voicemail/e-mail activities) or a form of *non-routine cognitive labor input* went up from 28.4% to 39.1% (an increase of 38%). In particular, phone-based communication went up from 22.5% to 31.5% (an increase of 40%). Pre-EDM, a significant percentage of case manager work time was allocated towards posting detailed summaries of medical report and other paper documents to a computer application called 'ExPRS'. The summaries were captured in the form of what are called ‘journal entries’ and they would often be verbatim copies of important sections of the paper document. Post-EDM, a majority of the paper documents were sent to the scanning service provider for electronic scanning and those documents would no longer be required to be ‘posted’ in a detailed manner to ExPRS journal entry system. Post-EDM, case managers could simply create a short journal entry about the receipt of the document and electronically attach a copy of the EDM document to the journal entry. The journal entries after EDM were reported to be much shorter (perceived to be up to 50% shorter) as case managers were simply linking the electronic documents directly to the journal entries, removing the need to post large portions of the original documents.

Post-EDM, time on other value-adding, non-routine activities involving critical thinking went up. Specifically, time spent on in-person meetings (see ‘MEETING’ activity group in Table 1) went up from 2.5% to 7.0% and time spent on writing/updating action plans (see ‘ACTIONPLAN’ activity group in Table 1) went up from 7.2% to 10.9%.

EDM introduces new activities in the post-EDM time use data. These EDM-related activities identified as part of the ‘EDM’ activity group in Table 1 took 8.3% of the time post-EDM. Of this 8.3%, 4.3% was devoted to new activities that had no close pre-EDM counterparts. Specifically, 4.3% of time was devoted to managing EDM inbox (which much like an e-mail inbox was continuously populated with new documents scanned into the system), uploading documents to EDM (case managers were supposed to upload electronically faxed documents to EDM themselves) and completing EDM document properties (each EDM document had seven identifying properties for case managers to fill in).

Personal activities (see ‘PERSONAL’ activity group in Table 1) went up from 11.3% to 12.4% (an increase of about 10%). Specifically, the activities in this group were personal break, lunch, and other personal time-off at work. EDM introduces some potentially productivity-enhancing, stress-reducing *slack* that is captured in the increase in the personal activities. Notably, the time use study would fail to capture the time spent at home by case managers on work-related activities such as documenting paper. From interviews, we did find that pre-EDM, many case managers were taking paper documents home to catch up on their document posting activity; however this was eliminated with the introduction of EDM: case managers that we talked to agreed that EDM cut down on overtime as well as on time spent doing office-related work at home.

We graphically present the key results of the activity analysis in figures 1a-1d.

To validate the results based on observational data from the time use study, we next analyzed the computer-captured ‘journal entry’ data for each of the four case managers for the pre-EDM and post-EDM (t=1) days they were observed. As mentioned earlier, case managers are expected to create what is called a ‘journal entry’ after completing any significant activity; the journal entries are thus an electronic trail of their activities. The results were striking and validated the observations made by us in the time use study. Specifically, we observed that paper medical report transcription/posting activity (a *routine labor input*) for all case managers dramatically dropped. For all but one case manager, the activity was eliminated post-EDM. This would validate our observation from the time use study that documentation activity dropped significantly post-EDM. The total number of physician or claimant or customer contact journal entries increased substantially from pre-EDM to post-EDM. In particular, the number of physician contact journal entries increased for all but one of the case managers, the number of claimant contact journal entries increased dramatically for all the case managers and the number of customer contact journal entries substantially increased for all but one of the case managers. This would validate our observation from the time use study that communication activity increased significantly post-EDM.

The results of the analysis on the journal entry data are graphically shown in figures 2a-2e. Note that the "Physician + Claimant + Customer Contacts" figure (figure 2b) aggregates the information presented in the "Physician Only" (figure 2c), "Claimant Only" (figure 2d) and "Customer Only" (figure 2e) figures. The disaggregated information is presented to show that all types of external contacts have in general increased post-EDM.

Next, we compute using the time use data the time savings that may be attributable to EDM and how the time saved is reallocated by the case managers. The net EDM-related time savings from this small case manager study seems to be at least 105 minutes. This corresponds to 20% of 505 minutes available in the entire workday. We arrive at 20% as follows (note gains/losses based on average of post-EDM (t=1) and post-EDM (t=2) compared with pre-EDM): reduction in documenting paper mail & paper faxes (gain of 21.3%), reduction in paper-related activities (gain of 7%), reduction in other documentation activity (gain of 0.7%), and increase in EDM-specific activities (loss of 8.3%).

The 105 minutes saved on account of EDM seems to be reallocated as follows (note average of post-EDM (t=1) and post-EDM (t=2) used below): more time on action plans (see ACTIONPLAN activity group) (19 mins), more time on other case mgmt (such as financial notes (eg. reserving), payments, medical case management activity, recording statements) (see OTH CASEMGMT activity group) (11 mins), more time on communication activity (i.e. phone/e-mail/voicemail) (see COMM activity group) (54 mins), more time on in-person meetings (see MEETING activity group) (at least 15 mins) and more personal time (see PERSONAL activity group) (at least 6 mins). This is shown graphically in figure 3.

5.2 EDM Impact on Time Use: Office-Wide Case Manager Time Use Data Analysis

The office-wide case manager time use study yielded a matched dataset of 2905 observations pre-EDM, 2763 observations post-EDM (t=1) and 3125 observations post-EDM (t=2). The detailed results of the analysis for the matched sample of 26 case managers are shown in Table 2, which shows the arithmetic average of times spent on various activities. We also discuss briefly the results of the mean analysis on the full sample of case managers (not just the matched sample). Since means can be subject to outlier-effects, we also compute medians of times spent on various activities. The median analysis is presented in Table 3. Further, for completeness of analysis, we also show non-parametric analysis (or counts analysis) on the activities in figures 6a-6d. The counts analysis shows the percentage of case managers reporting an increase vs. percentage of case managers reporting a decrease in particular activities. For ease of comparison, we show both pre-EDM and post-EDM statistics in the same table.

Each of the activities in the mean times table (or Table 2) is labeled as part of one of 11 activity groups in column 6: DOC PAPER, ACTIONPLAN, OTH DOC, OTH CASEMGMT, COMM, MEETING, OTH PAPER, RIGHTFAX, EDM, OTH FILEWORK, PERSONAL. Below we discuss the key results (note all comparison statistics below are comparing average of post-EDM (t=1) and post-EDM (t=2) time use data with pre-EDM data).

From the pre-EDM time-use data, we observe that on average 7.8% of the time of the case managers was spent documenting paper mail and paper faxes (a form of routine labor input). Assuming that the case managers work for 8hrs and 15 minutes, this translates to approximately 39 minutes spent daily documenting paper mail & paper faxes (a form of *routine labor input*). This form of documentation activity reduced to 1.8% post-EDM, a reduction of 77%. This is generally consistent with what was observed in the four case manager time use study. However, note that the level of this type of documentation activity was much higher in the four case manager time use study. We of course would not expect the results to be the same across the two time use studies because of several differences between them. For one, there is a significant difference in the sample size (4 versus 26) between the two data sets. Also, the observations were taken by a single researcher in the four case manager time use study, while they were taken by the case managers themselves in the office-wide time use study. Nevertheless, given the significant difference between the two numbers for the documentation of paper mail and paper faxes activity, we sought to understand whether there was any systematic reason for the observed difference. We found out that many case managers were simply *not* posting medical as they did not have enough time at work; they would simply send the paper documents to paper file upon receipt. Many case managers would *not* do medical file posting at work during regular hours:

some would stay overtime or do it at home. This would explain the significantly lower percentage of time spent on file posting observed in the office-wide time use study. Paper-related activity (excluding documenting paper mail & paper faxes) went down dramatically from 7% to 4.8%, a reduction of 31%. This is also consistent with what was observed in the four case manager time use study.

As seen from Table 2, the key result again is that the level of documentation activity went down dramatically and time spent documenting seems to have been re-allocated towards significantly higher communication activity (a *non-routine cognitive labor input*). The documentation activity (composed of ‘DOC PAPER’ and ‘OTH DOC’ activity groups or specifically, documenting paper mail and paper faxes, writing journal entries, documenting claim screen/details) went down from 21.3% to 11.5% (a reduction of 46%), whereas communication activity (‘COMM’ activity group or specifically phone/voicemail/e-mail activities) went up from 26.4% to 32.5% (an increase of more than 23%). In particular, phone-based communication went up from 19% to 22.5% (an increase of 18%). The above results are again consistent with what was observed in the four case manager time use study.

As observed in the four case manager time use study, EDM introduces new activities in the post-EDM office-wide time use data. These EDM-related activities identified as part of the ‘EDM’ activity group in Table 2 took 7.6% of the time post-EDM. Of this 7.6%, 5.8% was devoted to new activities that had no close pre-EDM counterparts. Specifically, 5.8% of time was devoted to managing EDM inbox (which much like an e-mail inbox was continuously populated with new documents scanned into the system), uploading documents to EDM (case managers were supposed to upload electronically faxed documents to EDM themselves), completing EDM document properties (each EDM document had seven identifying properties for case managers to fill in) and linking journal entries to EDM documents.

Personal activities (see 'PERSONAL' activity group in Table 2) went up from 10.9% to 13.7% (an increase of 26%). Specifically, the activities in this group were personal break, lunch, and other personal time-off at work. EDM introduces some potentially productivity-enhancing, stress-reducing slack that is captured in the increase in the personal activities.

Time spent on in-person meeting activity went down from 10.9% to 5.3% (decrease of 51%). This is *not* consistent with what was observed in the four case manager time study, where an increase in in-person meeting activity was observed. However, given that all employees, including managers, had online access to documents post-EDM, there would be need for fewer in-person meetings.

We graphically present the key results of the activity analysis in figures 4a-4b. Clearly, communication activity (COMM: phone/e-mail/voicemail) shows increasing trend over time, whereas documenting paper mail & paper faxes (DOC PAPER) and other documentation activity (OTH DOC: documenting impact, writing journal entries, documenting claim screen/details) and other paper-related activities (OTH PAPER) show clearly declining trends over time.

For completeness, we present the mean time use analysis on the full sample of case managers. We have 53 case managers in the pre-EDM time use study, 46 managers in post-EDM (t=1) time use study and 56 case managers in the post-EDM (t=2) time use study. The results are shown in

Table 7. The results are consistent with what is observed in the matched sample. Documenting paper mail and paper faxes (a form of routine labor input) declined significantly. Paper-related activity (excluding documenting paper mail & paper faxes) also went down dramatically. Documentation activity (composed of 'DOC PAPER' and 'OTH DOC' activity groups or specifically, documenting paper mail and paper faxes, writing journal entries, documenting claim screen/details) went down whereas communication activity ('COMM' activity group or specifically phone/voicemail/e-mail activities) went up. In particular, phone-based communication increased. EDM introduced several new activities in the post-EDM state. Personal activities also went up significantly.

Since mean time analysis may be vulnerable to outlier-effect, we computed the median statistic as well. The detailed results of the analysis for the matched sample of 26 case managers are shown in Table 3, which shows the median of times spent on various activities. Each of the activities in the table is labeled as part of one of 11 activity groups: DOC PAPER, ACTIONPLAN, OTH DOC, OTH CASEMGMT, COMM, MEETING, OTH PAPER, RIGHTFAX, EDM, OTH FILEWORK, PERSONAL. All % reported in the table are medians. We show the medians from two time use studies (pre-EDM and post-EDM (t=1)). Below we discuss the key results (note all comparison statistics are comparing post-EDM (t=1) time use data with pre-EDM data).

Time spent doing documenting paper mail & paper faxes activity went to nil post-EDM. Time spent on communication activity (phone/e-mail/voicemail) goes up from 23.7% to 30.6% (increase of 29%). Time spent communicating on the phone goes up from 18.8% to 23.1%

(increase of 23%). Time spent on in-person meeting activity went down from 10.3% to 2.2% (decrease of 79%). Time spent doing personal activities goes up from 9.7% to 14% (increase of 44%). The median analysis results are broadly consistent with the results from the mean analysis.

Next, we perform counts analysis (an example of non-parametric analysis) on the activities. The results of the analysis are shown graphically in figures 6a-6d. In each of those figures, "Increase" refers to the % of all case managers reporting an increase in the activity post-EDM (t=1) and "Decrease" refers to the % of all case managers reporting a decrease in the activity post-EDM (t=1). Please note that the percentages reported for each activity (under Increase and Decrease) in the figures do not add up to 100% because for clarity we do not show percentage of case managers reporting "no change" in that activity. A significant percentage of case managers often may not report any change in the frequency of a particular activity because the activity is missing from both the pre- and post-EDM time use data sets.

Figure 6a shows that number reporting a decrease in documenting paper mail & paper faxes activity as well as writing journal entries greatly exceeds the number reporting an increase in those activities. Specifically, about 65% of all case managers reported a decrease in documenting paper mail/faxes activity, whereas about 23% reported an increase in the same activity and 12% reported no change in that activity. At the same time, the number reporting an increase in documenting action plan/initial assessment activity exceeds the number reporting a decrease in that activity.

Figure 6b shows that the number reporting an increase in phone/voicemail/e-mail activity exceeds the number reporting a decrease in those activities. The number reporting a decrease in in-person meeting activity greatly exceeds the number reporting an increase in that activity. Figure 6c shows that the number reporting an increase in personal activities (break and lunch) greatly exceeds the number reporting a decrease in those activities.

Figure 6d shows the effect of EDM on various activity groups. Clearly, the percentage of case managers reporting a decrease in documenting paper mail/faxes as well as in other documentation activities greatly exceeds the percentage of case managers reporting an increase. The percentage of case managers reporting an increase in communication (phone/voicemail/e-mail) and in personal activities greatly exceeds the percentage of case managers reporting a decrease. The percentage of case managers reporting an increase in “other case management” activities exceeds the percentage of case managers reporting a decrease. The results of this non-parametric analysis are broadly consistent with the results from the mean and median time analyses.

Next, we compute using the office-wide self-reported time use data the time savings that may be attributable to EDM and how the time saved is reallocated by the case managers. The net EDM-related time savings from this small case manager study seems to be at least 51 minutes. This corresponds to 10.1% of 505 minutes available in the entire workday. We arrive at 10.1% as follows (note gains/losses based on average of post-EDM (t=1) and post-EDM (t=2) compared with pre-EDM): reduction in documenting paper mail & paper faxes (gain of 6%), reduction in paper-related activities (gain of 2.2%), reduction in other documentation activity (gain of 3.9%), reduction in in-person meeting activity (gain of 5.6%) and increase in EDM-specific activities (loss of 7.6%).

The 51 minutes saved on account of EDM seems to be reallocated as follows (note average of post-EDM (t=1) and post-EDM (t=2) used below): more time on communication activity (i.e. phone/e-mail/voicemail) (see COMM activity group) (31 mins), more time on other case mgmt (such as financial notes (eg. reserving), payments, medical case management activity, recording statements of claimants) (see OTH CASEMGMT activity group) (3 mins), and more personal time (see PERSONAL activity group) (17 mins). This is shown graphically in figure 5.

When we examine data from our time use study of four case managers, we find a net time savings of 105 minutes per day attributable to EDM. In contrast, when we analyze data from the office-wide time use study in which we have a matched sample of 26 case managers, we obtain a net time savings of 51 minutes. Each result comes with its own set of caveats: the larger time use study result is based on a larger data sample and hence is potentially statistically more reliable; however, the observations there are recorded by the employees themselves and it is not possible to ascertain that the same standard of judgment has been used to code the various activities. Although we requested case managers to document comments for each of the activities on the observation sheets, the instructions were not always followed. Further, case managers varied in their diligence in recording reasonably detailed comments for the activities. Both of these factors limited our ability to correct mis-codings.

The difference between the net time savings numbers largely stems from the difference in the pre-EDM times spent on documenting paper mail and paper faxes in the two time use studies. While the pre-EDM four case manager time use study indicated that 21.3% of time was spent on documenting paper mail and paper faxes, the office-wide time use study indicated that only 7.8%

of time spent on the same activity. This number is critical to the net time savings calculations. As already mentioned, in our efforts to find out the reason behind the discrepancy, we found out that many case managers were simply *not* posting medical documents as they did not have enough time at work; they would simply send the paper documents to paper file upon receipt. Many case managers would *not* do paper medical document trasnscription at work during regular hours: some would stay overtime or do it at home. These factors would directly impact the time recorded for the particular documentation activity in the pre-EDM state.

The four case manager study, albeit small, is potentially more accurate as all observations were taken by a single person and hence calibration error is minimized. In addition, the pre-EDM survey indicated that the average time spent transcribing paper medical reports was 103 minutes, which was much closer to what was observed in the smaller time use study.

5.3 EDM Impact on Time Use: Survey Data Analysis

The survey provided useful data to triangulate the results of EDM impact on time use as well as data to assess EDM-related time savings that would not be easy to capture through a time use study. According to the pre-EDM survey, the average time spent transcribing paper medical reports was 103 minutes, which corresponded remarkably well with what was observed in the four case manager time-use study. Post-EDM the time spent typing in medical reports declined to 17 minutes, a statistically significant change (Note we tested statistical significance of difference between pre-EDM and post-EDM numbers obtained from the surveys using two-sample unequal variance t-test). Also, pre-EDM the average time spent typing in legal documents was 27.8 minutes, which declined to 13.6 minutes post-EDM. The number of times per week a case manager would need to go to the filing area to retrieve a paper file declined from

6.3 (pre-EDM) to 2.3 (post-EDM), a statistically significant decline. Notably, the time to search for the desired document in the electronic claim file is only 20.7 *seconds* as opposed to 18.2 *minutes* pre-EDM with paper files. The number of paper faxes that a case manager would send per week declined from 9.2 (pre-EDM) to 4.7 (post-EDM), a statistically significant decline. This represents significant time savings as it would be quite time-consuming to prepare and send a paper fax. Pre-EDM, to send a paper fax, a case manager would need to print a fax intro sheet, prepare the sheet by filling out the relevant fields, print the document, attach the fax sheet to the printed document and place the prepared fax in the outgoing fax bin or physically walk to the fax machine to send the document. All of these steps combined would make the activity of sending a paper fax in the pre-EDM world significantly time-consuming. At least 60% of the survey respondents said that post-EDM, the time to send documents to the internal human resources such as field nurses, field investigators, and field legal staff had declined in general because these individuals now had online access to the electronic documents. The above survey results on perceived time savings are broadly consistent with the time savings observed in the time use studies. Further, these results amplify the time savings attributable to EDM obtained through analysis of time use data, as the time use methodology may fail to capture savings such as those related to searching or sending paper faxes.

5.4 EDM Impact on Communication Patterns: Survey Data Analysis

At least 36% of the survey respondents said that post-EDM, the number of times internal human resources such as field nurses, field investigators and field legal staff contacted case managers to send them documents had declined in general because these individuals now had online access to the EDM documents and would not need to call or e-mail the case managers to send them the documents. At least 20% of the respondents said that time spent communicating with doctors and claimants had increased post-EDM. Since the majority of case manager e-mails/phone calls seemed to be externally bound (i.e. to doctors and claimants), the reduction in calls/e-mails from internal employees does not compensate for the increase in calls/e-mails to external parties. This is consistent with the higher overall level of communication activity (phone/voicemail/e-mail) observed in the time use studies.

75% of the respondents said that post-EDM, number of e-mails received had increased. From the viewpoint of the case managers, this was a negative unanticipated consequence of EDM. With the rollout of the technology, the management at the insurance firm decided to make the work process change that medical providers and other parties interested in faxing documents to the case managers would be encouraged to send all correspondence to the RightFax number. All faxes sent to the RightFax numbers would pop up as e-mails with attachments in the email Inboxes of the case managers. The % of e-mails received from medical providers/doctors had increased from 17% to 28%, a statistically significant change. The % of e-mails received from customers had *decreased* from 41% to 30%, also a statistically significant change.

44% of the survey respondents said that post-EDM, the number of e-mails sent had also increased as case managers now had new ability to conveniently send faxes as e-mail attachments right from their computer desktops.

5.5 Econometric Analyses

As mentioned in the Introduction, we have here in this field research study a large quasi-experiment, in which the time of application of the intervention (in our case the EDM technology) to various entities (in our case the offices) is “as if” it was randomly determined i.e.

in which randomness is introduced by variations in specific office circumstances such as timing of the implementation of the technology that make it appear as if the technological treatment was randomly assigned to the offices. This allows us to use the OLS (Ordinary Least Squares) regression technique to assess the causal impact of EDM by incorporating the treatment variable as a regressor in the model. If the treatment variable is “as if” randomly determined, OLS is an unbiased estimator of the causal effect (Stock and Watson, 2007).

Specifically, we use the differences-in-differences regression technique to isolate the impact of EDM intervention on various performance and cost metrics. Differences-in-differences (D-in-D) is an effective technique to isolate the effect of an intervention/treatment (such as the introduction of a new technology) on the dependent variable of interest. The D-in-D estimator is the difference between the "average change in the variable of interest for the treatment group or the group that received the technological intervention" minus "the average change in the variable of interest for the control group or the group that did not receive the technological intervention." We use time fixed effects as well as office fixed effects in testing whether EDM (or treatment which appears as an independent variable in the regression) has any impact on the performance metric (or the dependent variable). The inclusion of office fixed effects and time fixed effects removes omitted variable bias resulting from exclusion of unobserved variables that vary across offices but are constant over time and variables that vary over time but are constant across offices. The mathematical representation of the general model that we estimate is presented below:

$$Y_{it} = ß_0 + ß_1X_{it-l} + ß_2\mathbf{W}_{it} + \gamma_2D2_i + \ldots + \gamma_nDn_i + \delta_2B2_t + \ldots + \delta_{12}B12_t + \eta CY + u_{it}$$

where $ß_0$, $ß_1$, $ß_2$, γ_2, …, γ_n, δ_2, …, δ_{12}, η are regression coefficients that need to be estimated, i = 1,2,…,n indicates the office, t = 1,2,…, 12 indicates the monthly time period, Y is the dependent variable, X_{it-l} is the binary treatment variable X_{it} lagged 'l' periods (X_{it} equals 1 if office i has received the treatment by time t and zero otherwise), $\mathbf{W}_{it}$ is a vector of pertinent control variables, $D2_i \ldots Dn_i$ are the binary variables for the offices, $B2_t \ldots B12_t$ are the binary variables for the months (to control for seasonal time effects), CY is the binary variable for the calendar year which equals 1 for year 2006 and u is the error term. Note binary variables for office 1 and time period 1 are excluded from the regression model to eliminate perfect multi-collinearity. Also note that the treatment variable in the model is lagged as appropriate, as EDM may have the maximum impact on a particular metric after some time. The lags may differ for different models as EDM may be expected to impact different metrics at different time periods.

We found that introduction of EDM is associated with the following effects on the performance metrics:

1) improvement in ability to meet or beat current year closure rate monthly goals that are dynamic in nature. This effect is observed at a 1-period lag and is statistically significant. (number of observations N=192) (see Table 4a). The logistic regression result implies that EDM increased the predicted log odds of meeting/beating current year closure rate goals by 1.78. Equivalently, EDM multiplied predicted odds of meeting/beating current year closure rate goals by $e^{1.78}$=5.93.
2) increase in the current year closure rate. This effect observed at a 1-period lag is however not statistically significant (number of observations N=192) (see Table 4a). The regression result implies a 0.9% increase in the current year closure rate associated with the implementation of EDM in the offices.

3) decrease in the previous clear closure rate. This effect observed at a 1-period lag is however not statistically significant (number of observations N=184) (see Table 4a).
4) decrease in the YTD avg. amount paid for physical therapy on a per-claim basis. This effect observed at a 3-period lag is significant at the 1% level (number of observations N=176) (see Table 4b). The regression result implies a reduction of $111 or 19% drop in the YTD average amount paid for physical therapy on a per-claim basis that is associated with the implementation of EDM in the offices. Interestingly, we also see higher medical management activity by the case managers. From the analysis of claim steps in the matched sample N=26 time use data, we observe approximately a 19% increase in medical management claim step activity (based on comparison between pre-EDM estimate and average of the post-EDM t=1 and t=2 estimates).
5) decrease in the YTD avg. amount paid for chiropractor care on a per-claim basis. This effect observed at a 2-period lag is significant at the 1% level (number of observations N=176) (see Table 4b). The regression result implies a reduction of $154 or 28% drop in the YTD average amount paid for chiropractor care on a per-claim basis that is associated with the implementation of EDM in the offices. Interestingly, we also see higher medical management activity by the case managers.
6) increase in the claim service team professionals (or case managers) retention rate (see Table 4b). This effect observed at a 1-period lag is significant at the 1% level (number of observations N=168). The regression result implies a 7% increase in the retention that is associated with the implementation of EDM in the offices.
7) decrease in YTD loss leakage (i.e. losses associated with leakage or overpayments when best practices associated with medical management and disability management are not

followed). This effect observed at a 4-period lag is however not statistically significant (number of observations N=176) (see Table 4c). The regression result implies a 4% decrease in the loss leakage that is associated with the implementation of EDM in the offices. Interestingly, we also see higher medical management activity by the case managers.

8) increase in TTD days (12 months rolling average) (i.e. number of days of temporary total disability for which disability benefits have to be provided). This effect is observed at a 4-period lag and is statistically significant at the 5% level (number of observations N=192) (see Table 4c). The point estimate though statistically significant implies only a 2% increase in TTD days that is associated with the implementation of EDM.

The detailed fixed effect pooled regressions are shown in tables 4a-4c. Note that the standard errors reported are heteroskedasticity-robust Huber/White standard errors. Further, note that though we did use office dummies, we do not show the coefficients corresponding to those dummies for sake of confidentiality. The variable names used in the models (see tables 4a-4c) are: EDM TREAT, which is the binary treatment variable appropriately lagged, TOT. STAFF, which is the total claim processing staff strength of the office, INC. CLAIM, which is the total number of incoming claims.

The above effects of EDM on various performance metrics are consistent with expectations. Although the effect of EDM on the current year closure rate is not statistically significant, the point estimate is positive and more importantly the ability to beat current year closure rate goals is positively impacted by EDM (and this effect is statistically significant). Most cases can be closed when the claimant returns to work in modified duty or full duty positions. Returning the claimants back to work in such positions often requires critical communication on the part of the case managers with all the three key parties involved: medical providers or doctors, customers or the employers of the injured workers and the claimants. We do know from the time use studies that EDM greatly frees up time to do this important value-adding communication activity and we do see level of this activity jump post-EDM. Importantly, most of the current year cases have most of their documents (such as medical reports) in the electronic form. Access to these documents is much easier and faster with EDM. This improves the speed of communications. From the survey, we know from the case managers perspective that one of the top three perceived benefits of EDM is faster access to claim documents (the other two being less time documenting paper mail, and better information sharing with other groups/individuals). Hence EDM would be expected to positively impact the ability of offices to meet/beat their monthly current year closure rate targets.

Just as the effect of EDM on current year closure rate is positive, its effect on previous year closure rate is negative (note the point estimate is negative although the effect is again not statistically significant). Given that previous year closure rate measures the closing of cases opened in years prior to the current year, most of these cases do not have their documents in the electronic form (note that the offices did not attempt to migrate any of the prior year old cases to EDM). Even though some of the freed up time because of EDM would be devoted to increased communication activity related to the older cases, follow-up activity and communication in general is slowed or held up because the documents belonging to those cases are not easily accessible. Hence, EDM would not be expected to positively impact previous year closure rate.

The above findings on closure rates are consistent with findings in previous research, in which adoption of new technologies has been shown to reduce production time in the stage of production where the technology is of value (Bartel et al 2004, p. 220). Further, the positive impact on current year closure rate and the negative impact on previous year closure rate seems to reduce the likelihood of Hawthorne effect, which refers to the effect of observation on people's behavior or performance.

It is interesting to see the statistically significant effects of EDM on physical therapy costs and chiropractor care costs on the claims. The reduction in these costs critically depends on the ability of case managers to manage medical treatment of claimants and ensure that only treatment that is medically necessary is covered. The claim step process that case managers engage in to achieve medical cost savings is technically labeled within the firm as "medical management." Medical management requires timely utilization of various medical resources available to the case managers to manage the medical costs and timely and regular follow-up with treating doctors and the claimants. The regular follow-up allows the case manager to determine whether the claimant is making objective progress. For example, in the context of physical therapy, it is important for the case manager to determine whether the injured worker is making objective progress in the therapy process. In the context of chiropractor care, it is important for the case manager to check whether improvement is evident within two weeks of start of care. EDM frees up time to engage in value-adding medical management, which crucially involves communication activity (note that we see evidence of higher communication activity from the time use studies). Further, from the survey, we know that approximately 48% of the respondents said that time freed up because of EDM allowed them to spend more time to follow-up on activities outlined in their action plans. Importantly, EDM allows for chronologically sorting of documents that allows case managers to quickly and accurately assess whether objective progress in the treatment program is being made, and if any changes in doctors/medications/therapy would help. The finding that EDM has a highly positive impact on the ability of case managers to reduce physical therapy costs and chiropractor care costs is especially significant in light of data from the interviews in which case managers revealed that pre-EDM they often did not document/post therapy notes into the claim files as they did not have time to do so. Lack of documentation of these notes would make it more likely for case managers to miss important warnings and chances to reduce therapy costs.

The positive effect of EDM on the retention rate of the case managers is also interesting. From the interviews, we do know that EDM has cut down on overtime work for case managers. Also, pre-EDM many case managers would take home work, especially documenting paper mail type of work. The documenting mail work would be perceived as low-skilled "secretarial work" and not the real and more interesting case management work that case managers wanted to do. This could be frustrating to some of the case managers. Post-EDM, this type of low-skilled "secretarial work" was dramatically reduced. EDM also resulted in a dramatic reduction in paper documents sitting on the desks of the case managers. Pre-EDM, the paper documents would simply pile up on the work desk, waiting for the case manager to "work" them. The rising pile of paper documents on the desk would cause mental frustration to the workers. EDM helped case managers stay more organized and removed their feeling of being overwhelmed by all the paper on their desks. Post-EDM, the number of backlogged documents sitting on the desk showed a dramatic drop consistent with the 88% of survey respondents saying that the number of inches of paper that they were receiving daily had declined. The average number of inches of paper received daily declined from 2.55 inches to 1.92 inches, a statistically significant drop. Based on data from the survey, the distribution of backlogged documents pre- and post-EDM is shown graphically in figure 7. A comparison of the two charts clearly indicates that the distribution of backlogged documents has dramatically shifted to the left (i.e. the number of backlogged paper documents on the desk has significantly declined). Lastly, the time use studies indicate higher level of personal time at work, which would imply lower level of work-related stress. All of the factors above would indicate that EDM made work more pleasant for the case managers, and this is reflected in the positive impact on the retention rate.

Finally, the EDM effects on the loss leakage and the temporary total disability metrics are also interesting. Though the effect on the loss leakage metric is not statistically significant, the point estimate is negative and consistent with expectations. As indicated previously, loss leakage captures the overpayments when best practices associated with medical management and disability management are not followed, where medical management and disability management are technical terms for processes used within the firm to describe case direction that results in medical cost savings and indemnity savings respectively. Controlling or reducing loss leakage critically depends on the ability of the case managers to stay on top of their cases and do continuous follow-up with medical providers, customers and claimants. Communication activity is key and timely assigning helpful resources such as nurses and investigators on the files is paramount to controlling leakage. The freed up time because of EDM allows higher level of value-adding communication activity and more time for thoughtful case management and investigation. Importantly, EDM also allows case managers to chronologically sort documents and more easily/quickly detect what is known as “injury creep” (similar to “scope creep” in IT projects), in which the treatment currently being paid for is for an injury that is not related to the original *covered* injury at work. Further, EDM makes timely receipt of important documents (such as claimant work status reports from doctors) more likely as external parties such as doctors simply fax them to the e-fax numbers of the case managers post-EDM. This makes it easier for case managers to cut off benefits in a more timely fashion, reducing possible overpayments. Given above reasons, EDM would be expected to reduce loss leakage. The higher closure rate and higher TTD (or number of temporary total disability days for which indemnity benefits are provided) are consistent. Since closure rate is the paramount performance metric, the case managers in their efforts to close out the cases may, after negotiating with the customer (or the employer of the injured worker) and the injured worker, pay out a higher number of disability days.

The fixed effect models yield consistent estimates; however, we might be able to get more efficient estimates by employing a random effects model. We have to, however, check that the random effects coefficients are not systematically different from the fixed effects coefficients, which are consistent. We do this by performing the Hausman test (Hausman, 1978), which allows us to test the null hypothesis that the fixed effects estimates are not systematically different from the random effects estimates. A high Hausman statistic would reject the null hypothesis, in which case we should would retain the fixed effects estimates, which are consistent. If we do not reject the null hypothesis, we would retain the random effects estimates, which are both consistent and efficient under the null. Table 6a shows the coefficients on the EDM TREAT variable obtained using fixed effects and random effects panel data estimation techniques and the corresponding Hausman statistics. The selected fixed effects or random effects coefficient is highlighted in bold in the table. We performed random effects GLS regressions for the sake of thoroughness, but found no highly notable differences between the fixed effects and the random effects coefficients.

We find that introduction of EDM is associated with the following effects on the cost metrics:

1) increase in next-day air courier costs (an increase of $2875 per month or 151% increase attributable to EDM). This effect is observed at a 1-period lag and is significant at the 1% level (number of observations N=192) (see Table 5a).
2) decrease in outside services fees for claims-related processing such as claim mail sorting, filing, indexing, and photocopying. The magnitude of the decrease is $20174 per month or a 38% decrease attributable to EDM. This effect is observed at a 4-period lag and is significant at the 1% level (number of observations N=120) (see Table 5a).
3) decrease in costs associated with mailing services (decrease of $2552 per month or 14% decrease attributable to EDM). Note that these costs cover all departments including claims. This effect is observed at a 5-period lag and is significant at the 1% level (number of observations N=192) (see Table 5a).
4) decrease in costs associated with offsite storage and maintenance of hard copy records (decrease of $849 per month or 34% decrease attributable to EDM). This effect is observed at a 4-period lag and is significant at the 1% level (number of observations N=168) (see Table 5b).

5) decrease in costs associated with incoming 800 number calls (decrease of $152 per month or 5% decrease observed with no lag; the point estimate is however not statistically significant (number of observations N=192) (see Table 5b)).
6) increase in costs associated with telephone usage (increase of $872 per month or 16% increase observed at a 1-period lag; the point estimate is however not statistically significant (number of observations N=192) (see Table 5b)).

The above effects on the cost metrics are in general consistent with expectations. When EDM was rolled out, all medical documents were required to be mailed next day air to the scanning service provider from the offices. This would have resulted in a spike in next day air shipping costs.

EDM also eliminates much of the paper-related processing that was previously outsourced to the on-site vendor. Thus, costs associated with paper handling would be expected to go down. Clearly, the functions associated with paper file handling, sorting and filing are minimized to a great degree with the implementation of EDM. Labor associated with those functions is substituted away by the new technology. In our main field research site, for example, we saw approximately 60% reduction in the labor force associated with the paper file handling functions. Further, associated with EDM implementation is the business process change that customers and medical providers are now encouraged to fax to case manager "Right Fax" or "e-Fax" numbers and not mail or paper-fax those documents to the offices. Thus, overall costs associated with mailing services should go down.

Paper documents are stored with the scanning service provider only for a short period of time before they are destroyed and closed files shipped to off-site storage service provider are also destroyed after some time. Thus, over time costs associated with offsite storage and maintenance of hard copy records should decrease, as more and more files are available only electronically.

The effect on incoming 800 number calls is uncertain; however it may be reasonably expected to go down as calls from customers might be expected to go down (because they now have access to many of the electronic documents). Consistent with increased phone-based communication activity observed with increased medical and disability management activity, overall costs associated with telephone usage might be expected to increase.

As with the performance or productivity metric regressions, we performed random effects GLS regression with the cost metrics. Table 6b shows the coefficients on the EDM TREAT variable obtained using fixed effects and random effects panel data estimation techniques and the corresponding Hausman statistics. Many of the Hausman statistics reported here are negative, meaning that the variance difference between the fixed effects coefficients and the random effects coefficients is not positive semi-definite. This is likely because of the finite sample that we have, in which the asymptotic assumptions of the Hausman test are not met. When we have such a situation, we just select the fixed effects estimates, which we know to be consistent. The selected fixed effects or random effects coefficient is highlighted in bold in the table. Though we performed random effects GLS regressions for the sake of thoroughness, there are no highly notable differences between the fixed effects and the random effects coefficients.

We now show a simple cost-benefit analysis of EDM at the insurance firm.

Costs:

There were one-time sunk costs associated with the implementation of EDM: business team costs associated with management and coordination of the overall implementation effort of $1.05 million, IT development costs (including development costs, infrastructure costs, etc.) of $4.37 million (over two years 2004 and 2005).

The average recurring IT costs associated with EDM (mostly maintenance and infrastructure costs) are expected to be about $3.12 million (average of 2006-2010 forecasted figures). Further, the variable cost of scanning and indexing medical and non-medical paper documents is expected to be about $3.4 million per year.

Further, there are additional next-day air courier costs attributable to EDM. This works out to about $0.28 million per year (=2875*12*8). There are additional costs associated with telephone usage of $0.08 million per year (=872*12*8). Thus, the total recurring costs associated with EDM is expected to be about $6.9 million per year.

Benefits:

There are many benefits that can be quantified in terms of dollars and many that cannot. Benefits quantifiable in dollars are as follows:

EDM is associated with a decrease in outside services fees for claims-related processing such as claim mail sorting, filing, indexing, and photocopying. This works out to about $1.94 million savings per year (=20174*12*8)

EDM is associated with a decrease in costs associated with mailing services. This works out to about $0.24 million savings per year (=2552*12*8). This would be an overestimate of the actual benefit as the mailing services cost data is for all units, including worker compensation claims, where EDM was rolled out.

EDM is associated with a decrease in costs associated with offsite storage and maintenance of hard copy records. This works out to about $0.08 million savings per year (=849*12*8).

EDM is associated with a decrease in costs associated with incoming 800 number calls. This works out to about $0.01 million savings per year (=152*12*8).

The total $ quantifiable benefits work out to about $2.3 million. Of course, there are many intangible benefits associated with EDM that were hard to quantify in terms of dollars given the data that was available to us. These other benefits would include an improvement in case closure rate, improvement in customer retention because of improved ability to deliver savings in physical therapy and chiropractor care to the customer, and improved case manager retention rate. We would suspect that the dollar value of these hard-to-quantify benefits to be the difference between $6.9 million (recurring costs of EDM) and $2.3 million (recurring $-quantifiable benefits of EDM).

6 Discussion

We have used a four-pronged research study to holistically assess the causal impact of an enterprise IT (EDM) on the workers compensation division of a large insurance firm. Through pre- and post-EDM interviews, time use studies, surveys and importantly analysis of office-level objective performance and cost data, we have qualitatively and quantitatively documented the causal impact of a specific IT application, electronic document management technology, which despite its salience in the context of information management has not been studied much in the information systems field. Through our "insider econometrics" empirical study (Bartel et al, 2004), in which we focused on the operations of a single firm, we assessed the impact of EDM at the process and office level. Insider insights obtained through direct contact with the managers and information workers were key in this type of "insider econometrics" study, as they reduced concerns about endogeneity bias and omitted-variable bias in the results (Bartel et al, 2004). Since we focus on a single firm, the results about digitization of work are applicable to the firm studied and future research may need to study other settings to obtain broader generalizibilty; in any case, we believe that the approach that we employ may be widely applicable in future research.

We demonstrated how EDM changed task composition at the individual level. EDM led to a significant decline in the substitutable routine labor input and an increase in non-routine cognitive labor input at the information worker level. Prior to EDM, the information workers in our setting would need to supply a significant amount of routine labor input for their work: they would need to type verbatim large sections of documents such as medical reports that were available only in paper form. Post-EDM, the paper documents were all scanned and made available in the electronic form. This obviated the need for the information workers to manually transcribe the paper documents. Thus, EDM directly impacted the supply of routine labor input, which was substituted away by the technology. In reducing the time to complete various routine tasks, EDM made time available to do other value-adding tasks that involved interaction and higher-order cognitive and analytic skills. With the deployment of IT, some "slack" developed, which allowed the information workers to "pack" in more units of value-adding tasks. This "IT-enabled slack" led to productivity enhancements in two distinct ways: first, as described above, the slack allowed information workers to spend more time on value-adding communication activities, which directly led to productivity and performance improvements. Secondly, "IT-enabled slack" allowed for more personal time relaxing/resting at work or at home (less overtime), which in turn led to less stressed-out, happier and more productive employees.

EDM also brought about an outward shift in the supply of routine informational inputs which complemented the non-routine cognitive labor input (such as interactions and communications) in the sense that they increased the productivity of workers performing nonroutine tasks that demanded those inputs. Pre-EDM information workers would transcribe only certain sections of the paper documents that they deemed salient for their work purposes i.e. information in the paper documents was not completely captured. Information workers exercised significant discretion in deciding which pieces of information to type in verbatim into the information capture system, because there was simply not enough time in the day to transcribe complete copies of the documents. Information workers would apply different lenses to look at the same document. Thus, pieces of information interpreted to be important by one information worker may not be captured by another worker, who interpreted them to be less important. The incomplete information entered into the system was thus of a lower quality. Post-EDM, complete copies of the documents were available in electronic form. No information was lost. In other words, post-EDM, both the *quantity* and *quality* of routine informational inputs significantly increased. This improvement in both the quantity and quality of the routine informational inputs increased the productivity and performance of workers performing non-routine tasks that demanded those inputs. We demonstrated the impact of shift in task composition of the workers on productivity and performance metrics at the office level

Mukhopadhyay et al (1995) have proposed several benchmarks to evaluate IT impact research. The first benchmark is theoretical foundation of the research. Our research has a strong theoretical foundation in the task model proposed by Autor et al (2003), which we described in detail in the Theory section above. The second benchmark concerns methodological issues. Our access to a quasi-experiment which makes available experimental controls alleviates the problem of confounding factors affecting the results. Further, the fact that this is an "insider econometrics" study, in which we gathered insider insights through direct contact with managers and information workers, reduces concern about endogeneity bias and omitted-variable bias in the results (Bartel et al, 2004). The third benchmark concerns modeling issues. Our analysis is at the application level, which eliminates aggregation-related issues associated with firm-level analyses (Mukhopadhyay 1997b). The fourth benchmark concerns the quality of data. We had unprecedented access to gather primary data through firm databases, firm reports and manuals, employee observations and interviews. Given that the firm collected the performance data through fairly-long established methods and used them for appraisals and planning, it is safe to assume that the quality of data is high.

7 Conclusion

We make several contributions in this research study. First, our research contributes to the IT impact literature by documenting the significant impact of a specific IT application, electronic document management, not yet examined sufficiently empirically in the economics of information systems literature despite its salience in the context of information management. Second, we demonstrate using a detailed empirical study how digitization of work changes task composition at the individual information worker level. We also show, at the information worker level, that digitization of work leads to a decline in the substitutable routine labor input and an increase in non-routine cognitive labor input, and that this non-routine cognitive labor input is an economic complement to digitization of work. Third, we unpack the black box of IT impacting performance and uncover a new micro-level mechanism as to how exactly IT can lead to significant payoff, especially in terms of information worker productivity. We show how with the deployment of IT, some "slack" may develop, which would allow the information worker to "pack" in more units of value-adding tasks such as communication activities. This "IT-enabled slack" is the new construct that we propose to add to the literature. Fourth, we contribute methodologically to the process perspective in the IS literature by using time use studies and differences-in-differences econometric analyses to assess the impact of EDM at the activity and process level. Given the spectacular variety of IT applications and the great need to document the precise causal impact of IT at a micro-level, there is a pressing need for application-specific, differences-in-differences quasi-experimental empirical studies. Our research study addresses that need by doing a rigorous differences-in-differences econometric analysis of the impact of EDM technology in a quasi-experimental setting. Fifth, given the diversity of IT applications and the lack of application-specific studies that use primary longitudinal data to look at the lagged effect of IT, we contribute to the IT impact literature by collecting panel data and analyzing the lagged effects of EDM technology on various performance and cost metrics.

8 Table and Figures

Table 1. Mean Time Use analysis on matched sample N=4 Single Customer Case Managers

*Note all % are means or arithmetic averages.

		PRE-EDM (N=4)					POST-EDM avg of (t=1) (N=4), (t=2) (N=4)	
Org. Category	**Activity**	**cat.**	**act.**	**activity%**	**ACTIVITY GROUP**	**%**	**ACTIVITY GROUP**	**avg %**
Doc	Sorting Incoming Mail	1	1	1.3	OTH PAPER			
Doc	Documenting Paper Mail + Paper Faxes	2	1	21.3	DOC PAPER	21.3	DOC PAPER	0.0
Doc	Documenting Action Plan/Initial Assessment	2	3	6.6	ACTIONPLAN	7.2	ACTIONPLAN	10.9
Doc	Writing Journal Entries	2	4	9.1	OTH DOC	9.7	OTH DOC	9.0
Doc	Financial Notes	2	5	1.9	OTH CASEMGMT	7.3	OTH CASEMGMT	9.4
Comm	Phone	3	1	22.5	COMM	28.4	COMM	39.1
Comm	Voicemail	3	2	1.3	COMM			
Comm	E-mail	3	3	4.7	COMM			
Comm	In-person meeting	3	4	2.5	MEETING	2.5	MEETING	7.0
Comm	Sending Paper Fax	3	5	0.6	OTH PAPER	9.1	OTH PAPER	2.1
Comm	Putting Together Paper Items to Mail / Fax	3	7	0.6	OTH PAPER			
Comm	Manage EDM Inbox (Complete/Forward Notifications)	3	9	0.0	EDM	0.0	EDM	8.3
Filework	Accessing Paper File	4	1	0.6	OTH PAPER			
Filework	File Sorting/Removing Duplicates	4	2	0.0	OTH PAPER			
Filework	Copying Files	4	3	1.3	OTH PAPER			
Filework	Electronic Formwork	4	4	1.3	OTH FILEWORK	2.6	OTH FILEWORK	0.6
Filework	Paper Formwork	4	5	0.0	OTH PAPER			
Filework	Payments	4	6	1.3	OTH CASEMGMT			
Filework	Printing from Systems (ExPrs, EDM, Etc.)	4	7	1.3	OTH PAPER			
Filework	Closing File from System	4	8	1.3	OTH FILEWORK			
Filework	Accessing EDM File	4	9	0.0	EDM			
Filework	Dragging & Dropping documents/right-faxes to EDM	4	11	0.0	EDM			
Filework	Complete EDM Document Properties	4	13	0.0	EDM			
Case Mgmt	RTW Plans	5	6	0.6	ACTIONPLAN			
Case Mgmt	Making decision to accept/reject referral	5	9	0.0	OTH CASEMGMT			
Case Mgmt	Medical Management	5	8	4.1	OTH CASEMGMT			
Case Mgmt	Recording Statements	5	11	0.0	OTH CASEMGMT			
Case Mgmt	Documenting Claim Screen / Details	5	12	0.6	OTH DOC			
Case Mgmt	Reviewing Paper Files	5	13	1.6	OTH PAPER			
Case Mgmt	Reviewing EDM Files	5	14	0.0	EDM			
Personal	Break	6	1	1.9	PERSONAL	11.3	PERSONAL	12.4
Personal	Lunch	6	2	9.4	PERSONAL			
Personal	Other	6	4	0.0	PERSONAL			
Administration	Printing / Stapling Incoming Right Faxes	7	1	0.6	OTH PAPER			
Administration	Drop Filing (both picking out and putting away docs)	7	8	1.3	OTH PAPER			
Other	Other Task	9	1	0.6	OTHER			

Figure 1a. Pre-EDM vs. Post-EDM Time Use (4 Case Manager/Single Customer Pod)

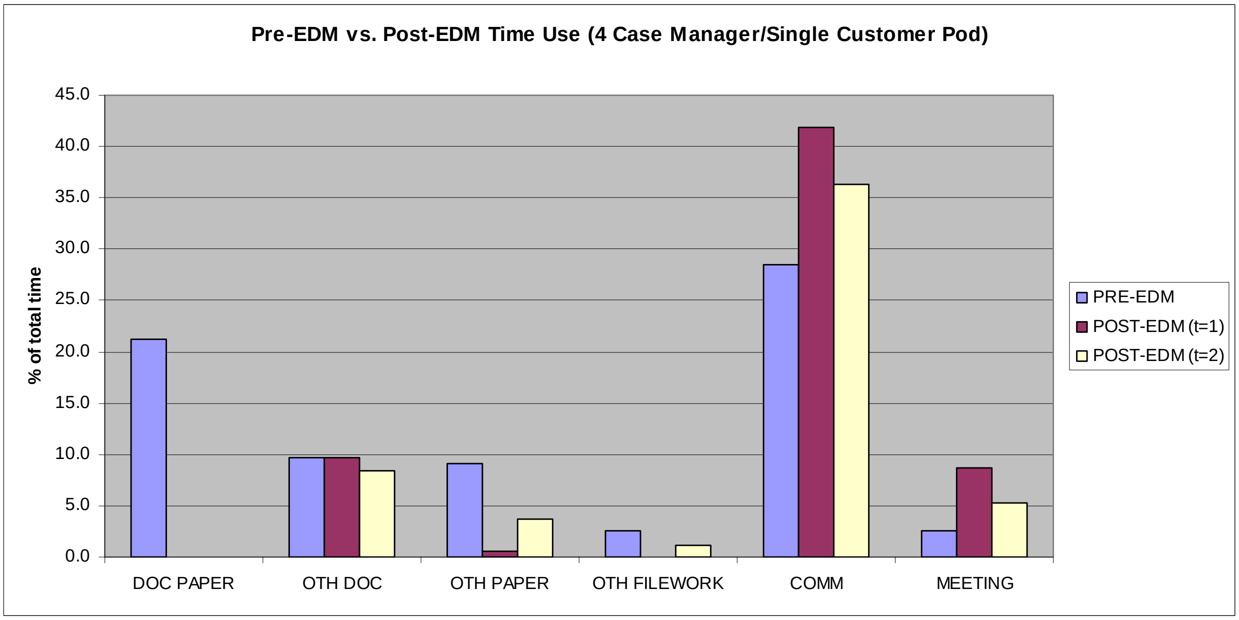


Figure 1b. Pre-EDM vs. Post-EDM Time Use (4 Case Manager/Single Customer Pod)

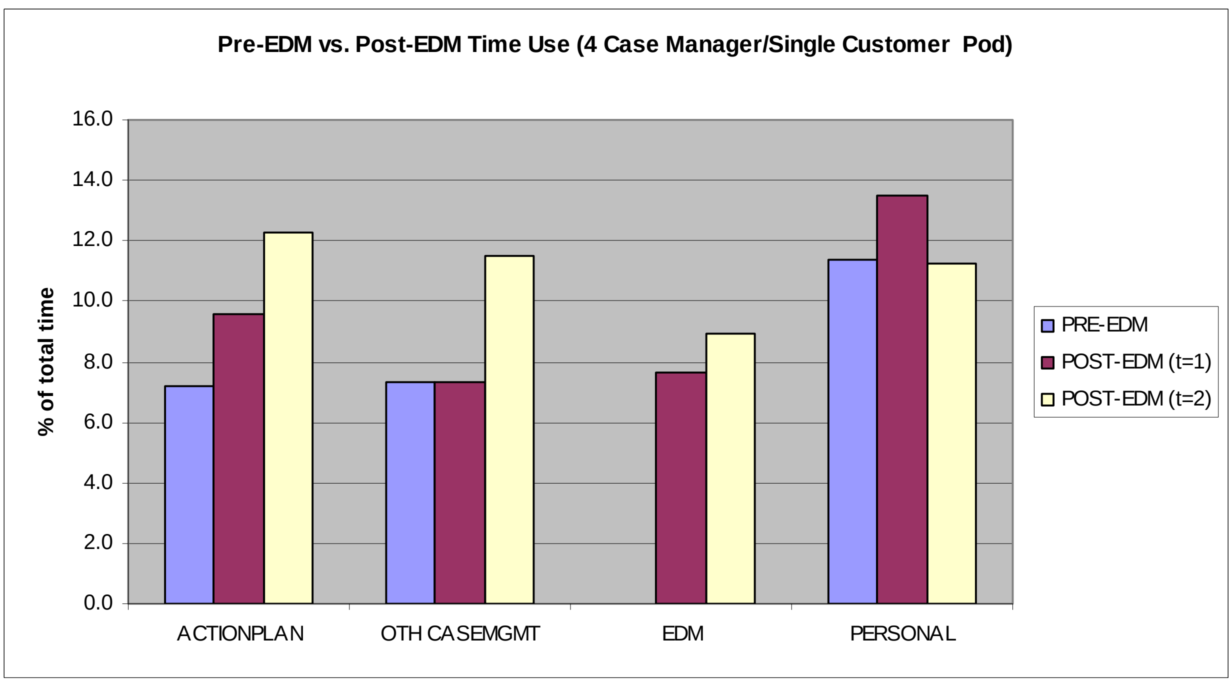


Figure 2a. Pre-EDM vs. Post-EDM Journal Entries (4 Case Manager/Single Customer Pod)

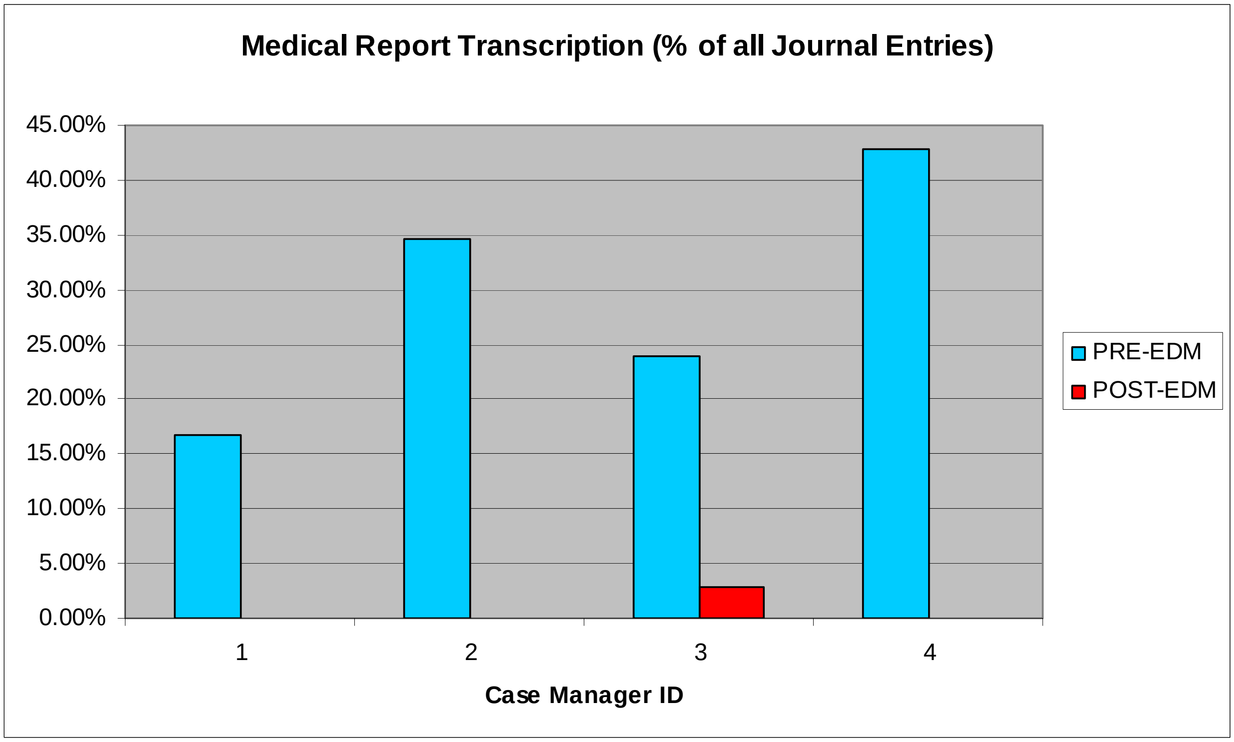


Figure 2b. Pre-EDM vs. Post-EDM Journal Entries (4 Case Manager/Single Customer Pod)

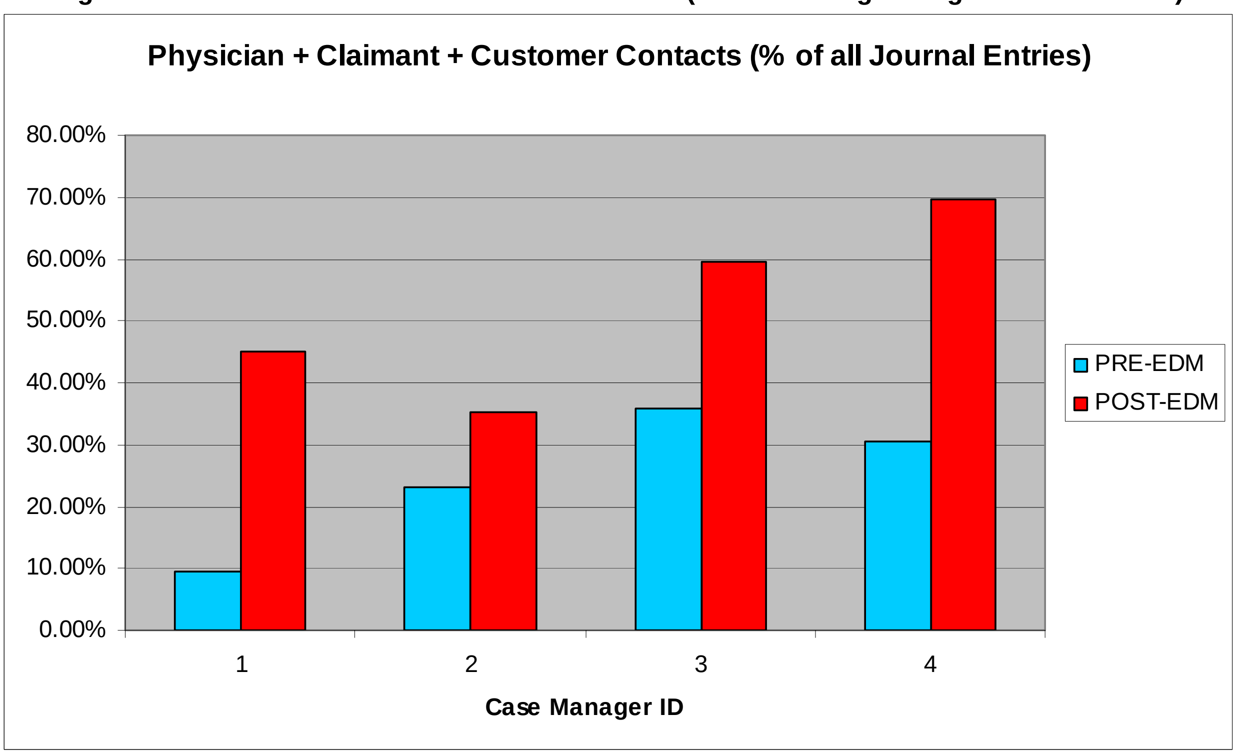


Figure 2c. Pre-EDM vs. Post-EDM Journal Entries (4 Case Manager/Single Customer Pod)

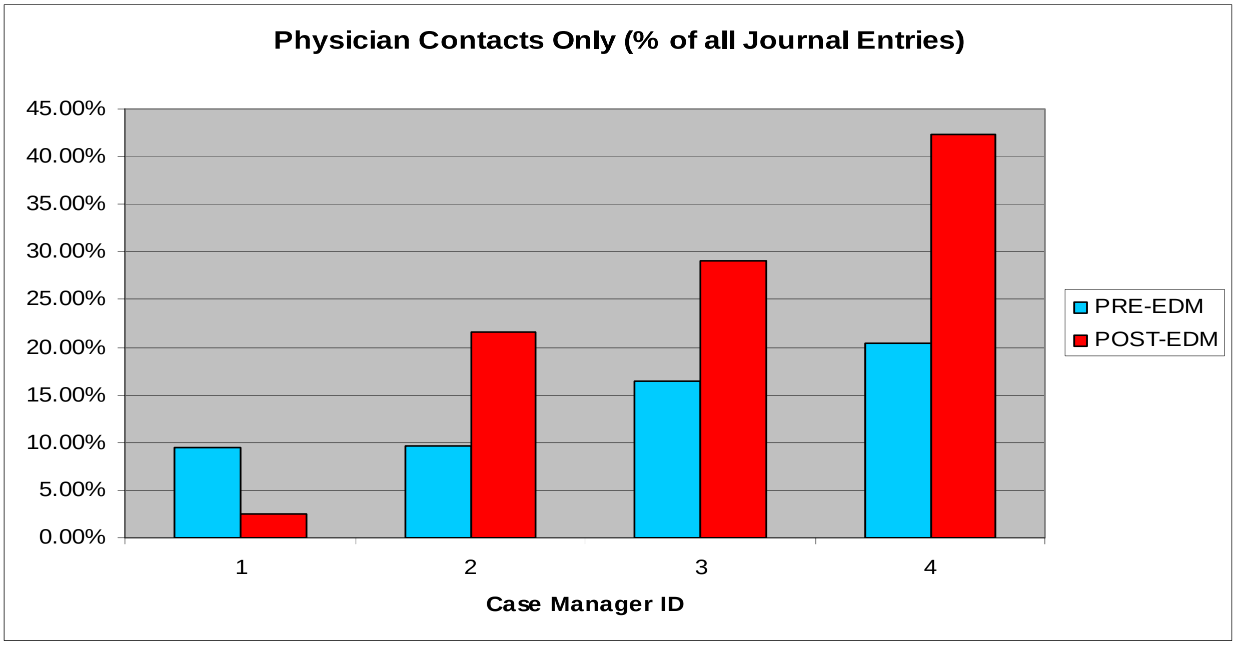


Figure 2d. Pre-EDM vs. Post-EDM Journal Entries (4 Case Manager/Single Customer Pod)

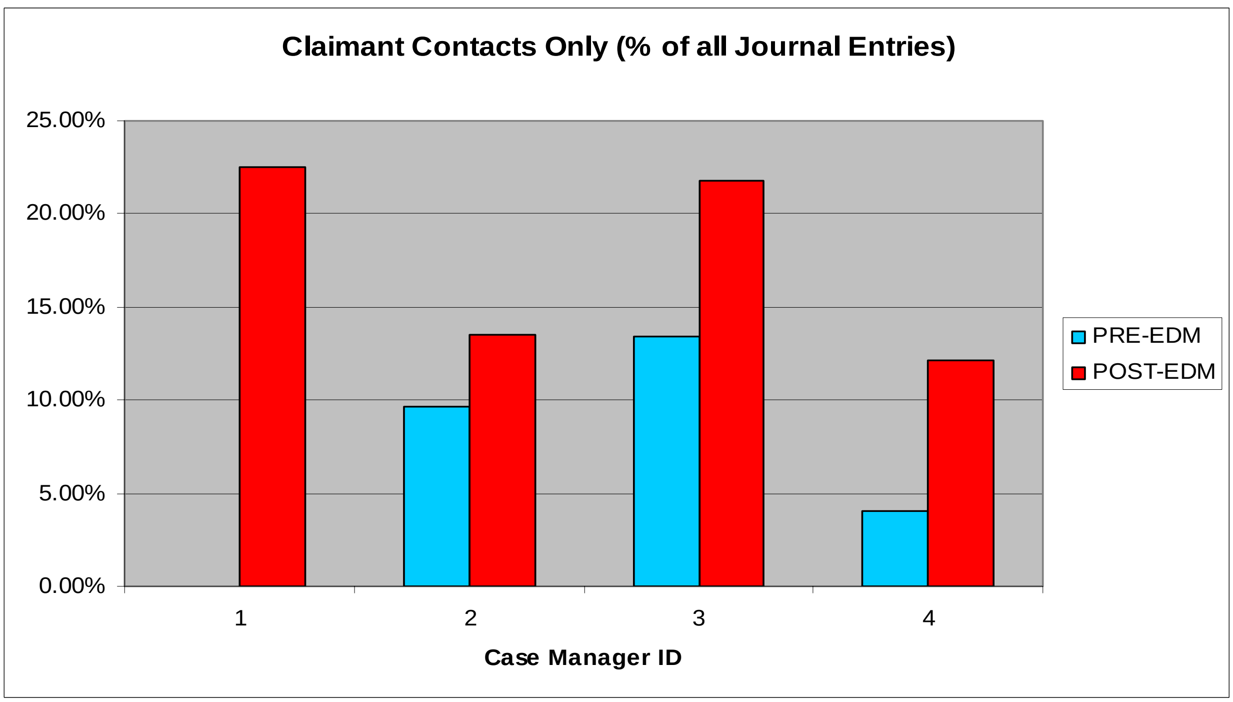


Figure 2e. Pre-EDM vs. Post-EDM Journal Entries (4 Case Manager/Single Customer Pod)

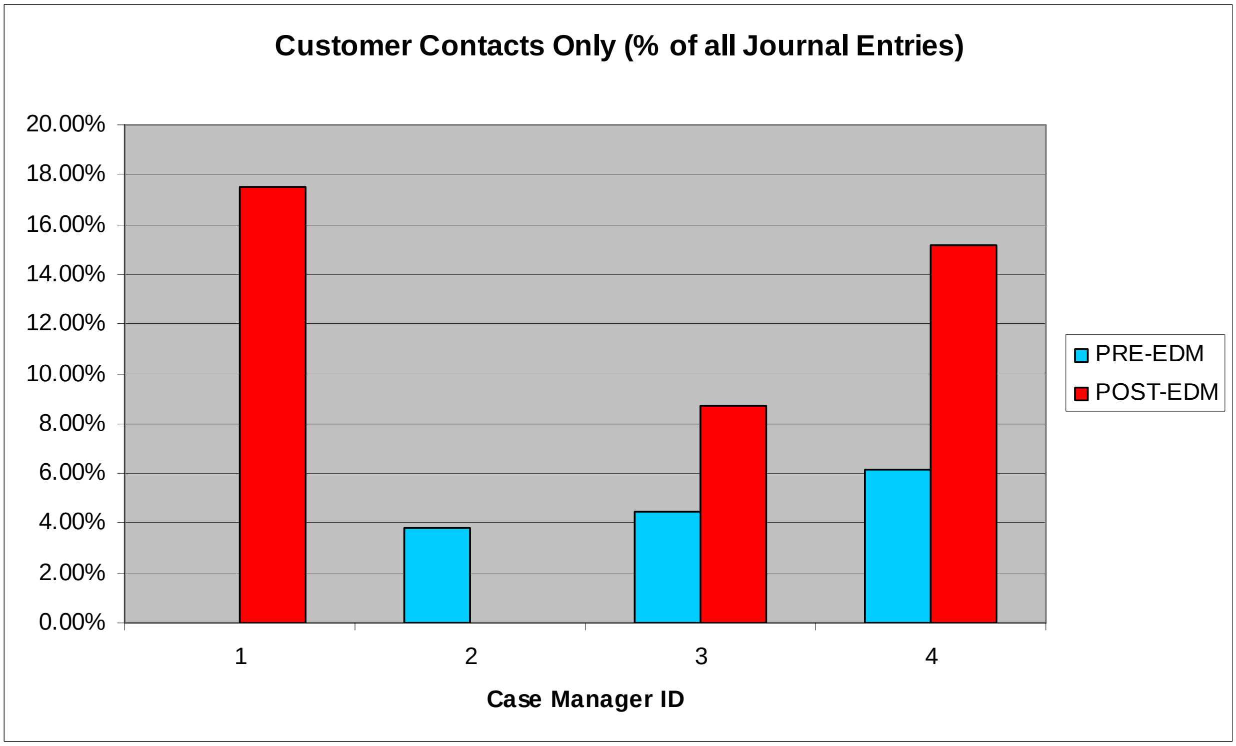


Figure 3. Re-Allocation of Net Time Savings (4 Case Manager/Single Customer Pod)

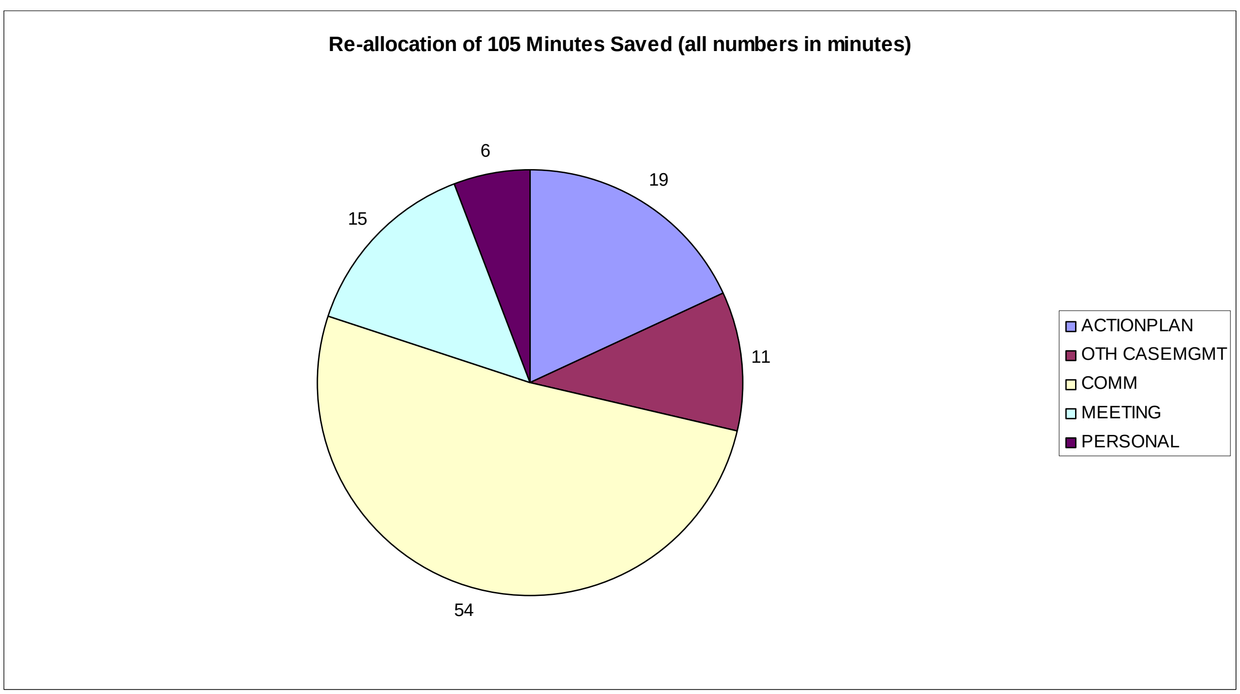


Table 2. Mean Time Use analysis on matched sample N=26 Case Managers

*Note all % are means or arithmetic averages.

								POST-EDM (N=26)		
		PRE-EDM (matched sample) (N=26)						t=1	t=2	
Category	**Activity**	**category**	**activity**	**activity%**	**ACTIVITY GROUP**	**%**	**ANALYSIS CAT.**	**activity%**	**activity%**	**avg %**
Mail	Sorting Incoming Mail	1	1	1.6	OTH PAPER	**7.0**	**OTH PAPER**	0.2	0.3	**4.8**
Mail	Opening Mail	1	2	0.2	OTH PAPER			0.4	0.1	
Mail	Extracting Mail	1	3	0.0	OTH PAPER			0.3	0.0	
Mail	Identifying Mail	1	4	0.4	OTH PAPER			0.0	0.5	
Mail	Delivering Mail	1	5	0.0	OTH PAPER			0.1	0.1	
Mail	Mailing Outgoing Mail	1	7	0.4	OTH PAPER			0.9	0.5	
Mail	Date-stamping Mail	1	9	0.0	OTH PAPER			0.0	0.0	
Doc	Documenting Paper Mail & Paper Fax	2	1	7.8	DOC PAPER	**7.8**	**DOC PAPER**	2.5	1.0	**1.8**
Doc	Documenting Impact	2	2	0.6	OTH DOC	**13.5**	**OTH DOC**	0.3	0.2	**9.7**
Doc	Documenting Action Plan/Initial Asses	2	3	8.1	ACTIONPLAN	**10.9**	**ACTIONPLAN**	8.8	10.6	**10.9**
Doc	Writing Journal Entries	2	4	11.3	OTH DOC			8.7	6.1	
Doc	Financial Notes	2	5	1.4	OTH CASEMGMT	**10.2**	**OTH CASEMGMT**	2.5	1.6	**10.7**
Comm	Phone	3	1	19.0	COMM	**26.4**	**COMM**	23.1	21.8	**32.5**
Comm	Voicemail	3	2	1.9	COMM			2.1	1.7	
Comm	E-mail	3	3	5.5	COMM			5.7	10.4	
Comm	In-person meeting	3	4	10.9	MEETING	**10.9**	**MEETING**	4.3	5.5	**5.3**
Comm	Sending Paper Fax	3	5	0.5	OTH PAPER			0.4	0.5	
Comm	Sending Right Fax	3	6	0.3	RIGHTFAX	**0.4**	**RIGHTFAX**	0.5	0.6	**0.7**
Comm	Putting Together Paper Items to Mail	3	7	0.4	OTH PAPER			0.2	0.3	
Comm	Manage EDM Inbox (Complete Notific	3	9	0.0	EDM	**0.0**	**EDM**	0.9	0.8	**7.6**
Filework	Accessing Paper File	4	1	0.8	OTH PAPER			0.8	0.1	
Filework	File Sorting/Removing Duplicates	4	2	0.3	OTH PAPER			0.1	0.1	
Filework	Copying Files	4	3	0.5	OTH PAPER			0.0	0.2	
Filework	Electronic Formwork	4	4	0.4	OTH FILEWORK	**0.8**	**OTH FILEWORK**	0.2	0.2	**0.4**
Filework	Paper Formwork	4	5	0.1	OTH PAPER			0.3	0.1	
Filework	Payments	4	6	1.2	OTH CASEMGMT			0.3	1.6	
Filework	Printing from Systems (ExPrs, Beauc	4	7	0.4	OTH PAPER			0.2	0.3	
Filework	Closing File from System	4	8	0.5	OTH FILEWORK			0.2	0.3	
Filework	Accessing EDM File	4	9	0.0	EDM			0.7	0.8	
Filework	Printing EDM File	4	10	0.0	OTH PAPER			0.3	0.1	
Filework	Dragging & Dropping/Uploading/Com	4	11	0.0	EDM			3.8	3.8	
Filework	Complete EDM Document Properties	4	13	0.0	EDM			0.9	0.8	
Filework	Linking Journal Entry to EDM Docume	4	14	0.0	EDM			0.2	0.1	
Filework	Exporting EDM Documents to deskto	4	15	0.0	EDM			0.0	0.2	
Case Managen	Opening New Claim (Fax to Call Cent	5	1	0.4	OTH CASEMGMT			0.2	0.0	
Case Managen	Sending Notice for File Jacket Creatio	5	2	0.1	OTH CASEMGMT			0.0	0.0	
Case Managen	Transfering Files to SDU or CST	5	4	0.1	OTH CASEMGMT			0.9	0.2	
Case Managen	Re-Identifying Files	5	5	0.5	OTH CASEMGMT			0.2	0.0	
Case Managen	RTW Plans	5	6	2.7	ACTIONPLAN			1.5	1.0	
Case Managen	Setting Up Referrals (RMD/Nurses/At	5	7	0.5	OTH CASEMGMT			0.3	0.5	
Case Managen	Medical Management	5	8	1.9	OTH CASEMGMT			4.3	3.4	
Case Managen	Making decision to Accept or Reject F	5	9	1.3	OTH CASEMGMT			1.0	0.4	
Case Managen	Assigning Claims (from TM/SCM to C	5	10	0.1	OTH CASEMGMT			0.0	0.2	
Case Managen	Recording Statements	5	11	2.8	OTH CASEMGMT			1.3	2.2	
Case Managen	Documenting Claim Screen / Details	5	12	1.6	OTH DOC			3.0	1.0	
Case Managen	Reviewing Paper Files	5	13	0.4	OTH PAPER			0.6	0.6	
Case Managen	Reviewing EDM Files	5	14	0.0	EDM			0.8	1.4	
Personal	Break	6	1	0.7	PERSONAL	**10.9**	**PERSONAL**	1.9	1.7	**13.7**
Personal	Lunch	6	2	9.0	PERSONAL			11.9	10.0	
Personal	Personal Phone Call	6	3	0.3	PERSONAL			0.1	0.1	
Personal	Other	6	4	0.9	PERSONAL			0.6	1.1	
Administration	Printing / Stapling Incoming Right Fax	7	1	0.7	OTH PAPER			0.0	0.4	
Administration	Sorting / Identifying Incoming Right Fa	7	2	0.2	RIGHTFAX			0.3	0.0	
Administration	Identifying Incoming Paper Faxes	7	6	0.0	OTH PAPER			0.2	0.0	
Administration	Distributing Incoming Paper Faxes	7	7	0.1	OTH PAPER			0.0	0.0	
Administration	Drop Filing (both picking out and putti	7	8	0.3	OTH PAPER			0.0	0.0	
Administration	Correcting Files (paper)	7	9	0.0	OTH PAPER			0.1	0.0	
Supervision/Ev	Conducting Informal QA of File(s)	8	2	0.0	OTHER			0.1	0.0	
Supervision/Ev	Providing Feedback to CMs	8	3	0.1	MEETING			0.0	0.9	
Other	Other Task	9	1	1.1	OTHER			0.6	3.4	
				100.0				100.0	100.0	

Figure 4a. Pre-EDM vs. Post-EDM Time Use (Office-Wide Study)

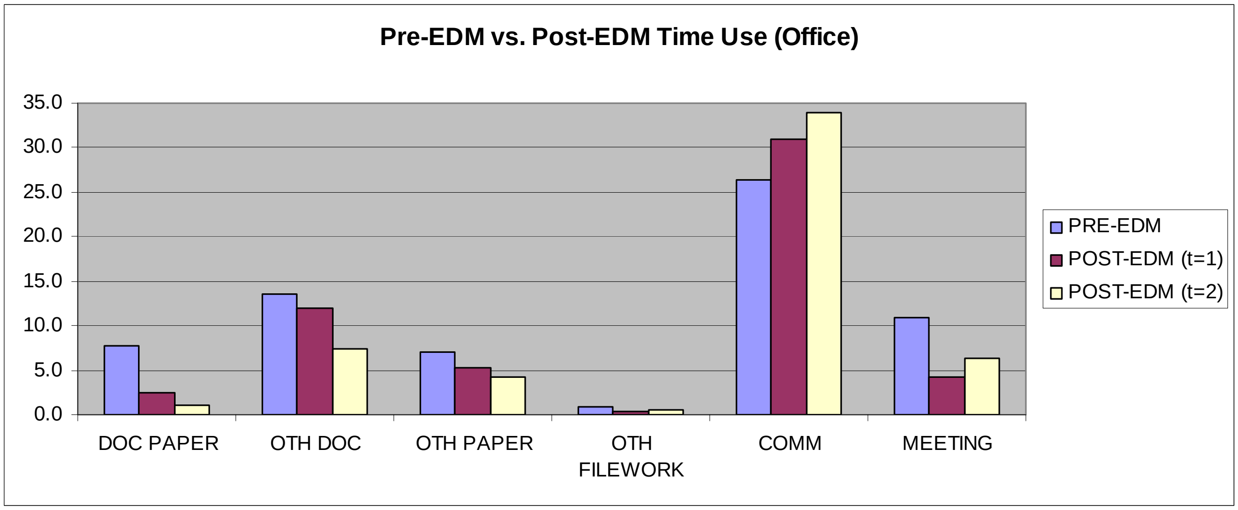


Figure 4b. Pre-EDM vs. Post-EDM Time Use (Office-Wide Study)

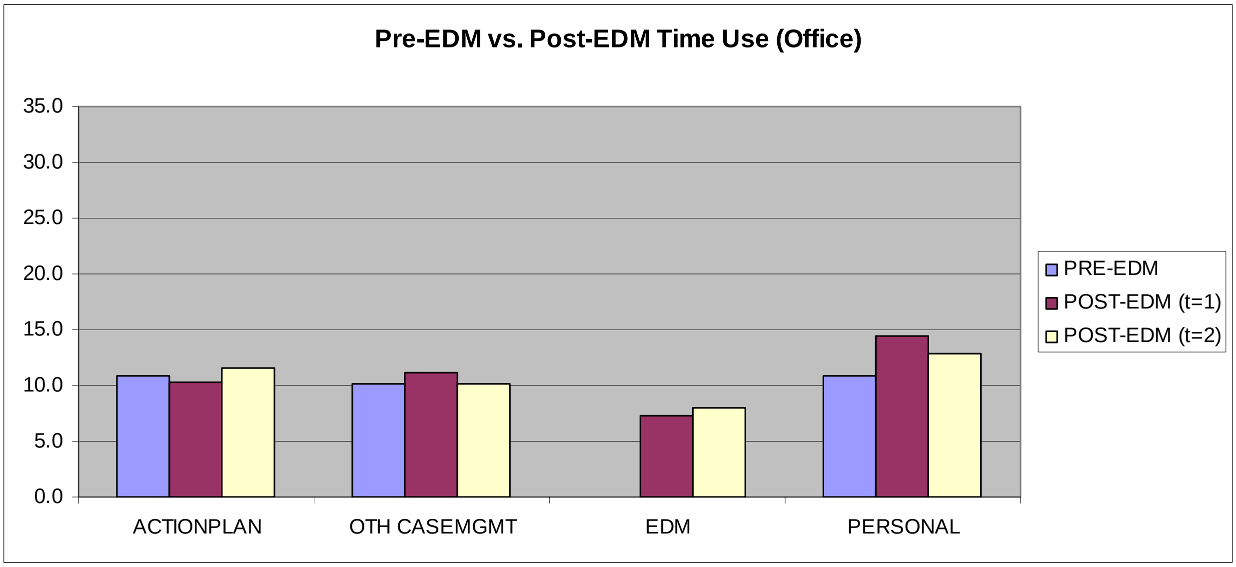


Table 3. Median Time Use analysis on matched sample N=26 Case Managers

*Note all % are medians.

								POST-EDM (N=26)	
		PRE-EDM (matched sample) (N=26)						t=1	
Category	Activity	category	activity	activity%	ACTIVITY GROUP	%	ANALYSIS CAT.	activity%	%
Mail	Sorting Incoming Mail	1	1	0.0	OTH PAPER	**0.0**	**OTH PAPER**	0.0	**0.0**
Mail	Opening Mail	1	2	0.0	OTH PAPER			0.0	
Mail	Extracting Mail	1	3	0.0	OTH PAPER			0.0	
Mail	Identifying Mail	1	4	0.0	OTH PAPER			0.0	
Mail	Delivering Mail	1	5	0.0	OTH PAPER			0.0	
Mail	Mailing Outgoing Mail	1	7	0.0	OTH PAPER			0.0	
Mail	Date-stamping Mail	1	9	0.0	OTH PAPER			0.0	
Doc	Documenting Paper Mail & Paper Fax	2	1	6.0	DOC PAPER	**6.0**	**DOC PAPER**	0.0	**0.0**
Doc	Documenting Impact	2	2	0.0	OTH DOC	**8.6**	**OTH DOC**	0.0	**4.1**
Doc	Documenting Action Plan/Initial Asses	2	3	4.1	ACTIONPLAN	**4.1**	**ACTIONPLAN**	5.1	**5.1**
Doc	Writing Journal Entries	2	4	8.6	OTH DOC			4.1	
Doc	Financial Notes	2	5	0.9	OTH CASEMGMT	**0.9**	**OTH CASEMGMT**	0.0	**1.0**
Comm	Phone	3	1	18.8	COMM	**23.7**	**COMM**	23.1	**30.6**
Comm	Voicemail	3	2	2.0	COMM			2.0	
Comm	E-mail	3	3	2.9	COMM			5.4	
Comm	In-person meeting	3	4	10.3	MEETING	**10.3**	**MEETING**	2.2	**2.2**
Comm	Sending Paper Fax	3	5	0.0	OTH PAPER			0.0	
Comm	Sending Right Fax	3	6	0.0	RIGHTFAX	**0.0**	**RIGHTFAX**	0.0	**0.0**
Comm	Putting Together Paper Items to Mail	3	7	0.0	OTH PAPER			0.0	
Comm	Manage EDM Inbox (Complete Notific	3	9	0.0	EDM	**0.0**	**EDM**	0.0	**1.0**
Filework	Accessing Paper File	4	1	0.0	OTH PAPER			0.0	
Filework	File Sorting/Removing Duplicates	4	2	0.0	OTH PAPER			0.0	
Filework	Copying Files	4	3	0.0	OTH PAPER			0.0	
Filework	Electronic Formwork	4	4	0.0	OTH FILEWORK	**0.0**	**OTH FILEWORK**	0.0	**0.0**
Filework	Paper Formwork	4	5	0.0	OTH PAPER			0.0	
Filework	Payments	4	6	0.0	OTH CASEMGMT			0.0	
Filework	Printing from Systems (ExPrs, Beauc	4	7	0.0	OTH PAPER			0.0	
Filework	Closing File from System	4	8	0.0	OTH FILEWORK			0.0	
Filework	Accessing EDM File	4	9	0.0	EDM			0.0	
Filework	Printing EDM File	4	10	0.0	OTH PAPER			0.0	
Filework	Dragging & Dropping/Uploading/Com	4	11	0.0	EDM			1.0	
Filework	Complete EDM Document Properties	4	13	0.0	EDM			0.0	
Filework	Linking Journal Entry to EDM Docume	4	14	0.0	EDM			0.0	
Filework	Exporting EDM Documents to deskto	4	15	0.0	EDM			0.0	
Case Managen	Opening New Claim (Fax to Call Cent	5	1	0.0	OTH CASEMGMT			0.0	
Case Managen	Sending Notice for File Jacket Creatio	5	2	0.0	OTH CASEMGMT			0.0	
Case Managen	Transfering Files to SDU or CST	5	4	0.0	OTH CASEMGMT			0.0	
Case Managen	Re-Identifying Files	5	5	0.0	OTH CASEMGMT			0.0	
Case Managen	RTW Plans	5	6	0.0	ACTIONPLAN			0.0	
Case Managen	Setting Up Referrals (RMD/Nurses/At	5	7	0.0	OTH CASEMGMT			0.0	
Case Managen	Medical Management	5	8	0.0	OTH CASEMGMT			1.0	
Case Managen	Making decision to Accept or Reject F	5	9	0.0	OTH CASEMGMT			0.0	
Case Managen	Assigning Claims (from TM/SCM to C	5	10	0.0	OTH CASEMGMT			0.0	
Case Managen	Recording Statements	5	11	0.0	OTH CASEMGMT			0.0	
Case Managen	Documenting Claim Screen / Details	5	12	0.0	OTH DOC			0.0	
Case Managen	Reviewing Paper Files	5	13	0.0	OTH PAPER			0.0	
Case Managen	Reviewing EDM Files	5	14	0.0	EDM			0.0	
Personal	Break	6	1	0.0	PERSONAL	**9.7**	**PERSONAL**	1.8	**14.0**
Personal	Lunch	6	2	9.7	PERSONAL			12.1	
Personal	Personal Phone Call	6	3	0.0	PERSONAL			0.0	
Personal	Other	6	4	0.0	PERSONAL			0.0	
Administration	Printing / Stapling Incoming Right Fax	7	1	0.0	OTH PAPER			0.0	
Administration	Sorting / Identifying Incoming Right Fa	7	2	0.0	RIGHTFAX			0.0	
Administration	Identifying Incoming Paper Faxes	7	6	0.0	OTH PAPER			0.0	
Administration	Distributing Incoming Paper Faxes	7	7	0.0	OTH PAPER			0.0	
Administration	Drop Filing (both picking out and putti	7	8	0.0	OTH PAPER			0.0	
Administration	Correcting Files (paper)	7	9	0.0	OTH PAPER			0.0	
Supervision/Ev	Conducting Informal QA of File(s)	8	2	0.0	OTHER			0.0	
Supervision/Ev	Providing Feedback to CMs	8	3	0.0	MEETING			0.0	
Other	Other Task	9	1	0.0	OTHER			0.0	
				63.4				57.9	

Figure 5. Re-Allocation of Net Time Savings (Office-Wide Time Use Study)

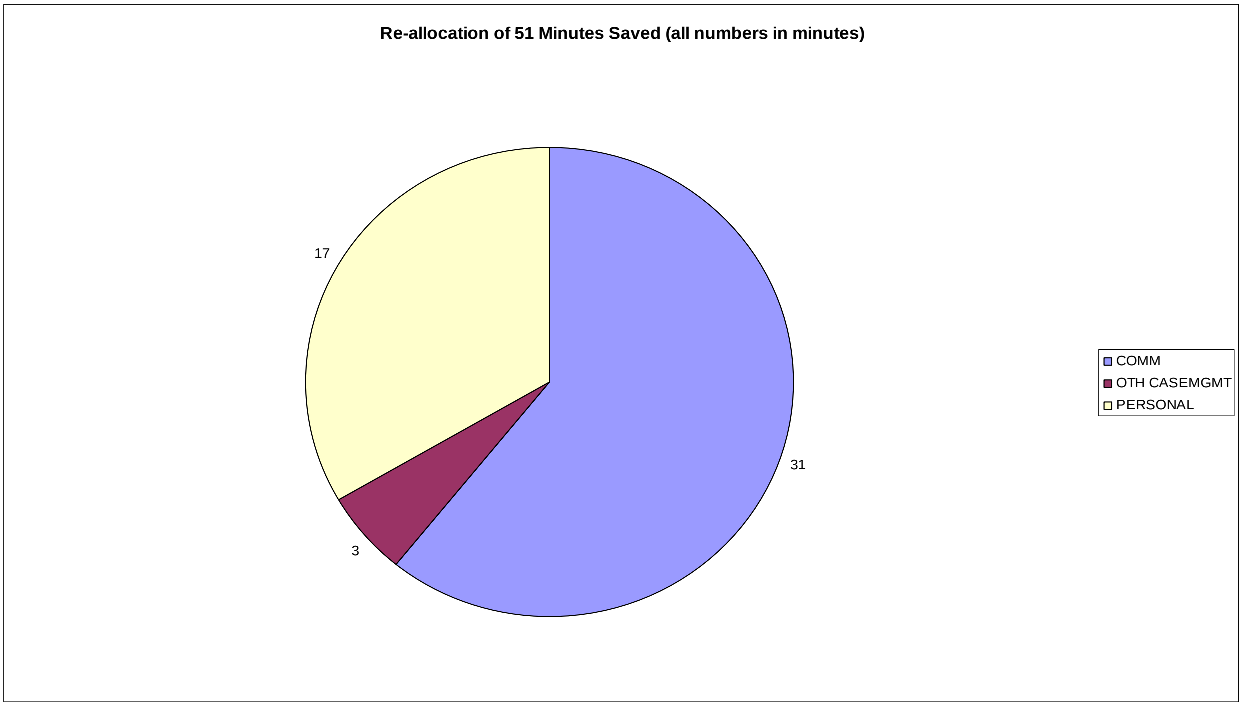


Figure 6a. Activity Counts Analysis (Documentation Category)

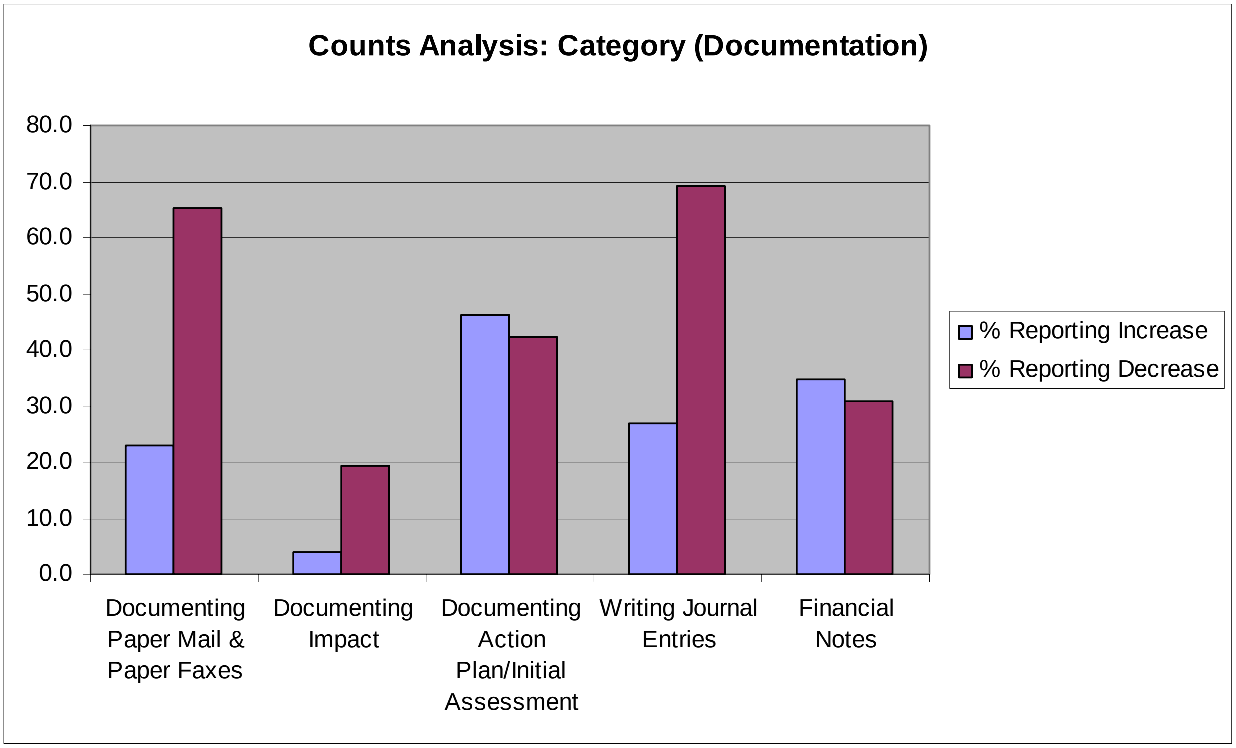


Figure 6b. Activity Counts Analysis (Communication Category)

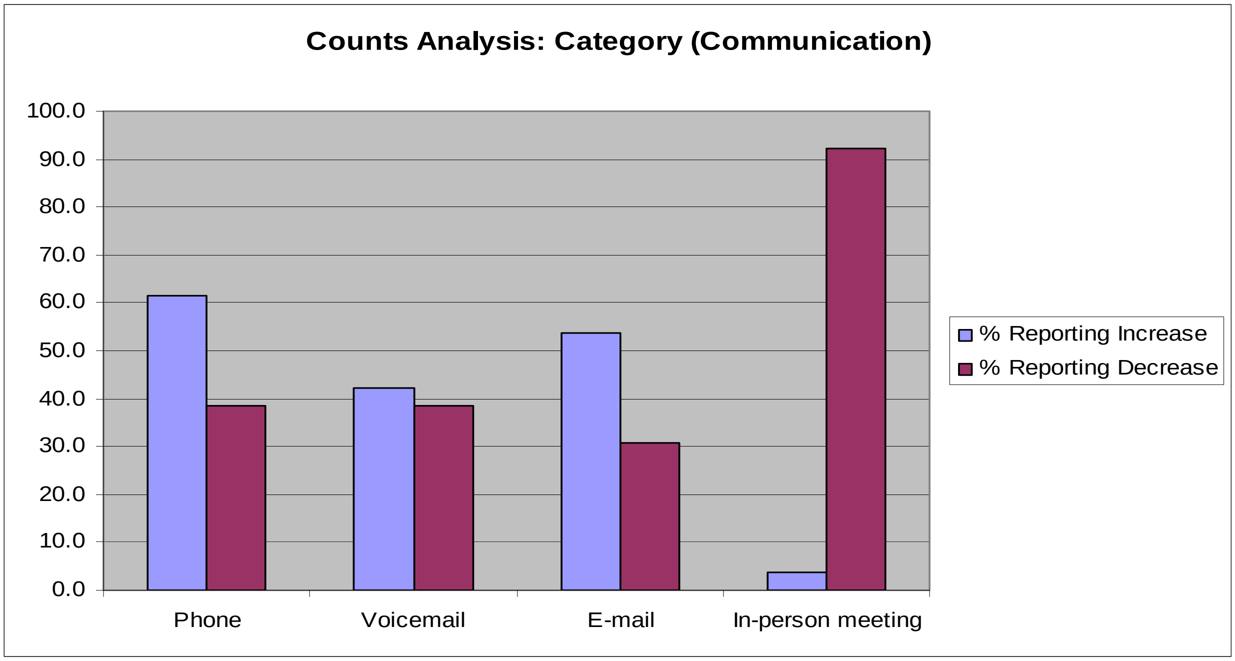


Figure 6c. Activity Counts Analysis (Personal Category)

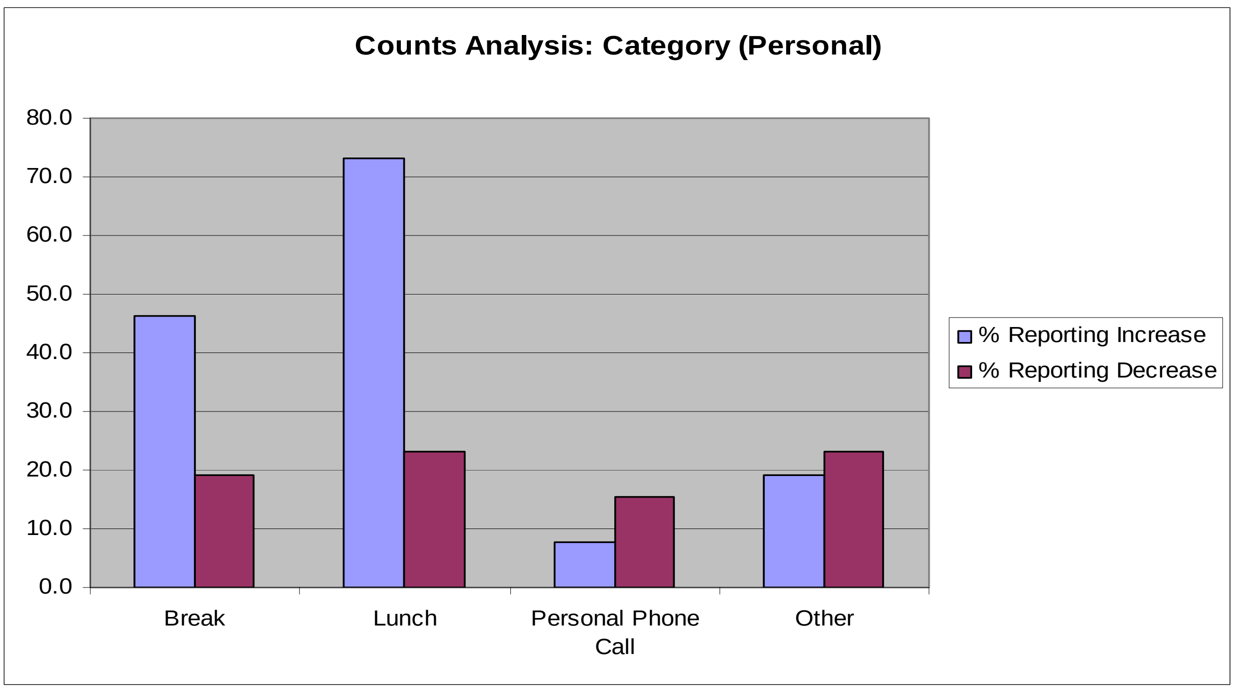


Figure 6d. Activity Counts Analysis (Based on Activity Groups)

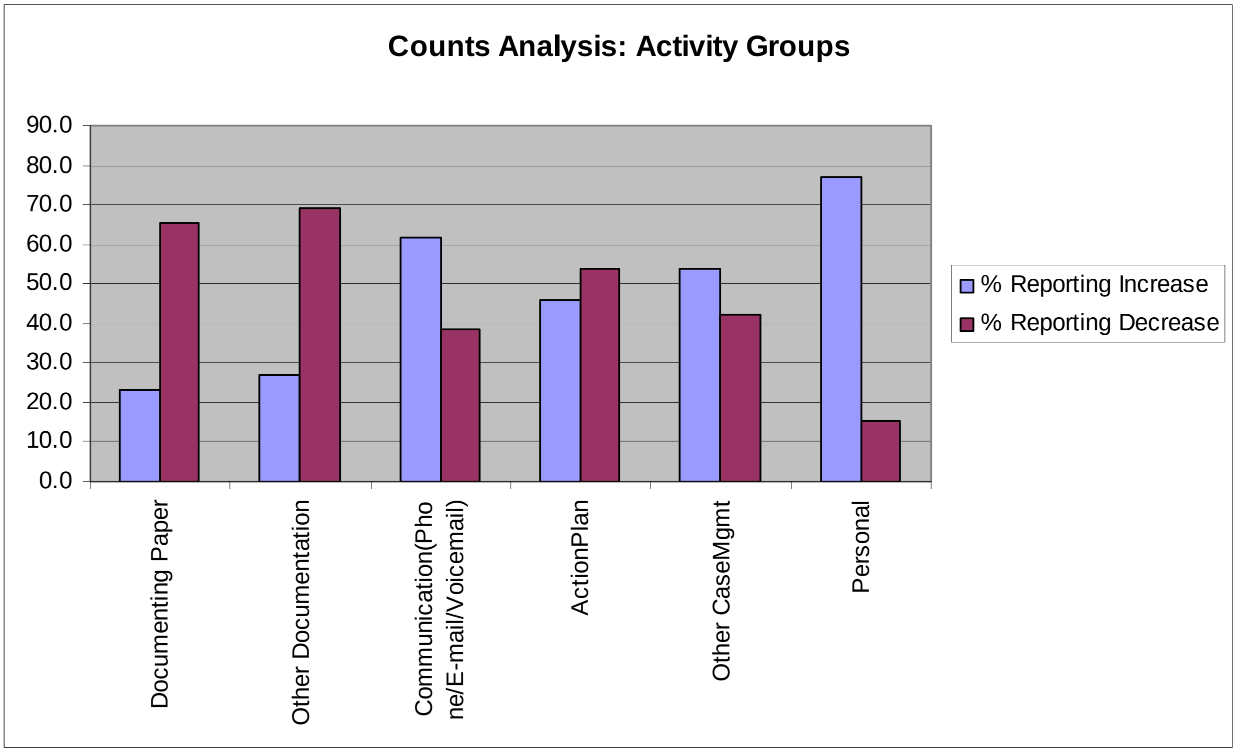


Table 7. Mean Time Use analysis on full sample PRE-EDM N=53, POST-EDM (t=1) N=46, (t=2) N=56

*Note all % are means or arithmetic averages.

		PRE-EDM (full sample) (N=53)						POST-EDM (t=1) (N=46)		(t=2) (N=56)
Category	Activity	category	activity	activity%	ACTIVITY GROUP	%	ANALYSIS CAT.	activity%	activity%	AVG
Mail	Sorting Incoming Mail	1	1	1.4	OTH PAPER	**6.2**	**OTH PAPER**	0.4	0.5	**4.6**
Mail	Opening Mail	1	2	0.3	OTH PAPER			0.3	0.3	
Mail	Extracting Mail	1	3	0.0	OTH PAPER			0.2	0.0	
Mail	Identifying Mail	1	4	0.4	OTH PAPER			0.0	0.4	
Mail	Delivering Mail	1	5	0.0	OTH PAPER			0.1	0.1	
Mail	Mailing Outgoing Mail	1	7	0.2	OTH PAPER			0.5	0.5	
Mail	Date-stamping Mail	1	9	0.1	OTH PAPER			0.0	0.3	
Doc	Documenting Paper Mail & Pape	2	1	7.3	DOC PAPER	**7.3**	**DOC PAPER**	2.8	1.1	**2.0**
Doc	Documenting Impact	2	2	0.3	OTH DOC	**14.5**	**OTH DOC**	0.7	0.3	**8.9**
Doc	Documenting Action Plan/Initial A	2	3	8.2	ACTIONPLAN	**9.7**	**ACTIONPLAN**	10.6	11.0	**12.9**
Doc	Writing Journal Entries	2	4	10.5	OTH DOC			6.9	4.6	
Doc	Financial Notes	2	5	2.8	OTH CASEMGMT	**11.7**	**OTH CASEMGMT**	2.4	2.0	**10.9**
Comm	Phone	3	1	20.5	COMM	**27.5**	**COMM**	19.4	22.1	**30.7**
Comm	Voicemail	3	2	2.3	COMM			3.7	2.9	
Comm	E-mail	3	3	4.6	COMM			5.9	7.4	
Comm	In-person meeting	3	4	9.4	MEETING	**9.5**	**MEETING**	4.1	3.9	**4.2**
Comm	Sending Paper Fax	3	5	0.6	OTH PAPER			0.3	0.4	
Comm	Sending Right Fax	3	6	0.2	RIGHTFAX	**0.3**	**RIGHTFAX**	0.8	0.9	**1.2**
Comm	Putting Together Paper Items to	3	7	0.5	OTH PAPER			0.2	0.3	
Comm	Manage EDM Inbox (Complete N	3	9	0.0	EDM	**0.0**	**EDM**	1.0	1.2	**8.3**
Filework	Accessing Paper File	4	1	0.5	OTH PAPER			0.5	0.1	
Filework	File Sorting/Removing Duplicates	4	2	0.1	OTH PAPER			0.3	0.1	
Filework	Copying Files	4	3	0.3	OTH PAPER			0.1	0.3	
Filework	Electronic Formwork	4	4	0.2	OTH FILEWORK	**1.2**	**OTH FILEWORK**	0.1	0.3	**0.6**
Filework	Paper Formwork	4	5	0.1	OTH PAPER			0.3	0.1	
Filework	Payments	4	6	1.7	OTH CASEMGMT			0.3	1.9	
Filework	Printing from Systems (ExPrs, B	4	7	0.2	OTH PAPER			0.2	0.2	
Filework	Closing File from System	4	8	1.0	OTH FILEWORK			0.2	0.5	
Filework	Accessing EDM File	4	9	0.0	EDM			0.9	0.8	
Filework	Printing EDM File	4	10	0.0	OTH PAPER			0.2	0.1	
Filework	Dragging & Dropping/Uploading/	4	11	0.0	EDM			3.7	4.4	
Filework	Complete EDM Document Prope	4	13	0.0	EDM			1.2	0.4	
Filework	Linking Journal Entry to EDM Do	4	14	0.0	EDM			0.1	0.2	
Filework	Exporting EDM Documents to de	4	15	0.0	EDM			0.0	0.1	
Case Manage	Opening New Claim (Fax to Call	5	1	0.3	OTH CASEMGMT			0.4	0.0	
Case Manage	Sending Notice for File Jacket C	5	2	0.0	OTH CASEMGMT			0.0	0.0	
Case Manage	Transfering Files to SDU or CST	5	4	0.2	OTH CASEMGMT			0.8	0.3	
Case Manage	Re-Identifying Files	5	5	0.3	OTH CASEMGMT			0.1	0.1	
Case Manage	RTW Plans	5	6	1.5	ACTIONPLAN			2.5	1.8	
Case Manage	Setting Up Referrals (RMD/Nurs	5	7	1.7	OTH CASEMGMT			0.5	1.1	
Case Manage	Medical Management	5	8	1.8	OTH CASEMGMT			3.7	2.6	
Case Manage	Making decision to Accept or Re	5	9	0.8	OTH CASEMGMT			0.6	0.2	
Case Manage	Assigning Claims (from TM/SCM	5	10	0.1	OTH CASEMGMT			0.0	0.1	
Case Manage	Recording Statements	5	11	2.1	OTH CASEMGMT			2.0	2.8	
Case Manage	Documenting Claim Screen / De	5	12	3.7	OTH DOC			3.3	1.9	
Case Manage	Reviewing Paper Files	5	13	0.4	OTH PAPER			0.4	0.7	
Case Manage	Reviewing EDM Files	5	14	0.0	EDM			0.9	1.7	
Personal	Break	6	1	0.9	PERSONAL	**10.7**	**PERSONAL**	1.8	1.9	**14.1**
Personal	Lunch	6	2	8.6	PERSONAL			11.7	10.4	
Personal	Personal Phone Call	6	3	0.3	PERSONAL			0.3	0.2	
Personal	Other	6	4	0.9	PERSONAL			0.6	1.2	
Administration	Printing / Stapling Incoming Righ	7	1	0.7	OTH PAPER			0.0	0.3	
Administration	Sorting / Identifying Incoming Rig	7	2	0.1	RIGHTFAX			0.3	0.3	
Administration	Identifying Incoming Paper Faxe	7	6	0.1	OTH PAPER			0.4	0.0	
Administration	Distributing Incoming Paper Fax	7	7	0.1	OTH PAPER			0.1	0.0	
Administration	Drop Filing (both picking out and	7	8	0.2	OTH PAPER			0.0	0.1	
Administration	Correcting Files (paper)	7	9	0.0	OTH PAPER			0.0	0.0	
Supervision/E	Conducting Informal QA of File(s	8	2	0.1	OTHER			0.0	0.0	
Supervision/E	Providing Feedback to CMs	8	3	0.0	MEETING			0.0	0.4	
Other	Other Task	9	1	1.2	OTHER			0.9	1.9	

Table 4a. Differences-In-Differences Fixed Effects Pooled Regressions

	Dependent Var.		
Independent Var.	**Current Yr. Closure Rate (TREATMENT LAG=1)** **OLS (N=192)**	**Beat Current Yr. Closure Rate Goal (TREATMENT LAG=1)** **LOGIT (N=192)**	**Previous Yr. Closure Rate (TREATMENT LAG=1)** **OLS (N=184)**
EDM TREAT	0.005 (0.008)	1.778 (0.738) **	-0.006 (0.007)
TOT. STAFF	0.001 (0.0007)	0.152 (0.090) *	0.0004(0.001)
INC. CLAIM	-2.71e-06 (0.000014)	0.001 (0.001)	-1.19e-05 (0.00002)
FEB	0.331*** (0.014)	-2.397 (0.941)**	0.037** (0.0167)
MAR	0.460*** (0.012)	-2.510 (0.928)**	0.080*** (0.0155)
APR	0.517*** (0.012)	-1.202 (0.964)	0.113*** (0.015)
MAY	0.555*** (0.011)	-0.935 (0.989)	0.149*** (0.015)
JUN	0.581*** (0.011)	-1.055 (0.996)	0.183*** (0.015)
JUL	0.603*** (0.0122)	-0.937 (1.043)	0.210*** (0.016)
AUG	0.622*** (0.011)	-2.812** (1.005)	0.244*** (0.016)
SEP	0.641*** (0.012)	-2.047* (1.049)	0.269*** (0.016)
OCT	0.658*** (0.012)	-1.631 (1.049)	0.292*** (0.016)
NOV	0.673*** (0.012)	-1.054 (1.122)	0.317*** (0.018)
DEC	0.685*** (0.012)	-0.398 (1.103)	0.348*** (0.018)
YEAR	0.013*** (0.011)	1.917** (0.840)	0.008*** (0.010)
R^2	0.999	LOGIT (not relevant)	0.993
F-stat (p-value)	24031 (0.0)	LOGIT (not relevant)	1903.59 (0.0)

Heteroskedasticity-robust Huber/White standard errors are reported in parentheses for OLS regressions. For logistic regression standard errors are reported in parentheses.

Note: coefficients for office dummies not shown for sake of privacy

*** indicates significance at the 1% level
** indicates significance at the 5% level
* indicates significance at the 10% level

Table 4b. Differences-In-Differences Fixed Effects Pooled Regressions

	Dependent Var.		
Independent Var.	Avg. Physical Therapy Paid (TREATMENT LAG=3) OLS (N=176)	Avg. Chiropractor Care Paid (TREATMENT LAG=2) OLS (N=176)	Staff Retention Rate (TREATMENT LAG=1) OLS (N=168)
EDM TREAT	-111.175*** (20.116)	-154.59*** (23.674)	0.054*** (0.020)
TOT. STAFF	-7.856*** (2.038)	-2.87 (2.047)	
FEB	121.196*** (35.969)	110.439*** (34.717)	0.058 (0.040)
MAR	158.928*** (36.765)	177.27*** (35.037)	0.042* (0.022)
APR	215.312*** (37.164)	272.276*** (39.970)	0.007 (0.015)
MAY	216.254*** (36.177)	291.177*** (37.878)	0.008 (0.014)
JUN	239.921*** (38.322)	303.909*** (37.773)	-0.004 (0.012)
JUL	250.334*** (42.072)	312.658*** (40.683)	-0.008 (0.013)
AUG	263.871*** (42.738)	335.501*** (42.947)	-0.005 (0.014)
SEP	208.256*** (39.057)	275.933*** (39.169)	0.004 (0.013)
OCT	173.479*** (37.886)	241.965*** (38.526)	0.007 (0.014)
NOV	136.052*** (38.406)	212.260*** (39.578)	-0.001 (0.013)
DEC	121.543*** (38.701)	204.914*** (40.158)	
YEAR	-107.531*** (23.366)	-40.806 (26.332)	-0.040** (0.019)
R^2	0.990	0.9885	0.996
F-stat (p-value)	976.56 (0.0)	996.67 (0.0)	4055.89 (0.0)

Heteroskedasticity-robust Huber/White standard errors are reported in parentheses for OLS regressions.

Note: coefficients for office dummies not shown for sake of privacy

*** indicates significance at the 1% level
** indicates significance at the 5% level
* indicates significance at the 10% level

Table 4c. Differences-In-Differences Fixed Effects Pooled Regressions

	Dependent Var.	
Independent Var.	**Loss Leakage (TREATMENT LAG=4) OLS (N=176)**	**Temporary Total Disability (TTD) (TREATMENT LAG=4) OLS (N=192)**
EDM TREAT	-0.001 (0.0009)	0.687** (0.275)
TOT. STAFF		0.037 (0.040)
FEB	0.0002 (0.0007)	0.238 (0.336)
MAR	-0.0004 (0.0009)	0.739** (0.358)
APR	-0.0005 (0.0009)	0.830** (0.413)
MAY	0.0005 (0.0011)	1.273*** (0.421)
JUN	0.0001 (0.0010)	1.321*** (0.386)
JUL	0.0007 (0.0011)	1.017*** (0.376)
AUG	0.0004 (0.0012)	1.159*** (0.409)
SEP	0.0008 (0.0012)	1.051** (0.417)
OCT	0.0016 (0.0012)	0.610 (0.452)
NOV	0.0005 (0.0012)	0.791 (0.484)
DEC	0.0005 (0.0012)	0.682 (0.447)
YEAR	0.0014* (0.0007)	0.715** (0.309)
R^2	0.990	0.999
F-stat (p-value)	1430.12 (0.0)	10784.65 (0.0)

Heteroskedasticity-robust Huber/White standard errors are reported in parentheses for OLS regressions.

Note: coefficients for office dummies not shown for sake of privacy

*** indicates significance at the 1% level
** indicates significance at the 5% level
* indicates significance at the 10% level

Table 5a. Differences-In-Differences Fixed Effects Pooled Regressions

	Dependent Var.		
Independent Var.	**Next-Day Air Courier Costs (TREATMENT LAG=1)** **OLS (N=192)**	**Outside Services Fees (TREATMENT LAG=4)** **OLS (N=120)**	**Mailing Services Costs (TREATMENT LAG=5)** **OLS (N=192)**
EDM TREAT	2875.437*** (477.546)	-20174*** (4070)	-2552*** (748)
FEB	392.375 (415.614)	566 (1450)	26 (660)
MAR	900.882** (432.653)	656 (1483)	-550 (1753)
APR	-195.261 (438.989)	1197 (1548)	-613 (683)
MAY	703.336 (492.153)	1544 (1490)	-547 (682)
JUN	2062.371** (806.583)	-14917** (6850)	-433 (714)
JUL	-1858.691** (777.315)	20168*** (6267)	42 (739)
AUG	2001.746*** (693.941)	943 (3706)	245 (722)
SEP	421.371 (485.223)	1506 (2751)	110 (743)
OCT	1840.871** (757.082)	387 (3456)	142 (802)
NOV	-198.656 (460.183)	178 (3137)	15 (773)
DEC	1138.96** (547.182)	-435 (3846)	-165 (788)
YEAR	-120.859 (343.570)	-138 (2706)	-457 (568)
R^2	0.8176	0.9683	0.9808
F-stat (p-value)	48.76 (0.0)	1008.12 (0.0)	2158.12 (0.0)

Heteroskedasticity-robust Huber/White standard errors are reported in parentheses for OLS regressions.

Note: coefficients for office dummies not shown for sake of privacy

*** indicates significance at the 1% level
** indicates significance at the 5% level
* indicates significance at the 10% level

Table 5b. Differences-In-Differences Fixed Effects Pooled Regressions

	Dependent Var.		
Independent Var.	**Off-site Records Storage Costs (TREATMENT LAG=4) OLS (N=168)**	**Incoming 800 Calls Costs (TREATMENT LAG=0) OLS (N=192)**	**Telephone Usage Costs (TREATMENT LAG=1) OLS (N=192)**
EDM TREAT	-849*** (316)	-151 (132)	871 (584)
FEB	-337 (452)	-189* (105)	-123 (557)
MAR	-387 (461)	151 (141)	795 (630)
APR	127 (509)	-51 (117)	14 (501)
MAY	16 (492)	270* (137)	-17 (520)
JUN	54 (445)	-229* (120)	-178 (422)
JUL	530 (416)	-125 (113)	235 (506)
AUG	284 (430)	-269* (146)	-142 (457)
SEP	166 (469)	-680*** (233)	-961** (471)
OCT	439 (487)	-323 (248)	-16 (699)
NOV	13 (448)	-1307*** (318)	-1854*** (701)
DEC	-148 (427)	-176 (124)	-614 (616)
YEAR	936*** (281)	-89 (119)	-156 (523)
R^2	0.86	0.97	0.93
F-stat (p-value)	49.46 (0.0)	778.17 (0.0)	400.40 (0.0)

Heteroskedasticity-robust Huber/White standard errors are reported in parentheses for OLS regressions.

Note: coefficients for office dummies not shown for sake of privacy

*** indicates significance at the 1% level
** indicates significance at the 5% level
* indicates significance at the 10% level

Table 6a. Comparison of EDM TREAT coefficient in Fixed Effects vs. Random Effects Regressions

Dependent Var.	Fixed Effects Model	Random Effects Model	Hausman statistic (p-value)
Current Yr. Closure Rate	0.005	**0.004**	**2.41 (0.99)**
Previous Yr. Closure Rate	**-0.006**	-0.008	**25.31 (0.04)**
Avg. Physical Therapy Paid	-111.175	**-111.132**	**0.98 (1)**
Avg. Chiropractor Care Paid	-154.590	**-154.647**	**0.61 (1)**
Staff Retention Rate	0.0545	**0.0548**	**0.02 (1)**
Loss Leakage	-0.00127	**-0.00128**	**0.02 (1)**
Temp. Tot. Disability. (TTD)	0.6877	**0.6718**	**4.72 (0.9894)**

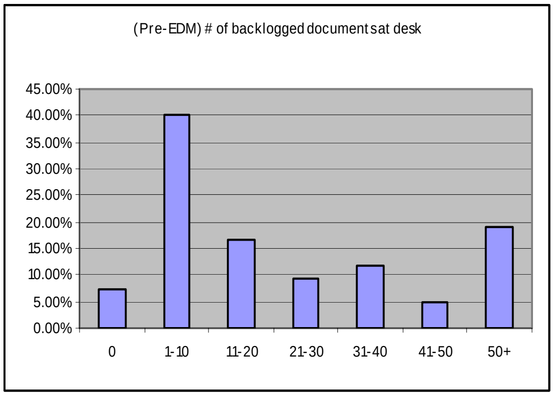
Note: All regressions contained the controls shown in tables 4a-4c, office dummies, month dummies, year dummy. The selected fixed effects or random effects coefficient is highlighted in bold.

Table 6b. Comparison of EDM TREAT coefficient in Fixed Effects vs. Random Effects Regressions

Dependent Var.	Fixed Effects Model	Random Effects Model	Hausman statistic (p-value)
Next-Day Air Courier Costs	2875	**2839**	**0.71 (1)**
Outside Services Fees	**-20174**	-25387	**Negative**
Mailing Services Costs	**-2552**	-2576	**Negative**
Off-site Records Storage Costs	**-849**	-933	**Negative**
Incoming 800 Calls Costs	-151	**-154**	**0.09 (1)**
Telephone Usage Costs	**871**	797	**Negative**

Note: All regressions contained the controls shown in tables 4a-4c, office dummies, month dummies, year dummy. The selected fixed effects or random effects coefficient is highlighted in bold.
The negative hausman statistic arises because of the finite sample, in which the asymptotic assumptions of the test are not met. In such cases, we pick the fixed effects coefficient, which we know to be consistent.

Figure 7. Pre-EDM vs. Post-EDM Distribution of Backlogged Documents at Work Desk



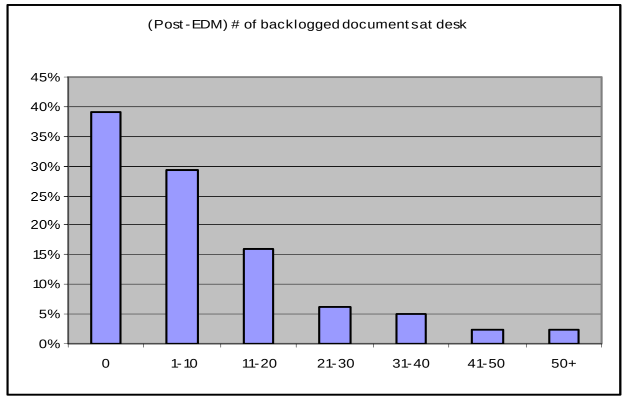


Figure 8. Task Model (Autor et al, 2003)

Routine Manual Ex. Sorting and repetitive assembly	**Routine Analytic** Ex. Calculations and record-keeping
Non-routine Manual Ex. Driving a vehicle, mopping, cleaning	**Non-routine Analytic** Ex. Problem solving and complex communications

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10 Appendix

A1. Pre-EDM Activity List

Cate	Category	Activ	Activity
01	Mail	01	Sorting Incoming Mail
01	Mail	02	Opening Mail
01	Mail	03	Extracting Mail
01	Mail	04	Identifying Mail
01	Mail	05	Delivering Mail
01	Mail	06	Collecting Outgoing Mail / Files / Documents
01	Mail	07	Mailing Outgoing Mail
01	Mail	08	Requesting Old Files from Iron Mountain
01	Mail	09	Date-stamping Mail
02	Documentation	01	Documenting Mail / E-Mail / Faxes
02	Documentation	02	Documenting Impact
02	Documentation	03	Documenting Action Plan/Initial Assessment
02	Documentation	04	Writing Journal Entries
02	Documentation	05	Financial Notes
03	Communication	01	Phone
03	Communication	02	Voicemail
03	Communication	03	E-mail
03	Communication	04	In-person meeting
03	Communication	05	Sending Fax
03	Communication	06	Sending Right Fax
03	Communication	07	Putting Together Paper Items to Mail / Fax
03	Communication	08	Requesting Duplicate Communication from Outside (Attorney, Provider, Etc.)
04	Filework	01	Accessing Paper File
04	Filework	02	File Sorting/Removing Duplicates
04	Filework	03	Copying Files
04	Filework	04	Electronic Formwork
04	Filework	05	Paper Formwork
04	Filework	06	Payments
04	Filework	07	Printing from Systems (ExPrs, Beaucomps, Etc.)
04	Filework	08	Closing File from System
05	Case Management	01	Opening New Claim (Fax to Call Center)
05	Case Management	02	Sending Notice for File Jacket Creation - New Claim
05	Case Management	03	Sending Notice for File Jacket Creation - Transferred Claim
05	Case Management	04	Transfering Files to SDU or CST
05	Case Management	05	Re-Identifying Files
05	Case Management	06	RTW Plans
05	Case Management	07	Setting Up Referrals (RMD/Nurses/Attorneys, Etc.)
05	Case Management	08	Medical Management
05	Case Management	09	Making decision to Accept or Reject Referral
05	Case Management	10	Assigning Claims (from TM/SCM to CMs and Nurse TM to MCMs)
05	Case Management	11	Recording Statements
05	Case Management	12	Documenting Claim Screen / Details
05	Case Management	13	Reviewing Paper Files
06	Personal	01	Break
06	Personal	02	Lunch
06	Personal	03	Personal Phone Call
06	Personal	04	Other
07	Administration	01	Printing / Stapling Incoming Right Faxes
07	Administration	02	Sorting / Identifying Incoming Right Faxes
07	Administration	03	Distributing Incoming Right Faxes
07	Administration	04	Sending Incoming Right Fax Notifications
07	Administration	05	Picking-Up Incoming Faxes
07	Administration	06	Identifying Incoming Faxes
07	Administration	07	Distributing Incoming Faxes
07	Administration	08	Drop Filing (both picking out and putting away docs)
07	Administration	09	Correcting Files (paper)
07	Administration	10	IDing Claims with Multiple Volumes for Audits
08	Supervision/Evaluation	01	Conducting Formal QA of File(s)
08	Supervision/Evaluation	02	Conducting Informal QA of File(s)
08	Supervision/Evaluation	03	Providing Feedback to CMs
09	Other	01	Other Task

A2. Post-EDM Activity List

Cat	Category	Act	Activity
01	Mail	01	Sorting Incoming Mail
01	Mail	02	Opening Mail
01	Mail	03	Extracting Mail
01	Mail	04	Identifying Mail
01	Mail	05	Delivering Mail
01	Mail	06	Collecting Outgoing Mail / Files / Documents
01	Mail	07	Mailing Outgoing Mail
01	Mail	08	Requesting Old Files from Iron Mountain
01	Mail	09	Date-stamping Mail
02	Documentation	01	Summarizing/Posting Medical/Non-Medical Paper Mail or Paper Faxes into ExPRS
02	Documentation	02	Documenting Impact
02	Documentation	03	Documenting Action Plan/Initial Assessment
02	Documentation	04	Writing Journal Entries (Make sure that activity code 1 above is not applicable before choosing this one)
02	Documentation	05	Financial Notes
03	Communication	01	Phone
03	Communication	02	Voicemail
03	Communication	03	E-mail (for Right Fax see activity code 6 below)
03	Communication	04	In-person meeting
03	Communication	05	Sending Paper Fax
03	Communication	06	Sending Right Fax
03	Communication	07	Putting Together Paper Items to Mail / Fax
03	Communication	08	Requesting Duplicate Communication from Outside (Attorney, Provider, Etc.)
03	Communication	09	Manage EDM Inbox (Complete Notifications/Forward Notifications)
03	Communication	10	Share EDM Notification (share document/file)
04	Filework	01	Accessing Paper File
04	Filework	02	File Sorting/Removing Duplicates
04	Filework	03	Copying Files
04	Filework	04	Electronic Formwork
04	Filework	05	Paper Formwork
04	Filework	06	Payments
04	Filework	07	Printing from Systems (ExPrs, Beaucomps, EDM, Etc.)
04	Filework	08	Closing File from System
04	Filework	09	Accessing EDM File
04	Filework	10	Printing EDM File
04	Filework	11	Dragging & Dropping/Uploading/Committing documents/Right Faxes to EDM File
04	Filework	12	EDM Redaction of electronic documents
04	Filework	13	Complete EDM Document Properties
04	Filework	14	Linking Journal Entry to EDM Document
04	Filework	15	Exporting EDM Documents to desktop
05	Case Management	01	Opening New Claim (Fax to Call Center)
05	Case Management	02	Sending Notice for File Jacket Creation - New Claim
05	Case Management	03	Sending Notice for File Jacket Creation - Transferred Claim
05	Case Management	04	Transfering Files to SDU or CST
05	Case Management	05	Re-Identifying Files
05	Case Management	06	RTW Plans
05	Case Management	07	Setting Up Referrals (RMD/Nurses/Attorneys, Etc.)
05	Case Management	08	Medical Management
05	Case Management	09	Making decision to Accept or Reject Referral
05	Case Management	10	Assigning Claims (from TM/SCM to CMs and Nurse TM to MCMs)
05	Case Management	11	Recording Statements
05	Case Management	12	Documenting Claim Screen / Details
05	Case Management	13	Reviewing Paper Files
05	Case Management	14	Reviewing EDM Files
06	Personal	01	Break
06	Personal	02	Lunch
06	Personal	03	Personal Phone Call
06	Personal	04	Other
07	Administration	01	Printing / Stapling Incoming Right Faxes
07	Administration	02	Sorting / Identifying Incoming Right Faxes
07	Administration	03	Distributing Incoming Right Faxes
07	Administration	04	Sending Incoming Right Fax Notifications
07	Administration	05	Picking-Up Incoming Paper Faxes
07	Administration	06	Identifying Incoming Paper Faxes
07	Administration	07	Distributing Incoming Paper Faxes
07	Administration	08	Drop Filing (both picking out and putting away docs)
07	Administration	09	Correcting Files (paper)
07	Administration	10	IDing Claims with Multiple Volumes for Audits
08	Supervision/Evaluatio	01	Conducting Formal QA of File(s)
08	Supervision/Evaluatio	02	Conducting Informal QA of File(s)
08	Supervision/Evaluatio	03	Providing Feedback to CMs
09	Other	01	Other Task

A3. Sample Observation Sheet

Observation #	Emp ID	Approx. Time of Observation	Category Code	Activity Code	Claim Step Code	Required Notes
Example		**8:00**	**2**	**1**	**5**	**Documenting medical report in ExPRS**
1						
2						
3						

A4. Pre-EDM Survey

Pre-EDM Paper-Based Work

1. Most recently, what has been your average open case load?

2. On average, how many new cases do you get every week?

3. On average, how many cases do you close every week?

4. How many inches of paper (medical reports, forms, litigation documents, etc) do you typically receive every day via mail?

5. What percentage of the paper mail that you receive daily are
   a) Medical reports or medical documents? (specify %)
   b) Legal documents? (specify %)
   c) State forms? (specify %)
   d) Field investigator reports? (specify %)
   e) Other (specify %)

Please check that TOTAL of (a) through (e) is 100%

6. How much time on average do you spend every day typing in medical reports into ExPRS?

7. How much time does it take on average to type in a typical medical report into ExPRS?

8. How much time on average do you spend every day typing in legal documents into ExPRS?

9. How much time does it take on average to type in a typical legal document into ExPRS?

10. What is the typical number of paper documents that you have received prior to today but that you have yet to enter into ExPRS? These are backlogged documents sitting on your desk that you will get to typing into ExPRS once you have some available time.
    a) 0 documents
    b) 1-10
    c) 11-20
    d) 21-30
    e) 31-40
    f) 41-50
    g) 50+

11. How many times in a week do you need to retrieve the claim file from the filing area?

12. When you need to retrieve the paper file from the filing area:

a) what percentage of the time do you send the request to Pitney Bowes staff and wait for the file to be sent to you? (specify %)

b) what percentage of the time do you go to the filing area and retrieve the file yourself? (specify %)

13. How long does it take on average for you to get the paper file once you have sent the request to Pitney Bowes staff?

14. How many minutes does it take on average for you to go to the filing area and retrieve the file yourself?

15. Once you have the paper file in your hands, how long does it take on average for you to search for the desired document in that file?

16. How many minutes does it take for you to prepare a paper file to be sent for IME/peer review?

17. On average, how many times in a week do you have to prepare and send a paper fax?

18. How many minutes does it take to prepare and send a paper fax?

19. On average, how many electronic faxes (through RightFax) do you receive every day?

20. What % of these electronic faxes need to be printed and sent to file?

21. What % of your e-mail messages need to be printed and sent to file?

22. After you have sent a document to file, how many days does it take for the document to show up in the proper file?

23. What % of the time that you receive a new document do you make a paper copy for yourself and keep the copy at your desk for quick reference?

24. In a typical week, how often do the following individuals contact you to send them documents? Please write N/A if this question is not applicable to you.

	0-1 times	2-3	4-5	6-7	8 or more
Field Nurses	☐	☐	☐	☐	☐
Field Investigators	☐	☐	☐	☐	☐
Field Legal	☐	☐	☐	☐	☐
Medical Bill Operations Staff	☐	☐	☐	☐	☐

25. How long does it take for you to send the documents requested by the following individuals? Please estimate total time from request of document to actual receipt. Please write N/A if this question is not applicable to you.

	10 min or less	10 min – 1 hr	1-4 hrs	4-8 hrs	1-2 business days	3 or more business days
Field Nurses	☐	☐	☐	☐	☐	☐
Field Investigators	☐	☐	☐	☐	☐	☐
Field Legal	☐	☐	☐	☐	☐	☐
Medical Bill Operations Staff	☐	☐	☐	☐	☐	☐

Pre-EDM Communications

1. On a typical day, how many phone calls do you receive?

2. On a typical day, how many phone calls are you able to make?

3. What percentage of your telephone calls in a typical week come from
   a) Medical Provider Office/Doctor?(specify %)
   b) Customer?(specify %)
   c) Claimant?(specify %)
   d) Claimant's attorney?(specify %)
   e) Field Investigator/Field Nurse/Staff Legal? (specify %)
   f) WC (or Workers Compensation) staff?(specify %)
   g) Other? (specify %)

4. What percentage of telephone calls that you make in a typical week are to
   a) Medical Provider Office/Doctor?(specify %)
   b) Customer?(specify %)
   c) Claimant?(specify %)
   d) Claimant's attorney?(specify %)
   e) Field Investigator/Field Nurse/Staff Legal? (specify %)
   f) WC staff?(specify %)
   g) Other? (specify %)

5. On a typical day, how many e-mails do you receive?

6. On a typical day, how many e-mails are you able to send?

7. What percentage of your e-mails in a typical week come from
   a) Medical Provider Office/Doctor?(specify %)
   b) Customer?(specify %)
   c) Claimant?(specify %)
   d) Claimant's attorney?(specify %)
   e) Field Investigator/Field Nurse/Staff Legal? (specify %)
   f) WC staff?(specify %)
   g) Other? (specify %)

8. What percentage of e-mails that you write in a typical week are to
   a) Medical Provider Office/Doctor?(specify %)
   b) Customer?(specify %)
   c) Claimant?(specify %)
   d) Claimant's attorney?(specify %)
   e) Field Investigator/Field Nurse/Staff Legal? (specify %)
   f) WC staff?(specify %)
   g) Other? (specify %)

9. Please estimate the number of minutes or hours that you spend communicating over the phone or e-mail with the following individuals in a typical week.
   a) Medical providers/doctors
   b) Customers
   c) Claimants

10. How much time do you spend communicating over phone or e-mail with the following individuals in a typical week?

	<1hr	1-2 hrs	2-3 hrs	3-4 hrs	4 or more hours
Field Nurses	☐	☐	☐	☐	☐
Field Investigators	☐	☐	☐	☐	☐
Field Legal	☐	☐	☐	☐	☐
Medical Bill Operations Staff	☐	☐	☐	☐	☐

11. For a typical case that you handle, how many total phone contacts are made with the following people until the case is closed:
   a) Medical Provider Office/Doctor
   b) Customer
   c) Claimant

Qualitative/Wrap-up

1. How do you see EDM technology affecting your work? your performance?

2. What concerns do you have about EDM?

3. If EDM made more free time available to you, how would you plan to use that extra time?

4. Do you see EDM affecting your objective performance metrics? Which ones?
   a) Closure rate
   b) Timely first pays
   c) Timely ICP
   d) Best Practices Scores
   e) Processing financial notes
   f) **Other Metrics**. **Please specify**.

A5. Post-EDM Survey

Post-EDM Work (17 questions)

1. Most recently, what has been your average open case load?

How does this compare to pre-EDM (circle answer)?
    Increased
    Decreased
    Stayed the same

2. On average, how many new cases do you get every week?

How does this compare to pre-EDM (circle answer)?
    Increased
    Decreased
    Stayed the same

3. On average, how many cases do you close every week?

How does this compare to pre-EDM (circle answer)?
    Increased
    Decreased
    Stayed the same

4. Post-EDM, how many inches of paper (medical reports, forms, litigation documents, etc) do you typically receive every day via mail? [] (inches)

How does this compare to pre-EDM (circle answer)?
    Increased
    Decreased
    Stayed the same

5. What percentage of the paper mail that you receive daily are
    a) Medical reports or medical documents? (specify %)
    b) Legal documents? (specify %)
    c) State forms? (specify %)
    d) Field investigator reports? (specify %)
    e) Other (specify %)

Please check that TOTAL of (a) through (e) is 100%

6. Post-EDM, do you spend any time typing in medical reports into ExPRS (yes/no)?

If you answered “yes”, please answer the following question:
6 (a) How many minutes on average do you spend every day typing in medical reports into ExPRS? [] (mins)

7. Post-EDM, do you spend any time typing in legal documents into ExPRS (yes/no)?

If you answered "yes", please answer the following question:
7 (a) How many minutes on average do you spend every day typing in legal documents into ExPRS? [] (mins)

8. What is the typical number of paper documents that you have received prior to today but that you have yet to enter into ExPRS? These are backlogged documents sitting on your desk that you will get to typing into ExPRS once you have some available time.
   a) 0 documents
   b) 1-10
   c) 11-20
   d) 21-30
   e) 31-40
   f) 41-50
   g) 50+

9. Please answer the following questions comparing your post-EDM experience to your pre-EDM experience

	Yes	**No**	**No Change Or About the Same**	**Can't say**
Claim summaries completed earlier (than pre-EDM)?	☐	☐	☐	☐
Able to put more time into the quality of action plans?	☐	☐	☐	☐
More time to follow-up on activities outlined in action plans?	☐	☐	☐	☐
More time to discuss claim status with customers?	☐	☐	☐	☐
Able to take more recorded statements?	☐	☐	☐	☐
Easier to more accurately reserve claims?	☐	☐	☐	☐

10. Post-EDM, how many times in a week do you need to retrieve the claim file from the filing area?

11. Post-EDM, how many minutes does it take on average for you to get the paper file once you have sent the request to Pitney Bowes staff?

12. How much time does it take on average for you to search for the desired document in the electronic claim file (please remember to specify seconds/minutes)?

13. How many minutes does it take for you to prepare an electronic claim file to be sent for IME/peer review?

14. Post-EDM, how many times on average in a week do you have to prepare and send a paper fax?

15. Post-EDM, what % of your e-mail messages need to be printed and sent to file?

16. What % of the time that you receive a new document do you make a paper copy for yourself and keep the copy at your desk for quick reference?

17. Post-EDM, in a typical week, how often do the following individuals contact you to send them documents? Please write N/A if this question is not applicable to you.

IMPORTANT: For each row, please compare to pre-EDM in the last column using the following key:
I: Increased relative to pre-EDM
D: Decreased relative to pre-EDM
S: Stayed the same relative to pre-EDM

	0-1 times	2-3	4-5	6-7	8 or more	I / D / S
Field Nurses	☐	☐	☐	☐	☐	
Field Investigators	☐	☐	☐	☐	☐	
Field Legal	☐	☐	☐	☐	☐	
Medical Bill Operations Staff	☐	☐	☐	☐	☐	

18. How long does it take for you to send the documents requested by the following individuals? Please estimate total time from request of document to actual receipt. Please write N/A in the box if this question is not applicable to you.

IMPORTANT: For each row, please compare to pre-EDM in the last column using the following key:
I: Increased relative to pre-EDM
D: Decreased relative to pre-EDM
S: Stayed the same relative to pre-EDM

	10 min or less	10 min – 1 hr	1-4 hrs	4-8 hrs	1-2 business days	3 or more business days	I / D / S
Field Nurses	☐	☐	☐	☐	☐	☐	
Field Investigators	☐	☐	☐	☐	☐	☐	

Field Legal	☐	☐	☐	☐	☐	☐	
Medical Bill Operations Staff	☐	☐	☐	☐	☐	☐	

Post-EDM Communications (11 questions)

1. Post-EDM, how many phone calls do you receive on a typical day?

How does this compare to pre-EDM (circle answer)?

Increased
Decreased
Stayed the same

2. Post-EDM, how many phone calls are you able to make on a typical day?

How does this compare to pre-EDM (circle answer)?

Increased
Decreased
Stayed the same

3. Post-EDM, what percentage of your telephone calls in a typical week come from
   a) Medical Provider Office/Doctor?(specify %)
   b) Customer?(specify %)
   c) Claimant?(specify %)
   d) Claimant's attorney?(specify %)
   e) Field Investigator/Field Nurse/Staff Legal? (specify %)
   f) WC staff?(specify %)
   g) Other? (specify %)

4. Post-EDM, what percentage of telephone calls that you make in a typical week are to
   a) Medical Provider Office/Doctor?(specify %)
   b) Customer?(specify %)
   c) Claimant?(specify %)
   d) Claimant's attorney?(specify %)
   e) Field Investigator/Field Nurse/Staff Legal? (specify %)
   f) WC staff?(specify %)
   g) Other? (specify %)

5. Post-EDM, how many e-mails do you receive on a typical day?

How does this compare to pre-EDM (circle answer)?

Increased
Decreased
Stayed the same

6. Post-EDM, how many e-mails are you able to send on a typical day?

How does this compare to pre-EDM (circle answer)?

Increased
Decreased
Stayed the same

7. Post-EDM, what percentage of your e-mails in a typical week come from
   a) Medical Provider Office/Doctor?(specify %)
   b) Customer?(specify %)
   c) Claimant?(specify %)
   d) Claimant's attorney?(specify %)
   e) Field Investigator/Field Nurse/Staff Legal? (specify %)
   f) WC staff?(specify %)
   g) Other? (specify %)

8. Post-EDM, what percentage of e-mails that you write in a typical week are to
   a) Medical Provider Office/Doctor?(specify %)
   b) Customer?(specify %)
   c) Claimant?(specify %)
   d) Claimant's attorney?(specify %)
   e) Field Investigator/Field Nurse/Staff Legal? (specify %)
   f) WC staff?(specify %)
   g) Other? (specify %)

9. Post-EDM, please estimate the <u>number of minutes</u> that you spend communicating over the phone or e-mail with the following individuals in a <u>typical week</u>.
   a) Medical providers/doctors [] <u>(mins)</u>

How does this compare to pre-EDM (circle answer)?
Increased
Decreased
Stayed the same

b) Customers [] <u>(mins)</u>

How does this compare to pre-EDM (circle answer)?
Increased
Decreased
Stayed the same

c) Claimants [] <u>(mins)</u>

How does this compare to pre-EDM (circle answer)?
Increased
Decreased
Stayed the same

d) Internal Liberty staff [] <u>(mins)</u>

How does this compare to pre-EDM (circle answer)?
Increased
Decreased

Stayed the same

10. Post-EDM, how much time do you spend communicating over phone or e-mail with the following individuals in a typical week? Please write N/A in the box if this question is not applicable to you.

IMPORTANT: For each row, please compare to pre-EDM in the last column using the following key:
I: Increased relative to pre-EDM
D: Decreased relative to pre-EDM
S: Stayed the same relative to pre-EDM

	<1hr	1-2 hrs	2-3 hrs	3-4 hrs	4 or more hours	I/D/S
Field Nurses	☐	☐	☐	☐	☐	
Field Investigators	☐	☐	☐	☐	☐	
Field Legal	☐	☐	☐	☐	☐	
Medical Bill Operations Staff	☐	☐	☐	☐	☐	

11. For a typical case that you handle, how many total phone contacts are made with the following people until the case is closed:
    a) Medical Provider Office/Doctor

How does this compare to pre-EDM (circle answer)?
Increased
Decreased
Stayed the same

b) Customer

How does this compare to pre-EDM (circle answer)?
Increased
Decreased
Stayed the same

c) Claimants

How does this compare to pre-EDM (circle answer)?
Increased
Decreased
Stayed the same

Qualitative/Wrap-up (8 questions)

1. How has EDM technology affected you work? your performance?
2. Has EDM made more time available to you to perform other tasks? How have you used the freed up time?

3. What do you like least about EDM? What do you like most about EDM?

4. If you were in charge, what would you do differently to EDM?

5. Please indicate whether you agree or disagree with the following assertions about EDM or the impact of EDM.

	Strongly Agree	**Agree**	**Neither Agree Nor Disagree**	**Disagree**	**Strongly Disagree**
Find info more quickly					
Make better informed decisions					
Respond to internal Liberty requests faster					
Provide better service to customers					
Post-EDM processes/procedures are appropriate					
Bring cases to conclusion faster					

6. Please rank order from 1 (=most important benefit) to 6 the benefits of EDM from your point of view. If a particular choice is NOT a benefit, please write NB.

a) Faster access to claims documents
b) Less time documenting mail
c) Less time responding to document requests
d) Better customer service
e) More technical work such as medical management versus document management
f) Better information sharing with other groups/individuals

7. How has EDM affected your objective performance metrics?

	Increased / Improved	Decreased / Deteriorated	Stayed the same
Disposition Rate	☐	☐	☐
Timely ICP Score	☐	☐	☐
Timely First Pay Score	☐	☐	☐
Best Practices Scores	☐	☐	☐
Processing Financial Notes	☐	☐	☐

8. If EDM has had an impact on other performance metrics, please specify them here:

ESSAY 3

IT AND PRODUCTIVITY: NEW LARGE SAMPLE EVIDENCE FROM POST-RECESSION 2003-2005 PERIOD*

Abstract

Given the fundamental nature of the IT-productivity link in the IS discipline, the diversity of firm-level data in terms of sources and time periods analyzed in prior research has not been very encouraging. Further, though the IT productivity paradox has been laid to rest on the basis of prior firm-level and industry-level studies, the nature of the relationship needs continuous investigation especially after periods of significant economic activity or inactivity. There has been little firm-level empirical research to examine the IT productivity relationship after the dot-com boom or post 2001-02 economic recession in the U.S.

We have gathered and analyzed a large primary source firm-level dataset about IT investments that spans the 2003-2005 period, which is post 2001-2002 economic recession in the US. In doing so we have extended previous firm-level work done by Brynjolfsson and Hitt (1995), Lichtenberg (1995), Hitt and Brynjolfsson (1996), and Kudyba and Diwan (2002). To the best of our knowledge, this is the first large sample firm-level IT investments dataset from the post Internet-boom era. Importantly, in contrast to previous studies, most of our data captures actual IT expenditures versus IT budgets. Further, the coverage of industries in our dataset is more balanced than that in prior research.

Using a variety of econometric analyses, we have confirmed the positive and highly statistically significant relationship between IT and gross output or value-added for the most recent time period. Further, we have shown that the contribution of IT to firm-level performance measures such as value-added has not dramatically changed from what was observed in the first firm-level IT productivity studies which analyzed data from the 1988-1992 period. In contrast to Kudyba and Diwan's (2002) observation about increasing returns to IT based on their analysis of the 1995-1997 Internet boom era dataset, we present evidence of an inverted U-shaped returns curve, with returns now close to what they were in the pre-Internet era. We have also shown that use of IT flow (a measure of actual IT expenditure or IT budget) versus IT stock (a capitalized measure of IT that includes hardware capital and IT labor) does not produce a significant change in the magnitude of the estimated IT elasticities. We have also documented the lagged effects of IT investments on firm-level productivity measures.

Keywords: Productivity, IT expenditure, production function

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* Based on joint work with my office mate, Dr. Harry Zhu. Harry Zhu contributed most significantly to data cleanup and variable construction, and write-up of the "Data Collection and Variable Construction" section in the paper. The paper benefited from useful discussions with Harry. Thanks to Drs. Peter Weill and Erik Brynjolfsson for creating the survey that was used to collect IT investments data as part of the SeeIT project at MIT.

1 Introduction

Using evidence from the IT payoff literature, Devaraj and Kohli (2000) point to several possible reasons behind the heterogeneity of results on the relationship between IT investments and payoff, including diversity of variables used in the different studies, the level of analysis (for example: industry level versus firm level) as well as the research design employed (for example: cross-sectional versus longitudinal). Several more recent review and meta-analysis type studies have pointed out a host of reasons behind the observed variance in the results on the IT investments-payoff link (Kohli and Devaraj, 2003; Melville et al., 2004; Piccoli and Ives, 2005). For example, industry sector or context, sample size, characteristics of data source (primary or secondary), type of dependent variable (profitability-based or productivity-based) can have an impact on IT payoff reported in the literature (Kohli and Devaraj, 2003). These recent studies have made several important recommendations to improve the reliability of IT payoff studies. For example, Kohli and Devaraj (2003) suggest that future studies should analyze longitudinal or panel data that is gathered from primary data sources and that spans several periods and several firms. Given the expense, time and difficulty of gathering primary source longitudinal data for a large sample of firms, it is not surprising to find that only a few studies meet the above recommendations.

There are a few large firm-level IT productivity studies that analyze data collected from over 300 firms that span several industries and several years (Bresnahan et al., 2002; Brynjolfsson and Hitt 1995, 1996, 2000, 2003; Dewan and Min, 1997; Hitt and Brynjolfsson, 1996; Kudyba and Diwan, 2002; Lichtenberg, 1995). Though these studies do not employ primary source data (they use secondary data obtained from sources such as IDG and CI Infocorp), they have a fairly rich set of data from secondary sources for a large sample of firms that cuts across several industries. Nevertheless, the diversity of datasets in terms of sources and time periods employed in this type of research is not very high. For example, Brynjolfsson and Hitt (1995, 1996, 2000, 2003), Dewan and Min (1997), Hitt and Brynjolfsson (1996), and Lichtenberg (1995) employ the same 1988-1992 dataset obtained from *IDG/ComputerWorld* (note: Bresnahan et al. (2002) and Brynjolfsson and Hitt (2003) also look at *Computer Intelligence InfoCorp* (CII) dataset from 1987-1994 and Lichtenberg (1995) also looks at a dataset obtained from *InformationWeek*). The newest firm-level data that has been analyzed is from the 1995-1997 period (Kudyba and Diwan, 2002) and it was obtained from *InformationWeek*. Industry-level data for as late as until year 2000 was analyzed by Stiroh (2002). However, no attempts have been made to gather and analyze a large sample of firm-level data from the post dot-com boom era or the post 2001-2002 US economic recession. There is also little firm-level research that looks at the lagged effects of IT investments. Lack of time-lagged studies has been pointed out as a potential reason for inconsistencies among studies that analyze the IT-firm performance link (Chan, 2000). Importantly, most prior large sample firm-level research has looked at *IT budgets* as opposed to *actual IT expenditures*. Given that actual IT expenditures may be different from IT budgets, this distinction is an important one. In this paper, we attempt to address the above limitations of the current state of firm-level IT productivity empirical research and seek to meet the recommendations such as those proposed by Kohli and Devaraj (2003) which were listed above.

Even though the original debate about IT-productivity paradox that spurred vigorous research activity on the IT-productivity link in the 1990s has been largely put to rest (Brynjolfsson and

Hitt 2000; Stiroh 2002), we believe that it behooves IS researchers to make diligent efforts to collect firm-level data from diverse sources regularly or at least after significant periods of economic growth or recession to assess how the contribution of IT to productivity has changed over time. If similar methodology is employed to analyze newer data, it would be possible to compare results with those obtained in prior studies which use data from different sample periods. Of course, for the results to be comparable, the size of the sample also needs to be as comprehensive as that from prior studies which have set the benchmark for firm-level IT productivity research. In this study, we construct a much newer large sample dataset which spans the post-recession 2003-2005 period and which is nevertheless similar in its construction to datasets analyzed in prior research. Importantly, most of our data (for 2003 and 2004) is about actual IT expenditures and not just IT budgets. The overall similarity in construction of the dataset and in the variety of econometric analyses performed on the data allow us to compare results in this study with those in prior studies. Our analyses enable us to answer the following primary questions: Has the relationship between IT and productivity changed since the dot-com bubble burst? Given results from prior studies, how has the relationship between IT and productivity changed over time? What are the lagged effects of IT investments on productivity?

Specifically, we make the following contributions in this paper. We gather and analyze a large *primary source* firm-level dataset about IT investments that spans the 2003-2005 period or post 2001-2002 economic recession in the US and in doing so we extend previous firm-level work done by Brynjolfsson and Hitt (1995), Lichtenberg (1995), Hitt and Brynjolfsson (1996) and Kudyba and Diwan (2002). While previous firm-level datasets were from the pre-Internet era (for example, 1988-1992 in Brynjolfsson and Hitt (1995, 1996) and Lichtenberg (1995)) and from during the dot-com boom era (1995-1997 in Kudyba and Diwan (2002)), we look at a significantly sized dataset which contains data on actual IT expenditures and investments, and financial performance for more than 300 firms from a period which is post-Internet bubble and post the first economic recession of this century. We also document the lagged effects of IT investments on firm-level productivity measures. In addition, we examine whether using IT flows versus IT stocks in the IT productivity regressions makes a material difference to the estimated IT elasticities.

2 Theory

Our work is grounded in the economic theory of production which has been extensively used in previous firm-level empirical research on the IT-productivity link. According to production theory, firms transform inputs to outputs using a "technology" which is represented mathematically by what is called a production function. The production function represents the maximum amount of output that can be produced using a given set of inputs and given "technology". Rationally-managed firms will continue to invest in an input until the last unit of input such as IT adds no more value than it costs (Hitt and Brynjolfsson, 1996). In other words, in equilibrium, marginal cost of the input equals value of the marginal output created by the last dollar invested in the input (Kudyba and Diwan, 2002) or the net marginal product of the input i.e. the additional output created for an additional unit of input minus cost of input is zero (Hitt and Brynjolfsson, 1996). The production function can be represented as follows:

$$Q = f(C, K, L)$$

where Q refers to total output measured in terms of sales or value-added, C is the IT capital stock, K is the non-IT capital, and L is the non-IT labor. Note C, K and L are also referred to as factor inputs. A popular form of the production function that is often used in this type of research is the Cobb-Douglas production function shown below. Note that we could have used a less restrictive production function specification such as the translog specification. However, as shown by Brynjolfsson and Hitt (1995), the use of the translog specification, instead of the more restrictive Cobb-Douglas specification, results in no significant differences in the estimated contribution of IT (C).

$$Q=C^{\beta_1}K^{\beta_2}L^{\beta_3}$$

Taking logs of both sides, we get

$$\log Q = \beta_1 \log C + \beta_2 \log K + \beta_3 \log L$$

The popularity of the Cobb-Douglas production function stems from the fact that its linear form (obtained by taking its logs) allows for easy estimation of the elasticities of the factor inputs. The elasticity of a factor input is the percentage change in the output due to a one-percent increase in the factor input. In the linearized form of the Cobb-Douglas function above, β_1, β_2 and β_3 refer to the elasticities of C, K, and L respectively.

The estimated IT elasticity measure can be used to compute gross marginal product of IT or the rate of return on IT, which is the amount of output produced for an additional unit of IT. The relationship between IT elasticity (β_1) and gross marginal product of IT (MP_C) is as follows:

$$MP_C = \frac{\beta_1}{(C/Q)}$$ where (C/Q) is the factor share of IT (C) in Output (Q)

3 Data Collection and Variable Construction

This study uses a unique dataset on IT expenditure by 347 large firms (mostly Fortune 1000 firms) during the period of 2003-2005. The data was collected by phone interviews using a questionnaire designed by the research team. The questionnaire was distributed to the firms prior to phone interviews. Approximately, 600 firms were contacted but many were privately owned or provided unreliable/incomplete data and were not included in the analysis dataset. The questionnaire asked the respondents to provide the replacement value of the firm's total stock of computer hardware, the total IT expenditure, the percentage of the IT expenditure classified as IT labor expenditure, the total number of information systems employees, other IT related information, and the industry in which the firm operated.

Since the 347 firms included in the final analysis dataset were public entities, we used Compustat to obtain financial information about them. This information included measures such as total capital, output, labor and related expenses, number of employees, and other financial data for the firm. We also obtained price indices from various sources to deflate monetary values to 2004 constant dollars. The panel has a total of approximately 850 observations (which varies depending on the model specification) out of 1041 possible observations if the panel were complete.

To allow us to compare our results with those from previous studies, we closely followed the variable construction methods in Brynjolfsson and Hitt (1995) and Kudyba and Diwan (2002). Their methods have been used in several other similar studies (Brynjolfsson and Hitt, 1996; Dewan and Min, 1997; Dewan et al., 1998; Hitt and Brynjolfsson, 1996). Table 1 summarizes the definitions and the construction of the variables. We provide a brief description of the variables below and refer the reader to the previous studies for further details.

Table 1. Variable Definitions and Construction

Variable	Construction	Source
Gross Output	Sales (Net) (data12), which is gross sales less discounts and returned sales, deflated by industry-specific Output Price (see below)	Compustat
Value Added	Non-deflated sales minus Cost of Goods Sold (COGS) (data41) and Selling, General & Administrative expenses (SG&A) (data189), deflated by industry-specific Value Added Price (see below)	Compustat
IT Capital	The replacement value of total stock of computer hardware, deflated by Investment Price (see below)	This study
IT Stock	IT Capital plus three times IT Labor	Calculation
Capital	Net Property, Plant & Equipment (PPE) (data8), deflated by Capital Price (see below), less IT Capital	Compustat
IT Flow	Total IT expenditure, deflated by Investment Price	This study
IT Labor	Labor portion of IT Flow, deflated by industry-specific Labor Price (see below)	This study
Labor	Labor and Related Expenses (data42), when available, or estimate using industry average Wages (see below) times number of employees, deflated by industry-specific Labor Price, less IT Labor, when available	Compustat
Industry	Consolidated industry sector based on self-reported industry and the NAICS code	This study and Compustat
Output Price	Chain-Type Price Indexes for Gross Output by Industry	Bureau of Economic Analysis
Value Added Price	Chain-Type Price Indexes for Value Added by Industry	Bureau of Economic Analysis
Investment Price	Price Indexes for Private Fixed Investment by Type	Bureau of Economic Analysis
Capital Price	GDP deflator for Fixed Investment	Economic Report of the President, 2007, Table B-7
Labor Price	Employment cost index of total compensation in private industry	Economic Report of the President, 2007, Table B-48
Wages	Average earnings of workers by major industry sector	Bureau of Labor Statistics

As in Kudyba and Diwan (2002), we chose to use two alternative measures for output: *Gross Output* and *Value-added*. *Gross Output* is the gross sales (from Compustat) of the firm deflated by industry-specific *Output Price* (see Table 1 for description of *Output Price* deflator). Value-added is gross sales less variable costs deflated by industry-specific *Value-Added Price* (see Table 1 for description of *Value-Added Price* deflator), where variable costs are the sum of *Cost of Goods Sold* and *Selling*, *General and Administrative* expenses (from Compustat). Note that the Output Price and Value-added price deflators are obtained from the Bureau of Economic Analysis. Value-added is considered to be less noisy and more comparable across industry sectors than sales (Dewan and Min, 1997). *IT Capital* is the replacement value of the total stock of computer hardware in the firm. *IT Stock* is the sum of *IT Capital* and three times *IT Labor*. This is justified given that the majority of the IT labor expenditures are used to produce software, which is a form of IT capital and assumed to be fully depreciated after three years. This assumption has been used in previous studies mentioned earlier (for example: see Hitt and Brynjolfsson (1996)). In addition, Brynjolfsson and Hitt (1995) show that the elasticity of IT Stock is relatively stable when the assumed depreciation time of the stock created by IT labor is varied from one year to seven years. Following Kudyba and Diwan (2002), we derived *Capital*, which is the non-IT capital of the firm, by subtracting *IT Capital* from *Net Property*, *Plant and Equipment* (from Compustat). Note that *Net PP&E* and *IT Capital* are deflated using *Capital Price* (obtained from the Economic Report of the President) and *Investment Price* (obtained from the Bureau of Economic Analysis) respectively. Please see Table 1 for details about the deflators. The Industry variable was constructed by grouping similar self-reported industries.

We include several flow variables. *IT Flow* is the annual total IT expenditure of the firm, deflated by *Investment Price*. This is the actual expenditure incurred by the firm. In contrast, previous studies have primarily used IS Budget. Since a firm may over- or under-spend the allocated IS budget, *IT Flow* in our study is a more accurate measure of IT spending (*note that we have actual IT expenditures for 2003 and 2004, but only IT budget for 2005, as the interviews were conducted in 2005*). *IT Labor* is the labor portion of IT expenditure, deflated by industry-specific *Labor Price*. As noted earlier, *IT Labor* is used to construct the *IT Stock* variable. *Labor*, which is non-IT labor expense, is derived by subtracting *IT Labor* (when available) from deflated *Labor and Related Expenses* as reported in Compustat. When the latter is not available, it is estimated using number of employees (from Compustat) and industry-specific *Wages* time series (from the Bureau of Labor Statistics).

The summary statistics of the dataset including the factor shares are shown in Table 2.

Table 2. Summary Statistics (in 2004 constant dollars, N=830)

	Total $(Annual Average)			Average Firm
	(in Billions)	% Gross Output	% Value-added	(in Millions)
Sales	$4,664	100%	531%	$16,865
Value Added	$878	18.8%	100%	$3,179
IT Stock	$103	2.22%	11.8%	$373
Capital	$1,686	36.2%	192%	$6,089
IT Flow	$73.5	1.58%	8.37%	$265
IT Labor	$25.3	0.54%	2.87%	$90.9
Labor	$645	13.8%	73.5%	$2,332

As in previous studies, the dataset in this study also consists of large firms. The average annual sales in the sample period were $16.8 billion, and the total sales were approximately $4.6 trillion. An average firm spent $265 million annually on IT, more than a third of which were IT labor expenditures. The gross output factor shares of (non-IT) capital and labor in this dataset (36.2% and 13.8%, respectively) are much lower than those in Brynjolfsson and Hitt (1996) (97.2% and 83.3%, respectively), while IT Flow (1.58%) is approximately the same as that in the previous study (1.63%). These differences may be attributed in part to the different industry mixes of the firms in the two datasets. The dataset of this study is more balanced: approximately 18.6% of the observations are from manufacturing sector, which is the largest but not overwhelmingly dominant industry sector. Energy, Finance, and Health sectors each accounts for more than 10% of the observations (see Table 3 for the sample distribution by industry sector). In contrast, the dataset of Brynjolfsson and Hitt (1996) was concentrated in manufacturing (the most capitalintensive industry sector in general), which accounted for approximately two-thirds of the firms in their sample. The lower factor share of labor input in this dataset may be a result of higher outsourcing of labor-intensive tasks in recent times (compared to period prior to 1992) in addition to a different, more balanced distribution of industry sectors in the dataset. However, if we compare the value-added factor shares (column 4 of Table 2) of the average firm with those in Brynjolfsson and Hitt (1995), the percentages are quite similar (e.g., 11.8% for IT Stock in this study vs. 9.35% for IT Capital plus IT Labor in Brynjolfsson and Hitt (1995)). As mentioned earlier, value-added is a more reliable measurement of output and we use it here to compute gross marginal product of IT. The similarity of value-added factor shares in our dataset and the one used in several prior studies makes our results comparable to those of prior work.

Table 3. Industry Sectors in the Sample

Industry Sector	N	%
Commodity	55	6.63
Consumer Product	29	3.49
Energy	90	10.84
Engineering	52	6.27
Food, Beverage, Hospitality & Travel	44	5.30
Finance	96	11.57
Health	90	10.84
IT	66	7.95
Manufacturing	154	18.55
Media	40	4.82
Professional Services	42	5.06
Retail	72	8.67
Total	830	100.00

This dataset has several strengths. The data was gathered via phone interviews and the values were verified against those of previous years. Thus the accuracy of data is likely to be higher than that obtained from secondary sources based on questionnaire surveys. The IT Expenditure data for years 2003 and 2004 are actual expenditures as opposed to IT budget. Since a firm may over- or under-spend IT budget, the measurement errors of IT Expenditure in our dataset should be smaller than those of IS Budget which has been used in previous studies. In addition, the firms in our sample are more balanced across several industry sectors, and thus our results should be representative of a broad cross-section of the economy.

Certain limitations of the dataset should be kept in mind. The IT-related information is self-reported, and with any kind of self-reported data, there is a possibility of a bias (for example, social desirability bias) creeping in. The data may have sample selection bias. However, the relatively large sample size should mitigate the impact of the bias. Further, we used a three-year average life assumption for the IT capital stock created by IT labor; thus the IT Stock was only an approximation of IT capital. However, prior research has shown that this assumption is reasonable and that the production function estimates do not vary much when the assumption is varied from one to seven years (Hitt and Brynjolfsson, 1996).

4 Data Analysis and Results

We first present a two-way scatter plot showing the relationship between the value-added measure of firm-level productivity and IT stock, both computed relative to industry average (Figure 1). The plot clearly reveals a positive relationship between IT stock and productivity.

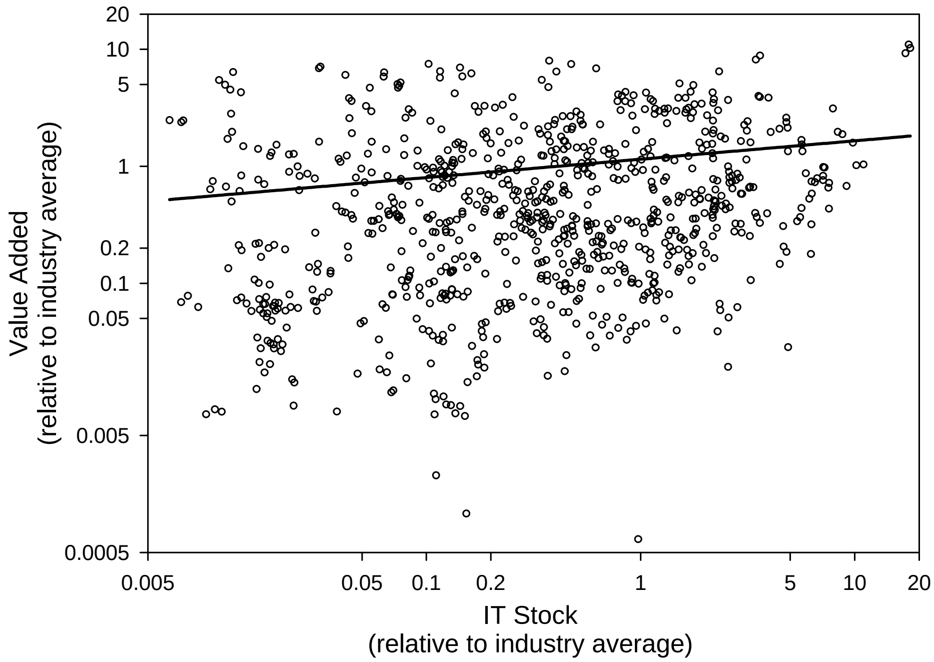


Figure 1. Value-added Productivity Measure vs. IT Stock Scatter Plot (2003-2005)

Table 4 shows the results of the year-by-year OLS regressions of value-added and gross output on IT stock and other factor inputs with industry group controls. The model specification for each year t=2003, 2004, and 2005 is as follows:

$$\log Q_i = \sum_j D_j + \beta_1 \log C_i + \beta_2 \log K_i + \beta_3 \log L_i + \varepsilon$$

where $\beta_1, \beta_2, \beta_3$ are the coefficients to be estimated, Q is value-added or gross output, C is the IT stock variable, K is non-IT capital, L is non-IT labor, i is the firm, j is the industry group, D_j is a dummy variable corresponding to industry group j and ε is the residual. The table shows that in the case of value-added regressions, the IT elasticity jumped from 0.065 in 2003 to 0.127 in 2004 and 0.123 in 2005. The value-added regression IT elasticity coefficient in 2003 is significantly different from the IT elasticity coefficient in 2004 (p=0.01); however the elasticities in 2004 and 2005 are not statistically different. In the case of the gross output regressions, the coefficients are increasing over time; however the coefficients are not statistically different across the different years. Importantly, across the different specifications, the coefficient for IT Stock remains positive and highly statistically significant.

Table 4. Year-by-Year OLS Regressions Using IT Stock With Industry Controls

	Value-added as dependent variable			Gross output as dependent variable		
	2003	2004	2005	2003	2004	2005
IT Stock (C)	.0649** (.0252)	.127*** (.0268)	.123*** (.0261)	.110*** (.0225)	.116*** (.0228)	.115*** (.0233)
Capital (K)	.670*** (.0616)	.507*** (.0735)	.609*** (.0471)	.335*** (.0417)	.304*** (.0514)	.404*** (.0452)
Labor (L)	.217*** (.0608)	.318*** (.0660)	.205*** (.0517)	.448*** (.0464)	.465*** (.0511)	.363*** (.0529)
Dummy Variables	Industry	Industry	Industry	Industry	Industry	Industry
N	284	286	262	290	289	267
R^2	98.9%	99.1%	99.1%	99.5%	99.5%	99.5%

*** p<0.01, ** p<0.05, * p<0.1; Huber/White heteroskedasticity-robust standard errors in parentheses

Table 5 shows the results of the OLS regression on the pooled data (from all years) and it includes both industry and time controls (see columns 2 and 5). The model specification is as follows:

$$\log Q_{it} = \sum_t D_t + \sum_j D_j + \beta_1 \log C_{it} + \beta_2 \log K_{it} + \beta_3 \log L_{it} + \varepsilon$$

where $\beta_1, \beta_2, \beta_3$ are the coefficients to be estimated, Q is either value-added or gross output, C is the IT stock variable, K is non-IT capital, L is non-IT labor, i is the firm, t is the time period, j is the industry group, D_t is a dummy variable corresponding to time period t, D_j is a dummy variable corresponding to industry group j, and ε is the residual. For dependent variable value-added, the second column of the table shows that IT elasticity is 0.107 which is not statistically different from the IT elasticity of 0.088 reported in a similar econometric regression in Brynjolffson and Hitt (1996).The gross marginal product or gross rate of return of IT stock based on IT elasticity obtained from value-added regression is 91% (=0.107/0.118), which is only marginally lower than the gross marginal product of 94.9% reported in Hitt and Brynjolfsson

(1996). (Note gross marginal product of IT is equal to IT stock elasticity divided by the percentage of IT Stock in value-added.) Figure 2 shows the increasing gross marginal product of IT from 2003 to 2005, increasing from 49% in 2003 to 110% in 2004 to 116% in 2005.

Our results reported here are significantly different from the increasing returns results reported in Kudyba and Diwan (2002), who compare their value-added regression results to those reported in Hitt and Brynjolfsson (1996) and claim that IT elasticity has increased from the 1988-1992 period to the 1995-1997 period. We believe that our results may be more directly comparable to those reported in Hitt and Brynjolfsson (1996) because unlike Kudyba and Diwan (2002) who use IT flow (or IT budget dedicated to IT equipment) instead of IT capital stock in their value-added regressions, we use IT stock in our value-added regressions, just like Hitt and Brynjolfsson (1996) did. We do not find evidence of increase in IT elasticity from the 1988-1992 period to the 2003-2005 period. If we accept Kudyba and Diwan (2002) value-added regression results (even though the methodology is slightly different as pointed above), we can then graphically show (see Figure 3a) that IT elasticity has followed an inverted U-shaped curve, increasing in the 1995-1997 period and then declining to 1988-1992 levels in the 2003-2005 period. Kudyba and Diwan suggested increasing returns by plotting their estimates against estimates from prior studies. In Figure 3a, we extend their chart (see Kudyba and Diwan (2002), Figure 2, pg. 109) and suggest return estimates closer to those based on 1988-1992 data. Note that Figure 3a is based on data contained in Table 6. As pointed in the data section above, our interview questionnaire asked respondents to report *actual IT expenditures* (for 2003, 2004) versus *IT budgets;* our results are thus potentially less susceptible to error-in-variable bias as IT budgets may not mirror actual IT expenditures.

Table 5. Regressions using IT Stock with Industry and Time controls

	Value-added as dependent variable			Gross output as dependent variable		
	Pooled OLS	ISUR	2SLS	Pooled OLS	ISUR	2SLS
IT Stock (C)	.107*** (.0152)	. 0994*** (.0236)	. 114*** (.0182)	.114*** (.0130)	.0556** (.0189)	.111** (.0158)
Capital (K)	.589*** (.0391)	.509*** (.0309)	.595*** (.0363)	.347*** (.0284)	.279*** (.0215)	.355*** (.0320)
Labor (L)	.252*** (.0365)	.289*** (.0346)	.244*** (.0380)	.426*** (.0302)	. 241*** (.0221)	. 430*** (.0351)
Dummy Variables	Industry & Year	Industry & Year	Industry & Year	Industry & Year	Industry & Year	Industry & Year
N	832	768	542	846	786	550
R^2	99.0%	81.6-83.4%	-	99.5%	70.2-70.4%	-

*** p<0.01, ** p<0.05, * p<0.1; Huber/White heteroskedasticity-robust standard errors (except for ISUR) in parentheses

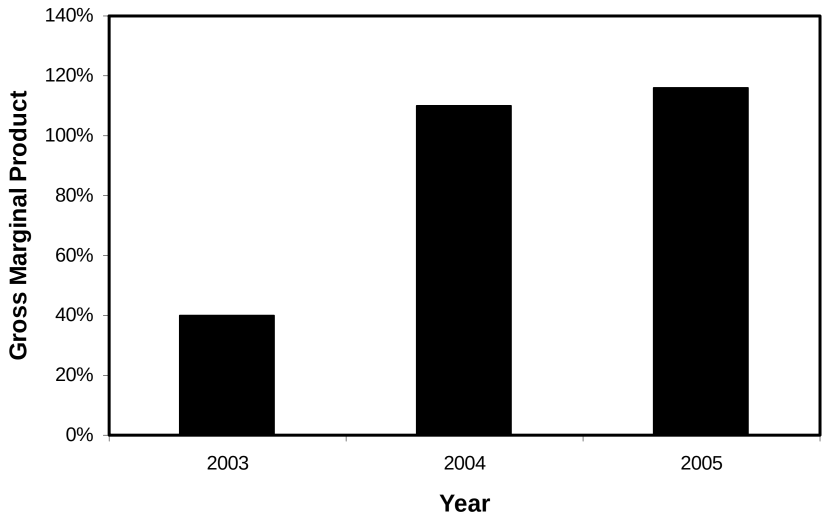


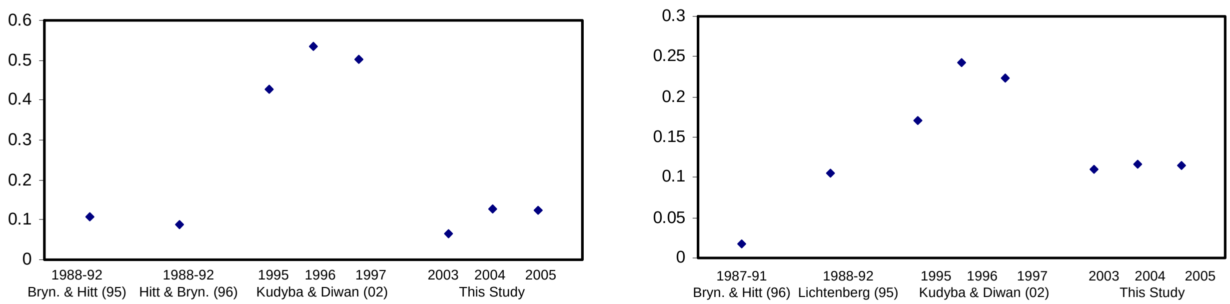
Figure 2. Gross Marginal Product of IT Stock Over Time

The pooled OLS regression results for gross output as a dependent variable are shown in column 5 of Table 5. It shows that IT elasticity is 0.114, which is remarkably similar to the elasticity obtained above in the value-added regression (0.107). Further, it is very close to 0.106 reported by Lichtenberg (1995). As in the value-added case, the results with sales or gross output as the dependent variable are significantly different from those reported in Kudyba and Diwan (2002). Plotting the coefficients from prior studies and this study, we again see an inverted U-shaped curve (see Figure 3b). While Kudyba and Diwan (2002, see Figure 1 on pg. 109) suggest increasing returns to IT based on comparison of results from analysis of the 1995-1997 data with those from prior studies, we provide evidence of declining returns post Internet-boom era and reversion to previous return estimates (based on the 1988-1992 data). Note that Figure 3b is based on data contained in Table 6.

Table 6. Trend of IT Elasticities

Source	Brynjolfsson and Hitt (1996)	Lichtenberg (1995)	Brynjolfsson and Hitt (1995)	Hitt and Brynjolfsson (1996)	Kudyba and Diwan (2002)			This study		
Factor	IT Capital	IT Capital	IT Stock[+]	IT Stock	IT Flow[++]			IT Stock		
Period	1987-91	1988-92	1988-92	1988-92	1995	1996	1997	2002	2003	2004
β^a	-	-	.109	.0883	.427	.535	.502	.0649	.127	.123
β^b	.0169[†]	.106	-	-	.171[‡]	.243[‡]	.223[‡]	.110	.116	.115

[a] Value Added as dependent variable; [b] Gross output as dependent variable; [+] Sum of IT Capital and IT Labor; [++] IS budget; [†] IT Capital and IT Labor are separate factors; [‡] IT Labor and Non-IT Labor are separate factors.



(a) Value Added as independent variable (b) Gross Output as independent variable

Figure 3. IT Elasticities (Value-added and Gross Output Regressions)

Next, we use ISUR (iterated seemingly unrelated regression) technique to potentially improve the estimation efficiency of our regressions. With ISUR, we estimate a system of three equations with a set of constraints that forces the estimated coefficients of certain variables to be the same across the system of equations. The system of equations is shown below:

$$\log Q_{i(2003)} = \beta_{(2003)} + \sum_j D_j + \beta_1 \log C_{i(2003)} + \beta_2 \log K_{i(2003)} + \beta_3 \log L_{i(2003)} + \varepsilon_{(2003)}$$

$$\log Q_{i(2004)} = \beta_{(2004)} + \sum_j D_j + \beta_1 \log C_{i(2004)} + \beta_2 \log K_{i(2004)} + \beta_3 \log L_{i(2004)} + \varepsilon_{(2004)}$$

$$\log Q_{i(2005)} = \beta_{(2005)} + \sum_j D_j + \beta_1 \log C_{i(2005)} + \beta_2 \log K_{i(2005)} + \beta_3 \log L_{i(2005)} + \varepsilon_{(2005)}$$

where $\beta_1, \beta_2, \beta_3$ are the coefficients to be estimated, Q is either value-added or gross output, C is the IT stock variable, K is non-IT capital, L is non-IT labor, i is the firm, j is the industry group, D_j is a dummy variable corresponding to industry group j, and ε is the residual. Note $\beta_1, \beta_2, \beta_3$ as well as the coefficients for the industry dummies are constrained to be the same across the equations. The coefficients and standard errors estimated by ISUR are unbiased provided each of the cross-section error terms is homoskedastic and uncorrelated with the input regressors. ISUR implicitly corrects for serial correlation and heteroskedasticity of error terms across years (Hitt and Brynjolfsson, 1996). In pooled OLS regressions, the latter two conditions are assumed for unbiased estimates and standard errors. Columns 3 and 6 in Table 5 presents the ISUR results. As seen from the table, the IT stock elasticity in the value-added regression declines only marginally from 0.107 (in pooled OLS regression) to 0.0994 (in ISUR regression) whereas the IT elasticity in the gross output regression declines from 0.114 (in pooled OLS) to 0.055 (in ISUR), with marginal deterioration in the standard errors, although the standard errors for the other factor coefficients improve somewhat.

To eliminate the possibility of simultaneity bias or to eliminate the possibility that it is not IT that leads to higher output but higher output that stimulates higher IT investments, we perform 2SLS regressions, using the lagged values of the independent variables (IT stock, Capital and Labor) as the instruments. The results are presented in Table 5 (see columns 4 and 7 for the dependent variables value-added and gross output respectively). The 2SLS regressions show no significant change in the factor elasticities when compared to the pooled OLS regressions. The Hausman specification test does not reject the hypothesis that the estimates of IT Stock were unbiased (Hausman, 1978). Thus we can eliminate the possibility of endogeneity biases leading to high IT elasticities.

Next, we look at the lagged effects of IT investments. We estimate year-by-year OLS regression models with lagged values of IT stock as an independent variable. The model specifications are as follows:

$$\log Q_{i\,(2004)} = \sum_j D_j + \beta_1 \log C_{i(2003)} + \beta_2 \log K_{i(2004)} + \beta_3 \log L_{i(2004)} + \varepsilon \; \ldots \text{(IT Stock LAG=1)}$$

$$\log Q_{i\,(2005)} = \sum_j D_j + \beta_1 \log C_{i(2004)} + \beta_2 \log K_{i(2005)} + \beta_3 \log L_{i(2005)} + \varepsilon \; \ldots \text{(IT Stock LAG=1)}$$

$$\log Q_{i\,(2005)} = \sum_j D_j + \beta_1 \log C_{i(2003)} + \beta_2 \log K_{i(2005)} + \beta_3 \log L_{i(2005)} + \varepsilon \; \ldots \text{(IT Stock LAG=2)}$$

where Q is either value-added or sales (gross output), $\beta_1, \beta_2, \beta_3$, C, K, L, D_j and ε are as defined previously.

The results for value-added as the dependent variable are shown in columns 2, 3, and 4 of Table 7 and for sales or gross output as the dependent variable in columns 5, 6, and 7 of Table 7. In general, we do not see evidence of higher elasticities with lagged values of IT stock. The point estimates in fact decline in magnitude as the number of lags is increased (see Table 8). However, it must be noted that the decline is not statistically significant: the coefficients for all the regressions (LAG=0,1,2 for year 2005 or LAG=0,1 for year 2004) are not systematically different from each other.

Table 7. Year-by-Year OLS regressions: Lagged Effects of IT Stock

	Value-added as dependent variable			Gross output as dependent variable		
	2004 (LAG=1)	2005 (LAG=1)	2005 (LAG=2)	2004 (LAG=1)	2005 (LAG=1)	2005 (LAG=2)
IT Stock (C)	.122*** (.0267)	.118*** (.0258)	.114*** (.0262)	.113*** (.0225)	.110*** (.0228)	.110*** (.0226)
Capital (K)	.507*** (.0737)	.610*** (.0472)	.609*** (.0472)	.304*** (.0515)	.404*** (.0453)	.402*** (.0452)
Labor (L)	.318*** (.0659)	.205*** (.0518)	.205*** (.0515)	.464*** (.0511)	.363*** (.0530)	.364*** (.0529)
Dummy Variables	Industry	Industry	Industry	Industry	Industry	Industry
N	286	262	262	289	267	267
R^2	99.0%	99.1%	99.1%	99.5%	99.5%	99.5%

*** p<0.01, ** p<0.05, * p<0.1; Huber/White heteroskedasticity-robust standard errors in parentheses

Note: LAG refers to IT Stock (C) lagged in the regression model

Table 8. IT Stock Coefficients with and without Lagged Effects

Dependent Variable	2004 (LAG=0)	2004 (LAG=1)	2005 (LAG=0)	2005 (LAG=1)	2005 (LAG=2)
Value-added	.127*** (.0268)	.122*** (.0267)	.123*** (.0261)	.118*** (.0258)	.114*** (.0262)
Gross Output	.116*** (.0228)	.113*** (.0225)	.115*** (.0233)	.110*** (.0228)	.110*** (.0226)

*** p<0.01, ** p<0.05, * p<0.1; Huber/White heteroskedasticity-robust standard errors in parentheses

Following Kudyba and Diwan (2002), we also test the use of actual IT expenditures or budgets (a flow variable) instead of IT stock in the year-by-year OLS regressions. The model specification for each year t=2003, 2004, and 2005 is as follows:

$$\log Q_i = \sum_j D_j + \beta_1 \log C_{(flow)i} + \beta_2 \log K_i + \beta_3 \log L_i + \varepsilon$$

where $\beta_1, \beta_2, \beta_3$ are the coefficients to be estimated, Q is value-added or gross output, $C_{(flow)}$ is the IT flow variable or the actual IT expenditure or budget, K is non-IT capital, L is non-IT labor, i is the firm, j is the industry group, D_j is a dummy variable corresponding to industry group j and ε is the residual. Columns 2, 3, and 4 in Table 9 show that in the value-added regressions the IT elasticity jumped from 0.064 in 2003 to 0.131 in 2004 and 0.124 in 2005. Columns 5, 6, 7 in

Table 9 show the estimated factor coefficients in the gross output regressions. It is interesting to see that the results *do not* change much from the results obtained when IT stock is used. The coefficients obtained using IT flow are very close to the coefficients obtained using IT stock.

Table 9. Year-by-Year OLS Regressions Using IT Flow

	Value Added as dependent variable			Gross output as dependent variable		
	2003	2004	2005	2003	2004	2005
IT Flow (C_{flow})	.0639** (.0274)	.131*** (.0289)	.124*** (.0277)	.109*** (.0233)	.114*** (.0241)	.108*** (.0244)
Capital (K)	.671*** (.0621)	.507*** (.0732)	.610*** (.0469)	.336*** (.0411)	.305*** (.0512)	.406*** (.0446)
Labor (L)	.215*** (.0608)	.316*** (.0655)	.202*** (.0517)	.446*** (.0461)	.462*** (.0511)	.360*** (.0526)
Dummy Variables	Industry	Industry	Industry	Industry	Industry	Industry
N	284	286	262	290	289	267
R^2	98.9%	99.1%	99.1%	99.5%	99.5%	99.5%

*** p<0.01, ** p<0.05, * p<0.1; Huber/White heteroskedasticity-robust standard errors in parentheses

Table 10 shows the results of the OLS regression on the pooled data (from all years) and it includes both industry and time controls. The model specification is as follows:

$$\log Q_{it} = \sum_t D_t + \sum_j D_j + \beta_1 \log C_{(flow)it} + \beta_2 \log K_{it} + \beta_3 \log L_{it} + \varepsilon$$

where $\beta_1, \beta_2, \beta_3$ are the coefficients to be estimated, Q is either value-added or gross output, $C_{(flow)}$ is the IT flow variable, K is non-IT capital, L is non-IT labor, i is the firm, t is the time period, j is the industry group, D_t is a dummy variable corresponding to time period t, D_j is a dummy variable corresponding to industry group j, and ε is the residual. As with the year-by-year OLS regressions, the coefficients do not change much when IT flow is used instead of IT stock in the regressions.

Table 10. Pooled OLS Regressions Using IT Flow with Industry and Time controls

	Value-added as dependent variable	Gross output as dependent variable
IT Flow (C_{flow})	.109*** (.0165)	.110*** (.0137)
Capital (K)	.589*** (.0392)	.348*** (.0282)
Labor (L)	.250*** (.0364)	.423*** (.0301)
Dummy Variables	Industry and Year	Industry and Year
N	832	846
R^2	99.0%	99.5%

*** p<0.01, ** p<0.05, * p<0.1; Huber/White heteroskedasticity-robust standard errors in parentheses

As in the case of the IT stock regressions, we next look at the lagged effects of IT investments captured as IT flows on value-added and gross output. The model specifications are as follows:

$$\log Q_{i\,(2004)} = \sum_j D_j + \beta_1 \log C_{(flow)i(2003)} + \beta_2 \log K_{i(2004)} + \beta_3 \log L_{i(2004)} + \varepsilon \ldots \text{(IT Stock LAG=1)}$$

$$\log Q_{i\,(2005)} = \sum_j D_j + \beta_1 \log C_{(flow)i(2004)} + \beta_2 \log K_{i(2005)} + \beta_3 \log L_{i(2005)} + \varepsilon \ldots \text{(IT Stock LAG=1)}$$

$$\log Q_{i\,(2005)} = \sum_j D_j + \beta_1 \log C_{(flow)i(2003)} + \beta_2 \log K_{i(2005)} + \beta_3 \log L_{i(2005)} + \varepsilon \ldots \text{(IT Stock LAG=2)}$$

where Q is either value-added or sales (gross output), $\beta_1, \beta_2, \beta_3, C_{(flow)}$, K, L, D_j and ε are as defined previously. The results for value-added as a dependent variable are shown in columns 2, 3, and 4 in Table 11 and for gross output as a dependent variable in columns 5, 6, and 7 in Table 11. In general, we do not see evidence of higher elasticities with lagged values of IT flow. The point estimates in fact decline in magnitude as the number of lags is increased. However, it must be noted that the decline is not statistically significant: the coefficients for all the regressions (LAG=0,1,2 for year 2005 or LAG=0,1 for year 2004) are not systematically different from each other.

Table 11. Year-by-Year OLS Regressions: Lagged Effects of IT Flow

	Value-added as dependent variable			Gross output as dependent variable		
	2004 (LAG=1)	2005 (LAG=1)	2005 (LAG=2)	2004 (LAG=1)	2005 (LAG=1)	2005 (LAG=2)
IT Flow (C_{flow})	.126*** (.0284)	.121*** (.0275)	.118*** (.0274)	.112*** (.0234)	.106*** (.0242)	.106*** (.0234)
Capital (K)	.507*** (.0734)	.610*** (.0470)	.608*** (.0469)	.304*** (.0512)	.405*** (.0447)	.403*** (.0446)
Labor (L)	.315*** (.0654)	.203*** (.0519)	.203*** (.0515)	.462*** (.0510)	.361*** (.0527)	.362*** (.0526)
Dummy Variables	Industry	Industry	Industry	Industry	Industry	Industry
N	286	262	262	289	267	267
R^2	99.0%	99.1%	99.1%	99.5%	99.5%	99.5%

*** p<0.01, ** p<0.05, * p<0.1; Huber/White heteroskedasticity-robust standard errors in parentheses

Note: LAG refers to IT Stock (C) lagged in the regression model

Overall, the above set of results indicate that the estimates do not change much when IT flow is used instead of IT stock in the regressions. The estimated IT factor coefficients remain positive and highly statistically significant. This is consistent with the findings in Kudyba and Diwan (2002).

5 Discussion and Conclusion

We have gathered and analyzed a large primary source firm-level dataset about IT investments that spans the 2003-2005 period, which is post 2001-2002 economic recession in the US. In doing so we have extended previous firm-level work done by Brynjolfsson and Hitt (1995), Lichtenberg (1995), Hitt and Brynjolfsson (1996), and Kudyba and Diwan (2002). To the best of our knowledge, this is the first analysis of a large sample firm-level IT investments dataset from the post Internet-boom era. Importantly, in contrast to previous studies, most of our data captures actual IT expenditures versus IT budgets. Since IT budgets are forecasted IT expenditures, they can certainly overestimate or underestimate actual IT expenditures, and hence the distinction is an important one. Further, the coverage of industries in our dataset is more balanced than that in prior research. Using a variety of econometric analyses, we have confirmed the positive and highly statistically significant relationship between IT and gross output or value-added for the most recent time period. Further, we have shown that the contribution of IT to firm-level performance measures such as value-added has not dramatically changed from what was observed in the first firm-level IT productivity studies which analyzed data from the 1988-1992 period. The similarity in construction of the dataset and in the variety of empirical analyses performed on the data has allowed us to compare results in this study with those in prior studies. In contrast to Kudyba and Diwan's (2002) observation about increasing returns to IT based on their analysis of the 1995-1997 Internet boom era dataset, we present evidence of an inverted U-shaped returns curve, with returns now close to what they were in pre-Internet era.

We have shown that our results are generally robust to a variety of specifications and estimation techniques. We have also shown that use of IT flow (a measure of actual IT expenditure or IT budget) versus IT stock (a capitalized measure of IT that includes hardware capital and IT labor) does not produce a significant change in the magnitude of the estimated IT elasticities. We have also documented the lagged effects of IT investments on firm-level productivity measures. Though the magnitude of estimated IT elasticities declines with the increase in the number of lags of the IT stock or IT flow independent variable in our regressions, the decline is marginal and the elasticity coefficient remains positive and highly statistically significant.

Given the fundamental nature of the IT-productivity link in our discipline, the diversity of sources of firm-level data analyzed in prior research has not been very encouraging. Further, though the IT productivity paradox has been laid to rest on the basis of prior firm-level and industry-level studies, the nature of the relationship between IT and productivity needs continuous investigation especially after periods of significant economic activity or inactivity. Given the importance of understanding the potentially evolving nature of the IT-productivity relationship and the need to validate prior results from a variety of sources (secondary as well as primary) more firm-level research is called for. The difficulties of gathering a large sample of data required to conduct this type of research may explain why papers based on more recent data and diverse sources have not been forthcoming. The difficulties may however be overcome by multi-university and university-industry collaboration. Future research may include gathering a much longer time sample of data than what was analyzed in this study; it would especially be interesting to analyze a dataset spanning both an economic recession and recovery (for example: 2000-2005). Our future research efforts lie in that direction.

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ESSAY 4

IT PRACTICES AND CUSTOMER SATISFACTION AT 138 LARGE FIRMS*

Abstract

This paper explores what high-performing firms specifically do to gain the greatest benefits from their IT investments. It identifies several IT-specific factors such as Data/Process Standardization, Systems Integration and Application Integration as practices that are correlated with significant IT impact on a key business performance metric: customer satisfaction. The firms interviewed in this study represent large companies that invest significantly in enterprise software applications such as customer relationship management, sales force automation, enterprise resource planning and knowledge management. Through a set of matched interviews with multiple respondents at 138 firms, we identify several concrete practices as well as cultural variables that are associated with positive IT impact on customer satisfaction, and perhaps equally importantly, several practices where the effects are not positive.

Keywords: Standardization, Systems Integration, Application Integration, Customer Satisfaction

* Note Section 2 of this essay overlaps in part with Essay 1 in this thesis.

1 Introduction

In a survey of 659 CEOs by the London School of Economics (Compass Group 1999), only 25% of the executives were satisfied with the performance outcomes of IT investments made by their firms. Though executive perceptions of the impact of IT investments may be a noisy indicator of actual impact, the finding does seem to suggest that there are considerable differences in performance results firms obtain from their IT investments. It is now well accepted that investments in technology alone cannot lead to guaranteed enhancements in firm performance. However what is still not clear is what else exactly needs to be done to extract the maximum value from IT. When companies invest large amounts in IT but fail to see correspondingly significant increases in performance levels, that may be attributable to the lack of investment in other complementary factors like human and business resources. Achieving competitive advantage from IT is typically dependent on coupling IT with other company-specific, inimitable, and possibly intangible organizational, human, and business resources (Miller and Rice 1967; Walton 1989; Benjamin and Levinson 1993; Keen 1993; Powell and Dent-Micallef 1997). IT-specific intangible assets play a potentially important role in explaining heterogeneity in performance of firms that make similar investments in IT.

Using evidence from the IT payoff literature, Devaraj and Kohli (2000) point to several possible reasons behind the heterogeneity of results on the relationship between IT investments and payoff, including diversity of variables used in the different studies, the level of analysis (for example: industry-level versus firm-level) as well as the research design employed (for example: cross-sectional versus longitudinal). Several more recent review and meta-analysis type studies have pointed out a host of reasons behind the observed variance in the results on the IT investments-payoff link (Kohli and Devaraj 2003; Melville et al. 2004; Piccoli and Ives 2005). For example, industry sector or context, sample size, characteristics of data source (primary or secondary), type of dependent variable (profitability-based or productivity-based) can have an impact on IT payoff reported in the literature (Kohli and Devaraj 2003). Although these recent studies have made several important recommendations to improve the reliability of IT payoff studies, we still do not have a clear understanding as to when, how and where IT can be used to enhance the performance of the firm. Not discounting the importance of methodological issues, we feel that an important reason why some studies may fail to show a positive correlation between IT and performance may in fact be because many firms *truly fail* to improve their performance from just investing in IT. There seems to be significant heterogeneity in the abilities of different firms to invest in important complementary organizational assets (or factors) that can be crucial to extracting value from IT.

Notwithstanding the knowledge that complementary intangible assets matter in IT-led performance, firms continue to differ in their capacities to extract the maximum value from IT in terms of performance improvements. There is a real need for more empirical research to identify various specific intangible investments that should be coupled with IT investments to improve the overall IT payoff. Further, though many studies in the past have looked at impact of IT on financial performance of firms, few research studies have looked at process-level impact of IT (Barua et al 1995; Mooney et al 1995; Mukhopadhyay et al. 1997; Ray et al 2005). For example, investments in IT combined with complementary intangible investments may have an impact on the performance metric of a business function such as sales or customer service & support. Ray et al (2005) show that shared knowledge between IT and customer service units moderates the effect of investment in generic information technologies on customer service process performance. There is an increasing level of interest in the impact of IT on non-financial outcomes such as customer satisfaction and quality (Devaraj and Kohli 2000) as these types of process-level outcomes may be more directly and clearly impacted through first-order effects by IT and its intangible complements.

This empirical research study tries to fill an important gap in the IT business value literature: identification of IT-specific intangible investments such as investments in IT practices and organizational culture that allow firms to achieve favorable IT investment outcomes especially at the process-level. We believe that identification of effective IT practices and cultural elements will allow our research community to have a more significant impact on IT practitioners and executives in charge of making IT investments at their firms. It would not be surprising to hear from CIOs and CEOs alike that one of their top concerns is understanding best practices when it comes to IT implementation and having a better handle on what they need to do to make their IT investments work for their firms in terms of improving process-level outcomes. Specifically, in this study we address the following research question: what are some effective IT practices and IT-specific cultural elements that help explain performance improvement differentials on a process-level performance metric such as customer satisfaction? We identify via an econometric analysis of 138 firms, several such practices and cultural variables that allow firms investing significantly in IT to achieve superior improvements in customer satisfaction. Specifically, we find that in our cross-sectional sample of firms:

1) Data/process standardization and systems integration are positively correlated with IT impact on customer satisfaction.

2) Level of application integration is positively correlated with IT impact on customer satisfaction.

3) Cultural elements such as policy that "IT funding occurs only after a business need has been demonstrated" and perception that "network and e-business foundation provides firm with a competitive advantage in the market" are positively correlated with IT impact on customer satisfaction.

4) The level of access to internal data and systems for external entities such as customers, partners, and suppliers is negatively correlated with IT impact on customer satisfaction.

The results are based on analysis of data on firms that invest significantly in enterprise software applications such as customer relationship management (CRM) and enterprise resource planning (ERP). We expect that these firms that are heavy-users of IT would also tend to have the most effective IT practices and cultural variables that would allow them to achieve significant improvements in performance.

The remainder of the paper is organized as follows: Section 2 presents a review of the literature on IT Payoff and complementary investments. Section 3 presents the theoretical background and the testable hypotheses. Section 4 describes the data and presents the results obtained from econometric analyses. Section 5 discusses the results of the paper. Section 6 summarizes the key results of the paper, points out the caveats of the dataset and highlights next steps.

2 Review of Literature on IT Payoff and Complementary Investments

Some research has been done recently to study the complementarities between organizational investments and IT investments and their impact on the performance of a firm. It has been hypothesized that having IT resources combined with certain intangible organizational assets is more productive than having just those IT resources or just those organizational assets. In other words, the presence of specific intangible assets increases the marginal returns associated with IT assets and thus IT investments and investments in specific intangible assets are "complements" (Milgrom and Roberts 1990). Brynjolfsson, Hitt & Yang (2002) show that "the combination of computers and organizational structures creates more value than the simple sum of their separate contributions." (page 176). This implies that investments in information technology and investments in specific organizational assets are complements. The intangible organizational factors (or practices or assets) identified can be used to assess the true impact of IT on performance by looking at the relative marginal impact of the interactions between IT and these other factors. They represent the "unobserved" or omitted variables in the regression that attempts to assess the contribution of IT assets to performance. These omitted variables lead to unusually high (or unrealistic) coefficients on computer assets in the regression relating those assets to firm market value, and including specific interaction terms to take into account the coupling of IT and complementary organizational variables lowers the coefficients to more reasonable values (Brynjolfsson, Hitt and Yang, 2002).

Davern and Kauffman (2000) further underscore the importance of complementary assets in creation of potential value from IT and in impacting what they call "value-conversion contingencies." According to them, conversion from "potential IT value" to "realized IT value" is dependent on the satisfaction of several "value-conversion contingencies" that include investments in various complementary assets. They present several examples of generalized value conversion contingencies across multiple levels of analysis (2000, Table 1). For example, to realize maximum value from new software applications being introduced, firms also need to invest in a complementary asset, the infrastructure, which is needed to leverage and integrate the applications.

The primary organizational variables identified in the literature to be complementary with IT are human capital measured in terms of worker skills, education and training; worker composition and workplace organization measured in terms of the degree of decentralization; business process redesign or redesign of tasks; CEO or senior management attitude/practices; organizational culture, and organizational learning.

2.1 Coupling IT with Human Capital (Skills, Education, Training)

Bresnahan et al (2002) find that IT and human capital interactions (but not levels of these variables individually) positively predict firm performance. Specifically, they find that IT combined with a more skilled or a more highly-educated work force leads to higher performance. Their work thus presents evidence for the complementarities between IT and human capital measured in terms of skills and education. As investments in new technology are made, it is important for the firm to make investments in employees who are educated, skilled and comfortable enough to be able to use the new technology effectively. For example, simply investing in a new technology without adequately training existing staff in the use of that technology or without investing sufficiently in the screening and acquisition of employees that would thrive in the new environment would be counter-productive. Skilled human resources would be needed not only to properly administer the technology and take care of technology-specific issues but also to effectively use it and manage it.

As new IT is deployed, it is also important for the firm to seek out employees who are highly skilled at doing non-routine information processing or exception handling, which becomes especially key in a work environment where most of the routine information processing has been substituted away by IT. As IT reduces the amount of time spent on routine information processing, the extra time made available to employees can be more productively used by them in high-level cognitive processing, leading to higher employee value creation. Employees capable of high-level cognitive processing become especially valuable resources in firms that are heavy IT users. Investments in human resource practices that focus on the hiring, development and retention of employees skilled at more demanding cognitive work can be key to recouping the full benefits of IT investments. IT typically also increases the total volume of data that is recorded and the total amount of information available for consumption in the organization. Skilled employees who can critically analyze and effectively synthesize vast amounts of information can potentially add tremendous value to the organization that invests heavily in IT.

2.2 Coupling IT with Worker Composition and Workplace Organization

Francalanci and Galal (1998) present evidence of the impact of the combined effect of IT and worker composition on performance. They define worker composition as the percentage distribution of managers who perform supervisory tasks, professional workers who perform specialized production-related tasks, and clerical workers, who perform administrative tasks. They find that increases in IT coupled with increases in the proportion of managers lead to higher performance and that decreases in fraction of professional workers and clericals combined with increases in IT lead to higher performance.

The above results are consistent with theoretical predictions. Information processing theory provides support for decentralized decision-making as a way to increase the information processing capacity of an organization. As information processing requirements of an organization increase, firms tend to decentralize decision-making by increasing the number of self-contained, functional units (Galbraith 1973, 1977). This decentralization in response to increased requirements to do quick and unstructured decision-making leads to an increase in the managerial component of work or higher percentage of managers in the organization. At the same time, transaction economics theory tells us that decentralized decision-making makes it costlier to coordinate between units and agency theory tells us that decentralization increases the probability of opportunistic behavior that cannot be directly observed by the principal (Jensen and Meckling 1992). In other words, decentralized decision-making increases both transaction and agency costs. This is where IT can be extremely useful. It can support and extend management control by increasing the monitoring that can be done and thereby help lower agency costs (Francalanci and Galal 1998). It can also enable easier coordination between groups and independent units and thereby help lower transaction costs.. Thus, it is expected that as the managerial component of the organization increases, higher use of IT can reduce both transaction costs and agency costs, and improve overall firm performance. At the same time, IT has a deskilling effect on professional workers, in the sense that some of the routine tasks performed by them can be substituted away by IT. Clerical workers performing mainly administrative roles face the greatest threat of substitution from IT. Consequently, it would be expected that increases in IT resources combined with decreases in professional workers and in clerical staff would lead to improvements in performance levels.

Bresnahan et al (2002) find that IT coupled with a more decentralized work organization and team-oriented production leads to higher performance. The link between organizational structure and IT can be understood in a similar way to that between worker composition and IT. As IT can potentially make available voluminous amounts of information, it can be easy for the decision-makers who must act on that information to get overwhelmed. To effectively leverage the information captured by IT, the firm should make investments in organizational structure or workplace organization to increase the information processing capacity of the organization. A decentralized workplace, where even lower-level employees have the authority to act upon the information to which they have access, can overcome the problem of managers becoming bottlenecks in terms of the total amount of information processed. Decentralization of decision-making rights can successfully incent employees to exert effort to process vast amounts of complex information. Similarly, team-based work can alleviate information processing bottlenecks at the managerial level that might be observed in traditional hierarchical organizations. Collective decision-making may help organizations alleviate the problem of bounded rationality and allow for better decisions to be reached in an environment of an abundance of data and information made available through information technology.

2.3 Coupling IT with Business Process Reengineering (BPR)

BPR (Business-Process Re-engineering) is defined by Hammer and Champy (1993) as the redesign of a process according to some performance measure such as cost, quality, service and speed. Devaraj and Kohli (2000) find that investments in IT when combined with BPR initiatives have a positive impact on firm performance. They find that impact of technology is higher when there is a higher degree of BPR activity and lower when there is a lower degree of BPR activity. In other words, BPR implementation and IT investment activity are complements, and higher BPR investments increase the returns associated with information technology investments. Specifically, they present evidence that BPR initiatives coupled with IT capital investments improves profitability of firms. This finding is in line with the theory of "business value complementarity" presented by Barua et al (1996), which implies that investments in IT and reengineering achieve higher performance when they are coupled and not when they are pursued in isolation.

Successful BPR initiatives can themselves be viewed as initiatives that require consideration of other complementary aspects, such as social, human, and technical aspects of process change. As Roy et. al argue (1998), it is important not to lose sight of the human and social aspects in BPR initiatives, if true gains in performance are to be realized. To maximize chances of re-engineering success in improving firm performance in some dimension, they argue that it is important to jointly optimize two classes of interdependent variables – "organizational adequacy" variables, which are related to the social and human aspects of the organization and "technical adequacy" variables, which are related to technical aspects such as the efficiency of the production processes. For example, use of IT to redesign a process should be combined with redesign of human tasks to fully exploit individual worker potential and with techniques to minimize worker resistance to process change by carefully managing anxieties and expectations. Only joint optimization of these complementary variables can ensure the success of BPR in increasing performance.

The implementation of a specific information technology, such as enterprise resource planning (ERP), can be used to understand the importance of BPR activity to extract the maximum value out of IT (Scheer and Habermann 2000). Successful implementation of ERP systems requires analysis of "as-is" business processes or existing business processes and then reengineering those processes to fit into the capabilities of the software that often captures the best-of-breed processes available. Reengineering business processes may involve minor changes to existing processes or replacing current processes with new ones. The scope of BPR activity may also vary from being local or limited to a few groups/regions to being global (Parr and Shanks 2000). Further, the timing of BPR activity may vary; BPR might be done before implementation of IT, after implementation of IT or in conjunction with implementation of IT. Though the associated BPR activities can often be painful, without thoughtful analysis and reengineering of existing business processes, the true power of the ERP software cannot be leveraged to improve firm performance.

2.4 Coupling IT with specific management practices

Both Davern and Kauffman (2000) and Tallon et al (2000) underscore the importance of management practices in realizing higher IT value. The involvement of senior management in making sure that adequate resources are allocated to the implementation of a new business application can be a key contingency in realizing value from the IT investment. Management practices that focus on aligning the IT investment strategy with the business strategy of the company (Henderson and Venkatraman, 1993; Woolfe 1993; Tallon et al 2000) and that encourage extensive IT investment evaluation will lead to higher values of perceived IT payoffs

(Tallon et al 2000). Management practices can thus be viewed as a crucial complementary asset that can impact the realization of maximum value from IT.

The CEO, in particular, can play a significant role in determining whether maximum performance gain can be obtained from IT. For example, CEO commitment to IT will enhance the effectiveness of implementation and use of IT (Henderson and Venkatraman, 1993), as adequate resources will be devoted to the adoption of IT and to its proper alignment with the business strategy (Kettinger et al., 1994). Neo (1988) similarly concludes that the organizational leadership of the firm can be a crucial factor that separates companies that successfully leverage IT from companies that fail at obtaining IT performance improvements. Keen (1993) also acknowledges that "management differences" can explain why some firms perform better than others, since some managers are better than others in "fitting" or coupling IT with the different complementary organizational and business resources.

The importance of the role of the human agency in extracting superior performance from IT can be justified in light of the organizational imperative perspective (Markus and Robey 1988) in which improved organizational performance or organizational change is seen to be the result of managerial actions and choices and not technology. Specific IT management practices employed by able CEOs can help explain why some organizations succeed while others fail even when the same level of IT investments are made and identical technologies are employed. For example, senior management may institute new incentives to encourage use of IT within the organization. In addition, new monitoring and reporting mechanisms may be put in place by the management to make sure that there are no abuses and that the incentives have the desired effect. Investments in IT have to be coupled with actual use of IT to produce positive improvements in performance

(Mukhopadhyay et al 1997; Devaraj and Kohli 2000). Given that actual use of IT is important, it seems reasonable to conclude that incentive systems that encourage the use of IT would be important as well.

2.5 Coupling IT with Organizational Culture

Organizational culture has been recognized as an important multi-dimensional variable in the determination of organizational performance. Organizational culture consists of three main dimensions: "a socio-cultural system of the perceived functioning of the organization's strategies and practices, an organizational value system, and the collective beliefs of the individuals working within the organization" (Marcoulides and Heck 1993, pp. 212). In a paper investigating the relationship between organizational culture and successful IT implementation, Harper and Utley (2001) identify five cultural variables that show a significantly positive correlation with successful IT implementation and five cultural variables that hinder successful IT implementation. Autonomy, trust, team-oriented work, flexibility, and free flow of information are shown to support success while cultural variables such as rigid rules, compliance, carefulness, preciseness, predictability are shown to be negatively correlated with success. Sutherland and Morieux (1988) also imply that the right "fit" between the use of IT and organizational culture can be a determinant of the effectiveness and efficiency of firms. They argue that organizational culture can promote or hinder the adoption of new technology and consequently impact the value that can be extracted from the technology. For example, an "IT phobic" culture can negatively impact firm performance because new technology is either not deployed or its correct use not properly understood and adopted. Employee attitudes can play an important role in how readily or widely new technology is accepted within the organization.

Powell and Dent-Micallef (1997) also show that the presence of cultural variables like open organization, open communications, and organizational flexibility that are complementary to IT lead to higher performance levels. They show that heterogeneity in firm performance can be traced to how well firms use IT resources to leverage complementary, though intangible, human and business resources. They identify six complementary human resources: open organization, open communications, organizational flexibility, organizational consensus, CEO commitment, and IT-strategy integration. The complementary business resources identified are supplier relationships, IT training, business process design, team orientation, benchmarking, and IT planning. They find that the complementary human resources explain the performance differentials to a greater degree than do the complementary business resources. Information processing theory predicts increasing decentralization of work, as the information processing requirements of organizations increase. Higher decentralization leads to higher transaction costs in communicating and coordinating across groups and also higher agency costs in terms of increased monitoring costs. The higher transaction and agency costs can however be circumvented by increased use of IT coupled with presence of organizational cultural attributes that promote open communication and free flow of information. Merely deploying some IT application that enables sharing of information may not produce the desired performance outcomes unless the organizational culture promotes information sharing by employees.

2.6 Coupling IT with Organizational Learning

Organizational learning is defined as a process via which new organizational knowledge gets created (Slater and Narver, 1995). It can be viewed as consisting of four main parts: information acquisition, information dissemination, shared interpretation, and development of organizational memory (Tippins and Sohi, 2003). Much research has been done to show the positive relationship between organizational learning and firm performance (Day 1994; Slater and Narver 1995). In the context of information systems, Tippins and Sohi (2003) show that the relationship between IT competency and firm performance is mediated by “organizational learning.” In other words, they show that IT affects firm performance not directly but indirectly through its effects on how an organization learns. When IT investments are made such that they aid in the four organizational learning processes, superior performance may be obtained. For example, firms that effectively use IT to learn more about their customers, suppliers and competitors can achieve better performance. Firms are increasingly geographically distributed and so mechanisms to ensure that information generated by use of IT is not only effectively captured but disseminated or shared among the employees in various geographic locations can be key to ensuring that all the information is powerfully leveraged. Processes to ensure that different groups in an organization develop a shared understanding of the information captured by IT systems can help in reducing transaction costs incurred in resolution of misunderstandings or semantic conflicts. Ichniowski et al (2003) relate higher levels of a form of organizational capital called “connective capital,” to higher performance. Connective capital is defined as the stock of human capital that employees can access through their connections to other workers. Trust can play an important role in the process of building new worker relationships that can lead to higher connective capital, and this can in turn increase the ease of sharing information among workers (Ichniowski et al 2003). Processes to help develop trust can be critical to organizational learning. Without trust, employees would be unwilling to share information with other employees within the organization or with suppliers or partners outside the organization. Potentially useful information generated by various IT systems under control of different groups or functions would not be aggregated or integrated and acted upon without a level of understanding and trust between the different groups.

3 Theory and Hypotheses

3.1 Resource-Based View and Contingency Theory

Our primary theoretical lens is the resource-based view (RBV), which has been used to analyze the role of IT intangible assets in impacting firm performance. According to RBV, differences in firm performance arise out of the heterogeneous distribution of resources among firms (Barney 1991, Tippins and Sohi 2003). Firms that have valuable, unique or relatively scarce, inimitable resources have a performance-advantage over firms that do not. In line with RBV, the mere presence of IT does not guarantee improvements in firm performance, as IT can be easily acquired by rival firms (Clemons and Row 1991; Powell and Dent-Micallef 1997); however, when IT is coupled with other complementary organization-specific intangible resources that are hard to imitate, a performance advantage can be realized. One possible way to make IT give a sustainable performance-related advantage is to embed it in the organization in such a way that maximally leverages the complementarities between IT and different organizational resources (Powell and Dent-Micallef 1997). Co-specialization of complementary resources (such that the resources have little or no value without the others) can also lead to a performance advantage that can be hard to achieve otherwise (Powell and Dent-Micallef 1997). In employing the RBV to assess the impact of IT on the performance of the customer service process, Ray et al (2005) claim that "tacit, socially complex, firm-specific resources explain variation in process performance across firm and that IT resources and capabilities without these attributes do not" (p. 625).

Contingency theory provides additional theoretical support for our hypotheses below. It has been extensively used to analyze the role of intangible assets in the IT and firm performance relationship, and it claims that optimal firm performance can be obtained by using resources that are congruent or that “fit” well with each other. Thus, when IT is combined with complementary (or in one sense “congruent”) organizational resources, better performance can be realized. Specifically, the role of these other resources is that of a mediator (in the sense of “fit as mediation”, see Venkatraman (1989)) and they can be viewed as a significant intervening mechanism that mediate the link between IT and performance. It may not be enough to throw IT at a process to improve its performance. Thoughtful investments in complementary, intangible organizational resources may be crucial to get optimal performance gains from the IT investments.

3.2 Customer Satisfaction

We used perceived IT impact on customer satisfaction as the primary performance variable of interest (or dependent variable) in this study. Although it would have been ideal to *also* have had access to profitability figures or other objective financial information about the firms in our study, we believe that impact on customer satisfaction (a process-level performance metric) can be relied upon as a reasonable proxy for bottom-line performance. Several studies in the research literature support the positive relationship between customer satisfaction and financial performance. For example, Agus et al (2000) found evidence that higher level of customer satisfaction leads to higher level of financial performance relative to the firm’s competitors. Anderson et al (1994) in their study of Swedish firms found that firms that achieve higher levels of customer satisfaction also are more profitable. In their sample of firms, they found that an annual one-point increase in customer satisfaction is associated with an increase of $7.48 million in net income over five years i.e. the annual one-point increase in customer satisfaction has a NPV (net present value) of $7.48 million. Ittner and Larcker (1998) also found in general a statistically significant positive relationship between customer satisfaction measures and future accounting performance. Why might higher customer satisfaction lead to higher profitability? The marketing literature (Fornell 1992, Anderson el al 1994) points to various possible reasons including increased loyalty on the part of customers, higher customer retention, lower advertising/marketing costs due to positive word-of-mouth on the part of current customers as well as enhanced firm reputation. Given that there is much empirical evidence to the positive impact of customer satisfaction on financial performance, we conclude that the dependent variable, customer satisfaction, in the hypotheses below is not only interesting in its own right, but also as a potential predictor of financial performance.

3.3 Access

It may not be sufficient to invest heavily in network-enabled business applications; access to these applications must be provided to employees in relevant work groups and possibly to external entities such as suppliers, customer, partners for the firms to be able to get the most out of these applications. As more employees in customer-focused groups are granted access to the business applications, more of them are empowered to help customers using information available in those applications and customer problems can potentially be resolved more quickly and efficiently. Similarly, providing application access to entities in your supply chain, including customers, suppliers and partners, can enable firms to serve their customers better. For example, Customer Relationship Management (CRM) applications are more beneficial when firms share customer-related information with their supply chain partners (Mithas et al, 2005). Further, business applications that are easily accessible (say via web-based mechanisms) may be used more frequently by employees as well as external entities. If we assume that the level of use of these applications might be dependent on their ease of accessibility, it might be reasonable to predict that the higher the number of business applications accessible by web-based mechanisms, the higher the IT impact on customer satisfaction. Judicial provision of IT application access to various entities is highly valuable, very firm-specific and difficult to imitate. Thus, according to the RBV, access should explain performance differential on the customer satisfaction metric. Thus, we have the following set of hypotheses:

Hypothesis 1.1: Higher access to Internet business applications for customer service & support employees should be positively correlated to IT impact on customer satisfaction.

Hypothesis 1.2: Companies that provide customers, suppliers, and partners access to internal data and systems should exhibit higher positive IT impact on customer satisfaction than those that do not.

Hypothesis 1.3: The ease of access to deployed business applications (captured in this study in terms of percentage of network applications that are accessible via internet/web-based mechanisms) should be positively correlated to IT impact on customer satisfaction.

The above hypotheses should be understood in light of an important caveat: proper rationing of access rights is essential to ensuring that higher access to internal IT systems and applications does not indirectly hurt performance. Only authorized individuals should be given access to systems. For example, employees in the research division of an investment bank should not have access to data or systems meant for the corporate finance division in the bank because of regulatory requirements of a Chinese wall between the two divisions. Further access should be promptly revoked when it is no longer needed. For example, when an employee leaves the firm or when a relationship with a partner is terminated, access should be promptly removed for obvious reasons. Secure access is as important as improved level of access. Security mechanisms may be essential to protecting customer data and ensuring that only properly authorized individuals are allowed access.

3.4 Standardization and integration

IT infrastructure has been recognized as an important resource that can influence a firm's ability to use IT strategically (Davenport and Linder, 1994; Ross et al 1996; Weill 1993). The variance in the flexibility of the IT infrastructure among firms, which is reflected in the differential use of standards for hardware, operating systems, communications network, data and applications, produces variance in the business value achieved by different firms from IT-enabled innovation (Broadbent and Weill 1997; Duncan 1995; Ray et al, 2005). Improved sharing of data among systems and applications, enabled by standardized data and processes as well as extensive systems integration and application integration, can lead to better understanding and faster resolution of customer issues that involve multiple, interdependent subunits of the organization. If there are standard definitions for data elements used in the enterprise, it might be easier for different intra-enterprise IT systems/applications to exchange data among them. Standards also facilitate cross-enterprise communication and coordination with supply-chain participants, including suppliers and partners. Integrating different enterprise applications can improve the level of customer service. For example, an order management application might be integrated with inventory, planning, and logistics applications to improve order processing speed. Aggregating data from different data sources and systems can also help improve customer satisfaction and increase customer retention. For example, banks may maintain account data for the same customer in different databases. Checking accounts, savings accounts, investment accounts and mortgage accounts may be maintained in different data sources, but the online banking portal, which is an important customer touch point, might aggregate data from these different sources and present to the customer a summary of all their assets and liabilities on a single web page (Gable, 2002). The convenience of viewing all account information on a single page can improve customer satisfaction. Investments in data and process standards, systems integration and application integration are highly valuable, very firm-specific and in general difficult to accomplish or imitate. Thus, according to the RBV, those types of investments should explain performance differentials on the customer satisfaction metric. Simply investing in diverse applications and systems without thoughtfully integrating them will not achieve optimal IT payoff; in fact, it may be detrimental to performance. Thus, we have the following hypotheses:

Hypothesis 2.1: Lack of standardized data and processes is negatively correlated to IT impact on customer satisfaction i.e. firms with lack of standardized data and processes exhibit lower positive IT impact on customer satisfaction.

Hypothesis 2.2: Lack of systems integration is negatively correlated to IT impact on customer satisfaction i.e. firms with lack of systems integration exhibit lower positive IT impact on customer satisfaction.

Hypothesis 2.3: The level of application integration (captured in this study in terms of the number of business functions such as marketing, sales, logistics, etc. that are linked to customer service & support data via the network applications) is positively correlated to IT impact on customer satisfaction.

3.5 Culture/Attitude

Companies in which IT investments are made in a systematic, thoughtful manner after demonstration of actual needs will be able to better address concerns of their customers, resulting in higher customer satisfaction. IT investments made in a haphazard way without careful consideration of requirements can result in much wastage and in reduction in the capacity to timely and adequately address customer problems. Further, a positive perception that the network and the e-business infrastructure of the firm provides it with a strategic advantage can also lead to higher investments in productivity-enhancing/quality-improving network-enabled business applications, which in turn can lead to higher customer satisfaction. Cultural elements such as those described above can be valuable in extracting the most out of IT investments. They are inherently highly organization-specific and in general difficult for other firms to adopt, as most organizations suffer from cultural inertia and change can often be hard to accomplish. Thus, according to the RBV, these cultural elements should explain performance differentials on the customer satisfaction metric. We have the following hypotheses:

Hypothesis 3.1: Companies in which IT funding occurs only after an existing business need has been demonstrated should exhibit higher positive IT impact on customer satisfaction than those in which that is not the case.

Hypothesis 3.2: Companies that perceive that the network and e-business foundation provides them with a competitive advantage in the market should exhibit higher positive IT impact on customer satisfaction that those in which that is not the case.

4 Data Collection and Analysis

4.1 Data Sample

The cross-sectional dataset is composed of 138 firms, which completed a pair of telephonically-administered structured questionnaires in 2005 about IT operations as well as customer service & support operations. Most of the firms are large with approximately 54% of the firms having more than 1000 employees. The firms came from 5 broadly defined industries: public sector (25%), manufacturing (24%), healthcare/pharmaceuticals (19%), retail/wholesale (19%) and financial services (13%). The companies were selected from the Dun & Bradstreet database using a probabilistic sampling technique. Two separate questionnaires were administered for each firm. The first questionnaire, which was about IT operations, was directed at an IT decision-maker within the firm. The second questionnaire, which was about the customer service & support business function, was directed at a business decision maker within the firm who was familiar with that particular function. The reason for the split-level design (two questionnaires separately targeting IT and business function personnel) was that there can be considerable differences in the depth of knowledge held by the decision-makers responsible for different functions in the organization. Though business decision-makers are increasingly IT-savvy and IT decision-makers are increasingly business-savvy, the possibility that this might not be the case calls for a split-level research design. That data from two decision-makers within each organization was obtained is one of the distinguishing features of this research study. Similar approach has been used by Ray et al (2005), who obtained a matched dataset of 72 firms.

The IT questionnaire focused on the enterprise applications deployed at the company, business functions automated and integrated by those applications, network infrastructure supporting those applications and the corporate culture in regard to the use of technology and networking. The customer service & support questionnaire focused on the business processes supported and automated by technology, metrics used to measure the impact of technology on business operations, perceived impact of the technology on those metrics and business barriers to improved performance. Most of the decision-makers interviewed were at the director level or higher in the organization. We are hopeful that targeting senior decision-makers has improved the quality of data gathered through the surveys. To qualify for the study, the firms had to have at least one fully deployed internet business application that supported customer service & support and that was accessible to more than 20% of the employees within that business function. The qualification criteria hopefully allows us to target firms that are heavy users of IT and that potentially have the most effective IT practices.

4.2 Dependent Variable

The dependent variable in this study is "Perceived IT Impact on Customer Satisfaction." This variable was operationalized by asking respondents in the customer service & support division the following question: "Estimate the % impact, positive or negative, that your network applications have had on customer satisfaction (with the service interaction) over the last twelve months." It is important to note that the actual customers of the firms answering the survey were *not* asked about their satisfaction with the service they were provided. Further, it is unclear from the data whether the customers were retail customers or business customers. Ideally, one could have administered the widely used scale developed by Parasuraman et al. (1988) to the firm's customers to assess customer service performance. However this would not be feasible for a large number of companies that were surveyed in this study. Given the infeasibility of asking customers of the firms in a large sample, "perceived customer service performance" was used in a recent study on the impact of shared knowledge between IT and customer service units on customer service process performance (Ray et al, 2005) in which managers were asked about their perceptions of customer service quality.

4.3 Analysis and Results

To analyze the collected data, we employed a three-step approach. Since the questionnaires were extensive and covered more ground than the research questions addressed by this study, we used a variable-reduction procedure based on principal components analysis (PCA) to narrow down the number of independent variables for the regression analysis.

First, we tested the relationship between the key variables collected from the interviews and IT impact on customer satisfaction using simple correlation, whose significance was tested using Pearson's product moment correlation coefficient (note for correlations between a dichotomous variable and a continuous variable, one could alternatively have computed point bi-serial correlation coefficient, but this coefficient is algebraically equivalent to Pearson's product moment correlation coefficient). This step yielded a set of additional independent variables that were significantly correlated to our dependent variable (IT impact on customer satisfaction). We added these variables to our existing list of independent/control variables that were covered by the hypotheses. In all, we had 16 observed independent variables that were used in the second step. The variables along with their short descriptions is shown in Table 1a below. The descriptions are useful to understand how data on various variables are actually captured i.e. they help understand the operationalizations of the key variables. Table 1b shows the key descriptive statistics for the independent variables and the dependent variable (Impact on Customer Satisfaction).

Table 1a. Variables and their Descriptions

Dependent Variable	Description
IT Impact On Customer Satisfaction	Estimate the % impact, positive or negative, that your network applications have had on customer satisfaction (with the service interaction) over the last twelve months.
Independent Variable	**Description**
Access Related Variables	
EmpLevelAccess	% of service & support employees with access to internet business apps (discrete coded; 1 through 6)
AccessToRemoteEmployees	Do remote employees have access to internal data and systems? (discrete coded; 1=yes)
AccessToCustomers	Do customers have access to internal data and systems? (discrete coded; 1=yes)
AccessToPartners	Do partners have access to internal data and systems? (discrete coded; 1=yes)
AccessToSuppliers	Do suppliers have access to internal data and systems? (discrete coded; 1=yes)
EaseOfAccess	% of all applications that are accessible via internet/web-based mechanism (discrete coded; 1 through 6)
SiteLevelAccess	% of company locations that can access the application (discrete coded; 1 through 6)
Standardization and Integration Related Variables	
LackStdDataBarrier	Is lack of standard data perceived as a barrier to productivity? (binary coded; 1=yes)
LackStdProcBarrier	Is lack of standard processes perceived as a barrier to productivity? (binary coded; 1=yes)
LackSysIntegBarrier	Is lack of systems integration perceived as a barrier to productivity? (binary coded; 1=yes)
LevelAppInteg	Number of applications integrated (discrete coded; 0 through 9)
UseOfDataMart	Data from network apps flows into a data warehouse/datamart (discrete coded; 1=yes 2=no)
DataStdEnforced	Data standardization is strongly enforced across all business units (Likert; 1=strongly disagree to 7=strongly agree)
Culture/Attitude Related Variables	
ITFundingAfter	New IT funding only after an existing business need has been demonstrated (Likert; 1=strongly disagree to 7=strongly agree)
LackWorkerTrainingBarrier	Is lack of worker training perceived as a barrier to productivity? (binary coded; 1=yes)
NetworkAsCompAdv	Network and e-business foundation provides the firm with a competitive advantage in the market (Likert; 1=strongly disagree to 7=strongly agree)

Table 1b. Descriptive Statistics of Key Variables

	Mean	Median	Std. Dev.	Min	Max
EmpLevelAccess	4.78	5.5	1.53	1	6
AccessToRemoteEmployees	0.81	1	0.39	0	1
AccessToCustomers	0.40	0	0.49	0	1
AccessToPartners	0.43	0	0.50	0	1
AccessToSuppliers	0.30	0	0.46	0	1
EaseOfAccess	3.85	4	1.33	2	6
SiteLevelAccess	5.43	6	1.21	1	6
LackStdDataBarrier	0.44	0	0.50	0	1
LackStdProcBarrier	0.55	1	0.50	0	1
LackSysIntegBarrier	0.51	1	0.50	0	1
LevelAppInteg	4.62	5	2.21	0	9
UseOfDataMart	1.58	2	0.5	1	2
DataStdEnforced	4.74	5	1.82	1	7
ITFundingAfter	4.90	5	1.85	1	7
LackWorkerTrainingBarrier	0.54	1	0.5	0	1
NetworkAsCompAdv	4.74	5	1.68	1	7
IT Impact on Customer Satisfaction	42.95	50	32.88	-40	100

In the second step, we used PCA to develop a smaller number of principal components than the number of observed independent variables. Since many of the independent variables are significantly correlated to each other (see Table 2), interpretation of coefficients on these variables in multi-variate regressions is difficult because of multi-collinearity problems. PCA yields uncorrelated principal components, which can then be used in regression models. Before performing PCA, we standardized the variables so that they all had mean 0 and standard deviation 1.

One way to separate the “important” principal components from the “less important” ones is to look at the scree plot that shows the eigenvalues corresponding to the principal components. The break from the steady downward slope distinguishes the “important” principal components from others that make up the scree. Figure 1 below shows the scree plot as a line graph (in which the break is more easily discernible). From the plot, it seems that there are 3 "important" principal components: Comp.1, Comp.2, and Comp.3. In interpreting the principal components, we examined loadings of the independent variables on the principal components. Loadings with absolute values greater than or equal to 0.4 were assumed to be "large" and significant. The loadings of these three components on the different independent variables is shown in Table 3 below.

We interpreted the three principal components as follows:

Comp.1 Standardization and Systems Integration which is composed of variables: LackStdDataBarrier, LackStdProcBarrier, LackSysIntegBarrier *(note these variables are negatively described; see Table 1a)*

Comp.2 Level of External Access which is composed of variables: AccessToCustomers, AccessToSuppliers, AccessToPartners

Comp.3 Level of Application Integration which is composed of variables: LevelAppInteg

In the third step, the component scores obtained from the principal components were used as predictor variables in a multi-variate linear regression model that had "impact on customer satisfaction" as the dependent variable. Note that the component scores, which are the scores of each case (or observation) for a given component, are computed by multiplying the standardized score on each variable with the corresponding loading of the variable on the principal component.

We present in Table 4 results from regression analysis that uses only these three components as independent variables (Model I).

Table 2. Correlation Matrix

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
A	1.00															
B	0.20*	1.00														
C	0.16*	0.13	1.00													
D	0.11	0.23*	0.47*	1.00												
E	0.16*	0.12	0.36*	0.55*	1.00											
F	-0.09	-0.07	0.09	0.10	-0.01	1.00										
G	0.25*	0.30*	0.19*	0.20*	0.10	0.23*	1.00									
H	-0.09	0.06	0.08	0.06	0.04	-0.05	0.03	1.00								
I	-0.14*	0.09	0.08	0.08	0.00	0.00	0.02	0.57*	1.00							
J	-0.06	0.04	0.12	0.17*	0.13	-0.07	-0.03	0.53*	0.51*	1.00						
K	-0.11	-0.08	-0.09	-0.10	0.13	-0.08	-0.07	-0.11	-0.08	-0.09	1.00					
L	-0.01	0.12	-0.01	-0.02	-0.05	0.00	0.08	-0.11	-0.06	-0.02	0.06	1.00				
M	0.10	0.08	-0.07	0.03	-0.12	0.04	-0.04	0.18*	0.38*	0.17*	-0.20*	-0.06	1.00			
N	0.02	-0.19*	-0.07	-0.09	-0.04	-0.01	-0.06	-0.39*	-0.38*	-0.29*	0.20*	-0.06	-0.26*	1.00		
O	-0.01	0.07	0.07	0.00	-0.01	-0.27*	-0.07	0.36*	0.30*	0.36*	-0.02	0.03	0.10	-0.18*	1.00	
P	0.06	-0.03	0.03	0.00	-0.01	0.03	0.13	-0.15*	-0.14*	-0.08	-0.01	-0.08	-0.09	0.11	-0.03	1.00

* indicates significant correlation (Key for variables stated below)

A	EmpLevelAccess
B	AccessToRemoteEmp
C	AccessToCustomers
D	AccessToSuppliers
E	AccessToPartners
F	EaseOfAccess
G	SiteLevelAccess
H	LackStdDataBarrier
I	LackStdProcBarrier
J	LackSysIntegBarrier
K	LevelAppInteg
L	ITFundingAfter
M	UseOfDataMart
N	DataStdEnforced
O	LackWorkerTrainingBarrier
P	NetworkAsCompAdv

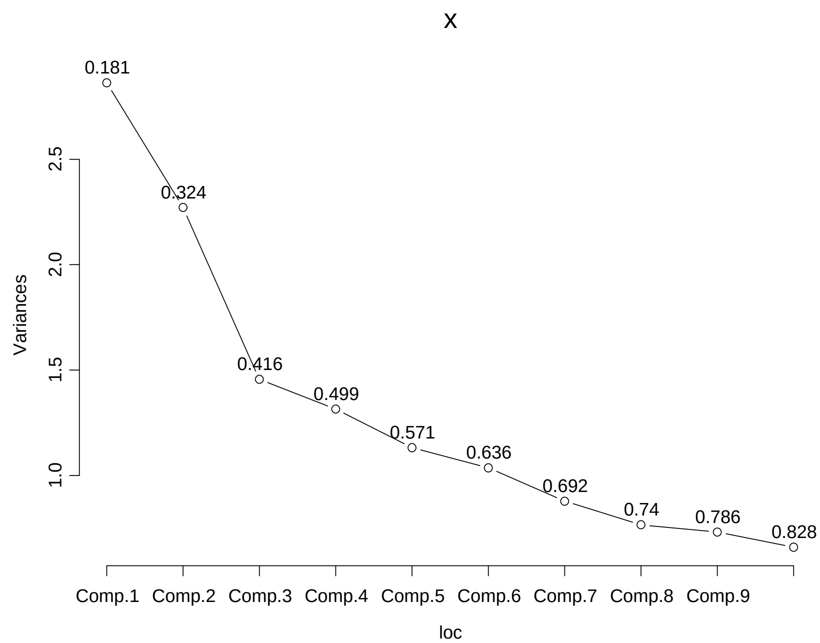

Figure 1. Scree Plot for the Principal Components

Table 3. Principal Component Loadings

	Comp.1	Comp.2	Comp.3
EmpLevelAccess			
AccessToRemoteEmployees			
AccessToCustomers		-0.43	
AccessToPartners		-0.45	
AccessToSuppliers		-0.41	
EaseOfAccess			
SiteLevelAccess			
LackStdDataBarrier	-0.42		
LackStdProcBarrier	-0.43		
LackSysIntegBarrier	-0.41		
LevelAppInteg			-0.40
UseOfDataMart			
DataStdEnforced			
ITFundingAfter			
LackWorkerTrainingBarrier			
NetworkAsCompAdv			

Table 4. Model I: OLS Regression of "IT Impact on Customer Satisfaction" on the Principal Components

	Dependent Variable	
Independent Variable	IT Impact on Customer Satisfaction	p-value
Comp.1 (Standardization and Integration) (1)	4.6387*** (1.6842)	0.0069
Comp.2 (Level of External Access) (1)	3.4608* (1.9399)	0.0772
Comp.3 (Level of Application Integration) (1)	-6.4934*** (2.4173)	0.0084

R^2: 0.1418
F-statistic:6.002 on 3 and 109 degrees of freedom with p-value=0.0007989
OLS standard errors are reported in parentheses
*** indicates significance at the 1% level
** indicates significance at the 5% level
* indicates significance at the 10% level
(1) The loadings for the variables for this component are negative

Table 4 shows that components 1 and 3 are significant at the 5% and 1% levels respectively, while component 2 is significant at the 10% level. Since we know the composition of the different principal components, the OLS regression results can be interpreted as follows:

Comp.1: Standardization and Systems Integration are positively correlated to IT impact on customer satisfaction (significant at 5% level). Note that the coefficient on the principal component is positive, whereas the loadings for the variables for the component are negative. However, the variables are negatively described: *lack* of standard data, *lack* of standard processes and *lack* of systems integration (see Table 1a). Hence it is the case that standardization of data and of processes and systems integration are positively correlated to IT impact on customer satisfaction. This is consistent with hypotheses 2.1 and 2.2.

Comp.3: Level of application integration is positively correlated to IT impact on customer satisfaction (significant at 5% level). Note that even though the estimated OLS coefficient on the principal component is negative, the variable that loads on this component has a negative sign. This result is consistent with Hypothesis 2.3.

Comp.2: Giving access to internet business applications, and internal data and systems to customers, partners, suppliers (or external entities) is negatively correlated to IT impact on customer satisfaction (significant at 10% level). Note that even though the estimated OLS coefficient on the principal component is positive, the variables that load on this component have negative signs. This result is *not* consistent with Hypothesis 1.2.

In the above regression analysis, we used three principal components which were obtained using the scree plot. Another criterion that is often used to select the number of principal components for subsequent analyses is the eigenvalue-one or the Kaiser criterion (Kaiser, 1960). The eigenvalues for the principal components are shown in figure 2. The Kaiser criterion yielded six principal components.

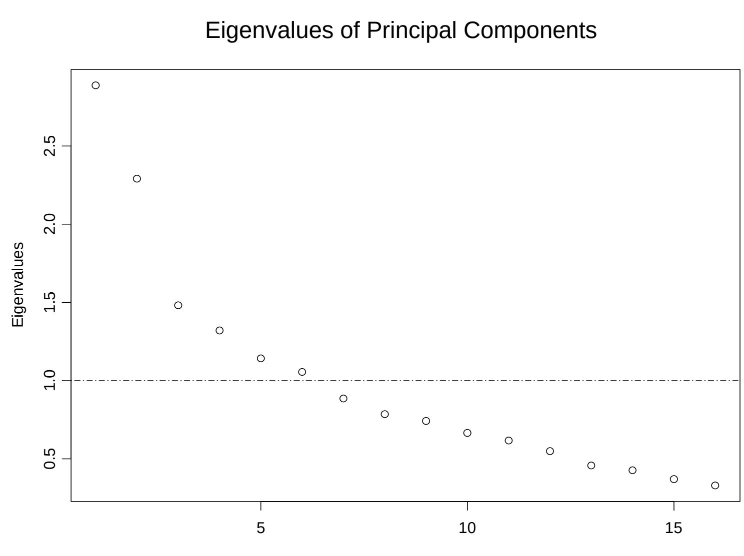

Figure 2. Eigenvalues for the Principal Components

Alternatively, one could also have chosen the number of principal components to be included in the regression using "proportion of variance accounted for" criterion combined with "interpretability" criteria. PCA on the set of 16 standardized independent variables also yielded 6 principal components, which explained a significant percentage (64%) of variance in the set of variables. The threshold for minimum proportion of variance to be accounted for by the principal component was chosen to be 5%. This reduced the number of principal components from 16 to 7. In interpreting the principal components, we examined loadings of the independent variables on the principal components. Loadings with absolute values greater than 0.4 were assumed to be "large" and significant. Six of the seven principal components were deemed interpretable and retained for further analysis.

The loadings of the six components on the different independent variables is shown in Table 5 below. We interpreted the six principal components as follows:

Comp.1 Standardization and Systems Integration which is composed of variables: LackStdDataBarrier, LackStdProcBarrier, LackSysIntegBarrier *(note these variables are negatively described; see Table 1a)*

Comp.2 Level of External Access which is composed of variables: AccessToCustomers, AccessToSuppliers, AccessToPartners

Comp.3 Level of Application Integration which is composed of variables: LevelAppInteg

Comp.4 Ease of Access to Applications and Lack of Worker Training which is composed of variables: EaseOfAccess, LackWorkerTrainingBarrier

Comp.5 IT Funding After Demonstration of Business Need which is composed of variables: ITFundingAfter

Comp.6 Network provides a competitive advantage which is composed of variables: NetworkAsCompAdv

Table 5. Principal Component Loadings

	Comp.1	Comp.2	Comp.3	Comp.4	Comp.5	Comp.6
EmpLevelAccess						
AccessToRemoteEmployees						
AccessToCustomers		-0.43				
AccessToPartners		-0.45				
AccessToSuppliers		-0.41				
EaseOfAccess				-0.66		
SiteLevelAccess						
LackStdDataBarrier	-0.42					
LackStdProcBarrier	-0.43					
LackSysIntegBarrier	-0.41					
LevelAppInteg			-0.40			
UseOfDataMart						
DataStdEnforced						
ITFundingAfter					-0.65	
LackWorkerTrainingBarrier				0.40		
NetworkAsCompAdv						-0.74

We present in Table 6 results from regression analysis that uses only these six components as independent variables (Model II). Table 6 shows that components 1, 2, 5, and 6 are significant at the 5% level, while component 3 is significant at the 1% level. Component 4 is not statistically significant. Since we know the composition of the different principal components, the OLS regression results can be interpreted as follows:

Comp.1: Standardization and Systems Integration are positively correlated to IT impact on customer satisfaction (significant at 5% level). Note that the coefficient on the principal component is positive, whereas the loadings for the variables for the component are negative. However, the variables are negatively described: *lack* of standard data, *lack* of standard processes and *lack* of systems integration (see Table 1a). Hence it is the case that standardization of data and of processes and systems integration are positively correlated to IT impact on customer satisfaction. This is consistent with Hypotheses 2.1 and 2.2.

Comp.3: Level of application integration is positively correlated to IT impact on customer satisfaction (significant at 1% level). Note that even though the estimated OLS coefficient on the principal component is negative, the variable that loads on this component has a negative sign. This result is consistent with Hypothesis 2.3.

Comp.5: Policy that new funding occurs only after an existing business need has been demonstrated is positively correlated to IT impact on customer satisfaction (significant at 5% level). Note that even though the estimated OLS coefficient on the principal component is negative, the variables that load on this component have negative signs. This result is consistent with Hypothesis 3.1.

Comp.6: Cultural perception that "network and e-business foundation provides firm with a competitive advantage in the market" is positively correlated to IT impact on customer satisfaction (significant at 5% level). Note that even though the estimated OLS coefficient on the principal component is negative, the variable that loads on this component has a negative sign. This result is consistent with Hypothesis 3.2.

Comp.2: Giving access to internet business application, internal data and systems to customers, partners, suppliers (or external entities) is negatively correlated to IT impact on customer satisfaction (significant at 5% level). Note that even though the estimated OLS coefficient on the principal component is positive, the variables that load on this component have negative signs. This result is *not* consistent with Hypothesis 1.2.

Note Comp.4 (ease of access; % of applications that are accessible by internet or web-based mechanisms; and lack of worker training perceived as a barrier to productivity) is *not* correlated to IT impact on customer satisfaction (p-value=0.1256).

Table 6. Model II: OLS Regression of "IT Impact on Customer Satisfaction" on the Principal Components

	Dependent Variable	
Independent Variable	IT Impact on Customer Satisfaction	p-value
Comp.1 (Standardization and Integration) (1)	4.6333*** (1.6192)	0.0051
Comp.2 (Level of External Access) (1)	3.4020* (1.8655)	0.0710
Comp.3 (Level of Application Integration) (1)	-7.0781*** (2.3395)	0.0031
Comp.4 (Ease of Access to Applications and Lack of Worker Training)	3.7147 (2.4061)	0.1256
Comp.5 (IT Funding After Demonstration of Business Need) (1)	-5.8525** (2.7324)	0.0345
Comp.6 (Network provides a competitive advantage) (1)	-5.8178** (2.7591)	0.0373

R^2: 0.2298
F-statistic:5.271 on 6 and 106 degrees of freedom with p-value=0.00008676
OLS standard errors are reported in parentheses
*** indicates significance at the 1% level
** indicates significance at the 5% level
* indicates significance at the 10% level
(1) The loadings for the variables for this component are negative

The similarity of these results (Table 6) to the results obtained from the previous regression model (Table 4) shows that the regression is fairly robust to the number of principal components included in the linear model. Note that R^2 of about 23% is relatively small (albeit acceptable for field studies), indicating that there is much unexplained variance in the dependent variable.

The principal components analysis followed by regression analysis were unable to test for Hypothesis 1.1 (as the independent variable, EmpLevelAccess, failed to be part of a principal component) and Hypothesis 1.3 (as Comp.4 was statistically insignificant in the regression).

The results do not change much with the addition of industry controls. In Model II (the extended model with the six principal components), the point estimate for Comp.2 (Level of External Access) is no longer statistically significant, even at the 10% level.

The results of the two models with the industry dummy variables in the regressions are presented in Table 7. Overall, the regression results point to the strong positive correlation between IT impact on customer satisfaction and standardization, systems integration and application integration.

Table 7. OLS Regressions of "IT Impact on Customer Satisfaction" on the Principal Components (With Industry Controls)

	Dependent Variable (IT Impact on Customer Satisfaction)	
Independent Variable	Model I (with Industry Controls)	Model II (with Industry Controls)
Comp.1 (Standardization and Integration) (1)	4.5169** (1.7451)	4.3796** (1.6785)
Comp.2 (Level of External Access) (1)	3.3504* (2.0141)	3.0765 (1.9389)
Comp.3 (Level of Application Integration) (1)	-6.7758** (2.6263)	-7.0236*** (2.5578)
Comp.4 (Ease of Access to Applications and Lack of Worker Training)		4.1309 (2.5171)
Comp.5 (IT Funding After Demonstration of Business Need) (1)		-5.7816** (2.7864)
Comp.6 (Network provides a competitive advantage) (1)		-5.9794** (2.8914)
R^2	0.1444	0.235
F-statistic	2.532 on 7 and 105 degrees of freedom, p-value=0.01903	3.133 on 10 and 102 degrees of freedom, p-value=0.001581
OLS standard errors are reported in parentheses *** indicates significance at the 1% level ** indicates significance at the 5% level * indicates significance at the 10% level (1) The loadings for the variables for this component are negative		

5 Discussion

The results are consistent with the assertion that high investments in IT need to be combined with investments in standardization, systems integration and applications integration to reap maximum benefits from IT. Just granting applications and systems access may not be sufficient; what seems to be important in terms of enhancing performance is standardization of data, processes, systems integration, and application integration.

Standardization of data and processes, systems integration and application integration leads to accurate, reliable and comprehensive information that allows for better resolution of customer issues. Lack of standardization of data may lead to inconsistencies in the data and possibly incorrect information being provided to customers. Customer data is often stored in multiple systems/databases and if these systems are not properly integrated, then customer problems may take much longer to resolve. The longer average time to resolution will inevitably lead to dissatisfied customers. Updates to non-integrated databases will not be coordinated and may lead to outdated information in some data sources. Old information may lead to incorrect resolution of customer issues. Different client-focused sub-units of an organization may use different applications to address customer needs. If these applications do not talk to each other i.e. if they do not share customer information, the organization misses an opportunity to view holistic/complete information on its customers and provide higher levels of customer service. Thus, the finding of the paper that standardization, systems integration and application integration are positively correlated to IT impact on customer satisfaction does seem intuitively appealing.

On the other hand, the finding that level of internal data and systems access to external entities such as customers, suppliers, and partners is negatively correlated to IT impact on customer satisfaction is somewhat puzzling. One would expect that customers when allowed access to internal data and applications would have quick access to relevant information and would be able to resolve many of their issues efficiently through self-service. Also, giving access to partners and suppliers would be expected to facilitate maximum information sharing and useful collaboration to meet the needs of the customer and provide optimal service. Nevertheless, we find in our dataset that providing access to external entities is negatively correlated to IT impact on customer satisfaction (see Models I and II in tables 4 and 6 respectively; note however that table 7 shows that the result is no longer statistically significant when industry controls are added to Model II). This finding might be a result of the caveats of the dataset that we mention in the conclusions section such as a small sample of firms from five different industries. However, the counter-intuitive result can also be understood from a close examination of the correlation matrix in table 2. There we see that the level of application integration variable (LevelAppInteg or 'K' in table 2) is negatively correlated with two access variables: AccessToCustomer ('C' in table 2) and AccessToSupplier ('D' in table 2). The negative correlation helps explain the negative impact of access on IT-related improvement in customer satisfaction. It is not enough for organizations to just provide customers, suppliers and partners access to internal data and systems; what is more important is to standardize data and processes, integrate systems and applications so that accurate, reliable, and comprehensive information is available throughout the organization. Further providing unrestricted access to external parties without carefully addressing security and access control issues might backfire (see caveat section after Hypotheses 1.1-1.3 above). Providing access without integrating internal data, systems, and applications and without addressing security issues adequately may be insufficient for improved positive IT impact on customer satisfaction. This is consistent with the strong complementarities between organization and IT found by Brynjolfsson and Hitt (2000). IT alone is not sufficient for success, and could even be counter-productive in some cases.

Finally, the first cultural finding that IT funding only after demonstration of business need is positively correlated to IT impact on customer satisfaction makes intuitive sense because IT investments in applications that do not adequately address a customer need will fail to improve customer satisfaction. On the other hand, IT projects that come out of systematic study of customer issues and needs will likely most adequately address them and lead to more satisfied customers. The second cultural finding – a shared perception that the network provides the firm with a competitive advantage is positively correlated to IT impact on customer satisfaction – makes sense because a shared understanding that the company's network is a strategic asset will lead to management support for higher investments in network-enabled business applications that have the capability to share data, provide high-quality information and thereby improve customer satisfaction.

6 Conclusions

Based on a detailed empirical analysis of data about the IT operations and customer service & support operations of 138 large firms that have at least one fully deployed internet business application to support customer service, we conclude that investments in IT-related intangible assets such as data/process standardization, systems integration, and application integration are investments in effective IT management practices that are significantly positively correlated to IT impact on an important business process performance metric such as customer satisfaction. Further, just providing internal data and systems access to external entities such as customers, suppliers, and partners is not correlated to positive IT impact on customer satisfaction; on the contrary, indiscriminately providing access to external entities may backfire, as we see a negative correlation between access to external entities and IT impact on customer satisfaction. Lastly, cultural elements such as thoughtfully spending on IT projects after business needs have been clearly demonstrated and firm-wide perception that the network and e-business foundation of the firm provides competitive advantage are significantly positively correlated to IT impact on customer satisfaction.

Several caveats about the data should be kept in mind to understand the limitations of the study. The results and conclusions in this paper should be interpreted keeping these limitations in mind. First, since many of the firms interviewed in this study were either privately held or were government sector or healthcare/pharmaceutical companies, objective financial performance data such as profitability data is either not reported or is not available. Hence, we are unable to match up for a reasonable sample size of firms the perceived impact on the key functional performance metric, customer satisfaction, with impact on objective financial performance metrics such as profitability. Second, the decision-makers interviewed were asked about their perceptions on the IT impact on customer satisfaction. The numbers reported may not be accurate because of response bias or social desirability bias. Since we do not have multiple respondents from the same firm answering the question about IT impact on customer satisfaction, we have no way to check the validity of the reported numbers. Third, the sample of 138 firms is a relatively small sample considering that they come from 5 different industries. Given the sample size, the high statistical significance of our results is encouraging. Fourth, as mentioned earlier, the dataset is cross-sectional and hence any conclusions are about associations/correlations and not about causation.

Future research may try to address some of the shortcomings of the data used in this study. It would be very useful to collect panel data so that causal hypotheses instead of correlational hypotheses could be explored. It would also be useful to target a larger sample of firms and actually measure directly some of the independent variables used in this research. For example, one could systematically define and precisely measure the level of data/process standardization and systems integration and then have a uniform way of comparing these variables across firms. Further, it would be useful to get *objective* data on IT impact on customer satisfaction or other *objective* financial performance data instead of data on *perceived* IT impact on customer satisfaction that was used in this study. Financial performance may be a better dependent variable as it is more easily comparable across firms than impact on customer satisfaction, as ways of measuring customer satisfaction could vary across firms. However, as noted earlier, financial performance is not a process-specific performance metric and IT impact on a process metric may be more desirable.

Overall, additional scholarly research to point out specific IT-related practices that allow firms that invest heavily in IT to differentiate themselves on the performance dimension from other firms that also invest heavily in IT would be a useful contribution to the management information systems field. This research would also be especially useful for practitioners who are continuously seeking ways to maximize the value they can extract from their IT investments. Pointing out specific intangible investments that should be coupled with IT investments and even helping firms prioritize those intangible investments can be tremendously valuable to executive decision makers, as they try to use IT to improve firm performance along various dimensions of interest to them.

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ESSAY 5

EXTENDING THE SWEETDEAL APPROACH FOR E-PROCUREMENT USING SWEETRULES AND RULEML*

Abstract

We show the first detailed realistic e-business application scenario that uses and exploits capabilities of the SweetRules V2.1 toolset for e-contracting using the SweetDeal approach. SweetRules is a uniquely powerful integrated set of tools for semantic web rules and ontologies. SweetDeal is a rule-based approach to representation of business contracts that enables software agents to create, evaluate, negotiate and execute contacts with substantial automation and modularity. The scenario that we implement is of electronic procurement of computers, with request-response iterated B2B supply-chain management communications using RuleML as content of the contracting discovery/negotiation messages. In particular the capabilities newly exploited include: SweetJess or SweetXSB to do inferencing in addition to option of SweetCR inferencing, SweetOnto to incorporate/merge-in OWL-DLP ontology, and effectors to launch real-world actions. We identify desirable additional aspects of query and message management to incorporate into RuleML and give the design of experimental extensions to the RuleML schema/model, motivated by those, that include specifically: fact queries and answers to them. We present first scenario of SCLP RuleML for rebates and financing options in particular exploiting the courteous prioritized conflict handling feature. We give a new SweetDeal architecture for business messaging aspect of contracting in particular exploiting the situated feature to exchange rulesets that obviates the need to write new agents in manner of the approach of the SweetDeal V1 prototype. We finally analyze how the above techniques, and SweetDeal, RuleML and SweetRules overall, can combine powerfully with other e-business technologies such as RosettaNet and ebXML

Keywords: RuleML, SweetRules, SweetDeal, semantic web, e-procurement

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* Joint work with Dr. Benjamin Grosof and Shashidhar Ganjugunte. This essay is based on the multi-authored paper (lead author: Sumit Bhansali, co-authors: Shashidhar Ganjugunte and Dr. Benjamin Grosof) presented at the 2005 International RuleML Conference.

1 Introduction

In this paper, we describe in detail a practical electronic contracting scenario that uses RuleML [1], the Situated Courteous Logic Programs (SCLP) knowledge representation [6], and the SweetRules V2.1 semantic web rules toolset [2] implementation [2] together to show how a real-world business application such as electronic procurement can be supported with semantic web [3] technologies including also OWL [3]. The electronic procurement application was chosen not only because of its wide applicability in e-business but also because it allows us to showcase different features of the new SweetRules V2 implementation. Specifically, we show how powerful features of the new implementation such as importing OWL-DLP ontologies into a rule-based knowledge base, executing real-world business processes such as sending e-mail from rules, and inferencing on RuleML rules obtained from ontologies as well as rulebases possibly expressed in different types of KR. The procurement example allows us to also see how different business functions/features such as rebates, financing scenarios, payment options, which might be applicable in a wide variety of business applications, can be expressed using the RuleML KR language.

From our investigation of the electronic procurement scenario, we suggest inclusion of specific features in future versions of the RuleML KR to support query and message management that would be useful especially in business applications involving iterated request-response communication, such as e-contracting applications. Finally, we also explain how our electronic contracting approach based on RuleML and SweetRules can relate to other e-business technologies such as RosettaNet [4] and ebXML [5].

The paper is organized as follows. In section 2, we provide a brief overview of the technologies – RuleML, SweetRules, and SweetDeal – that we use in this research. Section 3 provides an overview of our approach and scenario. Section 4 illustrates the expressive power of RuleML in representing key contract provisions, specifically those of financial incentives. Section 5 describes the iterated contract construction process in great detail. Section 6 concludes the paper.

2 Overview of Technologies

We provide below a short description of the different technologies used in this research.

2.1 RuleML

RuleML [1] is the emerging standard for representing semantic web rules. The fundamental KR used in RuleML is situated courteous logic program or SCLP, which has been demonstrated to be expressively powerful [6]. The courteous part of SCLP enables prioritized conflict handling, which in turn enables modularity in specification, modification, merging and updating. The situated part of SCLP enables attached procedures for "sensing" (i.e. testing rule antecedents) and "effecting" (i.e. performing actions when certain conclusions are reached).

2.2 SweetRules

SweetRules [2], a uniquely powerful integrated set of tools for semantic web rules and ontologies, is newly enhanced in V2.1. The new version of SweetRules include capabilities such as first-of-a-kind semantics-preserving translation and interoperability between a variety of rule and ontology languages (including XSB Prolog [7], Jess [8] production rules, HP Jena-2 [9], IBM CommonRules [10], and the SWRL [11] subset of RuleML), highly scaleable backward and forward inferencing, and easy merging of heterogeneous distributed rulebases/ontologies.

2.3 SweetDeal

SweetDeal [12] is an electronic contracting approach that uses SCLP RuleML to support creation, evaluation, negotiation, execution and monitoring of formal electronic contracts between agents such as buyers and sellers. The approach builds on top of the SweetRules toolset to showcase the power of SCLP, RuleML, and SweetRules, as a design -- and implemented prototype software -- in the specific business application of electronic contracting.

3 Overview of Approach and Scenario

The extended SweetDeal approach described in this paper consists of three primary pieces: communication protocol between the contracting agents, contract knowledge bases and agent communication knowledge bases. We briefly describe these below in the context of our specific scenario of electronic procurement –

3.1 Communication Protocol

In our scenario, the buyer, Acme Corp, is interested in purchasing computers of a particular configuration. The buyer attempts to establish a procurement contract with the seller, Dell Computers. We assume that Dell Computers is a preferred vendor of computers for Acme Corp. To establish the terms of the contract, the buyer and seller agents exchange messages in an iterated fashion.

The protocol of message exchanges is as follows: the buyer first sends an RFP (request for proposal) to the seller. The seller responds to the RFP with the proposal. Based on specific business criteria, the buyer chooses to accept or reject the proposal. The buyer may also suggest modifications to the proposal before accepting or rejecting it. The RFP message from the buyer contains specific details about the desired computer configuration. It also contains any queries to which the seller must provide answers in its proposal. The proposal message from the seller contains several formal contract fragments which describe useful business provisions such as rebates, financing options, as well as payment options for the buyer. In addition to specifying the contractual provisions, the seller also provides answers to the queries posed by the buyer. Finally, it may pose additional queries for the buyer that the buyer in turn must provide answers to in the next negotiation message. After the buyer is satisfied with the final contract proposal from the seller, it generates a purchase order that is sent to the seller. To complete the transaction, the seller delivers the order and the buyer makes arrangements to pay the seller via the chosen payment option. Any contingencies in the execution of the order/transaction are handled according to the terms of the contract.

3.2 Contract Knowledge Bases

Contract negotiation messages exchanged between the agents are RuleML knowledge bases that are executable within SweetRules V2.1 software. Contract knowledge bases contain the following six main technical components: rules, facts, ontologies including OWL-based ontologies as well as object-oriented default inheritance ontologies, effectors, f-queries and their answers, and conditional queries. We briefly describe each of these components below. Since RuleML as an XML-based markup language is fairly verbose and since the presentation syntax of RuleML has not yet been implemented completely in SweetRules, we use the IBM CommonRules (CR) V3.3 syntax in all our examples to allow for concise presentation and easier comprehension. In future, it would be more desirable instead to use the RuleML presentation syntax. See [16], especially the Rules language description, for the initial version of that presentation syntax, and see [2], especially its documentation, for its experimental extension to include the Situated feature and for its (currently, still partial) support in SweetRules.

3.2.1 Rules

RuleML rules express the if-then implications of the contractual fragments and form the bulk of the contract knowledge base. Each rule has a head and a body. The “head” is the part of the rule after the “then”, whereas the “body” is the part of the rule that follows “if” and precedes “then”. The example below shows a simple <rebate> rule: the seller might wish to provide a rebate offer to the buyer in the proposal. Specifically, the seller might wish to offer a rebate in the amount of $1000 to the buyer if the number of computers ordered by the buyer is more than 75. Due to current tool limitations of numeric types in translating CommonRules to RuleML, all numeric constants in the rule examples below are represented using strings, e.g., “75” is represented as “seventyfive”.

```
<rebate>
if
       quoteID(?QuoteID) AND quantityOfItemOrdered(?Q) AND
              isGreaterThan(?Q, seventyfive)
then
       rebateAmount(?QuoteID, thousand);
```

3.2.2 Facts

RuleML facts or assertions are rules that have no bodies. The simple examples below show facts that are specified in the RFP from the buyer to the seller. The quantity of item ordered by the buyer is 50 (computers) and the buyer is located in the state of Florida.(We assume that both buyer and seller are located in USA).

```
       quantityOfItemOrdered(eighty);
       buyerLocationState(florida);
```

3.2.3 Ontologies

Ontologies are vocabularies that express the background knowledge used by the contract rules. They can be either OWL [15] ontologies or rule-based object-oriented default inheritance ontologies. OWL ontologies used must be in the Description Logic Programs (DLP) [13] subset of OWL, i.e. in the subset of OWL that is translatable into LP rules. SweetRules V2.1 software allows for translation from OWL-DLP to RuleML rules. We show below a simple example of an OWL ontology that is used by the buyer. The ontology (procurement.owl) has three classes: *buyer, seller,* and *product*, and three object properties: *preferredVendorIs, buysProduct,* and *sellsProduct*. The ontology fragment also has some instance data: *computers is a product, Dell sells computers, Acme buys computers, Acme has Dell as a preferred vendor*. Since the ontology is in the DLP subset of OWL, a translation from OWL to RuleML exists and SweetRules V2.1 software can be used (see command C1 below) to convert the ontology to a rule-based knowledge base in RuleML.

```
translate owl clp c:\procurement.owl c:\procurement.clp          (C1)
```

The ontology (procurement.owl) is shown below:

```
<?xml version="1.0"?>
<rdf:RDF
    xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
    xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
    xmlns:owl="http://www.w3.org/2002/07/owl#"
    xmlns="http://www.procurement.org/procurement.owl#"
    xml:base="http://www.procurement.org/procurement.owl">
  <owl:Ontology rdf:about=""/>

  <owl:class rdf:ID="Buyer"/>
  <owl:class rdf:ID="Seller"/>
  <owl:class rdf:ID="Product"/>

  <owl:ObjectProperty rdf:ID="preferredVendorIs">
        <rdfs:domain rdf:resource="#Buyer"/>
        <rdfs:range rdf:resource="#Seller"/>
  </owl:ObjectProperty>

  <owl:ObjectProperty rdf:ID="buysProduct">
        <rdfs:domain rdf:resource="#Buyer"/>
        <rdfs:range rdf:resource="#Product"/>
  </owl:ObjectProperty>
```

```
  <owl:ObjectProperty rdf:ID="sellsProduct">
        <rdfs:domain rdf:resource="#Seller"/>
        <rdfs:range rdf:resource="#Product"/>
  </owl:ObjectProperty>

  <Seller rdf:ID="Dell">
       <sellsProduct rdf:resource="#Computers"/>
  </Seller>

  <Buyer rdf:ID="Acme">
        <preferredVendorIs rdf:resource="#Dell"/>
         <buysProduct rdf:resource="#Computers"/>
  </Buyer>

  <Product rdf:ID="Computers"/>
</rdf:RDF>
```

The translation of the ontology to rules is shown below. The translation has been slightly modified for ease of readability. Each of the predicates below would be prefixed in the original translation with a long namespace URI indicated in the OWL document above. The namespace URI has been removed from all predicates below.

```
<emptyLabel>
if
 buysProduct(?X, ?Y)
then
 Buyer(?X);

<emptyLabel>
if
 buysProduct(?X, ?Y)
then
 Product(?Y);

<emptyLabel>
if
 sellsProduct(?X, ?Y)
then
 Seller(?X);

<emptyLabel>
if
 sellsProduct(?X, ?Y)
then
 Product(?Y);

<emptyLabel>
if
 preferredVendorIs(?X,?Y)
then
 Buyer(?X);

<emptyLabel>
if
 preferredVendorIs(?X, ?Y)
```

```
then
 Seller(?Y);

<emptyLabel>
sellsProduct(Dell, Computers);

<emptyLabel>
preferredVendorIs(Acme, Dell);

<emptyLabel>
Buyer(Acme);

<emptyLabel>
Product(Computers);

<emptyLabel>
class(Product);

<emptyLabel>
class(Buyer);

<emptyLabel>
class(Seller);

<emptyLabel>
Seller(Dell);

<emptyLabel>
buysProduct(Acme, Computers);
```

Next we show a simple example of expressing an object-oriented default inheritance ontology using rules. In the example, *BuyWithCredit* is a subclass of *Buy*. *Buy* assigns the value "invoice" to the *paymentMode* property, but *BuyWithCredit* assigns the value "credit" to the *paymentMode* property, i.e., *BuyWithCredit* overrides the *paymentMode* property inherited by default from *Buy*. The courteous feature of SCLP RuleML is a powerful way to express default inheritance using rules. If only Buy(quoteID) is asserted (i.e. the buyer asserts that it wants to buy), then the payment mode is assumed to be invoice (by default). If the buyer specifically asserts BuyWithCredit(quoteID), then the default payment mode is overridden to be credit instead.

```
<buyRegular>
if
 Buy(?quoteID)
then
 paymentMode(?quoteID,invoice);

/* BuyWithCredit is a subclass of Buy */
if
 BuyWithCredit(?quoteID)
then
```

```
 Buy(?quoteID);

<buyCredit>
if
 BuyWithCredit(?quoteID)
then
 paymentMode(?quoteID,credit);

overrides(buyCredit, buyRegular);
```

3.2.4 Effectors

Effectors are a feature of the Situated extension of logic programs. An effector procedure is an attached procedure that is associated with a particular predicate. This association is specified via an effector statement that is part of the rulebase. When a conclusion is drawn about the predicate, an action is triggered; this action is the invocation of the effector procedure, and is side-effect-ful. In general, there may be multiple such effector statements and procedures in a given rulebase, e.g.., in a given SweetDeal contract/proposal. Effectors can execute real-world business processes associated with the execution of the contract. For example, an effector can be used by the buyer to send the purchase order (PO) to the seller (see <sendPO> rule below). If the vendor proposal has been approved, then the buyer sends the PO to the sales e-mail address of the vendor. The effector *sendPOtoVendor* is associated with the Java procedure *emailMessage* in the *Effector_EmailPO* class, whose path is indicated as *com.ibm.commonrules.examples.situated_programming_examples.familymsg.aprocs*. The Java procedure not shown here for brevity handles the e-mail messaging aspect of sending the PO to the vendor. The arguments to the effector predicate – seller e-mail address, location of the purchase order, approved proposal identifier – are passed as arguments to the Java procedure.

```
<sendPO>
if
  approvedVendorProposal(?Vendor, ?ProposalID) AND
  emailSalesAddress(?Vendor, ?SellerAddress) AND locationofPO(?Location)
then
  sendPOtoVendor(?SellerAddress, ?Location, ?ProposalID);
```

```
<emptylabel>
   Effector: sendPOtoVendor
   Class: Effector_EmailPO
   Method: emailMessage
   path:
"com.ibm.commonrules.examples.situated_programming_examples.familymsg.aprocs";
```

3.2.5 Fact-queries or F-queries

The traditional notion of the answer to a query in logic programs (and databases) is: a set of variable-binding lists. In modeling the exchange of contract proposals and associated dialogue between contracting parties, however, it is often convenient to model the answer to an inquiry as a set of facts instead. Accordingly, we have developed the design of f-queries (short for "fact queries") as a (fairly simple) experimental extension to RuleML. Note that, unlike the rest of what we describe of the SweetDeal approach in this paper, this f-queries feature is *not yet implemented in SweetRules*. RuleML f-queries are queries which have facts as their answers. They facilitate the iterated development of procurement contracts. Examples below show sample f-queries. Query#1 is an f-query from buyer to seller in which the buyer requests the seller for the unitPriceOfItem. Query#2 is an f-query also from buyer to seller in which the buyer asks the seller for the offeredProcessorSpeedInGHZ. Answers to these f-queries are provided by the seller as RuleML facts.

```
Query#1
<query>
    <_body>
       <fclit cneg="no" fneg="no">
         <_opr>
              <rel>unitPriceOfItem</rel>
           </_opr>
         <var>QuoteID</var>
         <var>Price</var>
        </fclit>
    </_body>
  </query>

Query#2
<query>
    <_body>
       <fclit cneg="no" fneg="no">
         <_opr>
```

```
            <rel>offeredProcessorSpeedInGHZ</rel>
          </_opr>
         <var>Speed</var>
        </fclit>
    </_body>
  </query>
```

3.3 Agent Communication Knowledge Bases

In addition to the contract knowledge bases that are shared/exchanged, the agents also have internal RuleML knowledge bases that contain rules to facilitate agent communication. The effectors feature of SCLP RuleML allows the agents to execute real-world business processes such as e-mail messaging. This feature is used by the agents to send the contract rulesets to each other. The actual e-mail messaging effector procedure is implemented as a Java method that employs the JavaMail API [14]. The communication process is triggered using the internal agent communication KB and the SweetRules V2.1 software that supports execution of Java methods attached as effectors to specified predicates in the KB. A simple example follows: the situated rule <sendRFP> allows the buyer to send the RFP ruleset to the sales e-mail address of the seller. The name of the effector in the situated rule is sendRFPtoComputerSeller. The effector specification consists of the name of the Java procedure (emailMessage), the Java implementation class that contains the method (Effector_EmailRFP), and the path to the class (com.ibm.commonrules.examples.situated_programming_examples.familymsg.aprocs).

The effector is executed when the buyer wants to buy computers and the seller sells computers and is in the preferred vendor list of the buyer. When the sendRFPtoComputerSeller predicate is concluded, the attached procedure “emailMessage” is called to execute the required action. The action consists of reading the RFP from the local file system and sending it via e-mail to the specified e-mail address of the sales department of the seller. For brevity, the Java code to implement the e-mail messaging is not shown here.

```
<sendRFP>
if
   wantToBuy(?Buyer, computers) AND seller(?Vendor) AND
       sell(?Vendor, computers) AND inPreferredVendorList(?Buyer, ?Vendor) AND
       emailSalesAddress(?Vendor, ?Address) AND
       locationofRFP(?Buyer, computers, ?Location)
then
   sendRFPtoComputerSeller(?Address, ?Location);

<emptylabel>
   Effector: sendRFPtoComputerSeller
   Class: Effector_EmailRFP
   Method: emailMessage
   path:
"com.ibm.commonrules.examples.situated_programming_examples.familymsg.aprocs";
```

4 Contract Business Provisions using RuleML

In this section, we present a few key contract fragments in the procurement contracting scenario and how SCLP RuleML can be used to express them. We intend to show how the expressive/declarative power of RuleML allows for easy addition and modification of key B2B contracting provisions. Specifically, we focus on expressing commonly used financial incentives such as rebates, discount pricing, and financing options. These incentives could be specified by the seller in its proposal. For the sake of simplicity and brevity, in this paper version some of the rules (e.g., about monthly payments in financing options) are highly specific to the particular scenario, rather than specified in more realistically general form.

4.1 Rebate

For example: the seller wishes to offer a rebate in the amount of $1000 to the buyer if the quantity of item ordered is greater than 75. This is represented as the <rebate> rule below.

```
<rebate>
if
       quoteID(?QuoteID) AND quantityOfItemOrdered(?Q) AND
       isGreaterThan(?Q, seventyfive)
then
       rebateAmount(?QuoteID, thousand);
```

4.2 Pricing Options

Example 1: If the buyer makes the purchase before April 1 then the unit price offered by the seller is $600; if the purchase is made before April 15, then the unit price offered is $650. This is specified as the <earlyPurchase> and <latePurchase> rules below. If both these rules apply, i.e., if the purchase was made before April 1, then precedence is given to the earlyPurchase rule. This precedence is specified using the courteous prioritization feature of SCLP (and of RuleML): see the overrides fact rule below.

```
<earlyPurchase>
if
       quoteID(?QuoteID) AND purchaseDate(?QuoteID, ?Date) AND
       isLessThan(?Date, oneApr05)
then
       unitPriceOfItem(?QuoteID, sixhundred);

<latePurchase>
if
       quoteID(?QuoteID) AND purchaseDate(?QuoteID, ?Date) AND
       isLessThan(?Date, fifteenApr05)
then
       unitPriceOfItem(?QuoteID, sixhundredfifty);

overrides(earlyPurchase, latePurchase);

MUTEX
       unitPriceOfItem(?QuoteID, sixhundred) AND
       unitPriceOfItem(?QuoteID, sixhundredfifty);
```

Example 2: If the purchase is made by the buyer before April 1 then the discount offered by the seller is 15%; if the purchase is made before April 15 then the discount offered by the seller is slightly lower at 13%. This is specified as the <earlyPurchaseDiscount> and <latePurchaseDiscount> rules below. Since both rules can be triggered when the purchase date is before April 1, the overrides fact rule is used to resolve the potential conflict in favor of the earlyPurchaseDiscount rule.

```
<earlyPurchaseDiscount>
if
       quoteID(?QuoteID) AND purchaseDate(?QuoteID, ?Date) AND
       isLessThan(?Date, oneApr05)
then
```

```
       discountPercentAlreadyIncluded(?QuoteID, fifteen);

<latePurchaseDiscount>
if
       quoteID(?QuoteID) AND purchaseDate(?QuoteID, ?Date) AND
       isLessThan(?Date, fifteenApr05)
then
       discountPercentAlreadyIncluded(?QuoteID, thirteen);

overrides(earlyPurchaseDiscount, latePurchaseDiscount);

MUTEX
       discountPercentAlreadyIncluded(?QuoteID, fifteen) AND
discountPercentAlreadyIncluded(?QuoteID, thirteen);
```

4.3 Financing Option

For example: If the financing is requested for 36 months by the buyer, the unit price of the item is determined to be $600, and the quantity ordered is 50, then the financing option offered by the seller is such that the monthly payment is $958 and the total interest paid is $4500 (see the <financing> rule below).

```
<financing>
if
       quoteID(?QuoteID) AND financeForMonths(?QuoteID, thirtysixMonths) AND
       unitPriceOfItem(?QuoteID, sixhundred) AND
       quantityOfItemOrdered(?QuoteID, fifty)
then
       monthlyPayment(?QuoteID, ninehundredfiftyeight) AND  totalInterest(?QuoteID,
fourthousandfivehundred);
```

5 Details of Procurement Contract Construction Using RuleML and SweetRules V2.1

In this section, we describe in detail the specific steps taken in constructing an e-contract between the buyer and seller using SCLP RuleML and SweetRules V2.1 in our electronic procurement scenario.

As described earlier, the buyer has a solo (or unshared) agent communication knowledge base that can be used to initiate the action of sending an RFP to a specific seller (in our example – Dell). We call this solo knowledge base – BSO1. BSO1 has the names of the different sellers, types of products offered by them, their respective sales e-mail addresses, and whether the sellers are in the preferred vendor list maintained by the buyer. The location of the RFP (which itself is a rule-based knowledge base) is indicated using the *locationofRFP* predicate. The rule that triggers sending the RFP to the seller is indicated by <sendRFP>: if the buyer wants to buy computers and the seller sells computers and is in the preferred vendor list of the buyer, send the RFP from the indicated local filesystem location to the seller's sales e-mail address. The predicate *sendRFPtoComputerSeller* is associated with the situated effector procedure *emailMessage*, which uses the JavaMail API to send the RFP ruleset to the seller via e-mail.

Buyer Solo KB – BSO1

```
wantToBuy(acme, computers);
seller(dell);
seller(staples);
sell(dell, computers);
sell(staples, officesupplies);
inPreferredVendorList(acme, dell);
inPreferredVendorList(acme, staples);
emailSalesAddress(dell, "sales@dell.com");
emailSalesAddress(staples, "sales@staples.com");
locationofRFP(acme, computers, "c:\\buyertosellerRFP.clp");

<sendRFP>
if
   wantToBuy(?Buyer, computers) AND seller(?Vendor) AND
  sell(?Vendor, computers) AND inPreferredVendorList(?Buyer, ?Vendor) AND
  emailSalesAddress(?Vendor, ?Address) AND
  locationofRFP(?Buyer, computers, ?Location)
then
  sendRFPtoComputerSeller(?Address, ?Location);

<emptylabel>
   Effector: sendRFPtoComputerSeller
   Class: Effector_EmailRFP
   Method: emailMessage
   path:
"com.ibm.commonrules.examples.situated_programming_examples.familymsg.aprocs";
```

In SweetRules V2.1, the "exhaustForwardInfer" command is given to derive all the conclusions from a given rulebase, and along with those conclusions to perform all the associated effecting actions that those conclusions trigger (i.e., sanction). For example, the command C2 below generates all the conclusions of BSO1 and (as an effecting action) sends the RFP to the seller.

The “clp” in the first two arguments of the command indicates that CommonRules V3.3. format is the input and output knowledge base format, the third argument gives the location of BSO1, and the fourth argument specifies that IBM CommonRules should be used indirectly as an underlying inference engine when performing inferencing. SweetRules V2.1 software allows for a choice of such underlying engines. In our example, SweetRules enables Jess or XSB, as well as CommonRules, to be used as indirect underlying engine; for each choice of underlying engine, it would generate semantically equivalent conclusions and perform the same set of triggered effecting actions

```
exhaustForwardInfer clp clp c:\buyertosellerSendRFP.clp CommonRules      (C2)
```

The RFP sent by the buyer to the seller is a collection of rules. The RFP consists of two parts -- a shared knowledge base that contains most importantly the required computer configuration details (we call this knowledge base BSH1) and a set of f-queries that request specific answers from the seller (we call this set of queries BFQ1).

BSH1 indicates the buyer name, quantity of item ordered, buyer state, and the required computer configuration details. The rule <checkOfferedConfiguration> is used by the buyer to check whether the vendor offered configuration satisfies the minimum requirements. Since RuleML built-ins are not currently directly and smoothly supported in SweetRules V2.1 beyond the SWRL subset of RuleML, we also provide several facts to support arithmetic comparison.

<u>Buyer to Seller RFP (BSH1)</u>

```
buyerName(acme);  /* buyer name is acme */
quantityOfItemOrdered(fifty);  /* quantity of item ordered is fifty */

/* buyer is located in the state of Florida */
buyerLocationState(florida);

/* speed of processor should be at least 2GHz */
requiredMinProcessorSpeedInGHZ(twogigahertz);
if
```

```
 requiredMinProcessorSpeedInGHZ(?Speed) and
 offeredProcessorSpeedInGHZ(?OfferSpeed) and isGreaterThan(?OfferSpeed, ?Speed)
then
 isSpeedAcceptable(true);

/* memory size should be at least 512 Mb */
requiredMinSizeofmemoryInMB(fivetwelvemb);
if
 requiredMinSizeofmemoryInMB(?Size) and offeredSizeofmemoryInMB(?Offersize) and
 isGreaterThan(?Offersize, ?Size)
then
 isMemorySizeAcceptable(true);

/* hard disk should be at least 40 Gb */
requiredMinSizeofharddiskInGB(fortyGB);
if
 requiredMinSizeofharddiskInGB(?Size) and offeredSizeofharddiskInGB(?Offersize)
 and isGreaterThan(?Offersize, ?Size)
then
 isHardDiskSizeAcceptable(true);

/* monitor size should be at least 15" */
requiredMinMonitorSizeInInches(fifteen);

if
 requiredMinMonitorSizeInInches(?Size) and
 offeredMonitorSizeInInches(?Offersize) and isGreaterThan(?Offersize, ?Size)
then
 isMonitorSizeAcceptable(true);

/* monitor should be a flat screen monitor */
requiredMonitorType(flat);

/* monitor resolution should be 1024x768 */
requiredMonitorResoluton(tenTwentyFourBySevenSixtyEight);

/* check if the configuration is acceptable */
<checkOfferedConfiguration>
if
  isSpeedAcceptable(true) and isMemorySizeAcceptable(true) and
  isHardDiskSizeAcceptable(true) and isMonitorSizeAcceptable(true) and
  offeredMonitorType(flat) and
  offeredMonitorResolution(tenTwentyFourBySevenSixtyEight)
then
  isOfferedConfigurationAcceptable(true);

/* The following are some facts in lieu of arithmetic built-ins. */
isGreaterThan(fourgigahertz, twogigahertz);
isGreaterThan(onezerotwofourmb, fivetwelvemb);
isGreaterThan(sixtyGB, fortyGB);
isGreaterThan(seventeen, fifteen);
```

BFQ1 is the collection of f-queries that ask the seller to specify the vendor quote identifier, the offered computer configuration details, the unit price of item, taxes as percent of price, service charge as percent of price, delivery charges for shipment, and the delivery time in days.

Buyer to Seller f-Queries (BFQ1)

```
<rulebase>
  <_rbaselab>
  <ind>FQueries</ind>
  </_rbaselab>
  <query>
    <_body>
       <fclit cneg="no" fneg="no">
         <_opr>
              <rel>quoteID</rel>
          </_opr>
         <var>QuoteID</var>
        </fclit>
    </_body>
  </query>

   <query>
    <_body>
       <fclit cneg="no" fneg="no">
         <_opr>
              <rel>offeredProcessorSpeedInGHZ</rel>
          </_opr>
         <var>Speed</var>
        </fclit>
    </_body>
  </query>

<query>
    <_body>
       <fclit cneg="no" fneg="no">
         <_opr>
              <rel>offeredSizeofmemoryInMB</rel>
          </_opr>
         <var>size</var>
        </fclit>
    </_body>
  </query>

<query>
    <_body>
       <fclit cneg="no" fneg="no">
         <_opr>
              <rel>offeredSizeofharddiskInGB</rel>
          </_opr>
         <var>Size</var>
        </fclit>
    </_body>
  </query>

<query>
    <_body>
       <fclit cneg="no" fneg="no">
         <_opr>
              <rel>offeredMonitorSizeInInches</rel>
          </_opr>
         <var>Size</var>
        </fclit>
    </_body>
  </query>

<query>
    <_body>
       <fclit cneg="no" fneg="no">
         <_opr>
```

```
                <rel>offeredMonitorType</rel>
            </_opr>
          <var>Type</var>
        </fclit>
    </_body>
  </query>

<query>
    <_body>
       <fclit cneg="no" fneg="no">
         <_opr>
                <rel>offeredMonitorResolution</rel>
            </_opr>
          <var>Resolution</var>
        </fclit>
    </_body>
  </query>

<query>
    <_body>
       <fclit cneg="no" fneg="no">
         <_opr>
                <rel>unitPriceOfItem</rel>
            </_opr>
          <var>QuoteID</var>
          <var>Price</var>
        </fclit>
    </_body>
  </query>


<query>
    <_body>
       <fclit cneg="no" fneg="no">
         <_opr>
                <rel>taxesAsPercentOfPrice</rel>
            </_opr>
          <var>QuoteID</var>
          <var>Taxes</var>
        </fclit>
    </_body>
  </query>

<query>
    <_body>
       <fclit cneg="no" fneg="no">
         <_opr>
                <rel>serviceChargeAsPercentOfPrice</rel>
            </_opr>
          <var>QuoteID</var>
          <var>ServiceFees</var>
        </fclit>
    </_body>
  </query>

<query>
    <_body>
       <fclit cneg="no" fneg="no">
         <_opr>
                <rel>deliveryChargesForShipment</rel>
            </_opr>
          <var>QuoteID</var>
          <var>DeliveryCharge</var>
```

```
        </fclit>
    </_body>
  </query>

<query>
    <_body>
       <fclit cneg="no" fneg="no">
         <_opr>
              <rel>deliveryTimeInDays</rel>
          </_opr>
         <var>QuoteID</var>
         <var>DeliverDays</var>
        </fclit>
    </_body>
  </query>
</rulebase>
```

After the seller receives the RFP, the seller send its rule-based contract proposal to the buyer. The proposal contains three parts – BSH1 (i.e. shared knowledge base transmitted from buyer to seller – see above), answers to f-queries posed by the buyer plus shared knowledge base that contains rules about pricing, rebates, financing options and other business provisions (we call this SSH1), and lastly f-queries for the buyer (SFQ1).

<u>Seller to Buyer (SSH1)</u>

```
/* quote ID is 1 */
quoteID(one);

/* computer configuration details */
offeredProcessorSpeedInGHZ(fourgigahertz);
offeredSizeofmemoryInMB(onezerotwofourmb);
offeredSizeofharddiskInGB(sixtyGB);
offeredMonitorSizeInInches(seventeen);
offeredMonitorType(flat);
offeredMonitorResolution(tenTwentyFourBySevenSixtyEight);

/* Pricing Rules */

/* if purchase date is before April 1 2005, then unit Price is $600;
   if purchase date is before April 15 2005, then unit Price is $650*/

<earlyPurchase>
if
       quoteID(?QuoteID) and purchaseDate(?QuoteID, ?Date) and
       isLessThan(?Date, oneApr05)
then
       unitPriceOfItem(?QuoteID, sixhundred);

<latePurchase>
if
       quoteID(?QuoteID) and purchaseDate(?QuoteID, ?Date) and
       isLessThan(?Date, fifteenApr05)
then
       unitPriceOfItem(?QuoteID, sixhundredfifty);
```

```
overrides(earlyPurchase, latePurchase);


MUTEX
	unitPriceOfItem(?QuoteID, sixhundred) and
	unitPriceOfItem(?QuoteID, sixhundredfifty);


/* there is no service charge */
if
	quoteID(?QuoteID)
then
	serviceChargeAsPercentOfPrice(?QuoteID, zeroPercent);

/* Delivery Options */

/* if delivery type is standard then delivery charge is $2500 for the order
   if delivery type is express then delivery charge is $5000 for the order
*/
<standard>
if
	quoteID(?QuoteID) and deliveryType(?QuoteID, standard)
then
	deliveryChargesForShipment(?QuoteID, twentyfivehundred);

<express>
if
	quoteID(?QuoteID) and deliveryType(?QuoteID, express)
then
	deliveryChargesForShipment(?QuoteID, fivethousand);
MUTEX
	deliveryType(?QuoteID, standard) and deliveryType(?QuoteID, express);


/* if delivery type is standard then delivery time in days is 14 days
   if delivery type is express then delivery time in days is 7 days
*/
<standardDeliveryTime>
if
	quoteID(?QuoteID) and deliveryType(?QuoteID, standard)
then
	deliveryTimeInDays(?QuoteID, fourteendays);

<expressDeliveryTime>
if
	quoteID(?QuoteID) and deliveryType(?QuoteID, express)
then
	deliveryTimeInDays(?QuoteID, sevendays);

MUTEX
	deliveryTimeInDays(?QuoteID, fourteendays) and deliveryTimeInDays(?QuoteID,
sevendays);

/* Additional assertions from Seller */
/* Financial Incentives */

/* discount */
/* if early purchase, then discount already included is 15% */
/* if late purchase, then discount already included is 13.33% */

<earlyPurchaseDiscount>
if
	quoteID(?QuoteID) and purchaseDate(?QuoteID, ?Date) and
```

```
        isLessThan(?Date, oneApr05)
then
        discountPercentAlreadyIncluded(?QuoteID, fifteen);

<latePurchaseDiscount>
if
        quoteID(?QuoteID) and purchaseDate(?QuoteID, ?Date) and
        isLessThan(?Date, fifteenApr05)
then
        discountPercentAlreadyIncluded(?QuoteID, thirteen);

overrides(earlyPurchaseDiscount, latePurchaseDiscount);

MUTEX
        discountPercentAlreadyIncluded(?QuoteID, fifteen) and
        discountPercentAlreadyIncluded(?QuoteID, thirteen);

/* rebate offer */
/* if quantity ordered is more than 75, then rebate of $1000 is applicable */
if
        quoteID(?QuoteID) and quantityOfItemOrdered(?Q) and
        isGreaterThan(?Q, seventyfive)
then
        rebateAmount(?QuoteID, thousand);
/* financing option */
/* if financing is requested for 36 months and unit price is 600 and quantity of item
ordered is 50, then monthly payment is available and is $958.33 and the
total interest is $4500 */
if
        quoteID(?QuoteID) and financeForMonths(?QuoteID, thirtysixMonths) and
        unitPriceOfItem(?QuoteID, sixhundred) and
        quantityOfItemOrdered(?QuoteID, fifty)
then
        monthlyPayment(?QuoteID, ninehundredfiftyeight) and totalInterest(?QuoteID,
        fourthousandfivehundred);

/* Sales Tax */
/* no sales tax in Florida */
<tax0>
if
        quoteID(?QuoteID) and buyerLocationState(florida)
then
        taxesAsPercent(?QuoteID, zeroPercent);

/* 5% sales tax in states other than Florida */
<tax5>
if
        quoteID(?QuoteID) and buyerLocationState(?X) and NotEquals(?X, florida)
then
        taxesAsPercent(?QuoteID, fivePercent);

MUTEX
        taxesAsPercent(?QuoteID, zeroPercent) and
        taxesAsPercent(?QuoteID, fivePercent);

/* Object-oriented default inheritance using rules */
/* If you buy, then default payment mode is invoice */
<buyRegular>
if
        Buy(?QuoteID)
then
        paymentMode(?QuoteID, invoice);
```

```
/* BuyWithCredit is a subclass of Buy */
if
      BuyWithCredit(?QuoteID)
then
      Buy(?QuoteID);

<buyCredit>
if
      BuyWithCredit(?QuoteID)
then
      paymentMode(?QuoteID, credit);

overrides(buyCredit, buyRegular);


MUTEX
      paymentMode(?QuoteID, credit) and paymentMode(?QuoteID, invoice);

isLessThan(twentyfiveMarch05, oneApr05);
isLessThan(twentyfiveMarch05, fifteenApr05);
isLessThan(fiveApr05, fifteenApr05);
isGreaterThan(eighty, seventyfive);
NotEquals(massachusetts, florida);
```

SFQ1 is collection of f-queries posed by seller for the buyer. The seller asks whether the buyer would like to buy and whether the buyer would like to buy with credit card. The seller also queries for the purchase date, delivery type and number of months of financing requested.

Seller to Buyer F-Queries (SFQ1)

```
<rulebase>
  <_rbaselab>
  <ind>FQueries</ind>
  </_rbaselab>
  <query>
    <_body>
       <fclit cneg="no" fneg="no">
         <_opr>
              <rel>buy</rel>
          </_opr>
         <var>Boolean</var>
        </fclit>
    </_body>
  </query>

   <query>
    <_body>
       <fclit cneg="no" fneg="no">
         <_opr>
              <rel>buyWCredit</rel>
          </_opr>
         <var>Boolean</var>
        </fclit>
    </_body>
  </query>

<query>
    <_body>
```

```
        <fclit cneg="no" fneg="no">
          <_opr>
                <rel>purchaseDate</rel>
            </_opr>
          <var>QuoteID</var>
          <var>Date</var>
         </fclit>
    </_body>
  </query>

<query>
    <_body>
       <fclit cneg="no" fneg="no">
          <_opr>
                <rel>deliveryType</rel>
            </_opr>
          <var>QuoteID</var>
          <var>Date</var>
         </fclit>
    </_body>
  </query>

<query>
    <_body>
       <fclit cneg="no" fneg="no">
          <_opr>
                <rel>financeForMonths</rel>
            </_opr>
          <var>QuoteID</var>
          <var>FinMonths</var>
         </fclit>
    </_body>
  </query>
</rulebase>
```

When the buyer receives the proposal ruleset from the seller, it answers the queries posed by the seller (see BA1 below) and then performs exhaustive inferencing on the resulting ruleset (BSH1 + SSH1 + BA1) to obtain the derived conclusion set (CS1). Logical inferencing allows the buyer to determine the key parameters (such as unit price, delivery charges, taxes, etc.) of the proposal and also whether the proposal meets minimum specified criteria in the RFP.

Answers to F-Queries posed by seller (BA1)

```
Buy(one);
BuyWithCredit(one);
purchaseDate(one, fiveApr05);
deliveryType(one, express);
financeForMonths(one, thirtysixMonths);
```

The conclusion set (CS1) tells the buyer that the offered configuration is acceptable, unit price of item will be $650, delivery time will be 7 days, % discount already included in the price is 13%, taxes are 5%, rebate amount is $1000, and payment mode is credit.

Conclusion Set (CS1) obtained from BSH1 + SSH1 + BA1

```
isLessThan(twentyfiveMarch05, oneApr05);
isLessThan(twentyfiveMarch05, fifteenApr05);
isLessThan(fiveApr05, fifteenApr05);
requiredMinProcessorSpeedInGHZ(twogigahertz);
quoteID(one);
requiredMinSizeofmemoryInMB(fivetwelvemb);
offeredSizeofmemoryInMB(onezerotwofourmb);
requiredMonitorResoluton(tenTwentyFourBySevenSixtyEight);
purchaseDate(one, fiveApr05);
quantityOfItemOrdered(eighty);
BuyWithCredit(one);
deliveryType(one, express);
NotEquals(massachusetts, florida);
isGreaterThan(fourgigahertz, twogigahertz);
isGreaterThan(onezerotwofourmb, fivetwelvemb);
isGreaterThan(sixtyGB, fortyGB);
isGreaterThan(seventeen, fifteen);
isGreaterThan(eighty, seventyfive);
creditCardNumber(one, ccNumber9876543298765432);
offeredSizeofharddiskInGB(sixtyGB);
overrides(earlyPurchase, latePurchase);
overrides(earlyPurchaseDiscount, latePurchaseDiscount);
overrides(buyCredit, buyRegular);
offeredMonitorSizeInInches(seventeen);
requiredMinSizeofharddiskInGB(fortyGB);
offeredProcessorSpeedInGHZ(fourgigahertz);
financeForMonths(one, thirtysixMonths);
requiredMonitorType(flat);
offeredMonitorType(flat);
buyerName(acme);
buyerLocationState(massachusetts);
requiredMinMonitorSizeInInches(fifteen);
offeredMonitorResolution(tenTwentyFourBySevenSixtyEight);
vendorName(dell);
serviceChargeAsPercentOfPrice(one, zeroPercent);
deliveryChargesForShipment(one, fivethousand);
isSpeedAcceptable(true);
Buy(one);
rebateAmount(one, thousand);
isMonitorSizeAcceptable(true);
isMemorySizeAcceptable(true);
isHardDiskSizeAcceptable(true);
isOfferedConfigurationAcceptable(true);
deliveryTimeInDays(one, sevendays);
discountPercentAlreadyIncluded(one, thirteen);
unitPriceOfItem(one, sixhundredfifty);
taxesAsPercent(one, fivePercent);
paymentMode(one, credit);
```

The final contract proposal that consists of BSH1, SSH1, BA1 is included in the Appendix.

6 Relationship of other B2B Technologies to our Approach

RosettaNet and ebXML are two very important and influential approaches to XML-based e-business messaging including about contracting and e-commerce. It is desirable to be able to use our SweetDeal approach together with such XML-based e-business messaging infrastructure. In this section, we discuss how SweetDeal and (SCLP) RuleML can be used with RosettaNet and with ebXML. The punchline is that they play well together; the SweetDeal contract rulesets can be carried as the “letters” content within the “envelopes” of RosettaNet or ebXML messages, i.e., within their messaging interfaces and protocols. In doing so, it is both possible and useful to utilize the (non-OWL) ontologies provided by RosettaNet and ebXML, and to perform sending of messages as actions.

6.1 RosettaNet

Next, we begin with RosettaNet, and discuss specifically how RosettaNet Partner Interface Processes (PIPs) can be used with RuleML in the context of our electronic procurement scenario. RosettaNet is a consortium of information technology, electronic components, semiconductor manufacturing and solutions providers, which seeks to establish a common language and standard processes for business-to-business (B2B) transactions. RosettaNet PIPs define business processes between trading partners. The PIP specifies the roles of the trading partners that participate in the business process as well as the business activities that compose the process. The PIP also specifies XML-based action messages or business documents that are exchanged between the roles during business activities. The specification of a standard structure for the business documents is a major part of the PIP specification. An example of a Rosetta Net PIP is

PIP3A1 which provides a detailed XML message guideline for implementing the Request Quote business process. A message fragment from PIP3A1 is shown below –

```
<ContactInformation>
       <contactName>
              <FreeFormText>A</FreeFormText>
              <EmailAddress>abc@xyz.com</EmailAddress>
              …..
       </contactName>
</ContactInformation>
```

The message fragment above specifies the structure for contact information for the buyer who sends the request for quote to the seller. Our SweetDeal approach can be used straightforwardly in combination with the exchange of RosettaNet PIP messages between the two parties. We can also directly use the standardized (non-OWL) ontological terms from the PIP messages in our rulebases. For example, the request for proposal (RFP) sent by the buyer to the seller in our scenario allows for use of the ontological terms in the RosettaNet PIP3A1 XML message guidelines. A SweetDeal quote (contract proposal) rulebase cf. our earlier scenario can then employ as predicates (i.e., as ontological terms) various properties drawn from the PIP specification, e.g., the unit price of the product, which is specified in RosettaNet using the following DTD segment –

```
<!ELEMENT unitPrice ( ProductPricing ) >
<!ELEMENT ProductPricing ( FinancialAmount , GlobalPriceTypeCode ) >
<!ELEMENT FinancialAmount ( GlobalCurrencyCode , MonetaryAmount ) >
<!ELEMENT GlobalCurrencyCode ( #PCDATA ) >
<!ELEMENT MonetaryAmount ( #PCDATA ) >
```

For example, the seller would specify the following fact rule in the proposal to the buyer:

```
unitPrice(?GlobalCurrencyCode, ?MonetaryAmount).
```

6.2 ebXML

Likewise, ebXML can be used in our scenario along with RuleML and the SweetDeal approach to support electronic contracting between two parties. Both the buyer and the seller in our scenario would maintain ebXML collaboration protocol profiles (CPPs) that would describe the specific business collaborations supported by each of the parties using the ebXML business process specification schema (BPSS). For example, the buyer CPP would show that the "request for proposal" is a business process that is supported by it. The details of "request for proposal" business process would be specified using the ebXML BPSS. The parties that will engage in the interaction protocol will reach agreement on how to collaborate by exchanging the CPPs to construct a collaboration protocol agreement (CPA), which fixes the protocol for interaction between the parties. Once agreement has been reached, ebXML messages in accordance with the collaboration agreement can be exchanged using ebMS (or ebXML Message Service). The payload of these messages can contain the RuleML rulebases to establish the electronic procurement contract.

7 Conclusions

In this paper, we have extended the SweetDeal approach and applied the extended approach using the new SweetRules V2.1 semantic web rules prototype software to a practical, real-world B2B application in the domain of electronic contracting. The electronic procurement contracting scenario that we have described in detail shows how semantic web rules technology, specifically RuleML and SweetRules, can be powerfully used in e-contracting.

8 References

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9 Appendix*

<u>Final Contract between Buyer and Seller</u>

```
buyerName(acme);  /* buyer name is acme */
quantityOfItemOrdered(fifty);  /* quantity of item ordered is fifty */

/* buyer is located in the state of Florida */
buyerLocationState(florida);

/* speed of processor should be at least 2GHz */
requiredMinProcessorSpeedInGHZ(twogigahertz);
if
 requiredMinProcessorSpeedInGHZ(?Speed) and
 offeredProcessorSpeedInGHZ(?OfferSpeed) and isGreaterThan(?OfferSpeed, ?Speed)
then
 isSpeedAcceptable(true);

/* memory size should be at least 512 Mb */
requiredMinSizeofmemoryInMB(fivetwelvemb);
if
 requiredMinSizeofmemoryInMB(?Size) and offeredSizeofmemoryInMB(?Offersize) and
 isGreaterThan(?Offersize, ?Size)
then
 isMemorySizeAcceptable(true);

/* hard disk should be at least 40 Gb */
requiredMinSizeofharddiskInGB(fortyGB);
if
 requiredMinSizeofharddiskInGB(?Size) and offeredSizeofharddiskInGB(?Offersize)
 and isGreaterThan(?Offersize, ?Size)
then
 isHardDiskSizeAcceptable(true);

/* monitor size should be at least 15" */
requiredMinMonitorSizeInInches(fifteen);

if
 requiredMinMonitorSizeInInches(?Size) and
 offeredMonitorSizeInInches(?Offersize) and isGreaterThan(?Offersize, ?Size)
then
 isMonitorSizeAcceptable(true);

/* monitor should be a flat screen monitor */
requiredMonitorType(flat);

/* monitor resolution should be 1024x768 */
requiredMonitorResoluton(tenTwentyFourBySevenSixtyEight);

/* check if the configuration is acceptable */
<checkOfferedConfiguration>
if
  isSpeedAcceptable(true) and isMemorySizeAcceptable(true) and
  isHardDiskSizeAcceptable(true) and isMonitorSizeAcceptable(true) and
  offeredMonitorType(flat) and
  offeredMonitorResolution(tenTwentyFourBySevenSixtyEight)
then
```

* includes final contract between buyer and seller, and proposed version of new RuleML DTD, specifically including the “query” element

```
  isOfferedConfigurationAcceptable(true);

/* The following are some facts in lieu of arithmetic built-ins. */
isGreaterThan(fourgigahertz, twogigahertz);
isGreaterThan(onezerotwofourmb, fivetwelvemb);
isGreaterThan(sixtyGB, fortyGB);
isGreaterThan(seventeen, fifteen);


/* Facts , F-Queries FROM Seller TO Buyer - Specified by seller */
/* Answers to F-Queries FROM Seller TO Buyer */

/* vendor name is Dell */
vendorName(Dell);

/* quote ID is 1 */
quoteID(one);

/* computer configuration details */
offeredProcessorSpeedInGHZ(fourgigahertz);
offeredSizeofmemoryInMB(onezerotwofourmb);
offeredSizeofharddiskInGB(sixtyGB);
offeredMonitorSizeInInches(seventeen);
offeredMonitorType(flat);
offeredMonitorResolution(tenTwentyFourBySevenSixtyEight);

/* Pricing Rules */

/* if purchase date is before April 1 2005, then unit Price is $600;
   if purchase date is before April 15 2005, then unit Price is $650*/

<earlyPurchase>
if
       quoteID(?QuoteID) and purchaseDate(?QuoteID, ?Date) and
       isLessThan(?Date, oneApr05)
then
       unitPriceOfItem(?QuoteID, sixhundred);

<latePurchase>
if
       quoteID(?QuoteID) and purchaseDate(?QuoteID, ?Date) and
       isLessThan(?Date, fifteenApr05)
then
       unitPriceOfItem(?QuoteID, sixhundredfifty);

overrides(earlyPurchase, latePurchase);


MUTEX
       unitPriceOfItem(?QuoteID, sixhundred) and
       unitPriceOfItem(?QuoteID, sixhundredfifty);


/* there is no service charge */
if
       quoteID(?QuoteID)
then
       serviceChargeAsPercentOfPrice(?QuoteID, zeroPercent);

/* Delivery Options */

/* if delivery type is standard then delivery charge is $2500 for the order
   if delivery type is express then delivery charge is $5000 for the order
```

```
*/
<standard>
if
       quoteID(?QuoteID) and deliveryType(?QuoteID, standard)
then
       deliveryChargesForShipment(?QuoteID, twentyfivehundred);

<express>
if
       quoteID(?QuoteID) and deliveryType(?QuoteID, express)
then
       deliveryChargesForShipment(?QuoteID, fivethousand);
MUTEX
       deliveryType(?QuoteID, standard) and deliveryType(?QuoteID, express);


/* if delivery type is standard then delivery time in days is 14 days
   if delivery type is express then delivery time in days is 7 days
*/
<standardDeliveryTime>
if
       quoteID(?QuoteID) and deliveryType(?QuoteID, standard)
then
       deliveryTimeInDays(?QuoteID, fourteendays);

<expressDeliveryTime>
if
       quoteID(?QuoteID) and deliveryType(?QuoteID, express)
then
       deliveryTimeInDays(?QuoteID, sevendays);

MUTEX
       deliveryTimeInDays(?QuoteID, fourteendays) and deliveryTimeInDays(?QuoteID,
sevendays);

/* Additional assertions from Seller */
/* Financial Incentives */

/* discount */
/* if early purchase, then discount already included is 15% */
/* if late purchase, then discount already included is 13.33% */

<earlyPurchaseDiscount>
if
       quoteID(?QuoteID) and purchaseDate(?QuoteID, ?Date) and
       isLessThan(?Date, oneApr05)
then
       discountPercentAlreadyIncluded(?QuoteID, fifteen);

<latePurchaseDiscount>
if
       quoteID(?QuoteID) and purchaseDate(?QuoteID, ?Date) and
       isLessThan(?Date, fifteenApr05)
then
       discountPercentAlreadyIncluded(?QuoteID, thirteen);

overrides(earlyPurchaseDiscount, latePurchaseDiscount);

MUTEX
       discountPercentAlreadyIncluded(?QuoteID, fifteen) and
       discountPercentAlreadyIncluded(?QuoteID, thirteen);

/* rebate offer */
```

```
/* if quantity ordered is more than 75, then rebate of $1000 is applicable */
if
       quoteID(?QuoteID) and quantityOfItemOrdered(?Q) and
       isGreaterThan(?Q, seventyfive)
then
       rebateAmount(?QuoteID, thousand);
/* financing option */
/* if financing is requested for 36 months and unit price is 600 and quantity of item
ordered is 50, then monthly payment is available and is $958.33 and the
total interest is $4500 */
if
       quoteID(?QuoteID) and financeForMonths(?QuoteID, thirtysixMonths) and
       unitPriceOfItem(?QuoteID, sixhundred) and
       quantityOfItemOrdered(?QuoteID, fifty)
then
       monthlyPayment(?QuoteID, ninehundredfiftyeight) and totalInterest(?QuoteID,
       fourthousandfivehundred);

/* Sales Tax */
/* no sales tax in Florida */
<tax0>
if
       quoteID(?QuoteID) and buyerLocationState(florida)
then
       taxesAsPercent(?QuoteID, zeroPercent);

/* 5% sales tax in states other than Florida */
<tax5>
if
       quoteID(?QuoteID) and buyerLocationState(?X) and NotEquals(?X, florida)
then
       taxesAsPercent(?QuoteID, fivePercent);

MUTEX
       taxesAsPercent(?QuoteID, zeroPercent) and
       taxesAsPercent(?QuoteID, fivePercent);

/* Object-oriented default inheritance using rules */
/* If you buy, then default payment mode is invoice */
<buyRegular>
if
       Buy(?QuoteID)
then
       paymentMode(?QuoteID, invoice);

/* BuyWithCredit is a subclass of Buy */
if
       BuyWithCredit(?QuoteID)
then
       Buy(?QuoteID);

<buyCredit>
if
       BuyWithCredit(?QuoteID)
then
       paymentMode(?QuoteID, credit);

overrides(buyCredit, buyRegular);


MUTEX
       paymentMode(?QuoteID, credit) and paymentMode(?QuoteID, invoice);
```

```
isLessThan(twentyfiveMarch05, oneApr05);
isLessThan(twentyfiveMarch05, fifteenApr05);
isLessThan(fiveApr05, fifteenApr05);
isGreaterThan(eighty, seventyfive);
NotEquals(massachusetts, florida);

/* answers to F-queries posed by seller */
Buy(one);
BuyWithCredit(one);
purchaseDate(one, fiveApr05);
deliveryType(one, express);
financeForMonths(one, thirtysixMonths);
```

RuleML DTD

```
<!--  RuleML V0.8 DTD, Monolithic version,
      for SCLP (i.e., Situated Courteous Logic Programs).
      This is somewhat EXPERIMENTAL in status. -->

<!-- Version date:  2003-04-22 .  From:  http://www.ruleml.org  -->
<!-- This DTD has been augmented with the answerSet element, please see below -->

<!--  Situated Courteous Logic Programs (SCLP) include expressively:
      prioritized conflict handling (Courteous feature), and
      procedural attachments for tests and actions (Situated feature).

      "Monolithic version" means without included modules for assembling
      the DTD document itself.

      This SCLP DTD is a strict (expressive) extension of RuleML V0.8 Hornlog
      with URI constants feature and object-oriented argument collection
      feature ("hornlog+ur+roli").

      This SCLP DTD includes
      some features that are a bit more EXPERIMENTAL in status,
      as compared to the Datalog or Hornlog DTD's of RuleML V0.8.
      However, earlier versions of SCLP RuleML have been
      implemented in SweetRules and SweetJess.

      This version of the DTD does contain, in a long appended comment,
      some explanation of the basic expressive concepts and of the
      element and attribute names.
      (Many of these names are terse/abbreviated for sake
      of making instance rulebase documents be more concise).

      For more extensive design comments, including comparisons to Hornlog
      and discussion of outstanding issues for revision or extension,
      see the corresponding abstract syntax document for SCLP.

      This version of SCLP DTD is "sclp-v14",
      revised from "sclp-v13" used in first versions of SweetRules
      and SweetJess.

      It specifies SCLP (i.e., Situated Courteous Logic Programs),
       with the URI constants feature ("ur"), and
       with the object-oriented arguments collection feature ("roli's"),
       and with the experimental feature of a query statement ("query")
         element that is defined in some other versions of RuleML V0.8 Hornlog;
       with also disjunction permitted in rule bodies, and
         conjunction permitted in rule heads (the "ltao" feature).

       Note SCLP permits literals to be classically negated, in the manner of
       "extended" LP originated by Gelfond & Lifschitz.  This is a limited
       sense of classical negation; it is actually expressively inessential.
```

```
       Let "cneg" stand for classical negation.
       For every predicate P, " cneg P " is essentially treated as if it were
       rewritten " P' ", where " P' " is a newly introduced predicate symbol.

       Note that one aspect of Courteous LP not represented here in
       the DTD is the syntactically reserved status of the "overrides"
       predicate that specifies the prioritization (partial ordering) among
       (default) rules.  This should probably be identified via use of the
       RuleML namespace, e.g., an instance rulebase should use
       "ruleml:overrides" and define the "ruleml:" namespace as the URI
       "http://www.ruleml.org".

       Overall, the main substantial difference in this version from
       SCLP dtd-v13 is that argument collections are supported, i.e., there
       are roli's and explicit tuples (i.e., tup's)


       Please send any comments to especially:
           Benjamin Grosof  email: bgrosof@mit.edu
                            homepage:  http://ebusiness.mit.edu/bgrosof
           Harold Boley  email:  Harold.Boley@nrc.ca

  -->

<!ELEMENT rulebase (
   (_rbaselab, (imp | fact | query | mutex | sens | effe)*)
      | ((imp | fact | query | mutex | sens | effe)+, _rbaselab?) )>
<!ATTLIST rulebase direction
          (forward | backward | bidirectional)
                              "bidirectional">
<!-- URI-valued (CDATA) attributes optionally specify an XML Schema
       on 'rulebase' root -->
<!ATTLIST rulebase xsi:noNamespaceSchemaLocation %URI; #IMPLIED>
<!ATTLIST rulebase xmlns:xsi %URI; #IMPLIED>
<!ENTITY % URI "CDATA">
<!ELEMENT _rbaselab (ind | cterm)>
<!ELEMENT imp ( (_head, ((_body,_rlab?) | (_rlab,_body?))? )
                     | (_body, ((_head,_rlab?) | (_rlab,_head)))
                 | (_rlab,((_head,_body?) | (_body,_head))) )>
<!ELEMENT fact ( (_rlab,_head) | (_head,_rlab?) )>
<!ELEMENT query ( (_rlab,_body) | (_body,_rlab?) )>
<!ELEMENT _rlab (ind | cterm) >
<!ELEMENT _head (cslit | atom | andh)>
<!ELEMENT _body (fclit | atom | cslit | flit | andb | orb | and)>
<!ELEMENT andb ((fclit | atom | cslit | flit | andb | orb)*)>
<!ELEMENT and ((atom)*)>
<!ELEMENT orb ((fclit | atom | cslit | flit | andb | orb)+)>
<!ELEMENT andh ((cslit | atom | andh)+)>
<!ELEMENT atom ((_opr, (ind | var | cterm)*)
                | ((ind | var | cterm)+, _opr))>
<!ELEMENT fclit ((_opr, (ind | var | cterm)*)
                       | ((ind | var | cterm)+, _opr))>
<!ATTLIST fclit cneg (%bool;) #IMPLIED>
<!ATTLIST fclit fneg (%bool;) #IMPLIED>
<!ENTITY % bool "yes|no">
<!ELEMENT flit ((_opr, (ind | var | cterm)*)
                | ((ind | var | cterm)+, _opr))>
<!ATTLIST flit fneg (%bool;) #IMPLIED>
<!ELEMENT cslit ((_opr, (ind | var | cterm)*)
                  | ((ind | var | cterm)+, _opr))>
<!ATTLIST cslit cneg (%bool;) #IMPLIED>
<!ELEMENT _opr (rel)>
<!ELEMENT rel  (#PCDATA)>
```

```
<!ATTLIST rel href %URI; #IMPLIED>
<!ELEMENT var  (#PCDATA)>
<!ELEMENT ind  (#PCDATA)>
<!ATTLIST ind href %URI; #IMPLIED>
<!ELEMENT cterm ((_opc, (ind | var | cterm | tup | roli)*)
                    | ((ind | var | cterm | tup | roli)+, _opc))>
<!ELEMENT _opc (ctor)>
<!ELEMENT ctor (#PCDATA)>
<!ATTLIST ctor href %URI; #IMPLIED>
<!ELEMENT tup   ((ind | var | cterm | tup | roli)*)>
<!ELEMENT roli ((_arv)*)>
<!ELEMENT _arv ((arole, (ind | var | cterm | tup | roli))
                   | ((ind | var | cterm | tup | roli), arole)) >
<!ELEMENT arole (#PCDATA)>
<!ATTLIST arole href %URI; #IMPLIED>


<!-- syntax for courteous and situated follows --->

<!ELEMENT mutex ((_oppo, _mgiv?) | (_mgiv, _oppo))>
<!ELEMENT _oppo (ando)>
<!ELEMENT _mgiv (fclit | atom | flit | cslit | andb | and | orb)>
<!ELEMENT ando (cslit, cslit)>

<!ENTITY % bind "bound|free">
<!ELEMENT sens ((_opr, ((_aproc, _modli?) | (_modli,_aproc)))
                | (_aproc, ((_opr,_modli?) | (_modli,_opr)))
                | (_modli,((_aproc,_opr) | (_opr,_aproc))) )>
<!ELEMENT effe ((_opr, _aproc) | (_aproc, _opr))>
<!ELEMENT _aproc (jproc | uproc)>
<!ELEMENT uproc (#PCDATA)>
<!ATTLIST uproc href %URI; #IMPLIED>
<!ELEMENT jproc ((clas, ((meth, path?) | (path, meth)))
                 | (meth, ((clas, path?) | (path, clas)))
                 | (path, ((meth, clas) | (clas, meth))))>
<!ELEMENT path (#PCDATA)>
<!ATTLIST path href %URI; #IMPLIED>
<!ELEMENT clas (#PCDATA)>
<!ATTLIST clas href %URI; #IMPLIED>
<!ELEMENT meth (#PCDATA)>
<!ATTLIST meth href %URI; #IMPLIED>
<!ELEMENT _modli ((bmode | bmtup | bmroli)*)>
<!ELEMENT bmtup ((bmode | bmtup | bmroli)*)>
<!ELEMENT bmroli ((_arbm)*)>
<!ELEMENT _arbm ((arole, (bmode | bmtup | bmroli))
                    | ((bmode | bmtup | bmroli), arole) )>
<!ELEMENT bmode EMPTY>
<!ATTLIST bmode val (%bind;) "free">

<!--
This is the dtd for the answers to be returned by an inference engine interface
in response to a query

The proposed EBNF is

answerset := answer*
answer := binding*
binding := var , cterm

/* here's a bit more elaborated version that makes the
role vs. type distinction, be independent of sequencing of children */

answerset := answer*  /* a list of binding lists */
```

```
answer := binding*  /* a binding list */
binding := BVar , BSubstitution
BVar := var
BSubstitution := cterm

-->

<!ELEMENT answerSet (answer*)>

<!ELEMENT answer (binding*)>

<!ELEMENT binding ((BVar, BSubstitution)|(BSubstitution, BVar))>

<!ELEMENT BVar var>

<!ELEMENT BSubstitution cterm>



<!-- Explanation of Abbreviations:

  rulebase = knowledge base of rules.
  direction = intended direction of inferencing.
  _rbaselab = rulebase label.  Name of a rulebase.
  imp = implication rule.
          (Note it does not employ *material* implication cf. classical logic.)
  fact:  Can be viewed logically as an implication rule that has an empty body.
  _head = head of a rule.  A.k.a. the "consequent" or "then" part of the rule.
  _body = body of a rule.  A.k.a. the "antecedent" or "if" part of the rule.
  _rlab = rule label.  Name of a rule.

  andb = AND'd (i.e., conjunctive) expression permitted in the body.
  and = AND'd (i.e., conjunctive) expression - a particular kind that is
          permitted in the body. The "and" of some body atoms.
          Similar to andb, but simpler.  Included for down-compatibility /
          back-compatibility, esp. with early versions of the Datalog and
          Hornlog sublanguages.

  atom = logical atom.  An expression formed from a predicate applied to a
            collection of its (logical) arguments.
  _opr = relational operator expression.  (This is for sake of upward
           expressive extensibility.)
  rel = relation.  A logical predicate.
  var = variable.  A logical variable.
  ind = individual.  A logical individual.
           (Can be viewed logically as logical function whose arity is zero.)



  "Lloyd-Topor And-Or" ("LTAO") feature syntax follows:

       Lloyd-Topor transformations permit more expressive heads and
       bodies in LP, by expressively reducing them (with tractable
       computational effort) to the simpler, more basic LP expressive form
       in which a head consists of a single literal and a body consists of
       a conjunction of literals.  In particular, it is straightforward to
       permit "OR" (disjunction) expressions in the body, and to permit
       "AND" (conjunction) expressions in the head.  We call this the
       "Lloyd-Topor And-Or" ("LTAO") feature.

  orb = OR'd (i.e., disjunctive) expression permitted in the body.

  Note that andb's and orb's can be nested.
```

andh = AND'd (i.e., conjunctive) expression permitted in the head.

Negation-As-Failure (a.k.a. "Normal" or "Ordinary" LP) feature syntax follows:

flit = negation-as-failure literal. A literal with negation-as-failure
          sign (fneg).
fneg = negation-as-failure sign. The sign is either positive or negative.
         Negative ("YES" value of attribute) means negated.
         Positive ("NO" value of attribute) means unnegated,
         i.e., the same as if the negation symbol does not appear.
bool = boolean.

"Extended" LP feature syntax follows:

Note SCLP permits literals to be classically negated, in the manner of "extended" LP originated by Gelfond and Lifschitz. This is a limited sense of classical negation; it is actually expressively inessential. Let "cneg" stand for classical negation.
For every predicate P, " cneg P " is essentially treated as if it were rewritten " P' ", where " P' " is a newly introduced predicate symbol.

cslit = classically signed literal, a.k.a. classical literal.
          A literal with classical-negation sign (cneg).
fclit = negation-as-failure classically signed literal. A literal with both
          classical-negation sign (cneg) and negation-as-failure sign (fneg).
cneg = classical negation sign. The sign is either positive or negative.
         Negative ("YES" value of attribute) means negated.
         Positive ("NO" value of attribute) means unnegated,
         i.e., the same as if the negation symbol does not appear.

URI constants feature syntax follows:

add @href? as attribute to (logical-) constant names, e.g., rel, ind, etc..
      (In this version, permits a URI.)

Complex (constructor) terms feature syntax follows:

cterm = complex term. A logical term of the form "f(...)" where f is a ctor.
_opc = constructor operator expression. (Similar in spirit to _opr.)
ctor = constructor. A logical function.

Object-oriented argument collections feature syntax follows:

tup = tuple of arguments. An ordered collection of arguments.
roli = role'd list of arguments. An unordered collection of arguments,
         with each member of the collecion being distinguished by an
         argument role name (arole).
_arv = argument role-value pair. An argument (value) together with its
         indicating argument role (arole).
arole = argument role. (See roli and _arv above.)

"Query element" feature syntax follows:

query = stored query specification. An EXPERIMENTAL feature.
            (If "query" element is indeed included in this version.)

Note that in this DTD version, tup's and roli's can be nested. This is an
  EXPERIMENTAL aspect of the object-oriented argument collections feature.

"Answer Set" element is for returning the answers of an inference engine:

The EBNF for this is as follows:
This is the dtd for the answers to be returned by an inference engine interface
in response to a query

The proposed EBNF is

```
   answerset := answer*  /* a list of binding lists */
       answer := binding*  /* a binding list */
     binding := BVar , BSubstitution
     BVar := var
   BSubstitution := cterm


   answerSet = Set of all answers
   answer = represents one particular binding list
   binding = is a list of variable/value bindings
   BVar = variable name
   BSubstitution = The value of the variable
```

Courteous feature syntax follows:

In Courteous LP, rules are treated as defaults, and prioritized conflict handling can be represented. Priorities between rules are represented via a binary predicate "overrides" which takes rule labels as arguments. "overrides" is syntactically reserved, but is otherwise an ordinary predicate - it can appear in general-form rules and be reasoned about, thus "overrides" facts can be inferred. Higher priority rules defeat lower priority rules. The prioritization ordering is a partial ordering.

mutex = mutual exclusion statement (a.k.a. "mutex").

A mutex is a kind of integrity constraint,
used to specify the scope of conflict in Courteous logic programs.
It contains an opposer part and a given-condition part.
The opposer part consists of two (classical) literals.
The given-condition part is similar to a rule body.
The mutex specifies overall that it is a prohibited contradiction
for the two literals to be concluded if the given-condition part
is concluded (i.e., holds).
The semantics of Courteous LP enforces consistency with respect to
this integrity constraint.

_oppo = opposer part of mutex. (See mutex above.)
_mgiv = given part of mutex. (See mutex above.)
ando = AND'd (i.e., conjuctive) expression permitted in the opposer part of
        a mutex. (See mutex above.)

Situated feature syntax follow:

sens = sensor link statement.

Sensing overall is the obtaining of facts from external attached procedures, during the testing of rules that contain particular kinds of literals. "External" here means external to the LP inferencing engine.

A sensor link statement specifies an association of a predicate P to an attached procedure A. "A" is also known as a "sensor procedure". Essentially, A can be viewed as a queryable virtual knowledge base of facts about P.
Let R be a rule in which literal L appears in the body, where L's predicate is P. During (situated LP) inferencing, when L's body is tested, A is invoked.
A sensor link statement also specifies an optional binding restriction pattern: i.e., for each of P's arguments, it can restrict that argument to be bound (rather than a free variable or cterm containing a free variable) when A is invoked (i.e., queried).

effe = effector link statement.

Effecting overall is the performing of side-effectful actions, via invoking external attached procedures, triggered by the drawing of particular kinds of conclusions. "External" here means external to the LP inferencing engine.

An effector link statement specifies an association of a predicate P to an attached procedure A. "A" is also known as an "effector procedure". Let literal L appear in the head of some rule(s), where L's predicate is P. During (situated LP) inferencing, suppose P(U) is concluded, where U is an instantiation of L's argument terms. Then A is invoked with instantiation U.

Note in this version, the sensed or effected literal might not actually be permitted to be classically-negated (i.e., if no cneg is specified in the sens or effe statement). However, such a restriction is expressively inessential.

_aproc = attached procedure. (See sens and effe above.)
jproc = Java (attached) procedure.

In the current EXPERIMENTAL design, a Java attached procedure is specified by its class, method, and (optional) path.

uproc = "universal" (attached) procedure. I.e., a procedure specified via some kind of stringname or URI.

This is an EXPERIMENTAL design. It is intended to support extensibility towards CGI's and Web services.

_modli = binding mode list. A binding restriction pattern for a sensor. (See sens above.)
bmode = binding mode. Indicates whether a particular argument is restricted to be bound vs. permitted to be a free variable or contain a free variable. (See sens above.)
bval = binding value. (See bmode above.)
bmtup = tuple (tup) of binding modes.
bmroli = role'd list (roli) of binding modes.
-->