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USING SYSTEMS DYNAMICS TO OPERATIONALIZE PROCESS THEORY IN INFORMATION SYSTEMS RESEARCH

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Abstract

The nature of quantitative research in information systems has been dominated by variance theories. Variance theories comprise constructs or variables and propositions or hypotheses linking them. Typically, researchers identify independent variables and a dependent variable and collect data to verify the hypothesized relationship between the two sets of variables. One of the major shortcomings of such an approach is that the temporal dimension is often lost because data are collected at a given point in time. In this paper, we present a research method that operationalizes process theory. Process theory recognizes that variables change over time and interact with each other. This approach is particularly useful to study the conversion of IT investments into IT assets, or the conversion of IT assets into organizational value. This conversion process, which is often subsumed into the black box that lies between the input (independent) variables and output (dependent) variable in variance theories, is recognized and formalized in process theory. We show how systems dynamics modeling can be used to operationalize process theory in the context of IS use. We demonstrate how we can study complex IS problems by developing dynamic hypotheses and then using systems dynamics modeling. The approach that we employ incorporates both qualitative (soft) and quantitative aspects and complements variance theory. We conclude by highlighting the contribution of this approach and the study results to both theory and research. Specific theoretical contributions lie in developing and communicating archetypal patterns of IS use as well as the ability to incorporate the effects of feedback in the context of IS use. An important contribution to research lies in the ability to explicitly relate IS use to productivity. The implication of such contributions to both theory and research is that practitioners can benefit from directly applicable results, especially when it comes to deciding management policies and strategies.

Introduction

Even after Brynjolfsson and Hitt (1998) published their resolution to the productivity paradox, subsequent studies have shown that questions regarding the impact of information systems on organizational and individual productivity still remain open. While some organizations have reaped benefits from IT investments, others have not been able to do so under similar business conditions. There are many direct and indirect influencers and determinants of how investments in IT are converted into performance or productivity effects. For instance, Motohashi (2001) has shown that while a firm is able to achieve benefits of IT investments directly by improving the efficiency in its production and distribution activities, back office modernization will indirectly affect the firm's performance. Another study by Thatcher and Oliver (2001) shows that both product quality and productivity interact to influence organizational performance. Chakraborty (1999) has shown that the marketing strategy of a firm determines *how* IT investments get translated into organizational performance. In addition, IT-enabled benefits tend to be qualitative and indirect. As a result, the diversity of measurement techniques could also lead to mixed results.

Mixed results are not necessarily bad for an academic discipline. In information systems research, they point to the multiple influences of other academic streams and the need for information systems researchers to deal with variables at different levels of abstraction (e.g., individual, group, and organizational) simultaneously. Dealing with multiple levels is, first, a measurement challenge and, more importantly, a theoretical and methodological challenge. This is because multiple influences in a research model often lead to reflexive relationships (A influences B and B, in turn, influences A). Multiple influences also diffuse the effect of IT variables on individual, group, and organizational performance (A influences B which, in turn, influences C and so on). Another problem with quantitative (statistical) models employed in IS research is that path weights, which capture the essence of bivariate relationships, cannot be translated gracefully into actionable items. For instance, in the heavily used technology acceptance model (TAM) (explained in Appendix A), a path weight of 0.45 between perceived usefulness and behavioral intention to use a system assumes a linear relationship between the two variables (when it is not). If the idea is to increase perceived usefulness, then the question "How do we increase perceived usefulness?" still remains unanswered. Consequently, there is a need to seek formulations of IS problems that respond well to the *how* aspect of research and practice.

Lucas (1999) revisits the issues of quantifiable and non-quantifiable IT-enabled value for organizations and focuses on weakness of measurement frameworks that fail to capture IT-enabled benefits. Willcocks and Lester (1999) start with the premise that many IT investments *still* do not show pay-offs. They base their solution to that problem by suggesting improved measurement frameworks.

The focus on improved measurement frameworks is an indication that we may not have accounted for all aspects that influence IT-enabled benefits, payoffs or value. From a research standpoint, the use of statistical modeling to capture the benefits of IS at various levels (and to analyze other areas in IS) is by far the preferred one. It is preferred over qualitative, interpretive methods or, as more recently suggested, process-oriented approaches (Crowston 2000; Markus and Robey 1988; Mohr 1982; Soh and Markus 1995).

Our objective is to show how the process theory approach can be used to address many of the gaps in information systems research. We will do so by first highlighting the importance of the role of processes in information systems and then by addressing and highlighting the importance of capturing the dynamics in information systems contexts. We then demonstrate the use of systems of systems dynamics methodology as a tool that operationalizes process theory in the context of IS use. In the next section, we discuss how these results are different from those obtained by employing statistical modeling. We discuss the applicability of process theory to other areas in IS. After we compare and contrast the pros and cons of using the suggested framework, we conclude by highlighting the relevance of system dynamics to operationalizing process theory in IS research. In order to maintain focus on the issues at hand we have included detailed appendixes to ensure that the specifics of the systems dynamics methodology and theoretical bases and formulations for variables are available for the interested reader.

The Role of Process Theory

We first define process theory by contrasting it with variance theory. Variance theories comprise constructs or variables and propositions or hypotheses linking them (Crowston 2000). The notion of a process connotes recurrence and a nonstationary view of things. By assuming a process view of the world, we can conceptualize events and outcomes in relation to each other. The primary attribute of this relationship happens to be time. Typically, if we view an order-entry process, we can view a successful order instance as: validate order, followed by check inventory, followed by a confirmation of the order (and update order file). This example highlights three of the five characteristics of a process adapted by Soh and Markus (1995). They are outcome, logical form, and the role of time. The outcome here is the successful creation of an instance of an order. This is a discrete outcome. In variance theory, the outcome is a variable (X or Y) which allows us to make formulations like, if X increases, Y increases. The logical formulation for our order entry process would be "if not valid order (necessary condition), then not [instance of a new order] (outcome)." The time ordering of events (validation to precede inventory check) is necessary to result in the creation of a new order. In variance theory (typically operationalized as regression modeling), $Y = (X_1, X_2, \ldots X_n)$ would imply that $X_1, X_2, \ldots X_n$ are necessary and sufficient to cause Y and the temporal relationships between the independent variables is ignored. While there are longitudinal and time-subscripted enhancements to variance theory approaches, they are, essentially, workarounds for associating the variation in Y to the variation in X's.

Another view of process is a transformation of an input (or a set of inputs) into an output (or a set of outputs). This systemic view of a process allows us to focus on the outcomes of processes (be they IT investment, IS management, IS use, decision support, IS enabled personal productivity, etc.). IS processes (and IS use processes in particular) fall under the category that Ackoff (1971) calls purposive systems.[1] Importantly, a process view allows us to frame our analysis in terms of *it does not matter what you have, what matters is what you do with what you have*. This view is brought out well by Marchand et al. (2000), who show how one of two banks (comparable in most respects) was able to leverage its IT investments significantly better than the other.

Dynamics in Information Systems

Dynamics, in its noun form, is "an interactive system or process, especially one involving competing or conflicting forces."[2] The notion of dynamics associated with information systems is cognate to conceptualizing the process view for information systems research. Responses to questions like "How do investments in IT get transformed into organizational value?" or "How does increasing the frequency of end-user training impact individual productivity?" depend on the competing or conflicting forces in an organization. Specifically, "competing or conflicting forces" at the individual level in the context of IS use may include task-technology fit (Goodhue and Thompson 1995), work pressure, and self-efficacy.

A more interesting perspective in information systems research is the changing nature of relationships between people, processes, and technology. People change, technologies change, and so do processes (organizational and personal). Given this, it is not surprising that TAM researchers have found the technology acceptance model to change when analyzed at different times. Szajna (1996) showed that the when using TAM, the model paths change over time. Venkatesh and Morris (2000) also identified such dynamics when they found that the effect of subjective norm on technology use behavior diminished with time.

The concept of dynamics also connotes delays and lags. A comprehensive survey of investments in IT and IT-enabled payoffs (Dedrick et al. 2003) has identified temporal lags as fundamental to understanding how different organizations experience different levels of IT-enabled payoffs at different periods. Variance theory leaves many gaps in the formulation and analysis of such lags and delayed effects. Kohli and Devaraj (2003) also underscore the importance to understand the dynamics of lags (based on longitudinal data) and process aspects after conducting a meta-analysis of 66 studies (48 of which *were* longitudinal studies).

Feedback is yet another construct that is closely related to both the process view and process dynamics. We will use feedback as the entry point into the case that presents systems dynamics modeling as a methodological tool to operationalize process theory in IS research. Appendix B describes the systems dynamics methodology. The objective of presenting and discussing this case is to show how systems dynamics modeling can integrate multiple sources of knowledge and insight and respond to the requirements of *both* process theory and variance theory. The idea is to demonstrate how to study IS use as a process over time.

A Dynamic View of the Technology Adoption Process

In the context of TAM, Bajaj and Nidumolu (1998) addressed feedback from IS usage to perceived ease of IS use. They reported strong statistical significance that past (lagged) usage significantly affects current ease of use. They concluded that their finding lends justification to the view that a longitudinal model is needed to better understand IS usage (Bajaj and Nidumolu 1998, p. 220). Bajaj and Nidumolu reflected further that "merely convincing users of the usefulness of the IS will not influence usage. A perception that the IS is easy to use will lead to a more positive attitude toward using it, which will lead to greater usage" (p. 220). From a systems dynamics perspective, this is an articulation of a reinforcing or a positive feedback loop.

We view IS use as a process with the outcome of interest as productivity (or effectiveness) at the individual level. The problem, one might argue, is that productivity is a variable. Since productivity varies with time, how can it be considered an outcome? However, if we are interested in sustained productivity over time, then that state, as a result of IS use, can be considered an outcome variable. In terms of logical form, while the use of an IS may (or may not) result in increased productivity, the non-use of IS may not decrease productivity (assuming the nature and quantum of work that could benefit from IS use remains unchanged).

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[1] A purposive system is a multi-goal seeking system, the goals of which have a common property. Production of that common property is the system's purpose. IS use is a purposive system because deriving additional value is the common property of the various information systems that are used by the user.

[2] *The American Heritage® Dictionary of the English Language* (4th ed.), Houghton Mifflin, Boston, 2000.

While this logical form is not clean, it is indicative of the changing nature of processes in organizations. This formulation is based on the competing and conflicting forces that influence how an IS is used to determine the efficiency and effectiveness (output and outcome) of the IS use process. For instance, when a user learns more functions, shortcuts, and workarounds, he or she is able to use the IS more efficiently—and, as a result, spends less time on the IS to achieve the same task goals.

Based on the steps outlined in Appendix B, we respond to the problem outlined in the previous paragraph by modeling a realistic work situation (shown in Figure 1). Here a user of an institutional IS (e.g., e-mail system) is confronted by an institutional change in the form of a new e-mail system. The primary focus is to model what happens *after* a new information system has been accepted (by an organization) and deployed. In a realistic scenario, volitional aspects of information system use are diluted by the fact that work must go on *regardless of how a user perceives* the system. The IS use process being modeled can be identified by five components or subsystems: IS use, IS-related task, IS-use related stress, computer self-efficacy, and individual productivity. Appendix E contains the reference modes for validating the results of this study. Each subsystem is explained in Appendix D. Figure 1 can also be considered the dynamic hypothesis for this study.

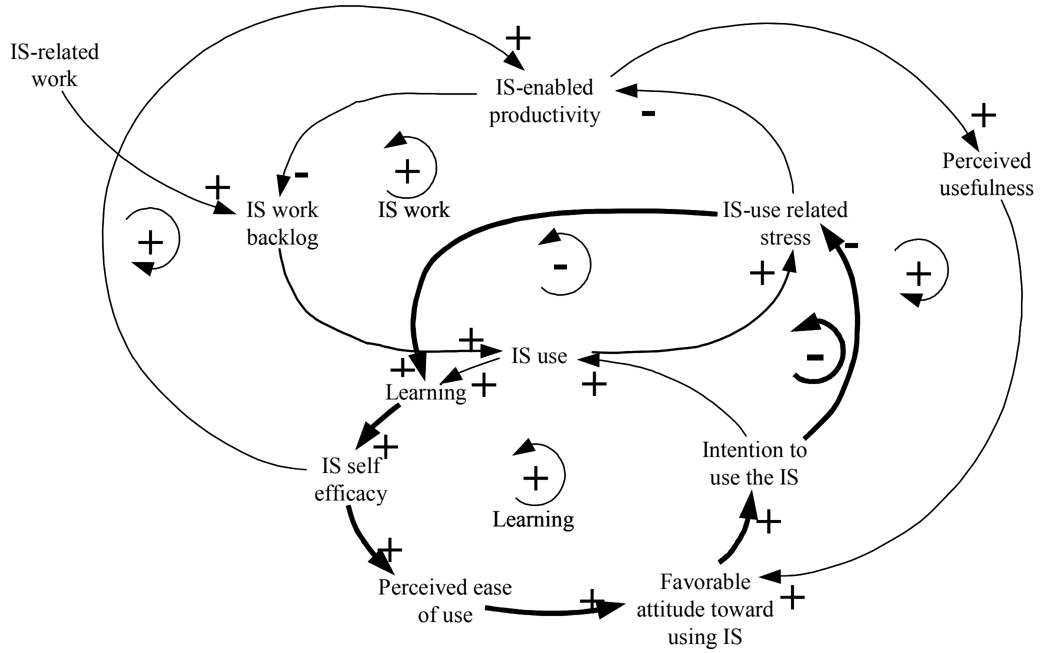

Figure 1. The Causal Loop Diagram Showing Causal Influences
(Appendix C Elaborates on How to Read Causal Influence Diagrams)

Most of the links (the arrows joining two constructs, also called causal influences) have been derived from past research (elaborated in Appendix D). To show the logic of the model, in Figure 2 we take perceived usefulness and attitude toward using the IS. Since past research has consistently shown that the path weights for this construct pair are positive, we label the link polarity to be positive (denoted by a + sign). This link is read as follows: *as perceived usefulness increases, favorable attitude toward using the IS increases*. Similarly *if the intention to use the IS is low* (i.e., the user does not really want to use the IS for whatever reason), *stress induced by IS use is going to be high* (Wastell and Newman 1996). Starting with any construct, readers can read through the entire chain of causal influences.

However, there are links like the IS self-efficacy and productivity link that IS researchers have shied away from. It is not difficult to argue that as a user's ability to use and apply an IS to work improves, the user's productivity will increase. Venkatesh and Davis (2000) employ a similar deductive logic once they demonstrate the effect of image (of an information system) on perceived usefulness of IS to be significant over time. They argue that higher image leads to higher support from the group (of users), which makes it easier to achieve goals only attainable through group membership, resulting in increased productivity and higher performance. Figure 1 also shows that IS-related work is the only exogenous variable. It can be considered analogous to extrinsic factors employed in TAM. The advantage of a causal influence diagram is the identification of reinforcing and counteracting loops. The loop with darkened arrows in Figure 1 exemplifies a counteracting or regulating loop. While there are four reinforcing (positive feedback) loops, there are two counteracting (negative feedback) loops.

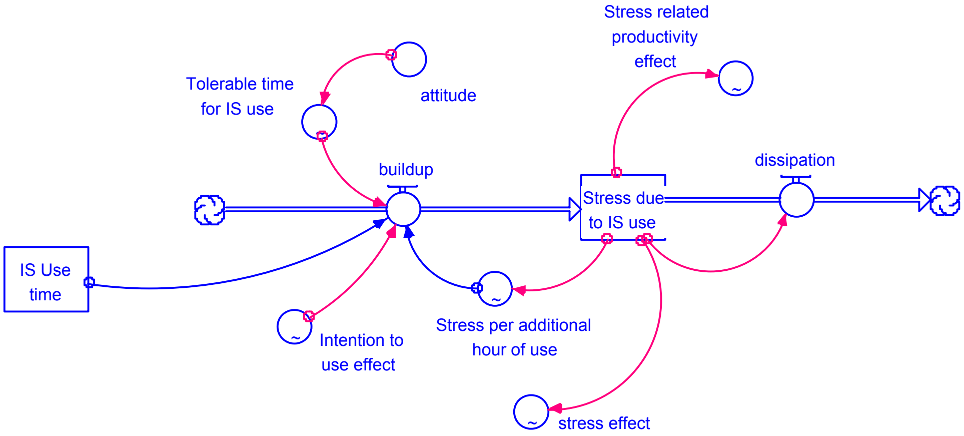

Figure 2. Flow Rate Diagram for a Portion of the Causal Influence Diagram

Figure 2 shows how we converted the causal influence diagrams into flow and rate formulations for a part of the causal influence diagram shown in Figure 1. We simulated the IS use process over 24 weeks using the Stella software (version 7.0.3) and validated the results against a behavior to time graph shown in Figure A.1 (the reference mode). We simulated four scenarios by varying two variables: tolerable work backlog and incoming work. Table 1 shows that the low value for incoming work (average time an individual spends using e-mail) is 1 hour and high value is 3 hours; for tolerable backlog the low value is 30 minutes and the high value is 3.5 hours. Important assumptions and formalisms for these simulation runs are discussed in Appendix D. We have chosen to show results for productivity changes over time. This is because productivity (measured on a scale from 0 to 1) is the outcome variable that informs management of the value of the information system. The results of simulation runs are shown in Figure 3.

The results in Figure 3 show that the productivity profile for simulation runs 1 and 3 are almost identical. The increase in productivity is most marked in the initial month and then levels out at approximately 0.67. The productivity profile for run 2 is similar to that for run 4 in that there is a productivity dip before a sustained increase and subsequent leveling out of an IS user's productivity. It is important to note that the lower productivities are associated with lower work pressures (i.e., lower levels of incoming work). It can be seen that a higher level of IS-related work leads to markedly higher levels of productivity. Productivity levels for runs 2 and 4 tend to converge at around the same level, although the productivity level for run 4 is marginally higher.

Table 1. Four Simulation Scenarios

Run #	Tolerable Work Backlog	Incoming Work
1	Low	Low
2	Low	High
3	High	Low
4	High	High

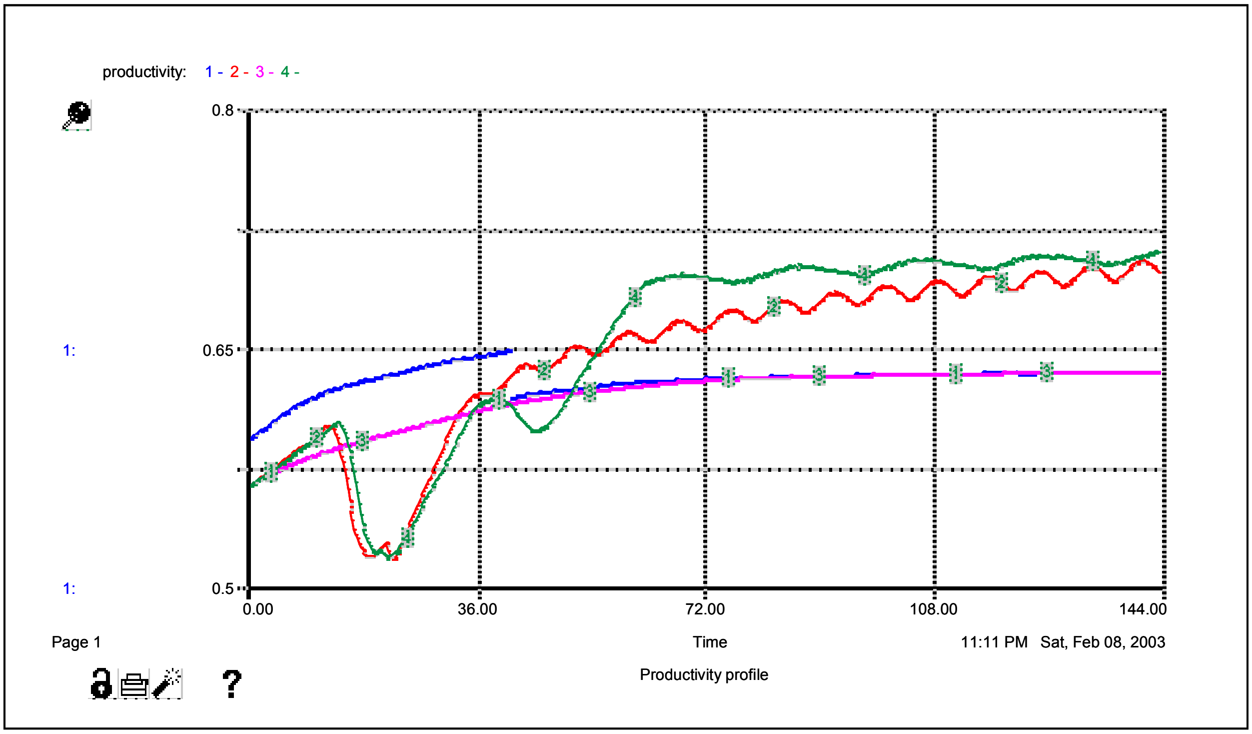

Figure 3. Comparative Results for Productivity for the Simulation Runs

These results suggest that in high-performing organizations (where work pressures tend to be higher) IS productivity will tend to be higher. On the other hand, in organizations and work situations where work loads are light, the level of productivity will taper off at lower levels, in spite of a positive relationship between intention to use the IS and actual IS use (i.e., a minimal level of volitional use that increases as the attitude toward using the IS becomes more favorable). It is useful to note that the time needed to reach the same level of improvement for the low workload case is identical (36 days or about a month). However, what follows is instructive in that the productivity increases to respond to the workload. In the dynamic hypothesis that we have employed, productivity is influenced by IS self-efficacy. The empirical results also appear to validate Bolt et al.'s (2001) findings that, in the context of training, computer self-efficacy has a greater positive effect on performance when task complexity is high than when task complexity is low. In this case IS-related work pressure is equivalent to higher work pressures and leads to higher productivity, especially when we consider the on-the-job learning component.

The other significant finding is that the productivity profile for simulation run 4 is higher than that for run 2. While high IS-related work is common to both of these runs, run 4 assumes a higher level of tolerable backlog. This seems to suggest that while positive work pressure is desirable from the productivity standpoint, more meaningful IS effectiveness can be obtained by reducing the pressures associated by IS use by being more tolerant of IS-use related backlogs. While such an approach may result in short-term productivity losses, the long-run productivity increases more that make up for the initial drop in productivity.

Discussion

The model can be deemed acceptable since the behavior of a main variable, productivity, matches the reference mode (at least two runs 2 and 4). For the other two runs, the lower value of productivity can be explained by reframing Parkinson's Law[3] as "productivity adjusts to respond to workload." This can also be understood as structure determines behavior. Structure implies the complex interlinkages among different parts in an IS use context and also includes soft variables like perceptions of ease of

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[3] According to Parkinson's law, work expands to fill the time available.

use, stress, perceived usefulness, etc. The specific behavior, in this case, is represented by the behavior of productivity over time. Once this kind of behavior is accepted as an archetypal reference mode, we can begin to understand why different researchers find that different versions of TAM hold at different points in time. One of the criticisms in the IS field has been the lack of laws that exist in the pure sciences. While it is not possible, nor advisable, for the field of IS to imitate the disciplinary metaphors of hard sciences, formalization of the IS use-based productivity archetypes would help in the convergence of mental models across researchers, practitioners, and policy makers.

Our main objective in this study was to formulate IS use as a process in order to demonstrate the utility and payoff associated with this approach. We would like to highlight three key aspects: (1) the nature and relevance of the dynamic hypothesis, (2) the complementarity of process and variance theories, and (3) the integrative nature of this approach.

The Nature and Relevance of the Dynamic Hypothesis

One of the problems with variance theory-based approaches lies in overlooking the transformation or conversion of investments in assets and assets into value (Soh and Markus 1995). In the example presented here, the question being addressed is, "How does IS use lead to increased productivity?" In asking this question, we are forced to address the logic of IS use, in a specific context. The dynamic hypothesis is developed using both deductive and inductive approaches. Deductive approaches are used to incorporate past and generic information, while the inductive approaches are typically grounded in primary data collected from the study site. These primary data often appear as reference modes and can be used to validate the analytical results.

The hypothesis is qualified as dynamic because it is an assertion about the behavior of the process (or the system) over time. The dynamic hypothesis is an appropriate response to Szajna (1996), who highlights the importance of incorporating the temporal dimension in studying IS use by saying that "the difficulties in the intention-usage relationship from pre- and post-implementation versions make an argument for the consideration of the experience component associated with TAM" (pp. 86). Szajna further states that, "the determinants of the role of experience may be the key to understanding the belief-intention-acceptance relationship" (p. 92). Our model explicitly incorporates the role of experience (as a learning loop) as shown in Figure 1. The formalized learning loop is explained in Appendix F. Simulation runs 2 and 4 in Figure 3 show the changing loop dominance between the stress loop and the learning loop.

The Complementarity of Process and Variance Theories

The process theory formulation is not an alternative to variance theory formulations for IS research. This is because the large compendium of useful and validated research that has been developed so far, while facing challenges, is a solid basis to build upon. The complementarity between past research on IS use by Davis (1989) and the large body of literature motivated by his research that is based primarily on statistical modeling and process theoretic approaches is shown in Figure 4, which shows the portion of our research model (dynamic hypothesis) that is directly premised on TAM (it is a subset of relationships between constructs shown in Figure 1).

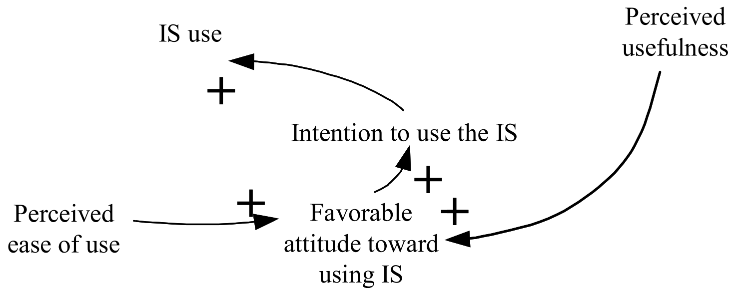

Figure 4. Part of the Dynamic Hypothesis Based on TAM

The main advantage of using past research to complement the construction of dynamic hypothesis lies in using validated theory to prime the model building process. In doing so, we derive two advantages. The first advantage is to assimilate experiential learning into existing theoretical models. In our example, actual time spent on the e-mail system were incorporated as well as the time that individuals expected to spend on the system. This also prompted us to calibrate the rate at which individuals increased their self-efficacy (via the learning loop). Complementing theoretical models with insights and viewpoints grounded in practice is important to incorporate contextual nuances into an IS use process. This mode of inquiry can also form the basis for responses to questions like "How can TAM research conducted in e-mail environments be applied to CAD environments?" In our view, while the essence of relationships between attitudinal variables remains unaltered, their magnitudes will differ across contexts. Therefore, process theoretic approaches like systems dynamics can preserve the essence of variance theoretic studies (which, in most cases is necessary) while including context specific variables and adjustments to accord sufficiency to understand, develop new insights about, and even predict IS use in specific contexts. This can be achieved by first conducting rigorous statistical analysis to identify important constructs and their relationships. Subsequently, using such constructs, systems dynamics-based dynamic and predictive models can be developed by incorporating additional variables that typically cannot be handled by rigorous statistical approaches. From a statistical standpoint, these variables tend to be latent (as opposed to manifest) and multidimensional and could include organizational culture, organizational maturity, quality of the IT department, etc.

The Integrative Nature of this Approach

Orlikowski and Iacono (2001) argue that current IS research should pay more attention to the actual technological artifacts in the studies. In their view, IT is too often viewed as a black box. One step in this direction is to expand our understanding of the structure of IS use models to incorporate not only technological artifacts but also other constructs that have an equally important bearing on IS use (in our case, we incorporated the IS-related workload and productivity). Additional technological artifacts and (behavioral or structural variables) can be added through the addition of relationships in our model. As demonstrated in the case study, some relationships have formal research support while other relationships are grounded in experience and context. We also believe that responding to the need to address specific technologies and not mere abstractions requires two things. First, we need to incorporate multiple perspectives. Second, we need to incorporate multiple theories. We need multiple perspectives because technology can viewed from multiple standpoints. Some view it as an intrusion, some as an empowering agent, some as a control tool, while others may view it as a necessary work artifact. Multiple perspectives are required to meaningfully operationalize the IT abstraction as theorized in a given body of literature. The need to incorporate multiple theories arises due to the complex nature of interactions that take place in IS contexts—which are almost always an interaction between people, processes, and technology. In Figure 1, we have incorporated both learning theory (the learning loop) and behavioral theory (TAM).

We have shown that scientific rigor can be preserved while using process theoretic approaches to study IS problems by employing systems dynamics modeling. Moreover, systems dynamics modeling allows us to integrate qualitative and quantitative variables over time. In addition, the ability to model delays (delays between outputs and outcomes, exemplified by "improvements in self efficacy will lead to sustained productivity levels after some time") is important to IS research, especially when it comes to evaluating IT effectiveness or value. The integrative perspective that systems dynamics provides not only allows us to handle reflexivity (e.g., while perceived ease of use does affect IS use, IS use also influences ease of use, albeit indirectly, via the learning loop), it also allows us to incorporate multiple viewpoints and theoretical models. Finally, the systems dynamics approach is scaleable in that it is applicable at individual, group, and organizational levels and beyond. Given that systems dynamics is an effective learning tool, and based on our findings and our experience using systems dynamics, we feel that the use of process theoretic approaches hold the promise to provide meaningful responses to Orlikowski and Iacono's call to pay attention to specific technologies, rather than concentrate on abstract concepts.

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Appendix A
The Technology Acceptance Model

The technology acceptance model (TAM) predicts that user acceptance of any technology is determined by two factors: perceived usefulness (U) and perceived ease of use (EOU). Perceived usefulness is defined as the degree to which a person believes that use of the IS will enhance his or her performance. Perceived ease of use is defined as the degree to which a person believes that IS use will be free of effort.

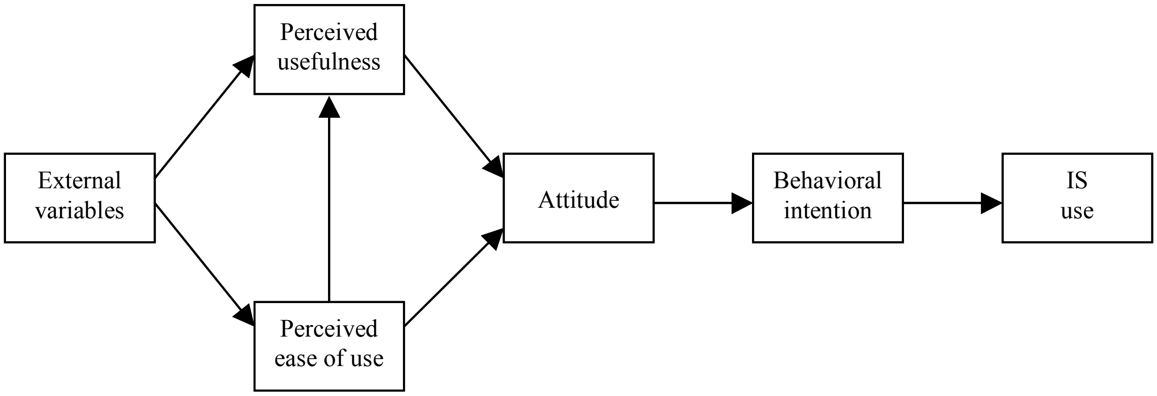


Figure A.1. The Technology Acceptance Model (Davis 1989)

Appendix B
The Systems Dynamics Methodology
(Source: Systems Dynamics Society, http://www.albany.edu/cpr/sds/)

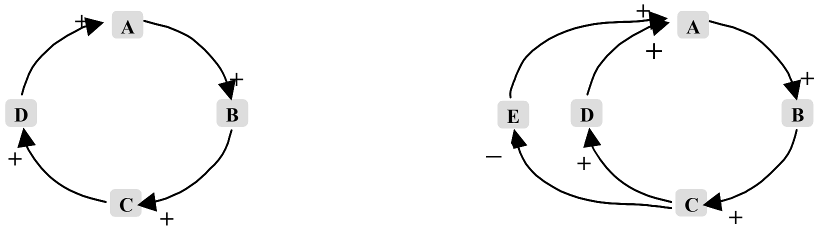
System dynamics is a methodology for studying and managing complex feedback systems, such as one finds in business and other social systems. In fact it has been used to address practically every sort of feedback system. While the word system has been applied to all sorts of situations, feedback is the differentiating descriptor here. Feedback refers to the situation of X affecting Y and Y in turn affecting X perhaps through a chain of causes and effects. One cannot study the link between X and Y and, independently, the link between Y and X and predict how the system will behave. Only the study of the whole system as a feedback system will lead to correct results. The methodology

- identifies a problem
- develops a dynamic hypothesis explaining the cause of the problem
- builds a computer simulation model of the system at the root of the problem
- tests the model to be certain that it reproduces the behavior seen in the real world
- devises and tests in the model alternative policies that alleviate the problem, and
- implements this solution

Rarely is one able to proceed through these steps without reviewing and refining an earlier step. For instance, the first problem identified may be only a symptom of a still greater problem.

Appendix C
Reading Causal Influence Diagrams

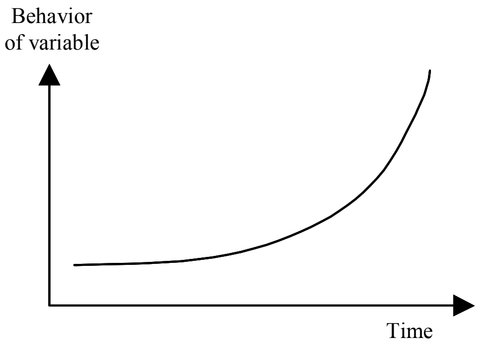
We can start reading a causal influence diagram at any point. Where we start is not important. What is important is the identification of cycles or loops. Loops can be characterized as positive feedback or negative feedback. Positive feedback loops are called reinforcing loops. Negative feedback does not imply that it is undesirable. On the other hand, negative feedback loops regulate or control behaviors that tend to get out of control (e.g., cost escalation, manpower attrition, runaway projects, etc.). In the same way, positive feedback loops can manifest themselves as either virtuous or vicious cycles. Take the loop shown in Figure C.1 (a). It can be a virtuous or vicious cycle depending on the state of variables. Starting anywhere, we could read the loop as follows: As A increases (or decreases), B increases (or decreases); as B increases (or decreases), C increases (or decreases); as C increases (or decreases), D increases (or decreases); as D increases (or decreases), A increases (or decreases).



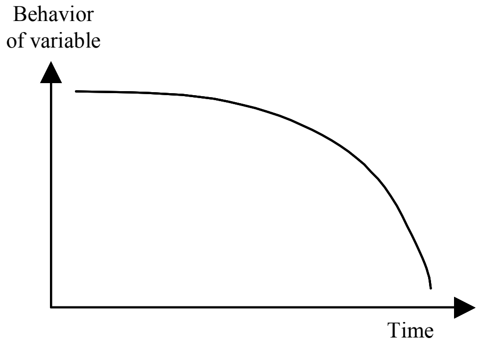
(a) (b)

Figure C.1. Sustaining Collapsing Loops or Reigning in Runaway Loops

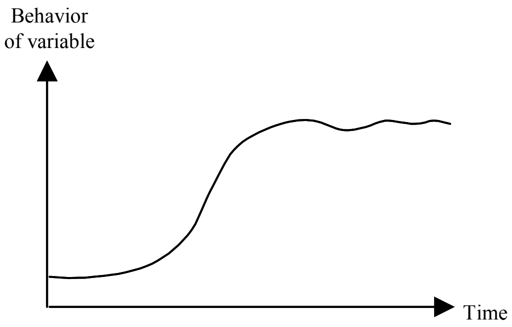
Over time, the behavior of any one of the variables shown in Figure C.1 (a) can be either



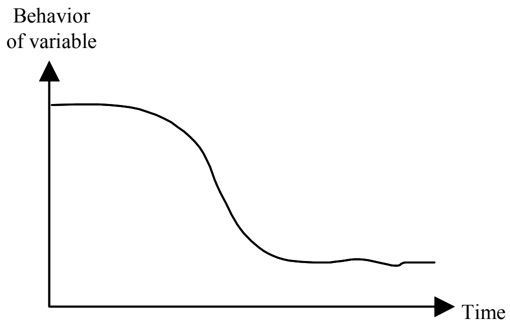
or



It is clear that the reinforcing loop either manifests itself as a runaway growth or an uncontrollable downward spiral—both of which are unsustainable propositions. The presence of a regulating loop as shown in Figure C.1 (b), by the presence of element E (as C increases, E decreases or vice versa), leads to steady-state behavior as shown by



or



The idea, then, is to sustain the steady-state behavior over time and seek to continuously seek out opportunities and practices that help prevent nosedives and unsustainable and unnatural growth spikes.

Appendix D
Constructs and Theoretical Support

IS use: IS use is conceptualized as the time spent using the IS and is measured in hours per day. IS use is premised on the logic that the user calibrates her usage depending on the IS-related task at hand. As the IS-related tasks increase or decrease, the user adjusts her time spent on the IS depending on how much work can be backlogged.

IS-related task: IS related task is conceptualized as a stream of tasks coming in everyday. Typically, an e-mail user can expect a certain number of incoming mail to which they need to respond. These inputs have been conceptualized in hours. As a user responds to e-mails, her work backlog reduces. The rate at which a user responds to e-mails is a function of her personal productivity with e-mail use.

IS use related stress: Being compelled to use information technology by the company and having to keep up with technological changes may increase the already considerable levels of job stress or role complexity of salespeople (Boles et al. 1997; Kwon and Chidambaram 2000; Roberts et al. 1997). We model that every individual has a normative limit on what she considers is a reasonable time spent in reading and replying to e-mails in a given day. That determines the IS-related stress for that individual depending on the extent to which actual use exceeds that threshold. Stress is dissipated by work completion. An important variable in this subsystem is the tolerable time for IS use. Just as some individuals like to use computers and may not mind spending time working on computers, there are others who would like to minimize their interaction with a computer. Tolerable time for IS use allows us to account for that aspect in the model.

Learning: Jawahar (2002) reported on the influence of dispositional factors on end-user performance. He identified goal setting and computer self-efficacy as influencing end-user performance. We have refined that finding to formulate a learning loop that is typically employed in systems dynamics and in psychology (see Appendix F). While Chau (2001) has reported that computer self-efficacy (or IS self-efficacy) has no significant effect on perceived usefulness and no significant effect on perceived ease of use, the model in Figure 1 shows that computer self-efficacy has no direct relationship to perceived usefulness. Thatcher and Perrewe (2002) demonstrate the negative link between computer anxiety and self-efficacy. We have incorporated that relationship by linking stress due to IS use to learning.

Productivity: The productivity sector accounts for the productivity due to IS use. The level of stress and the level of a user's computer self-efficacy determine productivity. As self-efficacy increases, productivity also increases. However, as the stress due to overuse of the IS increases, the productivity is diminished (Drury and Farhoomand 1999). In order to aggregate the effects from both stress and efficacy, we used an additive term to determine aggregate productivity. The productivity value varies between 0 and 1 and influences the rate at which backlog is reduced. This formulation is conceptually consistent with the notion of complementarity (albeit at the individual level) and the formulation of IT value as having supermodular characteristics (Barua et al. 1996).

TAM constructs: Previous research has shown that perceived usefulness and perceived ease of use constitute the two dominant factors that affect an individual's intention to use a system. Different studies (Adams et al., 1992; Hendrickson and Collins, 1996) of the causal relationships between perceived usefulness, perceived ease of use, and system usage have shown that Davis is correct in proposing that the indirect relationship between perceived ease of use and intention to use, mediated by perceived usefulness, is an important one. The assumption for intention to use IS is shown in figure D.1 as increasing with time (increasing from .05 to .30 on a scale of 0 to 1).

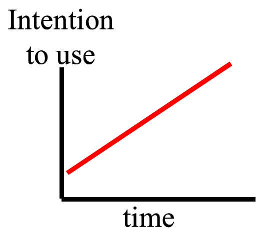
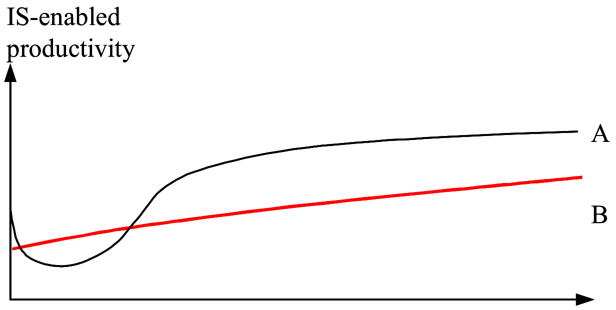


Figure D.1. Intention to Use

Appendix E
Reference Modes for E-Mail Use

In order to obtain reference modes—the graph of (problem) behavior over time is called a *reference mode*—we interviewed a diverse group of e-mail users. These included students as well as faculty members in a university as well as a group of e-mail users in a corporate setting. Common to both populations was a change in the e-mail system—from pine to Webmail for the university and from pine to Lotus Notes for the corporate site. For both sites we found that end-user reported user productivity increased over time after the new e-mail system was implemented (shown in Figure E.1). However, some users did not report significant increases in their IS-related productivity. Others reported significant improvements. Almost all users reported high satisfaction with the e-mail system with some complaining about occasional problems with e-mail outage.



A – This was a typical productivity profile reported by users who faced a high workload and stringent productivity requirement (low backlogs).

B – This was a typical productivity profile reported by users who faced a low to moderate workload levels and productivity requirement were not stringent (high backlogs were tolerable).

Figure E.1. User-Reported Reference Mode for IS-Related Productivity

The other relevant information for modeling purposes was that users who did not report very high productivity scores did not use e-mail intensively. Those reporting high productivity scores tended to be power users—users who received and sent a high volume of e-mail. Users reported that they typically spent about one to two hours on e-mail and generally checked e-mail. Heavy users spent anywhere between two to three hours per day using the e-mail system. Most of the users' time in the initial stages of the new e-mail deployment was spent in learning new functionalities and shortcuts and developing expertise in using those features. Another time-consuming activity included (re)building and managing address books.

Appendix F
Assumption of the Learning Curve

Psychologists interested in learning theory study learning curves. A learning curve is the graph of a function L(t), the performance of someone learning a skill as a function of the training time t. The derivative dL/dt represents the rate at which self-efficacy improves. If L_{Max} is the maximum level of performance of which the learner (IS user) is capable, it is reasonable to assume that dL/dt is proportional to L_{Max}-L(t). (At first, learning is rapid. Then, as performance increases and approaches its maximal value, the rate of learning decreases.) Thus,

$$\frac{dL}{dt} = k(L_{Max} - L(t))$$

where k is a positive constant. We can solve this linear differential equation to sketch the learning curve shown in Figure F.1

$$\frac{dL}{dt} + kL = kL_{Max}$$

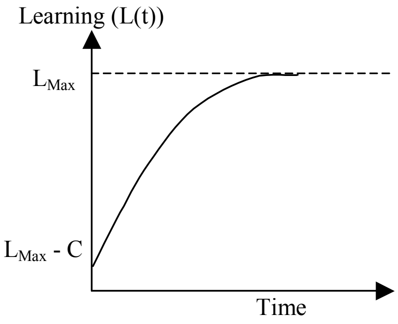


Figure F.1. Learning Curve

Let

$$I(t) = e^{\int k dt} = e^{kt}$$

If we multiply the differential equation by I(t), we get

$$e^{kt}\frac{dL}{dt} + kLe^{kt} = kL_{Max}e^{kt}$$

$$(e^{kt}L)' = kL_{Max}e^{kt}$$

$$L(t) = e^{-kt}\left(\int kL_{Max}e^{kt}dt + C\right) = L_{Max} - Ce^{-kt}$$

where the constant C has to be negative since it is reasonable to assume $L(0) < L_{max}$.