The Unintended Consequences of Implementing Information Technology: Understanding the Impact of Misalignment between Mental Models and Organizational Structure.

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Abstract

In this research, I study the unintended consequences of implementing information technology. Understanding the causes of these unintended effects is important because information technology is ubiquitous in the modern economy. I used three research protocols to study this phenomenon. The first approach was a literature review to explore and understand what was already written on the subject of implementing information technology. The second approach was an experiment using the beer distribution game to study the implementation of information technology. The third approach I used was a case study in which I used system dynamics modeling to study the information technology in an engineering and architecture firm.

I tested the implementation of information technology in the beer distribution game by modifying the play with a change that simulated implementing information technology. I compared the performance of test subjects with control groups that played the game at the same time, without the modification. I also compared the subjects' performance against the performance of trials first published in 1989. I hypothesized that implementing information technology would result in an immediate improvement of the teams' performance. The results of implementing information technology in the beer distribution game were not as expected; implementing information technology did not improve performance. When it became clear that my experimental hypotheses were incorrect, I went back to the literature to see if there was an explanation for this failure that could be derived from the literature on the beer game.

I studied the information technology in the case study firm in order to extend the learning from the experimental research. The results of the experiment were not as I expected; I learned a great deal about the effect of information technology in a very

controlled experimental setting. By expanding the research to include a case study I was able to explore the behavior in a more realistic environment. The beer distribution game provided me with an unexpected insight into the alignment of users mental models and the structure of the organization. The case study was completed using system dynamics tools to model, and then simulate, the effect of misalignment in a real world organization. Considering the results of the beer distribution game and the case study, I suggest that one explanation for the unintended consequences of implementing information technology is the misalignment of users' mental models with the altered structure of the organization after information technology is implemented.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

Information Technology (IT) might be considered the engine that drives today's economy. IT has become pervasive in the modern world. Complex computer systems run corporate financial systems; farmers are using computer programs to assist them as they plant and harvest their crops; children use computer systems to complete their science projects in elementary education[1]; and doctors use computerized systems to assist them in diagnosing illnesses and prescribing treatments. This is just a very small example of how omnipresent computers and information technology are in contemporary society. The list of applications of information technology goes on and can be found in virtually every aspect of life.

It is the author's observation and the premise of this research that the introduction of information technology does not always have the desired results. An increase in tendonitis due to usage of computers and keyboards in the workplace is not a desired effect of IT (Office of Communications and Public Liaison, 2006). An increase in worker stress due to the constant flow of information is not a desired effect of IT (O'Reilly, 1980). Spam and computer viruses are not intended effects when organizations and people are linked together with the Internet. These effects are a few examples of unanticipated side effects of information technology. The focus of this research is on information technology as it applies to organizations, and the unanticipated side effects that will be considered are those that appear to affect organizational performance.

The primary purpose of this research was to understand why the implementation of information technology frequently results in something other than the desired performance improvement. Sometimes the result of implementing information technology is a performance improvement in the expected dimension, but the magnitude of the improvement is less than expected. At other times the expected performance improvement does not materialize at all. At still other times the performance improvement has been accompanied by unanticipated effects, effects both positive and

[1] The author has observed this phenomenon first hand at science fairs attended with his children, where he observed the various science projects done at RC Haydon Elementary School in Manassas, VA

negative, which were never anticipated or expected when the information technology was implemented.

The hypothesis of this research is one that evolved throughout the research process. The research plan began with an experiment using the beer distribution game to understand the effect of implementing information technology in an experimental environment and to ascertain the hypothesis that the implementation of information technology should lead to performance improvement. Following the experiment, the plan was to take what was learned in the experiment and use a case study to extend the research from a purely experimental simulation into a real world organization. Ultimately, the results of the experiment did not support the initial hypothesis. This led to an extension of the literature review and an evolved hypothesis for the research.

The evolved and final hypothesis of this dissertation is that one of the underlying causes of these unanticipated effects of implementing information technology is the misalignment between the mental models of the people in the organization and the structure of the organization.

It is an accepted principle of system dynamics that the structure of a system gives rise to the behavior of the system (Sterman, 2000; Senge 1990). Structure doesn't mean the organizational structure which might be depicted by organizational charts, but the concept of structure primarily relates to the relationships of the actors and/or parts within the whole organization (systems perspective) and how these relationships influence the behavior of the organization over time (Senge, 1990). It is important to understand that this structure does not exist entirely outside of the human systems in the organization, but that the human systems are part of the structure. It is often difficult to understand the nature of this definition of structure, because the human systems acting within the structure are part of the structure. Changes made by the people in the system alter the structure of the system, although these changes are sometimes subtle. The structure of the system generates particular behaviors, or patterns of behavior, which are generally not understood by the actors in the system (Senge, 1990). "A fundamental principle of system dynamics states that the structure of the system gives rise to its behavior" (Sterman, 2000, p.28).

In researching the origins of system dynamics, I reviewed Forrester's work, *Industrial Dynamics,* published in 1961. The first principle of his work is the concept of information feedback systems. The concept of information feedback is a principal basis for system dynamics. "*An information-feedback system exists whenever the environment leads to a decision that results in an action which affects the environment and thereby influences future behavior*" [emphasis in the original] (Forrester, 1961, p.14). Forrester further goes on to state that systems of information-feedback are fundamental to all human endeavor. Everything we do is done in the context of an information-feedback system. The behavior of the system is determined by three characteristics, structure, delays, and amplification.

Structure is defined by Forrester as how the parts of the system are related to one another. Delays exist within the structure in the availability of information, in making decisions based on that information, and in taking action on the decisions made. Amplification exists within the structure when decisions, often driven by policies, are more forceful than might seem appropriate to the input (Forrester, 1961).

In addition to the notions described above, the concept of mental models is one which is widely discussed in psychology and philosophy (Sterman, 2000) and they play a fundamental role in the practice of system dynamics. O'Conner defines mental models as: "The ideas and beliefs we use to guide our actions. We use them to explain cause and effect as we see them and to give meaning to our experience." (O'Connor, 1997, p. 114) Senge says that mental models are "deeply ingrained assumptions…that influence how we understand the world and we take action." (P. Senge, 1990, p. 8)

Mental models contribute to the behavior of actors within a system. We all have our own experiences and filters that direct our perception of the world around us. These filters and experiences become our mental models, and influence how we react to the environment within which we live and work. Our behavior is a result of our mental models. Our beliefs of what can and cannot be done in various managerial and organizational settings are equally entrenched mental models (P. Senge, 1990).

The behavior of the system is defined by the structure of the system, the interaction of the components within the system. Some of the more important components of the organizational system are the humans within the organization. The behavior of the humans is influenced by the environment of the organization, as well as by the mental models of the actors within the system. This point is important because it leads directly to the usefulness of system dynamics in the study of organizational performance. The actors within the organization both influence the behavior of the organization, and are simultaneously influenced by the behavior of the organization. There is no clear cause and effect, but rather a complex network of relationships and feedback loops that control the overall system or organizational behavior.

Recent events serve to demonstrate that the scale of unanticipated side effects is far greater than tendonitis, over-stressed workers, and spam, although none of these issues should be minimized. In the March 9, 2005 issue of the *Journal of American Medicine*, researchers concluded that the Computerized Physician Order Entry (CPOE) systems being widely deployed in hospitals to reduce medication ordering errors are often having the reverse effect and are in fact facilitating medication errors (Koppel, 2005). This provides a compelling example of information technology having unexpected and unwanted effects, which are exactly opposite to the desired effect.

Following the terrorist attacks of September 11, 2001, the Federal Bureau of Investigation contracted with SAIC, a San Diego, California, research and engineering firm, to develop a new Virtual Case File (VCF) system to make it easier for agents to share information. The VCF was to be the cornerstone of the FBI's remodeled computer system. After spending nearly three years and $170 million, the director of the FBI, Robert Mueller, announced on March 10, 2005, that the FBI was officially canceling the contract with SAIC and would begin development of a substitute system in four phases (Borger, 2005). This was clearly an unexpected effect where information technology has cost the organization time and money, and has diverted management attention with no desired effect realized. This might be related to the enormous complexity of the problem, and to the rapid pace of change in information technology creating a situation where, in the time it took to develop the system, it was already overcome by events and obsolete.

Virginia Polytechnic Institute and State University (Virginia Tech) upgraded the Blackboard system used by students and instructional staff to communicate with each other and to exchange email, assignments, and other files. The upgrade was completed during the Christmas holiday in 2004. When students returned to classes for the spring semester, the resulting load on the system caused it to crash repeatedly. The system was virtually out of service for several days during the beginning of the semester while engineers and others struggled to understand the failure and provide a solution. This type of situation is not infrequent and characterizes a dysfunctional installation, one in which the complexity of the system was not fully understood and in which the problem did not manifest itself until after the system was under a full load. Fortunately for the faculty and students at Virginia Tech, the problem was not insurmountable and was resolved within a few weeks of first being identified. The unanticipated side effects of this problem include the loss of productivity for faculty, staff, and students. This problem was especially hard on the many distance learning students who have become dependent on this technology for their courses.

System failures are just one of the unanticipated side effects of introducing information technology. In this research, I examine unanticipated side effects through the use of system dynamics to model the organizational structure and behavior. I use system dynamics because it is my belief that the complexity of this problem can best be addressed through an examination of the underlying structures of the organization.

My examination begins with a review of the literature to develop a substantive theoretical basis for considering organizations as systems in my study. After I have established the basis for considering this problem as a systems problem, I examine the literature on performance measurement. I continue the foundational research by exploring the literature on information technology, both in terms of defining information technology and in terms of limiting the definition for the purpose of this study. I continue my research by briefly reviewing the system dynamics literature. Together, these areas provide the foundation for exploring how information technology affects the performance of organizations.

THE RESEARCH PURPOSE

Information technology has become a pervasive factor in human activities. Many organizations have become so dependent on information technology that the production and coordination tasks and processes used prior to the advent of today's technologies are no longer available. Information technology is expensive to acquire and maintain. Organizations do not implement this expensive technology simply because they have money to spend. Information technology is implemented within an organization because of an expectation that performance of the organization will be improved in some dimension by the new technology. It is my observation that the hoped-for performance improvement is frequently not achieved, or it is accompanied with other unanticipated effects. The purpose of this research is to search for an answer to the fundamental question; "Why does this happen?"

THE RESEARCH HYPOTHESIS AND APPROACH

In this research, the original hypothesis is that information technology does create unanticipated effects and does not always lead to the anticipated performance improvement results. In order to address this hypothesis, I review the literature that provides a foundation for the premise that the structure of the system can be represented by six interconnected networks that represent the "grossly different variables that will be encountered" (Forrester, 1961, p. 70). Understanding how these interconnected networks function within organizations could potentially lead to an understanding of why the unanticipated effects due to IT implementation occur. These six networks are first described by Forrester in his 1961 seminal work, *Industrial Dynamics*.

One of these networks is the materials network that describes the stock and flow of physical goods. The orders network represents orders resulting from decisions that have been made, but that have not resulted in changes to the stocks and flows in other networks. The money network represents the flow of cash throughout the organization. The personnel network deals with countable people, not person-hours of labor, although person-hours are a product of people multiplied by labor hours worked. The capital equipment network includes all of the capital equipment used to produce the goods and services of the organization. The information network is the interconnecting network that connects the other five networks to the decision functions throughout the organization. Forrester describes the information network as being unique and superior to the other networks (Forrester, 1961).

In the late 1950s when Forrester wrote *Urban Dynamics*, information technology was considerably different from that in use today. Over the past four decades, the information technology landscape has changed from a few large computers available for specialized research and computation to millions of computers networked together through the World Wide Web. In the late 1950s and early 1960s, much of the communication required within an organization was done through the creation and dissemination of hard copy memorandums or letters. There were several delays that contributed to the time it took for information to be delivered.

There might be a delay between dictating the letter, and approving it for delivery. Following the approval of the letter there might be multiple delays in delivering the letter. These delays include delays in the mail room at both sending and delivering organizations, as well as a delay while the postal service transports the letter. In the late 1970s Federal Express began to deliver packages and letters overnight, significantly reducing the delays in information delivery. In the mid 1980s, fax machines became ubiquitous, again reducing the delay in delivery. The mid 1990s saw the proliferation of the Internet, the World Wide Web, and email, again reducing the time it took for messages to be delivered. This proliferation however, did create unanticipated effects.

In an interview with Mr. Bob Massie, Associate Director for War Programs, U.S. Army Research, Development and Engineering Command, the author learned that Mr. Massie received 150 to 200 email messages a day. Mr. Massie estimated that each message required an average of two minutes to be reviewed. If Mr. Massie is correct and it requires two minutes to review each message, he would be required to spend between five and seven hours per day reading messages. The alternative is a heuristic that is used to simply remove messages from the queue in order to manage the amount of time spent reading email. The obvious downside is that no heuristic is going to be perfect, and the result will be that a message of some importance may be lost.

People understand that there are new capabilities inherent in email. People send email in order to be more effective communicators. It enables asynchronous communications. It enables the users to track entire threads of messages, with queries and responses in a single archive. It enables users to assign tasks to others with little interaction. It enables users to copy multiple recipients on a message. It also requires users to read and respond to many additional messages. It is an unanticipated consequence of implementing information technology that the US Army Associate Director for War Programs now must spend five to seven hours per day reading email.

The final and key hypothesis of this research is that one of the underlying causes of these unanticipated effects of implementing information technology is the misalignment between the mental models of the people in the organization and the structure of the organization. Information technology, by definition, modifies one of the six key networks in the organization. Implementation of new information technology alters the fundamental structure of the organization. Because the performance of the organization is the result of the behavior of the people in the system acting within the structure of the system, changing the structure of the system will change the performance of the organization. However, given the complexity of organizational structural changes due to the implementation of IT individuals' mental models in most cases do not align or understand these changes.

Organizations are increasingly complex, and operate in a world that is rapidly changing. This combination of complexity and speed leads to an environment where managers struggle to find effective tools to manage the organization. Academics struggle to understand the various challenges facing managers on a daily basis. Information technology is implemented in organizations with the expectation that it will fix a problem, improve a competitive position, or simply prevent the organization from becoming hopelessly mired in its existing systems. This dissertation contributes to the understanding of organizational behavior by linking the implementation of information technology to organizational behavior.

The research consists of three different research approaches. The first approach is a review of the extant literature to understand what has been done in this area already. The second approach involves using the beer distribution game as a research platform in which information technology can be introduced into a simulated world to observe the effect it has on the players' performance. I have previously discussed the behavior of a system being generated by the structure of the system. In that context, what is the purpose of using the beer distribution game in my research? To answer this question, I refer the reader to Peter Senge who said: "What exactly does it mean to say that structures generate particular patterns of behavior? How can such controlling structures be recognized? How would such knowledge help us to be more successful in a complex system? The beer distribution game provides a laboratory for exploring how structure influences behavior" (Senge, 1990, p. 45).

The third approach takes what I have learned from the literature review and the beer distribution game experiment and applies this learning to an actual organization by conducting a case study. I used system dynamics to study the effect of implementing information technology in an architecture and engineering firm. Finally, I synthesize what I have learned from the various research avenues into a single theory supporting why these unanticipated consequences of implementing information technology occur.

CHAPTER 2: LITERATURE REVIEW

INTRODUCTION TO THE LITERATURE REVIEW

It is my objective to understand why the implementation of information technology frequently produces unexpected results. The purpose of this chapter is to review the relevant literature and discuss the concepts that serve as the foundation of my research. I begin with a review of the literature on organizations, specifically focusing on research that has defined organizations as systems. This review of organizations as systems is foundational to the research that is, that organizations are systems, and systems theory can be used in researching organizational performance. This section walks through the history of systems thinking and provides support for the basic premise that organizations are systems and can be studied as systems.

Following the review of organizations as systems, research on organizational routines is examined and explored. The current research in this area supports the idea that organizational routines are part of the underlying structure of the organization and as such are responsible for much of the behavior of the organization.

System dynamics was planned to be used as a basic tool to explore the behavior of an organization as part of the research. Therefore, the next section of the literature review is an overview of important system dynamics principles and concepts. The review begins with an overview of modeling in general, because modeling is a principal foundation of system dynamics. This section is not a comprehensive review of all system dynamics theory, but simply a high level review of the history of the discipline, and some of the more common techniques used within the practice of system dynamics.

The next section of the literature review explores business models. This subject is reviewed because of its relevance in generalizing research from the experiment and the case study to organizations in general. The review explores many generic business models, and focuses on a specific model developed at MIT as a useful taxonomy of organizations based upon two dimensions. The first dimension is what the firm sells, while the second dimension is how the firm transforms the product being sold.

Information technology has evolved from a largely computational function to a communicative function, with the primary feature of much of the information technology implemented today being communication. The review explores the literature on communication and coordination, functions largely facilitated by information technology, and the impact upon organizational behavior and performance.

One of the premises of the research is that implementing information technology has an effect on organizational performance. The literature on organizational performance, performance measurement, productivity, and financial and non-financial measurement systems is reviewed in order to support the research. Some research was focused on the effect of Wall Street pressure on organizational performance; and on recent accounting reforms that affect organizations. Both of these are explored because information technology is vital in these areas.

The next section of the literature review is focused specifically on information technology. The research begins by exploring various definitions of information technology as a foundation for this research. Information technology is defined, and its usage is described. Information technology is described as having evolved into primarily a communication tool. The research further looks at the literature on the paradox of information technology – while investments have continued to grow in information technology, the performance and productivity gains are not as obvious as the expenses associated with information technology. Organizational transformation is reviewed as it is impacted by information technology. The effect of information technology on the performance of supply lines also briefly reviewed.

The research on information technology is extended to a specific technology instant messaging. Instant messaging is reviewed because it is a fairly new technology, because it is currently growing in its usage in the business world, and because it is clearly a communicative tool. The research on instant messaging focuses on the impact of the technology on the performance of the individual, as opposed to the performance of the organization. Communication and collaboration are defined as critical to the modern workforce.

An analogous situation is explored in the literature, the analogy of information technology and advanced communication tools to transportation. Both are pervasive in the production function, and both have seen significant improvements in cost and performance in recent years. The research on transportation explores some concepts of second and third order effects which have been seen in transportation over the past half century. The authors of this literature believe that improved communication in the workplace will result in effects similar to the ones seen in transportation.

This led to a review of the literature on delays and interruptions in the workplace. Both delays and interruptions have measurable effect on the performance of people, and they might be described as two sides of the same coin. Reducing one person's delay, may increase another person's interruptions.

The final section of the literature review is a lengthy review of the literature on the beer distribution game. The beer distribution game was to be used as a basis for the experimental phase of the research, and so it is explored in some depth. The research on the beer game covers its five decades of use as a tool to understand specific organizational performance.

ORGANIZATIONS

Since early biblical time, man has developed various theories to explain the operation and behavior of organizations. In this section, I establish the historical background that explains organizational behavior and performance through systems theory. I also summarize some of the works in the literature that support accepting the principle of organizations as systems.

The roots of system thinking can be found in Greek Philosophy (Beishon, 1980) and in the Christian Bible. One of the earliest references to systems thinking is developed by the Apostle Paul in his letter to the Church at Corinth; in it he writes:

> [14]Now the body is not made up of one part but of many. [15]If the foot should say, "Because I am not a hand, I do not belong to the body," it would not for that reason cease to be part of the body. [16]And if the ear should say, "Because I am not an eye, I do not belong to the body," it would not for that reason cease to be part of the

> body. [17]If the whole body were an eye, where would the sense of hearing be? If the whole body were an ear, where would the sense of smell be? [18]But in fact God has arranged the parts in the body, every one of them, just as he wanted them to be. [19]If they were all one part, where would the body be? [20]As it is, there are many parts, but one body.("1 Corinthians 12:14")

In the 1920s and 1930s, the biologist Ludwig von Bertanlanffy developed the idea that systems of a disparate nature, such as biological, mechanical, or sociological, could have similar structures, and therefore would display the same properties. People in other disciplines developed similar ideas, with some convergence of thought coming about in the 1950s with the formation of the Society of General Systems Research (Beishon, 1980). Writing in *Classics of Organization Theory* (Shafritz, 1996, p. 255), Shafritz and Ott credit Norbert Weiner with developing a model of an "Organization as an Adaptive System." Weiner writes that systems, whether biological, technological, or organizational use feedbacks in self regulation. That is, they identify problems, make changes, and receive feedback about the results of these changes in a continuous self adjusting loop.

In 1961, William G. Scott, writing in the *Academy of Management Journal,* published "Organizational Theory: an Overview and an Appraisal." In this work, he attributes modern organizational theory with the point of view that organizations are systems. It is further asserted that through this systems perspective scholars are able to answer questions about organizations that are not seriously considered in previous theories (Shafritz, 1996).

In the mid 1960s, Robert Katz and Daniel Kahn published *The Social Psychology of Organizations* (Shafritz, 1996). Katz and Kahn expressed the idea that organizations were open systems. They identified organizations as a special class of open systems that share properties in common with all open systems. These properties include the importation of energy from the environment, the transformation of that energy into some product, the exportation of that product, and finally the repeated importation of energy from the environment. Katz and Kahn also attribute the common characteristics of entropy, feedback, homeostasis, and equifinality to this special class of open systems.

Before Katz and Kahn, traditional organizational theories viewed human organizations as closed systems. Closed organizations were viewed as rational systems, pursuing the goals of economic efficiency, but not subject to exogenous influences. Katz and Kahn argue that this closed system view prevented organizations from understanding the feedback they considered vital for survival (Shafritz, 1996).

Later, James D. Thompson published *Organizations in Action*, in which he articulated the rational systems contingency perspective of organizations. Thompson says: "…we will conceive of complex organizations as open systems, hence indeterminate and faced with uncertainty, but at the same time as subject to criteria of rationality and hence needing determinateness and certainty" (Shafritz, 1996, p. 291). Together with Katz and Kahn, this work is the intellectual basis for the modern systems perspective (Shafritz, 1996).

Writing in *Systems Dynamics Review*, Russell Ackoff published an article entitled "Systems thinking and thinking systems" (Ackoff, 1994). In this work, he describes three types of systems: mechanical, organismic, and social systems. He describes enterprises/organizations as open, social systems. Ackoff focuses his attention on the consequences of considering enterprises as social systems. He pays special attention to the requirements for management to manage synthetically as opposed to analytically. This requirement is that management treats problems, not as separate isolated issues, but rather as part of the system, treated systemically. Further discussion focuses on an interesting area, the evolution of the relationship between supervisor and employee/subordinate. According to Ackoff, in 1900, 90% of employees could not do their job as well as their supervisor. In 1990, 90% of employees could do their job better than their supervisor (Ackoff, 1994). This evolution has a significant impact on the role of the supervisor.

"No individual has had more influence on quality management than Dr. W. Edwards Deming" (Evans, 2002, p. 90). Deming is perhaps best known for either his System of Profound Knowledge or his famous fourteen points. His System of Profound Knowledge consisted of four parts:

1.) Appreciation for a system.

2.) Understanding of variation.

3.) Theory of knowledge, and,

4.) Psychology (Evans, 2002).

W. Edwards Deming, one of the men many believe is responsible for the turnaround of Japan's economy after World War II, identifies appreciation for a system as the first element of his System of Profound Knowledge.

In his 1996 book, *The New Economics*, Deming dedicates an entire chapter to understanding and appreciation of systems. He states, "A system is a network of interdependent components that work together to try and accomplish the aim of the system" (Deming, 1996, p. 50). Deming further goes on to write that it is the job of management to direct the interdependent components to the common goal and that the common goal is for everyone to gain, *in the long run*. Deming includes many stakeholders, not just the stockholders, but also the customers, suppliers, the community, the employees, and the environment (Deming, 1996).

There is a long history of man trying to define organizations and developing theories to assist in managing these organizations. Over the past 100 years, there has been significant work in this area, with some of the most respected scholars and leaders in the field accepting the premise that organizations, or enterprises, are in fact open systems with behavior characteristic of this underlying structure. For the purpose of this research, this basic premise is accepted as axiomatic. Organizations are systems: they behave in ways that can be defined by systems behavior, and they can be studied and modeled as systems.

ORGANIZATIONAL ROUTINES

There is a considerable body of research and literature on the subject of organizational routines. This literature is reviewed here because it within this literature that researchers establish the theory of duality within the structure of the organization. Traditional theory of organizational routines suggests that organizational routines are a source of inertia within organizations. Feldman and Pentland (2003) argue that it is the duality of structure and performance within routines that creates opportunities for change.

Routines are described as nearly automatic procedures that are embedded in the organization's structure (Sterman, 2000). Traditional theory describes routines using three metaphors. The first of the three metaphors compares routines to individual habits; that is, the routines of an organization are comparable to the habits of an individual. The second metaphor compares routines to performance programs of organizations. This metaphor extends the first metaphor because performance programs require choices to be made, while habits are automatic, requiring no thought. The third metaphor likens routines to the genetic material of the organization; that is, they are persistent and determine the possible behavior of the organization (Feldman, 2003).

This third metaphor suggests that routines are equivalent to the structure of the organization. Sterman describes the dynamic behavior of systems as arising from their internal structure (Sterman, 2000). The behavior of a simple system, such as a Slinky®, can be attributed entirely to the internal physical structure of the system. Organizations are far more complex than a Slinky®, just as the structure of organizations is far more complex than the structure of a simple system like a Slinky®.

Feldman and Pentland extend the metaphor of the routine from the structure of an organization to a duality of structure and behavior. They argue that each of these metaphors describes organizational routines as limiting the effect of human agency within the system (Feldman, 2003). Human agency is defined as the temporally constructed engagements of actors within different structural environments, adjusting to changing situations (Emirbayer, 1998). More simply, human agency is described as the behavior of people over time within the context of the structure of an organization. Feldman and Pentland argue that the structure of the routine is the ideal form or schematic of the routine, that the performative or behavioral aspects of the routine that consist of the actions of people within the system are the routine in practice. The structure of the organization or routine becomes more concrete as the behavior of the participants comes into alignment with the structure. Extending this further, Feldman and Pentland describe routines as inherently improvisational, with the performative aspect of human agency creating a constant stream of variation as the participants react to the exogenous variables within the environment.

Organizational routines are used because organizations use routines to maximize efficiency and legitimacy, and to minimize or suppress conflict. For these reasons organizations use routines to achieve their work process (Feldman, 2003). The duality of organizational routines suggests that the underlying structure or genetic material of the routine is acted upon by people within the organization, and the alignment of this behavior and structure is critical to the performance of the organization.

SYSTEM DYNAMICS

Many of the problems faced by organizations today, including those that arise from the implementation of information technology, are complex and the solutions for these problems are not readily apparent. This difficulty in solving organizational problems is the result of many factors. Organizations are some of the most complex systems existing in the world today. This complexity is both combinatorial and dynamic. It is combinatorial in that large organizations have thousands of components acting together creating an astronomical number of possible combinations. It is dynamic in that the interactions of each of these components happens over time (Sterman, 2000). Other definitions of dynamic complexity include "situations where cause and effect are subtle, and where the effects over time of interventions are not obvious" (P. Senge, 1990, p. 71).

One approach to understanding problems is to create models of the phenomena. Models can be classified as being static, comparative static, or dynamic. A static model represents the phenomena at a single point in time. A political map of the United States in 2004 is a static model. It might be used to represent the difference in the presidential election results. A second type of model is a comparative static model. This type of model compares the phenomena at different points in time. Political maps comparing the results of the 2000 and 2004 presidential results are a comparative static model.

A second type of model is a comparative static model. This type of model compares the phenomena at different points in time. Figure 5 is a similar model of the election results. However, in this case it is a comparative static model in which the same phenomena are represented at two different time periods (McGarvey, 2004).

The third type of model is a dynamic model; dynamic models have been described in several different ways. Dynamic models "describe the very process by which a particular phenomenon is created…describing the change in rates over time" (Hannon, 2001, p. 5). Ford (1999) describes static models as helping to explain systems at rest, and dynamic models as helping to explain how a system changes over time. McGarvey (2004) describes dynamic models as trying to reflect changes in real or simulated time while taking into account the constant evolution of the model components.

The roots of system dynamics began with Jay Forrester and his colleagues at MIT in the late 1950s. Forrester (1961, p. 1) begins his introduction to *Industrial Dynamics* by writing:

> The manager's task is far more complex than the normal tasks for the mathematician, the physicist, or the engineer. In management many more significant factors must be taken into account. The interrelationships of the factors are more complex. The systems are of greater scope. The nonlinear relationships that control the course of events are more significant. Change is more the essence of the manager's environment.

Industrial Dynamics introduced the world to an entirely new perspective of management. Initially, *Industrial Dynamics* was used to study industrial management problems. Over time, the benefits of this discipline were embraced by others and it now includes work in corporate planning, public management, medicine, energy and the environment, the natural and social sciences, dynamic decision making, and complex nonlinear dynamics (System Dynamics Society, 2006). The discipline has gradually evolved through research and applications into what is known today as system dynamics.

"System dynamics is a methodology for studying and managing complex feedback systems, such as one finds in business and other social systems" (System Dynamics Society, 2006). Practitioners have used system dynamics to study a variety of different feedback systems. System dynamics is based on the theories of non-linear dynamics and feedback controls developed in the fields of mathematics, engineering, and physics. The concept of feedback is the essential element of this definition.

System dynamics permits the modeling of complex systems in which element A affects element B, which, through feedback loops, in turn affects element A. Studying the relationship between element A and element B, independent of the feedback relationship of element B to element A, will not lead to a holistic understanding of the system. A holistic view of the system is required in order to understand the system and discover the leverage points where interventions will have the greatest effect.

The system dynamics methodology identifies a problem, develops a dynamic hypothesis explaining the cause of the problem, builds a computer simulation model of the problem, tests the model to be certain that it reproduces the actual behavior, devises alternate policies or interventions to eliminate or reduce the problem, implements the proposed solutions in the model, tests the alternates in the model, and then implements the solution in the real world (System Dynamics Society, 2006). In this manner, the methodology becomes an effective management laboratory, as alternate policies or interventions can rarely be tested in the real system of interest without incurring substantive risk or expense. It is especially useful to test proposed solutions in dynamically complex systems because of the characteristics of these dynamical systems. Sterman (2000) writes that there are ten reasons why dynamic complexity arises in systems:

1) Systems are dynamic.
2) Systems are tightly coupled.
3) Systems are governed by feedback.
4) Systems are non-linear.
5) Systems are history dependent.
6) Systems are self organizing.
7) Systems are adaptive.
8) Systems are counterintuitive.
9) Systems are policy resistant.
10) Systems are characterized by tradeoffs.

It is these characteristics that make dynamic modeling a necessity. Rarely is one able to proceed through the dynamic modeling steps without reviewing and refining an earlier step. Much as the Shewhart cycle for learning and improvement, the famous Plan – Do – Study – Act , is an iterative process (Deming, 1996), the system dynamics modeling process is an iterative process.

There are three primary or fundamental modes of behavior described in the system dynamics literature. These three patterns are Growth, Decay, and Oscillations (Ford, 1999; Sterman, 2000). Growth is a result of a positive feedback structure in the system. Decay or goal seeking behavior arises from negative feedback loops. Oscillation is the result of negative feedback with time delays in the loop. In addition to these three patterns, there are several other common modes of behavior, including S-shaped growth, S-shaped growth with overshoot and collapse, and S-Shaped growth with overshoot and oscillation. These secondary modes are the results of non-linear feedback among the fundamental nodes of behavior (Sterman, 2000).

System dynamics modeling is frequently done with the use of two techniques. The first is the use of causal loop diagrams. Causal loop diagrams are valuable in capturing the interdependencies among the variables and the feedback process in place in the system.

The second technique is the use of stock and flow diagrams. “Stocks and flows along with feedback are the two central concepts of dynamic systems theory” (Sterman, 2000, p. 191). Therefore, to capture these concepts, the additional diagramming technique of stock and flow diagrams is used. The combination of the two techniques permits the representation of all of the important elements of a system with system dynamics modeling.

It is not the intention of this dissertation to provide a detailed description of system dynamics; for that there are many excellent books written on the subject, see (Ford, 1999; Forrester, 1961; Hannon, 2001; McGarvey, 2004; O'Connor, 1997; Sterman, 2000; Warren, 2002). Any of these books provides information on the practice of system dynamics. There are several different computer software modeling tools that can be used to perform system dynamics modeling. Each of them has its proponents, and all probably can be used with equally successful results. The modeling for my research was done using Vensim, a system dynamics modeling tool from Ventana Systems in Harvard, MA.

BUSINESS MODELS

The term "business model" is a very familiar one. A search of the Internet for the term "business model" received 7,410,000 hits.[2] Clearly there is interest in the concept of business models; however, there is something of a disconnect in the definition of the term "business model." A search of the academic literature does little to clarify the concept of business models. In my search for business models, I sought a taxonomy, one that could be used to classify various organizations into categories. The subject of the research is the unintended consequences of implementing information technology. My observation is that the implementation of information technology can have dramatically different effects on different organizations. One explanation for the differing effects is that enterprises have different organizational structures. Obviously, I cannot model every organization, or even every structure. However, research into the literature on business models is needed to develop some basis for extending the research from the organization I used for my case study to the larger universe of organizations that might benefit from this research.

GENERIC MODELS

In *Leading The Revolution*, Gary Hamel defined a business model as "nothing more than a business concept that has been put in practice" (Hamel, 2000, p. 66). Several other authors have attempted to define business models in a generic sense. Chesbrough and Rosenbloom (2002) identified six key functions of the business model:

1) It must articulate the value proposition;

2) It must identify a market segment;

3) It must define the value chain;

4) It must estimate both the cost structure and profit potential of the business;

5) It must describe the firm in terms of its value network; and

6) It must formulate the competitive strategy.

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[2] Search conducted by author using Google search engine on April 22, 2005.

In the article "The wheel of business model reinvention: how to reshape your business model to leapfrog competitors." Sven Voelpel (2004) and others defined the generic elements in a business model as clarifying:

1) The new customer value proposition;

2) A value network; and

3) The firm's leadership capabilities.

They add that the business model should be flexible enough to change with an ever-changing environment.

The article, "The generic information business model", published in the *International Journal of Information Management* (Alexopoulos, 2003), argues for a new business model that the authors call the Information Business Model, designed to meet the requirements of business today. Their generic business model has the following characteristics:

1) The model should be generic in scope and not define a particular business or industry;

2) The model should be complete, should capture core stakeholders information resources, tasks and success factors; and

3) The model needs to be both reusable and extensible; it must be flexible enough that it can be used with the company's other models and it must be extendable to other areas of the business.

Each of these perspectives describes a business model, yet none of them provides exactly the same information or value to researchers or management. Each of these descriptions prescribes some attributes that are important in the organization and operation of a firm. Like many other business models, these provide some useful frameworks and strategies. None of the models is useful in classifying a business in order to understand its structure and compare it to other similar firms.

MIT BUSINESS MODEL ARCHETYPES

In a 2004 paper, Peter Weil and others at MIT completed a multi-year study of businesses with the specific goal of developing a comprehensive typology that could be used to classify and compare for-profit enterprises. The paper entitled *Do Some Business Models Perform Better than Others?* (Weill, 2004) is the report of their study. The authors defined a business model as consisting of two elements: What the business does, and how the business makes money. The purpose of this research was to develop a model that could be used to classify and compare for-profit enterprises to determine whether there was a difference in the performance of the various models. The researchers developed several criteria for their typology:

1) The classification had to be intuitively sensible and classify business at the deeper *structural* level of how the business operated;
2) The classification had to be comprehensive; it had to be able to classify any for-profit enterprise;
3) The rules for classifying a business had to be clearly defined; and
4) The classification had to be conceptually elegant.

In extending the two critical elements of what the business does and how it makes money, the authors defined two fundamental dimensions of what a business does. The first dimension is what types of rights are sold; the second dimension is what types of assets are involved. In analyzing the first dimension, what types of rights are sold, the authors settled on four types of rights: Creator, Distributor, Landlord, and Broker (Weill, 2004).

There is one further distinction in the analysis of the types of rights sold: the distinction between those that significantly transform the asset that they are selling and those that do not. This distinction allows for the authors to distinguish between those companies that make what they sell (creator) and those that sell things others make (distributors). It is also important to note that in today's global economy, in which a firm may outsource the physical manufacturing of their products to others, the authors used design and management of the product as the criterion for classifying a firm as belonging to the manufacturing sector.

The authors extended the definition of landlord from its common meaning. They defined landlord as selling the right to temporarily use an asset, but not selling the ownership of the asset. Many businesses not normally thought of as landlords then fall into this classification. Several examples are cited in the paper: hotels sell the temporary use of a room, banks sell the temporary use of money, and contractors sell the temporary use of their people. Brokers are defined as matching buyers and sellers to facilitate sales. Brokers do not take ownership of a product as distributors do; they act only as a sales agent and receive a commission for their efforts.

In analyzing the second dimension, the authors settled on four types of assets: Physical, Financial, Intangible, and Human. The result of this classification is 16 possible models, only 7 of which the authors found to be in widespread use (Weill, 2004). The authors define the type of asset involved in the transaction as follows. Financial assets are assets that give their owners rights to future cash flows. This category includes cash, stocks, and insurance policies. Intangible assets include legally protected intellectual property such as copyrights, patents, and trade secrets, as well as brand image, knowledge, and goodwill. Physical assets include both durable and non-durable goods. Human assets include the use of people's time and effort, such as a contractor or professional services firm might provide. The authors note that creation or distribution of human assets logically complete their taxonomy; both are considered to be illegal throughout the world today and are included only for the sake of completeness.

The authors found seven business models to be in widespread use. The authors analyzed the 1000 largest publicly traded firms based in the United States. The firms selected were determined by gross revenues as reported in the COMPUSTAT database for the fiscal year 2000. The authors selected this database rather than the Fortune 1000 in order to limit the analysis to publicly traded firms in which all of the data required for their analysis would be available.

In analyzing the business models of these 1000 companies, the authors identified 1647 models. The difference is accounted for by some companies earning revenue in various models. The research team carefully analyzed the financial data of each company in order to correctly categorize the business. Of these 1647 models identified, 1590 were accounted for in the seven highlighted archetypes.

The archetypes identified in this paper are useful in a couple of ways. Not only do they help answer the question of whether some business models perform better than others, they provide a taxonomy that can be used to provide structure for comparison within model types. Even casual observation reveals that information technology has different effects on different companies and that information technology is deployed differently in different companies. Having a taxonomy to categorize companies is useful in making comparisons and generalizations.

One tool that is often used by management to measure company performance is benchmarking specific measures against others in the same industry. Weil et al. (2004) noted that their classifications of business models proved to be a significantly better predictor of operating income than industry classification. The implication is that although companies operate in the same industry and are classified as being in the same industry, their underlying business models, the structures of the companies, are different. Benchmarking against other firms in the same industry may not be a reliable means of comparison. It would be more important to compare against other firms with similar business models than firms with similar industry classifications.

COMMUNICATION/COORDINATION

Communication and coordination activities are essential to the success of organizations in the 21st Century. Beat F. Schmid, a professor at The University of St Gallen, Switzerland, writing in *Electronic Markets,* (Schmid, 2001) argues that a new industrialization has emerged, one in which the scarce resources are no longer the production resources, but instead are the communication or coordination resources. Others (T. Malone, 1987, , 2004; T. Malone, Rockart, J., 1992; T. Malone, Smith, S., 1988; Niman, 1992) have explored the impact that communication and coordination have on organizational performance.

"Human organizations and markets are possibly the most complex entities on our planet" (T. Malone, 1987, p. 1317). Thomas Malone begins his article "Modeling

Coordination in Organizations and Markets" with this simple, yet profound, statement. This paper is one of several that Malone has published studying organizational structure through the perspective of coordination structure. It is his assertion that this perspective is valid in understanding organizational structure because coordination is critical in the operation of the organization and because coordination activities are likely to be affected by information technology. It is important to explore Malone's models in some depth because this early research into the impact of coordination structures provides a foundation for my research.

Malone specifically defined the coordination structure as being the pattern of decision-making and communicating among a set of actors. These actors are working together to perform tasks in order to accomplish goals (T. Malone, 1987). His focus was on understanding these three costs for the coordination structures: the production costs, the coordination costs, and vulnerability costs.

The production costs were composed of two cost structures: the costs of production capacity and the costs of delays in production. Coordination costs include the costs for maintaining the infrastructure to enable communication among the actors, as well as any incremental costs for exchanging messages among the actors. Vulnerability costs were the "unavoidable costs of a changed situation," the costs incurred before an organization can adapt to a changed situation. These costs were modeled as the expected costs of actors failing to perform their tasks. In this early work, Malone concluded that he could define and mathematically analyze four generic coordination structures. This analysis could help in an understanding of the changes that have occurred in the structure of American business over the past century and could be used to speculate what might happen with the implementation and wide-spread use of information technology in the future (T. Malone, 1987). It is important to note that many of the information technologies taken for granted today were either not yet developed or not widely available when Malone published this article.

In a later piece, Malone collaborated with Stephen Smith (1988) to develop a quantitative model comparing the coordination structures Malone first introduced in his 1987 paper. Once again, Malone defined his analysis based upon production costs, coordination costs, and vulnerability costs. The major difference in the two papers is the depth and breadth of the mathematical modeling done in the second paper. Neil Niman (1992) takes a further look at Malone's analysis, and he extends Malone's definition of vulnerability costs to include opportunity costs. Niman concludes that those organizations that have the lowest opportunity costs are the least vulnerable, and therefore the most flexible.

The literature is replete with articles and studies on business models. My interest is in using business models to describe the structure of the organization, and ultimately the performance of the organization. In the next section, I examine methods of defining organizational performance.

DEFINE GOALS & PERFORMANCE MEASURES

Organizational Goals

In order to define performance measures, it is essential to understand the goals of the organization. There are those who would argue that making money is the goal of a business; in fact there are those who would argue that making money must be the only goal of an enterprise. While making money is a necessary goal of an organization, it is insufficient in and of itself. David Maister (1993) describes the goal of the professional service firm as having three legs, delivering outstanding service to the clients. Providing professional satisfaction to the employees, and achieving financial success for the firm. Brian Smith approaches the subject slightly differently. He says that "every other profit-making corporation also has the purpose of making money; focusing on that purpose, at the expense if others will naturally distract an organization's competitive advantage" (P. Senge, Kleiner, A., Roberts, C., Ross, R., Smith, B., 1994, p. 303). In *Principles of Modern Management*, the primary organizational objective of the Lincoln Electric Company is defined as making a better and better product that can be sold at a lower and lower price. Profit is the byproduct of this goal, profit is not the goal (Meigs, 1981).

There are clearly some differing opinions on what the goal is. One thought on the goal of the organization is a variation of the theme introduced by Maister. An organization can be described as sitting on a three-legged stool. The three legs of the stool are client or customer satisfaction, employee satisfaction, and investor satisfaction.

Each of these three independent goals is a requirement for success. Focusing on any of one of these goals at the expense of either of the other two is not a recipe for long-term success. When an organization focuses its efforts on one of the three goals, that area is expanded. To extend the analogy of the stool, that "leg" grows. A three-legged stool with one leg longer will not stand for long. Just as the stool will not stand long, an organization that focuses on only one area of performance will not be very stable.

Performance Management

Performance measurement, and therefore performance improvement, is a dynamic field with much written on the subject. It is reviewed here as a foundation for the observation that information technology is implemented in order to improve performance in some dimension. Information technology is sometimes used to directly improve standard financial measures such as return on investment, or simply profit. It is also implemented to improve overall productivity, although it will be demonstrated later in this paper that improvements in productivity do not necessarily result from the implementation of information technology.

In recent years, managers have sometimes asserted that new information technology was implemented not in order to improve performance, but rather because competitors had already implemented the newer technology. In fact this statement, while perhaps accurate on the face of it, fails to understand that implementing new information technology simply to keep up with the competitors has an underlying performance improvement goal. The goal isn't as obvious as those measured by standard financial measures, but it must nevertheless be recognized that there is a performance improvement expected when new technology is adopted to match competitors' advances. As an example, managers have stated that they implemented voice mail technology in the 1980s because the competitors did. In the 1990s this was followed by implementing corporate Web sites on the Internet. Arguably, neither of these was driven by a performance improvement goal; however there is an implicit goal. In the case of these two examples, the implicit goal may be as simple as maintaining customer market share.

Measurement

Measurement is the critical factor in performance management. There are a number of different approaches to management, including, but not limited to: Total Quality Management (Hackman, 1995), Management by Objectives (Drucker, 1954), The Balanced Scorecard (Kaplan, 1996), and numerous other related approaches. All of these approaches use some form of measurement to determine how well the organization is performing. Deming, Crosby, and Juran were three of the leaders of the Total Quality Management movement. All of them promoted some direct measure of the quality performance (Lowe, 1986).

Today, detailed financial performance information is available in seconds for virtually any publicly traded company. Anyone can log on to any of a number of free financial services and look up any publicly traded company, complete with current and historical data about the company's financial performance, including current stock price, market capitalization, earnings per share, and even estimated earning per share for the next quarter. Human resource departments track a number of different measurements of performance. These include measures of employee absence, employee satisfaction, and employee retention.

There are numerous measures of customer satisfaction. Many organizations track customer satisfaction in some form or another. For a service organization, satisfaction might be tracked by number of return calls required to fix a problem, or satisfaction might be measured using a survey taken after a customer visit. In fact, the American Customer Satisfaction Index tracks customer satisfaction across the economy.

Productivity

One measure of organizational performance that is often cited in the popular press is productivity. Many claims are made that information technology products will increase productivity. Many of these products are useful and might enhance the performance of the organization; however, it is dangerous to accept at face value the claim that they will improve productivity. The formula for productivity is deceptively simple. "Productivity, the measure of efficiency, is defined as the amount of output achieved per unit of input" (Evans, 2002, p. 4). One of the problems with understanding productivity may be that this is too simple a measure. Most modern organizations have multiple inputs into the process and produce multiple outputs.

In general, productivity can be measured in terms of labor, capital, or materials. The problem with measuring productivity with any of these single factors is that another factor can replace it. If the goal is to increase labor productivity, one could expend capital to acquire newer, faster production equipment and thereby reduce the time it takes to produce one item. Labor productivity is increased; that is, the efficiency of the output achieved per unit of labor input is increased. However, the total productivity of the organization may have been reduced. Bruce Chew writing in *Harvard Business Review* says that appropriately measuring productivity is essential. (Chew, 1998).

Financial Measures

Financial measures are probably the best understood measures of organizational performance. Most of these measures are governed by a common set of concepts, standards, and procedures, known as generally accepted accounting principles (GAAP). Accounting can be described as the art of measuring, communicating, and interpreting financial activity (Meigs, 1981). Financial measures include net income, return on assets (ROA), return on investments (ROI), and measures of net present value and cash flow. Each of these measures is well documented and generally well understood.

However, Stephen Fisher, Undersecretary of the Treasury for Domestic Finance, said some years ago, that our existing financial disclosure framework is inadequate (Taub, 2003). Fisher expressed hope that nonfinancial indicators can succeed in fully disclosing the information that investors need, where GAAP has failed. He had two primary concerns with the current financial reporting measures. First, the mindset of the accountant reporting the information is not the same as the investor reading the reports. Investors are more interested in understanding the likelihood of future events, whereas accountants are focused on identifying facts of what happened in the past. Second, he believed that the advances in information technology and telecommunications have widened the gap between corporate insiders and outsiders, with corporate insiders having near-real-time availability of data on near-term financial prospects. He insisted that this information needs to be organized and reported to investors on a systematic basis (Taub, 2003).

Nonfinancial Measures

Nonfinancial measures are much less well understood than financial measures. According to Ittner and Larcker (1998), most firms track some form of customer satisfaction measure. They also have found that there is mixed evidence on the relation between customer satisfaction indexes and financial performance. Furthermore, they found no evidence for claims that customer satisfaction provides incremental information on the firm's future financial prospects. In a second paper published by Ittner and Larcker (2003), they point out that non-financial measures are just as susceptible to manipulation by unscrupulous managers as financial accounting.

Ittner and Larcker have done extensive research and found that non-financial measures can be of significant value to organizations, if the organizations follow a few simple rules. Their research showed that companies that linked the non-financial measures that they tracked with financial performance produced significantly higher returns over a five-year period than those firms that did not follow this linkage.

In their paper, Ittner and Larcker (2003) identify several mistakes firms make in implementing non-financial measures. One of the challenges is identifying which non-financial measures to track, but even identifying which measures to track is not enough. The measures must be linked to the corporate strategy using some reasoned cause-and-effect model. Not only must there be some model of cause-and-effect between an organization's measures and strategies, but it is also essential to validate the linkage. Linking the non-financial goals to strategy isn't enough. Organizations need to set the right performance goals.

Measuring correctly is an important issue in measuring performance. Ittner and Larker (2003) write about firms that use measurements that are neither valid, in that they do not really measure what they purport to measure, nor reliable, in that the measurements don't reveal actual performance changes. Besides using crude and statistically inappropriate measuring tools, firms frequently do not decide which data they want before they measure it. The study focused primarily on customer satisfaction, but other nonfinancial measures were observed.

Industrial Management published an article entitled "Building Better Measurement" (Van Aken, 2002). In the article the authors, Van Aken and Coleman make several important points about performance measurement. They begin with relating the vital practice of performance measurement with the Malcolm Baldrige National Quality Award. Van Aken and Coleman identify five common problems with performance measurement:

1.) The use of too many metrics,

2.) The use of primarily or exclusively financial metrics,

3.) The use of only short-term metrics,

4.) The lack of alignment between metrics and strategies, and

5.) Metrics that drive the wrong performance measures.

Performance measures need to be linked to specific behaviors, and the cause-and-effect relationship between the desired behaviors and the metrics must be identified. In concluding the article, the authors write that development of performance measures is an iterative process improvement cycle (Van Aken, 2002). This point is important; the process of performance measurement is an iterative, ongoing process. An organization cannot simply establish a performance measurement system and assume that it will forever be a measure of success. The system needs to be continually realigned with the goal and strategies of the organization, the changing marketplace, and stakeholder requirements.

Wall Street Pressures

One of the great challenges facing executives today is reacting to the pressure of Wall Street. Managers are pressured to deliver consistent financial results, quarter after quarter. Public corporations in the U.S. today are largely managed on the basis of 90-day performance. This pressure for continuous short-term improvement can result in management making decisions that they know are not in the best interest of the firm for the long term, but that will result in short-term gains. This is creating real challenges for managers. Investors demand immediate results; *Financial Executive Magazine* (Anonymous, 2003) called this the era of "deliver or depart." This demand for short-term performance from executives is exacerbated by the incredibly volatile, and increasingly more complex, business environment.

There is substantial coverage on the pressures for short-term results in the literature on performance measurement, and on the connection between performance measurement and corporate strategies. One writer, Michael Sisk, asks: "Are the Wrong Metrics Driving Your Strategy (2003)?" He identifies three goals to keep in mind when developing metrics:

1.) Streamline and simplify – the capability exists to overwhelm management with data. In fact, there is a popular name for this; it is called "paralysis by analysis." Metrics need to be clear and concise. The manager who is buried under a mountain of data cannot and will not effectively use the data to lead the organization.

2.) Choose the right data. The best metrics provide leading indicators of where the firm is going and are linked to the bottom line. Do not rely on inaccurate data; make sure your information is valid and reliable.

3.) Do not let Wall Street dictate your metrics. Wall Street is very fickle. The measure of success for your industry will change; make sure you are not running the business based on poorly thought out metrics designed to please Wall Street analysts.

Public Accounting Reform and Investor Protection Act of 2002

Public Company Accounting Reform and Investor Protection Act of 2002, also known as Sarbanes-Oxley, might be an unexpected topic in a discussion on performance measurement. It is only 100 words long, but in those 100 words are the requirements that CEOs and CFOs must attest that the information in their Securities and Exchange Commission filings are accurate. The act also requires quicker filing of quarterly and annual reports and real-time disclosure of material events. These new rules will require strict documentation of the rules and processes in place in an organization to control how the information used for filings (the performance measurements) is generated, manipulated, and recorded (Worthen, 2003). Sarbanes-Oxley is likely to require investment in information technology for many firms to comply with the new requirements. These new technologies will enable companies that have lagged behind the technology curve to comply with the new laws.

INFORMATION TECHNOLOGY

Over the past 40 to 50 years, the term "information technology" has become commonplace in the lexicon of business. It has come to mean a variety of different things depending on the context of its usage. Within this paper, information technology is defined as technology used to manage and process information. In the early 1990s, a group of 12 industrial and government entities from the United States and Great Britain sponsored a research program at MIT. This five-year research program was known as the Management in the 1990s Program. Information technology was defined for this program as falling into six categories: computers, telecommunications, software, professional workstations, robotics, and chips (Allen, 1994). This definition expands information technology beyond the scope of technology used to manage and process information.

Robotics generally falls into the areas of production as opposed to organizational management. Chips is an interesting category, as it can certainly be argued that virtually all electronic information technologies have some component of chips incorporated into the systems. However, chips in and of themselves provide little value to the organizational manager who is trying to improve the performance of his or her organization. For the purpose of this paper, robotics and chips will be excluded from the definition of information technology.

In his landmark book, *Industrial Dynamics*, Jay Forrester (1961) defined several different interconnected networks that are "necessary to represent industrial activity." The sixth and most important network he describes is the information network. "Careful observation of the information network of an organization is essential to understanding its true character" (Forrester, 1961, p. 70). Over the more than 40 years since Forrester wrote these words, there have been dramatic changes in the technology used to manage and process the information in the information network of today's organizations. Thirty years later, Schein (1994) used a similar analogy in describing information and information technology. He compared the flow of information to the lifeblood of the system, and compared the information channels with the circulatory system.

In 1990, if people were asked what information technology was, their reply was likely to cover some aspects of computing. Computers were used to compute; they were large calculators; and they were used to "crunch numbers." A numerical input was manipulated, and an output report was generated. Ever since the first modern computers around the time of World War II, computers have excelled at computing (Brynjolfsson, 2000; T. Malone, Rockart, J., 1992). Today, if people were asked about information technology, they might offer an entirely different perspective. Certainly computers are still powerful numerical processors, and many routine tasks would be impossible without this numerical processing power. However, computers have become much more over the past 15 years: they have become tools that enable communication and collaboration in ways that were only dreamed of in the past.

Today, there is online banking, allowing customers to access their bank accounts from anywhere that has access to the Internet. Instead of listing unwanted items for sale in the classified ads of the local newspaper, sellers can invite the whole world to bid on their goods through services like eBay. Amazon.com has become one of the largest booksellers in the world, while the traditional brick and mortar booksellers have scrambled to offer their own online sales portals. Each of these is just a small example of how computers have changed our lives through communication capabilities. Certainly the processing power of the computers is required to enable this technology, but the real change has been brought about by the communication capabilities of interconnecting these computers. These capabilities have changed the cost structure of communication.

To illustrate this change, if an individual wished to sell a collectible magazine cover thirty years ago, he would have been able to advertise it in the local newspaper, but the pool of potential buyers would have been limited by the number of readers of that newspaper. If he wanted to expand the pool of potential buyers, he would have been able to list the item for sale in other newspapers, perhaps listing it in a larger metropolitan area newspaper for that area. This new listing would have had a moderate impact on the number of potential new buyers, as some of the readers of this new source were already likely to be readers of the local newspaper. Perhaps he would have been able to list it in a national magazine devoted to collectible magazine covers. The point is that the pool of potential buyers was limited by the means of communications available to the buyer and seller.

Today, with services like eBay, the buyer and seller both have a much larger potential marketplace. The means of communication has been greatly expanded, and this has empowered our society, our organizations, and each of us as individuals. Writing in 1948 in *Cybernetics*, Norbert Weiner wrote: "Of all of these anti-homeostatic factors in society, the control of the means of communications is the most effective and most important" (Weiner, 1948). Information technology has largely opened up the means of communication.

There is, however, a great risk that information technology could divide the world into those who have information technology, and those who do not. This division could take place on many different planes. It could be a purely geographic division, with people in developed countries having access to information technology and people in third world countries having limited or no access. It could be stratified within a country by both geography and economics. It could be stratified by age and or education, because the technology is changing so rapidly that people who haven't accepted or learned the new technology may entirely miss out on the benefits of the technology.

Over the past 40 years, firms have invested significant resources in information technology. Maris Maritsons *et al,* (1999) in an article in *Decision Support Systems,* writes about the productivity paradox, citing several studies that show how an investment in information technology is correlated to corporate revenue, but is not correlated with either productivity or profitability. Organizations have invested huge amounts in their information technology and telecommunications infrastructure with the expectations that one, if not both, of these measures will be improved.

There is some question as to whether this phenomenon is related to the inability of measuring systems to capture this data adequately. That is, perhaps the improvements are simply not reflected in standard economic efficiency statistics. There are some in the IT community who suggest this paradox may stem not from a failure of the measuring systems, but from a failure of organizations to take advantage of information technology improvements. The tendency is simply to automate, or speed up, the existing way of doing business.

In a study cited in the *Journal of Economic Perspectives*, Stephen Roach (Brynjolfsson, 2000) found that investments in information technology per white collar worker in the service sector rose several hundred percent in the period between 1977 and 1989. At the same time, output per worker remained flat. By the early 1990s, analysis on productivity at the firm level began to see improvement in this situation, with a clear positive relationship between investments in information technology and multi-factor productivity. Although the studies show a correlation between investment in information technology and increases in output and productivity, there were questions regarding the causality of this relationship. Research supports the idea that there is causality in both directions (Hu, 2005), that certain organizational characteristics made adoption of information technology more likely and more successful, while at the same time, information technology made certain types of firms more successful. Further research provides clear evidence that investments in information technology provided "substantial and statistically significant contribution to firm output" (Brynjolfsson, 1996, p. 541). "The evidence indicates that information technology has created substantial value for firms that invest in it" (Brynjolfsson, 2000, p. 37).

Information technology is most powerful when firms adapt how they do business to best complement the information technology (Brynjolfsson, 2000; Loveman, 1994; Nelson, 2003). Schein (1994) describes organizations being designed around the capabilities of information technology by conceptualizing and distinguishing three visions for information technology. The first he calls the vision to automate. In this scenario, the critical functions of the organization are automated, and the automated processes are handled by skilled professional operators. This vision seems to largely apply to production functions rather than management functions, and therefore falls out of the scope of my research.

His second vision was to "informate": to build accurate models of the critical processes of the organizations so everything could be understood by everyone in the organization. This vision he further disaggregated into a vision of informating up, where IT is used to aggregate and centralize information about the entire organization so that top management could effectively plan and control the organization. He also envisioned informating down, wherein the design of the organization makes the core processes recognizable by the workers who can then make decisions formerly made by management. This vision closely parallels one of the roles of a manager described by Deming: "A manager understands and conveys to his people the meaning of a system. He explains the aims of the system. He teaches his people to understand how the work of the group supports these aims" (Deming, 1996, p. 125).

Schein (1994) calls his third vision the vision to transform. In this scenario, he describes the radical concept of redesigning the organization to take advantage of the possibilities inherent in information technology. Michael Hammer takes this one step further in his book *The Agenda*. "The real power of the Internet lies in its capacity to integrate intercorporate business processes and the information systems that support them" (Hammer, 2001, p. 172). In 1992, Malone and Rockart envisioned an economy in which the organizational structure of today has been replaced by new information-technology-intensive structures. "In the Information Revolution, the firms that benefit most will be those that take advantage of new coordination technologies to better integrate the work of people within companies and to link companies more effectively to each other" (T. Malone, Rockart, J., 1992, p. 637).

The past 200 years have seen changes in how business and industry are structured. In the early 1800s, the United States was a nation populated by family farmers, small merchants and craftspeople. In the mid 1800s, the locomotive arrived on the scene and changed the world of transportation. This change began to enable entirely new ways of organizing, with large scale organizations coming into existence. By the mid 1900s, General Motors was the pinnacle of success in American business. During his Senate confirmation hearing to become Secretary of Defense, Charles E Wilson, then president of General Motors, was asked if he could make a decision that was adverse to General Motors. Wilson answered affirmatively, but added he couldn't conceive of such a decision, "because for years I thought what was good for the country was good for General Motors and vice versa" (C. Wilson, 2006).

General Motors achieved much of its success by being one of the largest companies of the time. Its success was facilitated by high levels of vertical integration within the company. The difficulties of coordinating with outside suppliers made this vertical integration a necessity for General Motors's success (Brynjolfsson, 2000). Today, however, information technologies have greatly reduced the cost and difficulty of inter-organizational communications. The largest company in the world doesn't manufacture anything; the company is Wal-Mart, the Arkansas-based retailer. Wal-Mart has used centrally managed information technology to develop and maintain its competitive advantage (Lundberg, 2002). Wal-Mart's business is all about coordination and communication with its suppliers worldwide.

General Motors had to vertically integrate in the first half of the last century when the technology didn't exist to enable the collaborative practices of a company like Wal-Mart. Today, the vertical integration that made General Motors a powerhouse in the last century is an albatross that GM management is trying to shake (Schnapp, 1998). One area where organizations can benefit greatly from information technology is in managing their supply lines.

In the next section I explore a specific information technology, instant messaging. This section is intended to illustrate one example of an information technology that is implemented with unexpected results.

Instant Messaging

Many workers are now "knowledge workers." Much of the work done by these individuals is collaborative, and much of that collaboration is done using various forms of information technologies. It is difficult to imagine the workplace today without email, cell phones, and computers. Management does not deploy these technologies simply because they are available, but because managers believe that the technologies will improve the performance of their organizations in some dimension. It may simply be that managers feel they must deploy the new technology in order to stay competitive with others in their industry, or they may deploy these technologies in order to gain a competitive edge. However, they do not deploy these technologies simply because they exist.

One of the technologies that is currently gaining acceptance in the workplace is instant messaging. In a paper entitled “The Unintended Consequences of Instant Messaging” the authors, Renneker and Godwin, explore how instant messaging affects individual worker performance and productivity (Renneker, 2003). The paper argues that instant messaging will increase workers’ communicative workload, will increase engagement in polychronic communications, and will increase the rate of interruptions experienced by the workers. Polychronic communication is defined as participating in multiple concurrent conversations (Renneker, 2003).

Instant messaging is a tool that enables workers to communicate one-on-one in a nearly synchronous mode using computer-based text messaging (Renneker, 2003). Others have defined instant messaging as “the next evolution of e-mail” (Castelluccio, 1999, p. 36). Instant messaging has some characteristics that make it similar to email, in that it is a text-based messaging system, but it also has characteristics that make it similar to the telephone, in that it is synchronous, interruptive, and interactive (Renneker, 2003).

Instant messaging even has a generally excepted acronym, IM. This in itself makes the technology recognizable (Castelluccio, 1999). Instant messaging has several unique characteristics. The first characteristic, and one that was not addressed in the Renneker and Godwin paper, is the open availability of instant messaging. Unlike many other information technologies deployed in IT infrastructures, instant messaging is widely available through free online services, such as AOL Messenger, Yahoo Messenger, and MSN Messenger. Unless an organization’s IT department is specifically blocking the use of any or all of these free services, instant messaging is being used within the organization. Instant messaging is in pervasive use by many teenagers and young adults, and as they move from college to the workplace, they expect to have it available for their use in the workplace. In addition to the free public chat systems, there are workplace instant messaging systems being deployed as part of the corporate information technology infrastructure in many organizations.

Instant messaging, unlike other information technologies, provides presence awareness, allowing users to know when a friend or co-worker is online and thus available for messaging. Mark Andreessen, while he was the Chief Technology Officer at AOL, attributed great importance to this capability. When he was talking about the technology, he was generally referring to AOL's open system, and he attributed significant psychological benefit to the ability of users to feel immediately connected to others in "Cyberspace" (Castelluccio, 1999). This capability becomes even more significant in enterprise systems. John McAfee, founder and chairman of Tribal Voice, an early supplier of instant messaging software, described his tool as trying to give people the feeling of true human contact (Castelluccio, 1999).

The default implementation of most instant messaging systems notifies the recipients of messages with pop-up notification windows on the screens of their computers. This is similar to the intrusive nature of telephone calls. However, unlike a telephone call, one cannot simply ignore an instant message; at the very least, one must interrupt what he or she is doing and minimize the instant message window in order to continue the original task. Instant messaging allows participants to engage in multiple instant messaging sessions at the same time. This polychronic communication is generally unavailable with other information technologies. Instant messaging is silently interactive; observers cannot easily determine when a user is interacting with another person because, unlike a telephone, instant messaging is silent. Today, instant messaging is largely ephemeral: there is no transcript of the exchange unless the users capture and store the exchange themselves (Renneker, 2003).

Instant messaging is intrusive, interruptive, interactive, silent, and growing in its use. All of these characteristics could be expected to have some impact on the performance of an organization. Renneker and Godwin (Renneker, 2003) predict a number of effects from instant messaging. First, they predict that instant messaging will increase users' communicative workload. Second, they predict that this increase in communicative workload will correspond with an increase in productivity up to a threshold that will vary between users, and then any further increase in communicative workload will correspond with declining productivity. Third, they predict that increased instant messaging usage will increase polychronic communications and that increased polychronic communications will result in declining productivity. Fourth, they predict that instant messaging users will experience a greater number of interruptions in their work.

Given the predictions of this paper, one must ask why anyone would deploy instant messaging. There are a number of issues to discuss here. First, the work of Renneker and Godwin considers the performance of the individual. However, each individual is only a subsystem within the larger organization, and Deming's work argues that the performance of the overall organization must be optimized. Optimizing the performance of the sub-organizations or of individual workers will not optimize the performance of the organization, so it could be that instant messaging will reduce the overall performance of each individual, while still contributing to performance improvement within the larger organization.

Other research has focused on why individuals use instant messaging when it is available. Cameron and Webster (2004) focused on three key drivers of instant messaging usage at the individual level. These drivers were critical mass, symbolic cues, and media richness.

Critical mass is the defining feature of all communication technologies. Communication technologies, by definition, cannot be successfully used by one person. Theory states that once a certain number of users have accepted a communication technology, use by others spreads rapidly. People are more likely to use a technology if others are also routinely using the technology and are therefore likely to respond to messages in the technology. The research of Cameron and Webster showed that critical mass was indeed a critical component of instant messaging usage. The service provides the greatest utility when many users are available.

Symbolic cues are the message that is conveyed by the communication medium, as opposed to the content of the message. Symbolic cues, primarily the appearance of informality by using instant messaging, were also a key driver in users' choice of the medium. Media richness is the capability of media to allow both verbal and non-verbal cues, to enable the conveyance of emotion, and to allow the use of natural language. Finally, Cameron and Webster (2004) studied Media richness and not surprisingly, the medium of instant messages was not considered rich. This factor has not contributed to its spreading usage.

In contemporary work environments, communication and collaboration are essential components of professional and managerial work. Renneker and Godwin (2005) argue that communication productivity is a reasonable proxy of worker productivity. This may be one of the reasons that organizations choose either to deploy corporate instant messaging systems, or to allow the use of the free public instant messaging systems. Many of these systems are represented, both by the popular media and by the marketing organizations of the companies that produce these products, as increasing worker productivity as a result of increased accessibility and speed of communications.

Transportation and Communication

There are many similarities between transportation and communication in their impact on organizational structure and performance. Both are pervasive factors of production, and both have seen significant improvement in their cost and performance over the past 150 years. Malone and Rockart (1992) presented a simple analogy between transportation and communications. Using simple ideas from economics, they described three categories of changes that were caused by the improvements in transportation. These three categories are substitution, increased use, and new structures.

As transportation systems improved and costs were reduced with the widespread use of trains and then automobiles, people began to substitute the new improved means of transportation for the older ones. People started using the train and later the automobile instead of the using horses and horse-drawn carriages.

The authors describe this as a first-order effect. Malone and Rockart define first-order effects as the substitution of a new replacement technology for an older technology. Others in the literature define first-order effects as the direct instrumental consequence, (Renneker, 2005) or the efficiency effect of the technology's use within a particular social context (Sproull, 1991).

As the transportation systems improved, people not only used the new systems to substitute for the previous modes of transportation, they began to increase their usage of transportation systems. People traveled farther and more frequently than they had in the past. Malone and Rockart (1992) describe this substitution as the second-order effect of improvements in the transportation system. Elsewhere, second-order effects are defined in the literature as the unintended consequences of a technology's use within a social context (Renneker, 2005; Sproull, 1991).

Eventually, as modern, cheap, and efficient transportation became ubiquitous, a third order effect was noted. This third-order effect is defined by Malone and Rockart as the creation of new structures dependent on the new technologies. Renneker and Godwin propose that third-order effects are differentiated from first and second-order effects in that they "represent technology users' creative responses to the first and second order effects" (Renneker, 2005, p. 9). This third-order effect was the development of transportation-intensive structures, such as distant suburbs, centralized shopping malls, and interstate highway systems. All of these new structures are dependent on cheap and convenient transportation systems. It is not likely that Henry Ford envisioned the changes that would take place 100 years after he began producing an automobile that could be afforded by the working class. Today, the world is experiencing record prices for gasoline products, but because of these new structures, many workers are trapped in suburban housing developments, forced to spend hours each day commuting to work and to pay increasing prices for the gasoline that is burned while sitting in stalled traffic.

Consider the unexpected effects that information systems, and specifically instant messaging, might have. The first-order effect might be to substitute instant messaging communication for telephone calls, face-to-face meetings, or emails. Because of the presence information provided by instant messaging systems, the user can generally see immediately if the intended recipient is online and available. In addition to presence, instant messaging generally limits the effect of social status on the communication process. Because there are few visual clues, the recipient of the request will have no immediate knowledge of the relative status of the initiator of the communication. In addition, unlike telephone calls and face-to-face meetings, instant messaging is not generally screened by secretaries or receptionists (Renneker, 2003). This allows users unfiltered access to one another, regardless of hierarchical status within the organization.

As users become more familiar with instant messaging, they might increase the amount of instant messaging communication in which they participate. This could be the result of several factors, including an increase in their personal productivity when they use instant messaging, or it could be that they find that instant messaging allows them to communicate with friends surreptitiously because of instant messaging's silent interaction and ephemeral nature. It could be the result of people "jumping the gatekeeper," going around the secretary or administrative assistant that might have previously screened the communications with senior staff members.

Renneker and Godwin (2005) propose that this second-order effect of increased usage is likely to lead to a third-order effect that would be the development of strategies to prevent others from contacting a user with instant messaging. Despite the impressions of users who initiate instant messaging requests that they have greater productivity because they have shorter delays in their tasks, users who receive instant messaging requests may find that the interruptions to their work are causing them to lose productivity. I review some research on interruptions and delays in the next section.

Interruptions and Delays

Researchers have been exploring the impact of interruptions and delays on worker productivity. There is support in the literature for the proposition that the fundamental unit of work in today's workplace is no longer the individual but is the group (Orlikowski, 1996; Sproull, 1991).

The workplace today is characterized by change. Historically a number of perspectives and models have developed on organizational change. Change was something that was planned for, and led by management (Yukl, 2002). Orlikowski notes three classic descriptions of change models: planned change models, technological change models, and punctuated equilibrium models (Orlikowski, 1996). Each of these models assumes that change and transformation is in fact transitory, that is, change happens during periods of change and once it is complete, the organization returns to stability. However, it is likely that change is no longer a transitory activity, but is in fact the new stability.

This transitory stage is the subject of Vaneman's (2002) research. He concluded that the production frontier, which had previously only been portrayed in the static sense of a system equilibrium, could be extended to a dynamic production frontier, one in which the inputs and outputs of the system were related not only statically, but could be viewed across time periods, and specifically across the transitory time period during organizational change. This new organizational reality, one of ever increasing complexity and continuous change, requires greater collaboration among co-workers in an organization.

Malone suggests in his book, *The Future of Work*, (T. Malone, 2004) that there will be a new norm in the structure of the workplace. No longer will people be tied to a single, centrally controlled organization, but they will operate in a loose hierarchy where individuals will compete with, and collaborate with one another in various combinations of teams depending on the specific needs of the project or assignment. Malone even suggests that new marketplaces will emerge with new organizational structures enabled by the enhanced communication and collaboration capabilities offered by today's communication technologies.

Collaboration by definition requires communication. Today, workers have many tools that enable them to communicate with one another. These tools vary in their cost, ease of use, degree of formality, and even in the disruptive nature of the tools. For instance, face-to-face meetings are still widely used means of communicating within the workplace. There are many costs associated with face-to-face meetings. These costs include the costs of simply gathering the people together, costs that can be extreme if the people are from geographically dispersed locations. Other costs include the costs of the meeting room, and although this is often simply an unused conference room, sometimes large meetings require the use of rented facilities. An important cost of face-to-face group meetings is coordination costs. Sproull defines these coordination costs as process costs; the difference between the potential contribution of all group members if each was contributing to his or her full potential, and the actual contribution of all the members (Sproull, 1991).

The past two decades have seen the advent of many new technologies that reduce the coordination costs in communication and collaboration. Many of these tools operate asynchronously, such as voice mail, email and the World Wide Web. Other technologies, such as instant messaging and cellular telephones, operate primarily as synchronous communication media. These technologies have the unwanted effect of interrupting the recipient of the message.

There is significant research on the effects of interruptions in the workplace. Interruptions in the workplace are defined as a synchronous interaction not initiated by the subject, and one that disrupts the current activity (O'Conaill, 1995). The effects of these interruptions are alarming and surprising. It is surprising that some interruptions actually improve knowledge worker performance. Although counterintuitive, research showed that when working on simple tasks, decisions were improved in terms of both speed and accuracy when decision makers were interrupted while completing the task (Speier, 2003).

Other research has shown that the effects of interruptions on worker performance are mitigated by a number of external factors. For example, individuals have varying needs for control of their workspace and time. Some individuals are characterized by a high need to control their activities, while others are much less concerned with this control and are in fact willing to flow with the activity. Individuals with high control needs are much more likely to be disrupted by interruptions and are likely to employ strategies to make themselves less available to synchronous communications, while at the same time availing themselves of the technologies to communicate synchronously with others. Social status within the organization plays a moderating role in the effect of interruptions. Specifically, the effect of interruptions by superiors is moderated by their relative status within the organization (Renneker, 2005).

Although research has shown that, while working on simple tasks, interruptions can improve performance, most of the work being completed by decision makers and knowledge workers today is not characterized as simple tasks. Much work today is demanding and complex. Interruptions in this type of work process have decidedly negative effects. Research has shown that decision accuracy and decision time are significantly degraded when workers are interrupted while performing complex spatial tasks (Speier, 2003). Others have concluded that overall interruptions and disruptions from unpredictable communications result in both in the decline of worker performance and an increase in worker stress (Renneker, 2005).

These results wouldn't be alarming if interruptions and delays were infrequent; however, anecdotal information suggests that interruptions, disruptions, and delays are a way of life for most knowledge workers. Research has shown that knowledge workers are interrupted more than occasionally. O'Conaill and Frochlich (1995) studied workers and determined that they were interrupted an average of 4 times an hour, with the average duration of each interruption being 2 minutes and 11 seconds. Marketers of new information technologies weave a seductive narrative of how each new communication technology will improve performance over its predecessors. Telephones were an improvement over telegraphs; email was an improvement over telephones; and instant messaging was an improvement over email. Each of these new technologies was promoted to reduce delays and improve productivity.

However, in practice, these improvements may largely be colored by the perspective of the users. Message recipients may have a very different perspective on the improvements than do message senders. It is a paradox of the technology that there can be two simultaneous, and apparently opposite, consequences from the deployment of information technology. Workers who are controlling their workspaces and work time may find that the new technologies are indeed improving their performance and productivity, while those workers who are interrupted may find it difficult to maintain their performance levels. Instant messaging is but one example of an information technology that has paradoxical consequences within the organization.

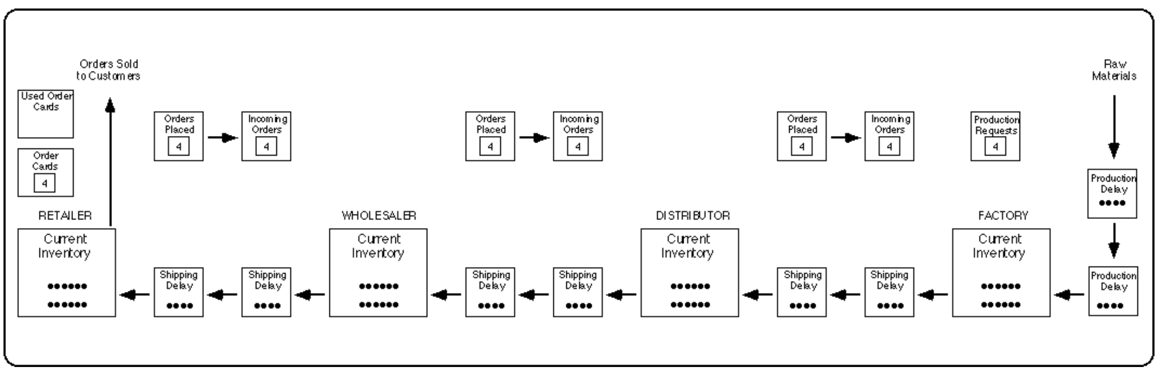
In the next section I introduce the beer distribution game. The beer distribution game has a long history of usage in studying organizational behavior. I use the game as a model to study the impact of implementing information technology.

THE BEER DISTRIBUTION GAME

The beer distribution game is a relatively simple four-player board game that has evolved from an idea first proposed by Jay Forrester at MIT in the late 1950s. This production distribution system game was first used at MIT in the summer session in 1958 (Martinez-Moyano, 2005). The game is a role-playing simulation that introduces a number of concepts in economic dynamics and computer simulation (Sterman, 1989b). The game has been used for a number of purposes. One purpose is to allow people to learn the realities of a four-point distribution system (Coakley, 1998). The game is also used by system dynamicists to introduce newcomers to the field of system dynamics (Martinez-Moyano, 2005). Peter Senge used the beer distribution game in his book, *The Fifth Discipline,* to illustrate how "problems originate in basic ways of thinking and interacting, more than in peculiarities of organizational structure and policy" (P. Senge, 1990, p. 27).

The beer distribution game is played on a board with four players, each playing the role of one node in a production distribution system (Figure 1 Beer Distribution Game Board) . Cases of beer are represented by tokens or coins, with orders being recorded on slips of paper and passed from player to player. Each player has a record sheet on which they record their effective inventory, either their actual inventory or their backlog. They also record the orders that they place each week.

Figure 1 Beer Distribution Game Board



The board represents a single brewery with the factory, distributor, wholesaler, and retailer individually represented. In normal play, one person manages each sector. Customer orders are provided exogenously on a deck of cards that is placed face down on the board before the game begins. Each play of the game represents one week, and players must go through five steps each week. Players are informed at the beginning of game play that the game will be played for a standard year of either 50 or 52 weeks, with each round representing one week.

Generally, the five steps for each week's activity are made in the following sequence. Each week, the retailer receives the customer orders., He or she then places orders for stock from the wholesaler, who orders from the distributor, who, in turn, orders from the factory. The factory does not place orders per se, but instead makes production requests to the factory floor.

Each player's objective is to minimize total costs for his or her production-distribution team. The costs for each team are calculated based on the inventory and backlog. Inventory holding costs are $0.50 per case per week. Costs for the backlog are $1.00 per case per week. Costs are accumulated at each node in the distribution chain, and the total cost for the production team is the sum of the accumulated costs for each node.

The rules of the game recommend that each player place a $1 wager in a pool, with the team with lowest total score splitting the entire collected sum. Sterman cites previous research that this small financial wager has a powerful motivating effect, and seems to improve subject performance (Sterman, 1989b). There may be compelling reasons to use this small wager as an incentive to player performance; however the Commonwealth of Virginia prohibits this at state colleges and universities. Therefore, no such wagers were used in any of the games used for my research.

Estimates suggest that thousands of subjects, including high school students, undergraduate and graduate students, and professionals in logistics and management seminars, have played the game. In 1989, the beer distribution game was the subject of a video essay on the McNeil-Lehrer news hour. In 1992, the System Dynamic Society began selling the basic board and supplies for the game. In the past 13 years, they have sold more than 8,000 of the games (Martinez-Moyano, 2005). The beer distribution game is a robust simulation tool that has been used for a number of management, academic, and research purposes, and that has stood the test of time in nearly five decades of use.

Game Play

Game play typically begins with the system in equilibrium: each node of the production distribution chain has an inventory of 12 cases of beer in stock. There are two shipping delays between the factory and the distributor, two shipping delays between the distributor and the wholesaler, and two between the wholesaler and retailer. Each of these shipping delays represents stock in transit between the nodes with stock taking two weeks to travel one node downstream from the supplier to the customer. At the beginning of the game, each of these delays is stocked with four cases of beer, meaning that between each node of the supply chain there are eight cases of beer in transit. In addition to the shipping delays, there are two production delays at the factory that represent the time to produce beer from the raw materials. In a concession to playability versus reality, it is assumed that the factory has unlimited raw materials from which to brew the beer.

In an early version of the game, Forrester recalls that the factory had a production process in place that was proportional to the employees. In order to increase production, the factory had to hire employees. In order to reduce production, the factory had to lay off employees. There was a six-week training delay before production would increase with the new employees, and the factory would have to give employees four weeks notice prior to termination. While this structure accented the instability in an actual production-distribution system, the dynamics of increasing and reducing production capacity came to dominate the game, and in the following year, the simplified version was restored (Martinez-Moyano, 2005).

Today, the factory generally has a large pile of chips representing cases of beer. The game is played with two simplifying assumptions. First, it is assumed that the factory has unlimited production capacity, second it is assumed that there is an unlimited supply of raw materials for the factory to use in production. Facilitators will recirculate the chips from the customer to the factory during the course of playing the game if required.

Game play begins with the instructor or facilitator instructing the subjects on how to play the game. The official instructions for game play require all players to place orders for four cases of beer the first two weeks. The game is very mechanistic, and having everyone follow the same order pattern at the beginning ensures that all subjects understand the mechanics of the game before they actually make any decisions. The facilitator typically either posts the number of the week of play on a whiteboard or uses some other method to prominently display each week of play to ensure that all players can see what week they are in when recording the information.

The five steps are played in sequence, with the first step being for the players to receive their incoming inventory and advance the shipping delays. In this step, players move the beer that is in the shipping delays one step forward, with the beer that has been in transit the longest arriving and being received into their inventory. The factory moves beer through the production delays at this time. Once again, in this step, the players make no decisions; they simply move beer along the playing board.

The second step is for each player to look at his or her incoming orders and to fill those orders. In this step, each player at the retailer position lifts the preprinted card with the orders from his or her customer. This beer is then shipped from the retailer to the customer. At the same time, the wholesaler moves stock from his or her inventory to the first shipping delay en route to the retailer. These shipping delays were emptied in the previous step when the retailer advanced the shipping delays to inventory. The distributor and factory also fill orders to their customers in the same fashion. Again, no decision is made by the players; they simply read the order slip and fill the orders.

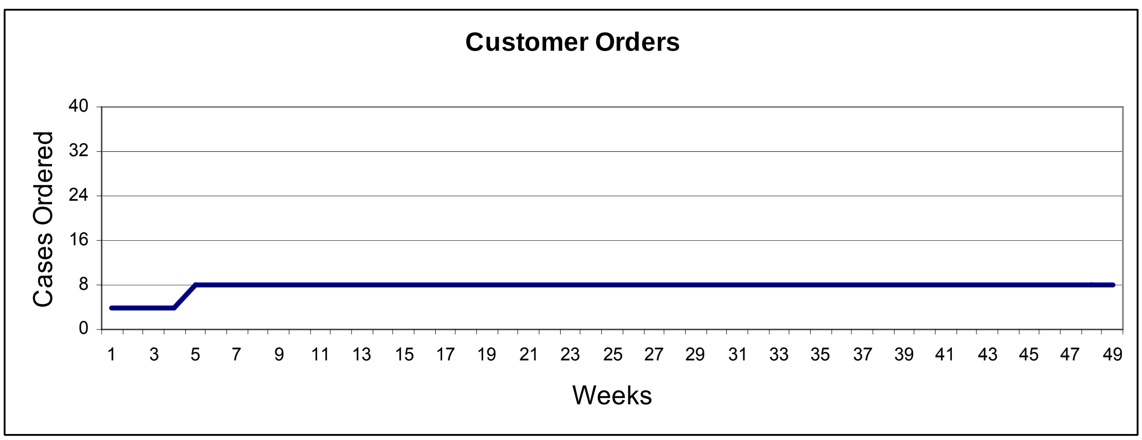
The third step is for the players to record their effective inventory. The record sheet used has a column for both inventory and backlog. Players are instructed that they cannot have both an inventory and backlog, and of course in the first two steps, all players have received the same orders and so everyone records the same information.

The fourth step is for the wholesaler and distributor to advance the order slips one box forward. This represents orders traveling in the mail, with each box representing a one week delay in the mail. The factory picks up the slip of paper from the production requests box and moves that number of chips from the raw materials pile to the first production delay. Throughout these first four steps, players have not made any decisions; they have simply followed mechanical instructions to ensure that stock is move correctly downstream and that orders flow correctly upstream.

In the fifth and final step, players decide how much beer they want to order from the upstream position. This is the one decision that players must make in the game. Players are motivated to keep their inventory as low as possible, while at the same time preventing backlogs. Inventory must be ordered, and there is a minimum delay of four weeks before orders placed today are filled. Four weeks is the optimal delay; it can be much longer depending on the upstream inventory positions (Sterman, 1989b).

Generally, the game is played with all players instructed to place orders of four cases of beer for the first two weeks in order to practice the mechanics of playing the game. Players also record their orders at this point on their record sheet. Once the instructor is certain that all players have completed the first week of the simulation, he or she will begin the second week by instructing the players to begin again at the first step. Generally, after the players have completed the process of play for two weeks, they understand the play, and can begin making ordering decision for themselves. The standard game protocol has a fixed customer request of four cases of beer each week for the first four weeks, with a step increase of four additional cases, for a total customer demand of eight cases of beer per week beginning at the fifth week. (Figure 2)

Figure 2 Beer Distribution Game Customer Orders



Game Modifications

A number of researchers have modified the customer demand to test the dynamics of various demand patterns. Kimbrough (2002) and others tested computer-based agents in the beer distribution game using various demand patterns, including stochastic demand patterns with a uniform distribution between 1 and 15. Machuca and del Pozo Barajas (1997) tested several different demand patterns, including the traditional step input, a sinusoidal demand pattern, an uneven demand pattern, and an aleatory demand pattern. Chen and Samroengraja (2000) tested the game with a variety of demand patterns as well.

In each of these studies cited, the authors used various computer-based simulations of the beer distribution game to test the effects of different demand patterns.

In standard game play, there is only the single change to the demand pattern at week five; the customer orders do not change again throughout the play of the game. At about the eighth or ninth week, instructors often stop the game and review how the players are to handle a backlog. At this point, players are generally comfortable with the mechanics of playing the game and the dynamics of the game have often set in with players beginning to accumulate backlogs. Backlogs are cumulative, with players attempting to fill the backlogged orders first, and then any new incoming orders. Any backlogged orders that are not filled remain recorded as backlog, along with any new orders that have not been filled. Frequently, players are reminded at the start of play that backlog units cost twice as much as inventory.

Game play continues in this step-by-step process for the remainder of the game. Generally, play is stopped after the 36th week. At this point, the typical system behaviors of oscillation, amplification and phase lag, collectively known as “the bullwhip effect”, have become apparent. The bullwhip effect is defined in literature as the phenomenon where orders to the supplier have a larger variance than sales, and this variance propagates upstream in the supply chain (H. Lee, Padmanabhan, V., Whang, S., 1997b). If players believe that the game will continue for the full year, they might be motivated to empty their inventory totally, as if they were going out of business. This behavior is called the horizon or end-game effect (Sterman, 1989b) and is avoided by stopping the game after 36 weeks.

Research Platform – Behavioral Aspects

The beer distribution game has been used as a research platform by a number of authors to study a number of different phenomena. Sterman (Sterman, 1989b) used the beer distribution game as a platform to study misperceptions of feedback in a dynamic decision making experiment. In this paper, Sterman has investigated the decision process of the subjects managing the supply line. As noted earlier with regards to General Motors and Wal-Mart, management of stock is a common problem faced by managers in the workplace. Most stock management problems are too complex for managers to determine an optimal strategy. Sterman proposed a decision process that assumed that in the absence of an optimal strategy, decision makers will choose a heuristic that is locally rational. In the beer distribution game, subjects are instructed not to discuss their orders, backlog, or inventory with the other participants; however, the nature of the game is such that the players may make assumptions regarding the activities of the other players. Players are seated next to one another at a table and can certainly see the inventory of others in the supply chain. This close proximity can contribute to the players' decision process.

Sterman observes that orders must be non-negative in most real-life situations and he proposes that:

$$O_t = MAX(0, IO_t) \tag{0.1}$$

Orders equal the maximum of either zero or the Indicated Orders IO_t, where the Indicated Orders are the orders that are indicated by other pressures, or the orders that the manager of this node believes are appropriate for this time period. He theorizes that the Indicated Order rate is based on an anchoring and adjustment heuristic chosen in order to (1) replace expected losses (sales) from the stock; (2) reduce the discrepancy between the desired stock and the actual stock; and (3) maintain an adequate supply line of unfilled orders. (Sterman, 1989b) He proposes that the anchor is the expected Loss Rate *(eLr)*, while adjustments are made to correct the difference between the desired and actual stock, *(AS)* and the desired and actual supply line *(ASL):*

$$IO_t = eLr + AS_t + ASL_t. \tag{0.2}$$

Sterman reviews several potential formulations of expected losses, and settles on using adaptive expectations:

$$eLr_t = \theta L_{t-1} + (1-\theta)eLr_{t-1}, 0 \le \theta \le 1 \tag{0.3}$$

where L_{t-1} is the actual loss for the previous period, t-1, and eLr_{t-1}, is the expected loss rate for the previous period, t-1. He chooses this formulation because expected losses are relatively stable and easily recognized by the players managing the stock. Loss rate is locally available to the players, and adjustments are then made to the orders to adjust the desired inventory (stock) and supply line. He makes no assumptions that players actually calculate the orders using the assumptions, nor that this equation represents an optimal solution to the problem; he simply theorizes that this model represents the players' behavior.

Sterman reported on 48 trials with 192 subjects, collected over 4 years. The sample came from undergraduate and graduate students at MIT, participants in a short course on computer simulation, and executives from a major computing firm. Trials in which significant accounting errors were made were discarded, and the final study is based on the results of 11 trials of 44 subjects. Sterman simulated the proposed decision rules in order to obtain benchmark costs for the teams as a whole and for the individual sectors.

The average team cost was 10 times greater than the optimal benchmark cost. The ratio of actual versus benchmark costs was similar in all of the sectors. Examination of the results revealed several patterns. The trials were all characterized by instability and oscillation. Subjects took an average of 21 weeks to recover the initial inventory. The trials were all characterized by amplification; the amplitude of the orders increased steadily from the retailer to the factory. As noted earlier, customer orders increased from four cases to eight cases per week in week five. The average peak order rate at the factory was 32 cases, an amplification of 700%. The trials were also characterized by phase lag. Customer orders changed in week 5. Retail orders peaked on average at week 16. Factory orders peaked at week 20. Sterman notes that the behavior of all the subjects "exhibits significant regularities" (Sterman, 1989a, p. 331).

Sterman concluded from his experiments that the proposed heuristic was strongly supported. Further analysis of the experiment was completed to try to determine why the subjects use a rule that produces such non-optimal results. Sterman concluded that there are several misperceptions responsible for this performance.

First, he concluded from reviewing the results that that subjects anchor the desired stock on the initial level of the stock. Second, he concluded that most subjects failed to account for the supply line. Because of the delays in receiving beer, subjects often over-ordered, and when the increased orders began to arrive, subjects cut their orders back. However, the beer in the supply line continued to arrive and swelled inventories. Finally, Sterman reviewed the experience of the subjects in a post-game debriefing. Subjects were asked to graph their perception of the customer orders. Most believed that the customer orders were oscillating with peaks anywhere from 12 to 40 cases per week. Only the retailers were aware of the actual customer demand, and the other players were astonished to learn what the actual pattern of customer orders was.

The subjects attributed the cause of their own performance to exogenous variables: in this case, the customer orders. Their beliefs reflected an 'open-loop' conception of the system dynamics. That is, they believed that the dynamics of the system arose from exogenous changes. When queried on how they might have improved their performance, subjects typically responded with improving their ability to respond to external shocks, and not on changing their stock management policies (Sterman, 1989a).

Sterman draws a number of additional conclusions from his research. Noting that the beer distribution game is indeed simplified compared to the real world in which customer orders do not generally follow a step input, he questions if this research be generalized to a real world situation. That is, can it be generalized to situations where a more realistic demand pattern is presented? His conclusion is yes, it can be generalized. He found no statistical difference between the performances of the upstream subjects – the wholesaler, distributor, and factory – from the performance of the retailer. Unlike the retailer who was faced with only a step input, the upstream subjects were faced with very dynamic and noisy order patterns. This conclusion is further supported by the research using computerized versions of the beer distribution game cited earlier, where different demand patterns were tested.(Sterman, 1989b)

Sterman further asks if this experiment reflects behavior found in real production-distribution systems. After all, this model is a very simple representation of a fairly complex system. There are a number of concerns that he addresses. Managers in real production-distribution systems generally have access to more information than is available in the beer distribution game. However, managers in the real world are often faced with having data that isn't useful, too much or too little data, out-of-date information, or other contradictory information. Managers generally have more time to consider their decisions in the real world, and managers may be able to use decision aids to assist them. Despite these limitations, he concludes that the proposed model of using an anchoring and adjustment heuristic does indeed meet the required condition, not of equivalence to the real world decision making, but to the weaker requirement that both the proposed heuristic and the real world decision making policies exceed the abilities of the decision makers (Sterman, 1989a).

It is well documented that many markets and industries are prone to business cycles and instabilities. Managers in these situations do not entirely ignore the goods that they have on order; however, the problem is not localized, but is one of aggregation. The goods on order at the wholesaler are not even known to the retailer, the retailer is trying to optimize the performance of his operations, and is ordering stock to meet his current demand. In turn, the wholesaler is aggregating orders from multiple retailers, and trying to optimize the orders to his upstream partners. Sterman (Sterman, 1989b) concluded that verification of his supply line hypotheses needs further research, not simply on the process of individual decision makers but on the accuracy of supply line information at a global level. He further concluded that a heuristic may produce stability in one setting but oscillation in another – this difference is entirely due to the endogenous structure of the system.

Research Platform – Operational Aspects

A number of others have used the beer distribution game to study and illustrate supply chain behavior. Lee (H. Lee, Padmanabhan, V., Whang, S., 1997a) and others writing in *Sloan Management Review* define the variability in orders from retail seller to factory as the "bullwhip" effect. They cite examples from both Proctor & Gamble with the manufacture and sales of Pampers; and Hewlett-Packard with the variation in sales of one of its printers as real world examples of the bullwhip effect. The authors accept that Sterman attributes the oscillation and amplification that they call the bullwhip effect to human behavior, "such as misconceptions about inventory and demand information" (H. Lee, Padmanabhan, V., Whang, S., 1997a, p. 94). "In contrast we show that the bullwhip effect is a consequence of the players' rational behavior within the supply chains' infrastructure" (H. Lee, Padmanabhan, V., Whang, S., 1997a, p. 94).

They identify four major causes of the bullwhip effect, which are now commonly cited as operational causes, as opposed to the behavioral causes first identified by Sterman. The first cause, Demand Forecast Updating, is essentially equivalent to Sterman's anchoring and adjustment heuristic. Sterman proposes that people order based on prior period inventories (anchors) and make adjustments to the stock and supply chain to correct discrepancies between the current stock and the desired stock. In demand forecast updating, Lee et al. argue that the wholesaler bases his orders on the demand from the retailer. The order placed by a downstream customer is interpreted by the upstream supplier as a demand signal indicator. In the real world, as opposed to the beer distribution game, retailers must use some method to forecast future demand. Lee proposes that one such method is exponential smoothing where future demands are updated based on new daily demands. The orders sent to the supplier include the amounts needed to replenish the stock for current orders, as well as any necessary safety stocks. Safety stocks are defined in the literature as "stocks held to buffer against exogenous uncertainty in demand and deliveries" (R. Croson, Donohue, K., Katok, E., Sterman, J., 2005, p. 19). When the retailer orders safety stock, this is seen as demand by the wholesaler, who in turn orders from the distributor with the safety stock as part of the demand. Each node in the supply chain contributes to the amplification of the orders from retailer to factory when they order their own safety stock, based on the demand forecast from their customers (H. Lee, Padmanabhan, V., Whang, S., 1997a).

The second cause the authors identified is order batching, the practice of batching orders to a supplier once a period, instead of providing continuous demand to a supplier as nodes receive their own orders. A number of factors in the structure of the system are identified that make batch ordering a rational decision for managers. These include both the cost of processing both orders from the purchaser's side, and the cost of processing invoices from the supplier side. Since the processing costs are virtually the same for orders/invoices of single items as for large batches, there are systemic incentives to order larger quantities on some periodic basis. In addition to the cost of placing the orders frequently, there is the cost of shipping. There are often significant differences between full truckloads and less-than-truckload shipping rates. This discrepancy in costs creates economic incentives to order in batches, further aggravating the amplification and oscillation (H. Lee, Padmanabhan, V., Whang, S., 1997a).

A third contributor is price fluctuation. Lee et al. note that forward-buying constitutes $75 billion to $100 billion of inventory annually in the grocery business. These orders are the result of special promotions, price discounts, rebates, coupons, and other price fluctuations. If holding the inventory costs less than the price savings, it clearly makes sense for the individual manager to buy when prices are low. In low-margin markets where goods are turned over rather quickly, such as the grocery business, this makes sense. The reverse of this phenomenon is seen when automobile dealers and manufacturers issue incentives to unload excess inventory. At this point, the cost of holding the inventory is greater than the "loss" against profit from selling at a discounted price.

A final cause identified for the bullwhip effect is called rationing and shortage gaming. In this case, when manufacturers or suppliers have a shortage, they develop schemes to allocate the scarce resources to their customers. One scheme is to supply the customers based on some percentage of their orders. Of course, when customers discover this practice, they simply order more than they really need in the expectation that they will get what they require.

The research suggests that there are a number of solutions to these various problems. "Inventory researchers have long recognized that multi-echelon inventory systems can operate better when inventory and demand from downstream sites is available upstream" (H. Lee, Padmanabhan, V., Whang, S., 1997a, p. 97). This suggests that information technology has the capability to help address the problem of the bullwhip effect in production distribution systems. Much as Sterman recommends that players in the beer distribution game must look for the leverage points within the supply chain, Lee et al. suggest that if managers understand these causes of the bullwhip effect, they can find methods to mitigate the problem. Eliminating the incentives within the system that make each of the strategies described desirable can only be done by addressing the structure of the system.

Information Sharing

Lee, So, and Tang (2000) modeled a two-level supply chain and concluded that information sharing had little value to the retailer, but manufacturers could realize inventory and cost reductions with information sharing. Machuca and del Pozo Barajas (1997) took this research a step further. In their research, they studied the beer distribution game and developed a network version of the game.

They had two objectives in developing their networked version of the beer distribution game. The first objective was to develop a version of the game that would operate over the Internet, thus allowing participation in the game-playing process from distant centers. The second objective was to demonstrate the value of Electronic Data Interchange, or EDI, in reducing communication delays between businesses and to provide support for EDI in the European Union. To illustrate the effect of EDI on performance, they studied the game by eliminating one or both of the information delays in the game. They concluded that the best way to demonstrate the advantage of EDI was to replace the human players with subroutines. By eliminating the human players and one information delay, they were able to demonstrate reductions in costs between 21% and 41%. When they eliminated both delays, they realized cost reductions of between 40% and 60%.

Croson and Donohue (2003) extended the research in information sharing in the supply line. They conducted an experiment using undergraduate business students and an electronic version of the beer distribution game to test the hypothesis that "The bullwhip effect will not occur when the demand distribution is known and stationary" (Croson, 2003, p. 11). In this experiment, subjects were told that the demand was uniformly distributed between 0 and 8 cases per week. In order to control for the possibility that the subjects might not understand the meaning of uniform distribution, their instructions included the phrase "Demand is U(0,8), meaning (0,1,2,3,4,5,6,7,or 8) is equally likely in each period." The results of the experiment, 82% of the observations involved an increase in variance of orders between roles, led them to reject the hypothesis.

A second hypothesis, that participants wouldn't under-weigh the supply line when the demand was known and stationary, was also rejected. In this case, all of the 44 participants under-weighed the supply line by patterns similar to those found by Sterman. In a second experiment conducted the same day with different participants, Croson and Donohue (2003) explored the effect of sharing inventory information throughout the supply line.

One of the differences between the electronic version of the game and the manual board game is the ability of the researcher to fully isolate the subjects in the supply chain. When playing the manual board game, subjects can easily see the inventory positions of all nodes in the supply chain. In this study, the inventory position of all players in the production-distribution system was displayed by a bar chart on the individuals computer screen. Several hypotheses were tested regarding the value of information sharing, with the primary hypothesis being that sharing information across the supply line would reduce the bullwhip effect. The results of the study were that while information sharing did reduce the bullwhip effect, it did continue to persist. It appeared from this study that information sharing benefited upstream positions more than downstream positions (Croson, 2003).

In order to further understand the effect of information sharing on the bullwhip effect, Croson and Donohue conducted further experiments designed specifically to test the value of information sharing. The participants were drawn from a pool of Carlson MBA students enrolled in an Operations Management course. In the first experiment, the control experiment, participants only saw their own inventory information. As in the previous experiment, the participants were told that the retail demand would be uniformly distributed between 0 and 8 cases per week. In the second experiment, the participants were given inventory information on their upstream partners. That is, the retailer saw the information for the wholesaler, distributor and factory inventories, while the distributor only saw his own inventory and the factories inventory. In the third experiment, the participants only saw the inventory information for themselves and their downstream partners. The results of this study clearly showed that the value of information sharing depended on where the information resided. Sharing downstream information was more effective in reducing the bullwhip effect than sharing upstream information.

Interestingly, the study also highlighted how information sharing can lead to worse performance. This performance was noted as a result of a subject's frustration from having information about supply chain partner's performance, but not having the ability to act upon it. Post-game interviews highlighted the fact that subjects were often frustrated by the failure of their partners to use the information available (R. Croson, Donohue, K., 2005).

Table 1 Bullwhip Effect

Cause of "The Bullwhip Effect"	**Description**	**Articles**
Behavioral		
Stock Anchors	Subjects anchor the stock, that is they determine the desired stock to maintain based on the initial stock in the system.	(Sterman, 1989a)
Supply Line Under-weighing	Subjects failed to account for the supply line, often over-ordered and then cut their orders back below requirements to maintain their desired stock when orders from prior periods began to arrive.	(Sterman, 1989a)
Safety Stock	Subjects maintain a stock in excess of the desired inventory to protect them from exogenous demand spikes. *i.e.* Subjects maintain excess stock to	(H. Lee, Padmanabhan, V., Whang, S., 1997a)

Cause of "The Bullwhip Effect"	Description	Articles
	protect them from expected customer demand variations.	
Coordination Stock	Subjects maintain a stock in excess of the desired inventory in order to protect them from endogenous demand spikes. *i*.e. Subjects maintain excess stock to protect them from the non-optimal decision made by players in other positions.	(R. Croson, Donohue, K., Katok, E., Sterman, J., 2005; H. Lee, Padmanabhan, V., Whang, S., 1997a)
Operational		
Demand Forecast Updating	Forecasting is based on the demand from the immediate customer downstream. These orders are processed as information signals on future demand, even when these orders include orders for excess stock required for coordination or safety.	(H. Lee, Padmanabhan, V., Whang, S., 1997a)
Order Batching	Two forms of order batching, periodic ordering (customers order on a	(H. Lee, Padmanabhan, V., Whang, S., 1997a)

Cause of "The Bullwhip Effect"	Description	Articles
	periodic cycle), and push ordering (sales people "borrow" from future sales to meet periodic quotas).	
Price Fluctuation	Stock is purchased in advance of requirements because of special price incentives	(H. Lee, Padmanabhan, V., Whang, S., 1997a)
Rationing and Shortage Gaming	Rationing during periods when demand exceeds supply results in exaggerated demand by downstream partners attempting to meet their actual requirements	(H. Lee, Padmanabhan, V., Whang, S., 1997a)
Information Sharing		
Bi-directional sharing	Bullwhip effect is lessened when information on demand and inventory is shared across the supply chain.	(Croson, 2003; R. Croson, Donohue, K., Katok, E., Sterman, J., 2005; H. Lee, So, K.,Tang, C., 2000; Machuca, 1997)
Upstream Information Sharing	Sharing upstream information has limited effect on the bullwhip effect	(Croson, 2003; R. Croson, Donohue, K., Katok, E., Sterman, J., 2005; H. Lee, So, K.,Tang, C., 2000)
Downstream	Sharing downstream information was most	(Croson, 2003; R. Croson, Donohue, K., Katok, E.,

Cause of "The Bullwhip Effect"	Description	Articles
Information Sharing	effective in reducing the bullwhip effect.	Sterman, J., 2005)

Other Research

The literature supports two primary causes of the bullwhip effect in the beer distribution game and in supply chains in general. The first, behavioral causes, is the focus of Sterman's 1989 research. The second primary cause of the bullwhip effect is the operational aspects of supply chain instability; the work of Lee and others has documented these causes. In the paper, "Order Stability in Supply Chains: Coordination and the Role of Coordination Stock" (R. Croson, Donohue, K., Katok, E., Sterman, J., 2005), the authors assert that the literature supports both of these explanations for the Bullwhip effect.

In this paper, they also propose an additional behavioral cause of the instability, which they call "coordination risk." Some changes or perturbations to a supply line are both unanticipated and exogenous. An example of this perturbation is customer demand. The literature is replete with research that documents the robustness of the bullwhip effect in the face of this exogenous factor. Other perturbations are endogenous to the system. An example cited in the literature is a manager who suspects that his or her customers or suppliers will not make optimal decisions; he or she may deviate from the equilibrium strategy to build a buffer stock to protect against this risk. Croson et al. termed this uncertainty of the endogenous actions of others "coordination risk." This additional stock will cause variability in the orders to the suppliers and may result in system instability. This buffer stock is different from the safety stock previously discussed that was defined as a buffer against exogenous variables. Croson et al. call this additional buffer stock "coordination stock." Their research finds that modest coordination stock significantly lowered order variability and costs by keeping the system further from the unstable region where supplier out-of-stock conditions dominate the dynamics of the supply line. Their research further supports behavioral causes of the bullwhip effect (R. Croson, Donohue, K., Katok, E., Sterman, J., 2005).

To test their hypothesis that a behavioral cause was responsible for the bullwhip effect, the authors eliminate the four commonly cited operational causes of supply line bullwhip. These four causes previously detailed by Lee and others are: order batching, gaming due to shortages, price fluctuations, and demand signaling. In the standard beer distribution game, several of these operational factors are eliminated simply by the standard protocol. Order batching is eliminated because there are no costs associated with the ordering process and no discounts for quantity orders. Gaming is eliminated because there is both unlimited production capacity and because each node orders from and ships to only one other node. Prices are fixed, and customer demand is exogenous, eliminating forward buying. This leaves demand signaling as the only operational cause of the bullwhip effect not eliminated in the beer distribution game.

Prior research has treated customer demand in a number of different ways. Sterman (1989a) used a step function, while Kimbrough and others used stochastic demand to test their theories (2002). Machuca and del Pozo Barajas (1997) tested several different demand patterns, including the traditional step input, a sinusoidal demand pattern, an uneven demand pattern, and an aleatory demand pattern. Croson and Donohue (2003) used a known stationary demand pattern. In all of these prior studies, there was demand variability, and demand was unknown to the participants other than the retailer. Since this demand variability could conceivably cause demand forecast updating, all operational causes of the bullwhip effect were not eliminated by the experimental design. In order to isolate the system test from behavioral causes, the researchers eliminated demand variability by using a constant demand and informing all participants of the demand before the game.

Their first experiment was designed to test the hypothesis that the bullwhip effect will not occur when demand is constant and the system begins in equilibrium. The results of this experiment show that the bullwhip effect is persistent even when demand is constant and known by all participants. Prior research has shown that participants significantly under-weigh the supply line when managing complex systems. The authors model a decision rule to compare the results of the experiment with a simulated optimal rule. Following Sterman, they propose for orders $O_{i,t}$, placed in week t by the person in role i:

$$O_{i,t} = MAX\{0, CO_{i,t} + \alpha_i(S'_{i,t} - \beta_i SL_{i,t}) + \varepsilon_{i,t}\} \tag{0.4}$$

Where CO is Customer Orders, S' is desired inventory, S' is actual on-hand inventory, and SL is the supply line of unfilled orders. As in Sterman, α is the fraction of the stock shortfall ordered each week and β is the fraction of the supply line ordered each week. Also as in Sterman, both α and β have optimal values of 1, as subjects should order the entire inventory or supply line shortfall each week. Since the customer demand is known and constant, desired on-hand inventory is zero, and desired on-order inventory is that which is required to ensure deliveries of 4 cases per week (R. Croson, Donohue, K., Katok, E., Sterman, J., 2005).

The proposed equation can also be interpreted as a behavioral decision rule in which CO_{it} is the Customer Orders for the person in role i, placed during week t. The authors modeled the expected customer orders with the following equation:

$$CO_{i,t} = \theta_i IO_{i,t-1} 1 + (1-\theta_i) CO_{i,t-1} \tag{0.5}$$

where IO is the actual Incoming Orders. The results of the experiments showed that for the value of α, the fraction of the shortfall ordered each week, 73% of the subject were significantly less than the optimal value of 1. For β, 78% of the estimates are significantly below 1. For 59% of the subjects, β was not significantly greater than 0, indicating that participants tended to ignore on-order inventory in making their ordering decisions. Contrary to researchers' expectations, the bullwhip effect remains, even when demand is constant and known by all subjects (R. Croson, Donohue, K., Katok, E., Sterman, J., 2005). This unexpected result must lead to further questions.

In the Sterman experiment (1989b), the system is knocked out of equilibrium by the step increase from four to eight cases in week five. When demand is both known and constant, what caused the system to deviate from equilibrium? To try to answer this question, the researchers ran a second experiment with the same subjects. After a short break, the participants were reassigned to new teams, maintaining their original position in the production-distribution system. In this case, the subjects had full knowledge of the demand, and they had experience playing the game. The bullwhip effect persisted, although there was improvement. The authors note that this failure to account adequately for the supply line despite experience is consistent with prior research (Diehl, 1995).

Experience is not adequate to correct supply line under-weighing, but that doesn't explain the causes of this spontaneous deviation from equilibrium. In the earlier experiments, there was a change in demand that caused the deviation. In these two experiments, there was no trigger. Further examination of the results showed that the deviation was largely triggered by non-retailers deviating from equilibrium.

Post-play questionnaires helped to shed light on the phenomenon. Players responded that while they understood that ordering 4 units every week was the optimal strategy, they didn't believe that their teammates understood this policy. In order to protect themselves against their teammates' irrational behavior, they were motivated to obtain additional inventory as a buffer stock (R. Croson, Donohue, K., Katok, E., Sterman, J., 2005).

In order to test this theory of coordination risk, the researchers ran a second experiment in which the players were initially given excess inventory. The optimal inventory is known to be zero cases of beer when there is a known constant demand. In the second experiment, subjects were given an initial inventory of 12 cases. This was chosen because 12 cases is the traditional inventory in the beer distribution game, and because an inventory of 12 cases was thought to be greater than the coordination stock. The results of the experiment supported the hypothesis that excess inventory would reduce order variability. The researchers compared the costs of holding excess inventory with the costs of supply chain instability by comparing the results of experiment 2 and experiment 3. The cost of holding excess inventory in the form of coordination stock was more than offset by the increased stability in the supply chain, although researchers cautioned that this result is highly dependent on the price structure. In the beer distribution game, holding costs are half of the backlog costs, but the benefits of excess coordination stock may not be as clear with different costs structures (R. Croson, Donohue, K., Katok, E., Sterman, J., 2005).

If the bullwhip effect is the result of subject's belief that the other participants in the experiment do not fully understand the optimal ordering policy, then creating common knowledge of the optimal policy should reduce the bullwhip effect by decreasing order variability and eliminating supply line under-weighing. The results of this experiment show performance improvement over the baseline experiment, but the bullwhip effect is resilient.

A fourth and final experiment was run with three of the four positions being replaced by computers. The human participants were told what the optimal policy was, and they were told that the other participants, the computers, were programmed to follow that optimal policy. The results of this experiment showed an improvement over the performance of the baseline experiment, experiment 1, but no significant improvement over performance in experiment 3. Failure to use the optimal rule and lack of common knowledge appeared to be the primary causes of the bullwhip effect (R. Croson, Donohue, K., Katok, E., Sterman, J., 2005).

Four major findings emerged from these experiments:

1.) The bullwhip effect is persistent even with a known and constant demand.

2.) The uncertainty that others will follow the optimal rules is defined as coordination risk, and may cause deviations from equilibrium that trigger the bullwhip effect.

3.) Coordination stock provided to buffer against endogenous deviations from the optimal policy does reduce the bullwhip effect.

4.) Publicly explaining to the participants the optimal ordering rules does improve performance.

As a result of these experiments, the researchers drew several conclusions. The bullwhip effect is persistent, and experience is unlikely to eliminate this phenomenon. The bullwhip effect is a behavioral phenomenon, as well as an operational phenomenon. People's mental models make it difficult to control systems that include feedbacks and delays, and training and decision aids may be required to obtain improvement. The notion of optimal behavior is contingent upon people's beliefs that the other agents in the production-distribution system also understand the optimal rules. Evidence suggests that many people believe that their counterparts will behave in a capricious and unpredictable manner.

Electronic Versions

Although there is a consistent record of usage, the beer distribution game is not without some controversy, albeit minor. Over the past 20 years, the advances in personal computers and communication technologies have resulted in a number of different computerized beer distribution game simulations. One of the drawbacks to using the beer distribution game is the amount of time required to play the game. According to Sterman (1989b) it generally it takes about 90 minutes to provide the instructions and play the manual board game. My experience is that both for graduate students at Virginia Tech and for other volunteer subjects, it takes closer to 120 – 150 minutes to complete the game.

There are a number of factors that contributed to the length of time required to play the game, including playing the game at multiple sites while using a video broadcast system to interconnect them. No teams were split across sites, but the administration of the game requires that all teams be at the same step of the game at all times.

In addition to the amount of time required, there are significant bureaucratic and administrative tasks that must be done by the player as the game is played. These tasks include counting inventory, calculating backorders, and recording effective inventory. Additionally, the subjects at Virginia Tech included a number of students for whom English was not their first language. This may have contributed to difficulties in understanding the direction given and may have caused greater playing time than experienced by Sterman. Many of the problems noted with playing the manual beer distribution game are addressed by computer simulations (Jacobs, 2000; Machuca, 1997). The major advantages of playing a computerized version of the beer distribution game are a significant reduction in the time required to play the game, with some authors noting that the game can be played in as little as 45 minutes, and reduction in calculation errors. (Coakley, 1998)

There are several reasons why the board game may be preferred. One issue is that the majority of computer simulations of the beer distribution game do not replicate the board game with 100% fidelity (Eren, 2005). McGarvey (McGarvey, 2004) makes several changes to the game in his simulation, published in *Dynamic Modeling for Business Management*. The most notable change is that he eliminates the backlog at the retailer. He argues that in a real-life situation, the beer-purchasing consumer is not going to wait a week in order to receive his beer, and that backlogs simply are not realistic at that point of the supply chain. He also changes the cost structure of the game. The MIT Web-based beer distribution game also uses different cost calculations in its simulation (Eren, 2005).

There are several reasons why the computerized version is preferable to the manual board game. Primary among them are the reduction in time required to play the game, the reduction of errors made in calculating the various inventories and backlogs, and the reduction in the time required to prepare the materials for the debriefing. Other reasons include the ability to vary the incoming demand pattern to test varieties of responses and far greater control over the playing process. Anyone who has experienced the beer distribution game knows it is only steps away from chaos.

Among the reasons to prefer playing the manual game is the general reliability of the manual game. Even today, computers and networks can have failures, and they always seem to come at the most inopportune times. (Coakley, 1998) Despite what appears to be overwhelming support for the computerized version, there are experts, notably Jay Forrester and Dennis Meadows, who are cited in interviews as saying that only the manual board game allows players to experience all of the features that a real system has to offer (Martinez-Moyano, 2005). It can certainly be argued that the chaos that develops around the manual board game closely models the chaos that is often the characteristic of business today. Peter Senge describes at length how the scenario of the board game maps to the reality of life as a retail beer merchant. The merchant he depicts has a workweek that seems to be characterized by chaos, interruptions, and delays. These are workplace characteristics shared by many knowledge workers in today's economy.

For nearly 50 years the beer distribution game, either or in its current configuration or as an earlier version of a production-distribution system, and either in its original board game format or in one of its many electronic versions, has proven to be a valuable proxy to study the dynamics of an organization. The beer distribution game is most frequently used to study supply chain dynamics, and more specifically to study the bullwhip effect. These nearly five decades of history make the beer distribution game a useful proxy to study organizational behavior.

The supply chain modeled by the beer distribution game is simple enough for subjects to grasp the basic principles fairly quickly. It is complex enough to demonstrate complex system behaviors, specifically demonstrating the order amplification, lag times, and oscillations commonly known as the "bullwhip" effect. Researchers have used this platform to study a variety of behaviors.

This research uses the beer distribution game to study the effect of introducing information technology into an organization. A number of studies have been done on the effect of information sharing on the bullwhip effect (Chatfield, 2004; F. Chen, Drezner, Z., Ryan, J., Simichi-Levi, D, 2000; Steckel, 2004), and my intention is to study the effect of implementing information technology on an organization by using the beer distribution game as a simulation proxy for an organization.

LITERATURE REVIEW GAP SUMMARY

Literature on information technology is extensive, as is the literature on the beer distribution game, the literature on organizational performance, and the literature on system dynamics. Researchers have explored these subjects in many compelling ways. My research of the beer distribution game literature did not uncover previous research in which the beer distribution game was modified during the game play. There was some research that used the beer distribution game as a proxy to explore the impact of information technology and my research built upon that foundation. In addition to reviewing all of the literature that I could find on the beer distribution game, I wrote two of the leading system dynamics scholars, John Sterman at MIT, and Paolo Goncalves at the University of Miami, with inquiries about my proposal to research the effect of implementing information technology by modifying the beer distribution game. Both men were encouraging, both thought the proposal was interesting, and not something that had been done by others. Dr. Goncalves was especially encouraging and offered much advice on how to proceed.

My research of the literature did not turn up any examples of using system dynamics to model the hypothesis that the alignment of mental models with the organizational structure after the implementation of information technology was critical in the success of information technology. When I completed the beer distribution game experiment I did extend my literature review to explore the concept of alignment with regards to information technology. This exploration is documented in Chapter 5, at the end of the experimental results. It is documented there because it was not part of the original literature research. The literature was specifically revisited when I discovered that implementing information technology in the beer distribution game did not have a positive affect on performance.

The review of the literature that was completed after the experiment discovered a number of articles that studied the use of information technology as a change agent for an organization. This research reviewed the alignment of management behaviors as a mechanism for the success of the implementation. Other research considered the alignment of workers behavior with information technology. This research was conducted in a number of different fields. However, none of the research used either the beer distribution game, or system dynamics to address the alignment issue.

The research documented in this dissertation is unique in that it combines an experimental approach, the beer distribution game, with a case study using system dynamics. The beer distribution game was used because it was believed to provide a laboratory setting in which an experiment could be conducted when implementing information technology. The research was extended to the case study firm using system dynamics because the system dynamics modeling process allows us to capture the complex interactions between many variables. This approach to study and research an issue using an experiment in combination with a case study is unique in the literature.

CHAPTER 3: EXPERIMENTAL RESEARCH DESIGN

In trying to understand the unanticipated effects of implementing information technology, several different research strategies were used. The first strategy used was be a thorough review of the relevant extant literature to understand which theories have been developed by others in the area of interest. In conducting the literature review, research was done in areas of organizational development, system dynamics, and information technology. This literature review was described in the previous chapter.

The second strategy was to use an experiment to test some specific hypotheses and develop and expand the theory on the effects of implementing new information technology. The experiment was conducted using the beer distribution game. As discussed in the previous chapter, the beer distribution game has a long history of being used to understand organizational behavior.

The third strategy was to conduct a case study through which to evaluate the impact of information technology in a real world organization. This strategy was carried out through the use of system dynamics modeling. The case study was used to extend the knowledge and understanding developed during the experiment. Studying the effect of implementing information technology in an artificial environment, such as the beer distribution game, is valuable. Using system dynamics to model and simulate behavior in an organization confirms the results from the experimental research.

The review of the literature developed from the beer distribution game has shown that there are two primary theories explaining the performance of subjects in the beer distribution game. The first theory can be described as the behavioral theory. This is developed originally from John Sterman's paper "Modeling Managerial Behavior: Misperceptions of Feedback in a Dynamic Decision Making Experiment", published in *Management Science* (1989b), and extended by the research of Sterman and others. This theory was explored in detail in the previous chapter. Briefly the theory suggests that subjects in the beer distribution game perform poorly because of behavioral or mental model misperceptions of the dynamics involved in the system. The second theory that explains the performance of subjects in the beer distribution game contrasts with the behavioral theory and suggests that the performance is a result of operational or structural aspects of the game, and that in fact the performance is a result of players making rational decisions within a system. This theory was develop by Lee, Padmanabhan, and Whang in the paper "Information Distortion in a Supply Chain: The Bullwhip Effect"(2000) also published in *Management Science*.

There are two theories and each is supported in the literature for explaining the behavior of subjects in the beer distribution game. This research does not attempt to resolve the issue of these two competing theories; rather it accepts that each of these theories is valid, and that the beer distribution game can be used as a platform to test the effect of implementing new information technology on a simulated organization.

Previous studies of information technology as an agent of organizational change, as well as theories on organizational routines, suggest that the alignment of the mental models with organizational structure is critical to the implementation of information technology. This theory can be tested through the implementation of information technology in the beer distribution game. By implementing information technology without any attempt to align the mental models - and therefore the behavior - of the participants with the new organizational structure, the research can test the hypothesis that mental model/structural alignment is critical in the implementation of information technology. I choose to use the beer distribution game as an initial proxy of organizations for several reasons. Previous studies have modified the beer distribution game to study the performance of subjects in a simulated supply chain environment. Studying the effect of implementing information technology in an organization is difficult in an experimental setting. Organizations are complex and can be likened to living organisms, in that they have predictable patterns of behavior that are characterized by stages of development (Quinn, 1983). Like living organisms, organizations experience birth, growth, maturity, and death (Sutton, 1987). It is difficult to conduct controlled experiments within an organization. The goal of organizations is performance, while the goal of experiments is learning these divergent goals of performance and learning make conducting controlled experiments difficult.

There is a commonly held misconception that the Hippocratic Oath begins "First, Do No Harm" (Records, 2006). While this is not, and apparently has never been, part of the Hippocratic Oath, it is nevertheless a useful construct for researchers and consultants. Changing variables in a meaningful way and then studying the effect on the organization is not generally acceptable. That is why this research is to study the effect of implementing information technology first through the beer distribution game, by modifying the game with the simulated implementation of information technology. Armed with what I learned in the implementation of information technology in the beer distribution game I can study the unanticipated effects of implementing information technology in a real organization.

EXPERIMENTAL DESIGN

There is a rich history of using the beer distribution game as a simulated model of supply chain dynamics. This research differs from the previous work in two key aspects. Previous work has been used to study the behavioral factors that contribute to the bullwhip effect. This research used the bullwhip effect as a measure of organizational performance and studied the impact of information technology on the simulated organization. Second, previous research on the impact of information sharing on the organization has focused on the benefits of information sharing up and down the supply chain. This previous work has studied information sharing in systems that are in equilibrium. This research studied the effect of information sharing on a system that is not in equilibrium, and is in fact experiencing instability. This is not inconsistent with the fact that information technology is frequently implemented during the growth, maturity, and decline life cycles of an organization, life cycles often characterized by instability.

The standard protocol for playing the beer distribution game is well documented and is available from the System Dynamic Society. The subjects in this research played the game in the standard fashion, exactly following the standard game instructions. At week 20 the lead facilitator paused the game and made one change to the playing process. At week 20, the facilitator divided the teams playing the game into two groups. The first group was told that no change was being made to their play of the game. The second group was told that a change was being made to their game play. The following script was read to all participants.

SCRIPT – At this point, we will be making a small change to the game. The "owners" of the supply chain have decided to implement information technology in order to improve the performance of the distribution system. This information technology will eliminate the information delays in the ordering system. Customer orders are not part of the distribution system, and arrive in some distribution over the week. Orders from the retailer, wholesaler, and distributor are batched and sent up the supply chain weekly. As before, customer orders will still be placed on the board face down. From now on, you will place your orders placed slips in the orders placed box with the number of cases ordered face up. This will enable all of your supply chain partners to know how many cases have been ordered at each level in the supply chain. You may use this additional information in placing your orders. Also, as before, you will not be allowed to discuss this information with the other participants.

After the script was read and any questions regarding this change answered, the players in the second group were instructed to mark IT on their record sheet. This was used later to ensure that I was able to separate the teams with IT from the teams that did not implement IT. Play resumed with week 21. Play continued through week 40 with the game being stopped at the end of the 40th week. The record sheets were collected and the standard post game debrief was completed.

There were several hypotheses tested with the beer distribution game experiments. The first hypothesis was simply that the performance of the teams that implemented information technology would be better than the performance of the teams that did not. This hypothesis was tested by comparing the performance of the teams that implemented information technology against the teams that did not implement information technology.

The second hypothesis was that implementation of information technology would reduce the bullwhip effect. The bullwhip effect is the oscillation and amplification of orders up the supply line from the retailer to the factory. The oscillation and amplification in the teams were measured and then the results of the teams that implemented information technology were compared to the results of the teams which did not.

The third hypothesis was that subjects who implemented information technology would no longer under-weigh the supply line. Recall that Sterman (Sterman, 1989b) first identified under-weighing the supply line as a contributing factor to the poor performance of players. Under-weighing the supply line is defined as the failure of the players to account adequately for the stock that has already been ordered, but not yet been received, when making stock-ordering decisions.

The fourth hypothesis was that the results of the teams that did not implement information technology would be comparable to the results of Sterman's trials first documented in 1989. (Sterman, 1989b) Sterman estimated four key parameters of performance when he completed his research in the 1980s. This research estimated the same parameters of performance for the contemporary trials, and compared the results to Sterman's original studies. This comparison was done as a control to compare the performance of subjects of this research with the subjects of Sterman's earlier work.

Finally, the fifth hypothesis was that the teams that did implement information technology would not be comparable to Sterman's trials, This hypothesis was tested in the same way as the fourth hypothesis.

Hypothesis 1

Hypothesis 1 – *the performance of teams will improve with the implementation of information technology*. The standard protocol for measuring performance of teams in the beer distribution game is total team cost. This standard metric was used as a measure of team performance. In completing his 1989 study of the beer distribution game, Sterman simulated the game and noted that the optimal team cost for the game is $204. However, the average cost for his participants was $2028 (Sterman, 1989b). Sterman's study began with 48 teams and 192 subjects. During the play of the game, there were several chances for subjects to make errors in calculating their effective inventory. As noted before, play of the game is hectic and the pace of play can be quite brisk. Subjects who have large quantities of beer in the pipeline can make errors in simply counting the quantity of beer that is in the inventory. Additional calculation errors can be made when subjects are filling orders and backlogs. Sterman eliminated from his study teams where subjects experienced calculation errors, reducing the number of trials from 44 to 11. As previously noted, many later studies used computer simulations to eliminate this administrative burden and the subsequent counting and calculation errors. The beer distribution game is played as part of the ENGR 5104 Applied Systems Engineering Course at Virginia Tech in order to immerse the students in the dynamic system experience. The game is played on the standard board game, and it was this game that was modified for this research to study the implementation of IT.

None of the teams had a perfect record of calculating their effective inventory. The model was built for this research to calculate the effective inventory based on the orders placed within the supply chain and to compare it to the effective inventory as recorded by the participants. This variation was significant in some cases. As noted, there was a precedent to eliminate records of teams that failed to calculate their inventory accurately. However, eliminating these teams would have eliminated all of the data collected for this research. In order not to drop all data, the studies in this research were completed using the calculated data. The data collected is included in Appendix 3 of this document, along with the model that simulated the play and calculated the effective inventory of each player. It was assumed that recording the order placed was an easier task than recording the effective inventory, and required no counting or computation therefore it was a more accurate reflection of the actual position of each player in the game. The model assumed that this data was correct and calculated the effective inventory and supply lines of each player in the trial based on the recorded orders placed[3].

The first hypothesis was tested by doing a number of comparisons. The first comparison was a comparison of the teams with IT (Test Group) against the teams without IT (Control Group) over the entire 40-week period of play. The second comparison was a comparison of the Test Group (with IT) against the Control Group (without IT) over the first 20 weeks of the test. This comparison was done to investigate whether there was a significant difference between the Control Group and the Test Group that is not explained by the introduction of IT. A third comparison was the Test Group

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[3] Immediately after one set of trials, it was noted that one player in the retail position recorded orders placed that exactly matched the known demand pattern of the customer. When the player was questioned about the ordering pattern, she was unable to explain how the ordering decision was made. When reviewing the model behavior for that trial, it appears that the player did not accurately record the orders placed, and it is hypothesized that she recorded the orders received.

against the Control Group over the final 20 weeks of play. This test complements both of the prior comparisons. Comparison of the Test and Control Groups was done using the Mann-Whitney U test as detailed by Siegel (1956). The Mann-Whitney U test is a non-parametric test that may be used to compare two independent groups. The test is used to compare the median of two sample populations. The null hypothesis is that the two samples are drawn from a single population, and therefore the medians are equal. The Mann-Whitney U test only requires that the two samples be independent, and the observations be continuous. Croson and Donohue (2003) use the Mann-Whitney U test to compare results in their study of the value of information sharing in a supply line. Table 4 highlights the tests being used for Hypothesis 1.

Table 2 Hypothesis 1

Comparison	**Period of Comparison**	**Question being answered**	**Statistical Test**
Control Group vs. Test Group	40 weeks – 40 weeks	Did IT improve Performance?	Mann-Whitney U Test
Control Group vs. Test Group	1st 20 weeks – 1st 20 weeks	Is there a performance difference not explained by IT?	Mann-Whitney U Test
Control Group vs. Test Group	2nd 20 weeks 2nd 20 weeks	Did IT improve performance?	Mann-Whitney U Test

Hypothesis 2

Hypothesis 2 – *Implementation of IT will reduce the bullwhip effect*. In order to test this hypothesis I defined the bullwhip effect as an increase in magnitude of orders from node to node. That is, I compared the average variance between the retailer and wholesaler; wholesaler and distributor; and distributor and factory over the course of the experiment to determine whether the implementation of information technology impacted the bullwhip effect. The evaluation was done using the sign test, a non parametric test detailed by Siegel (1956) and also used by Croson and Donohue to test for a reduction in the bullwhip effect (Croson, 2003). The test is simple and has only one underlying assumption, which is that the variable under consideration has a continuous distribution. Following Croson and Donohue, I defined an increase in the variance of orders from role to role as a success, and a decrease in this variance as a failure. The results of these tests were compared across the Control and Test Groups using the sign test along with the Mann-Whitney U test as with Hypothesis 1. Table 5 illustrates this comparison.

Table 3 Hypothesis 2

Comparison	**Period of Comparison**	**Question to be answered?**	**Statistical test used**
Control Group vs. Test Group	40 weeks – 40 weeks	Does the implementation of IT reduce the bullwhip effect?	Sign Test; Mann-Whitney U Test
Control Group vs. Test Group	1st 20 weeks – 1st 20 weeks	Is there a difference in the bullwhip effect across groups not explained by IT?	Sign Test; Mann-Whitney U Test
Control Group vs. Test Group	2nd 20 weeks – 2nd 20 weeks	Is there a difference in the bullwhip effect across groups not explained by IT?	Sign Test; Mann-Whitney U Test

Hypothesis 3

The third Hypothesis tested with the beer distribution game experiment was:

Hypothesis 3 – *subjects will no longer under-weigh the supply line with the implementation of information technology*. Sterman's (Sterman, 1989b) research demonstrated that the bullwhip effect present in the beer distribution game was due to two factors. The first factor is that the subjects anchored their inventory to the initial inventory with which they began the game with. The second factor is the failure of subjects to fully weigh the supply line in their ordering process. The implementation of information technology should increase subjects' knowledge of materials on order, and this knowledge of materials on order may also translate to increased awareness of materials in the supply line. Ideally, participants should equally weigh their supply line and their inventory. Sterman interprets β "…as the fraction of the supply line taken into account. If $\beta = 1$, the subjects fully recognize the supply line… If $\beta = 0$, goods on order are ignored" (Sterman, 1989b, p. 332). I used the participants' regression estimates to evaluate whether the implementation of information technology improved the performance of the subjects in this area. I compared the two populations by evaluating the regression equation for values of β. Then, to complete the analysis, I used the Mann-Whitney U test to compare the populations, as was done in evaluating the first two hypotheses. Table 6 illustrates the analysis of Hypothesis 3.

Table 4 Hypothesis 3

Comparison	**Period of Comparison**	**Question to be answered**	**Statistical tests used**
Control Group vs. Test Group	40 weeks – 40 weeks	Does the implementation of IT eliminate the under-weighing of the supply line?	Regression analysis & parameter equation significance Mann-Whitney U Test
Control Group vs. Test Group	1st 20 weeks – 1st 20 weeks	Is there a difference in the under-weighing of the supply line not explained by IT?	Regression analysis & parameter equation significance Mann-Whitney U Test

Comparison	Period of Comparison	Question to be answered	Statistical tests used
Control Group vs. Test Group	2nd 20 weeks – 2nd 20 weeks	Is there a difference in the under-weighing of the supply line not explained by IT?	Regression analysis & parameter equation significance Mann-Whitney U Test

An important consideration in completing the analysis of the beer distribution game was to understand why the players made the ordering decision they made. Previous research in this area has included post-game surveys of the players' decision process. A survey was developed to elicit this information from the players in this research. I recorded 19 trials with approximately 76 subjects participating. The number of subjects is at least 76; however, on several occasions, I had two players in one position in order to accommodate an uneven number of students participating in the experiment. To date, 37 of the subjects have completed the survey of their decision process. The survey questionnaire, the approval letter from the Institutional Review Board (IRB), the detailed explanation of the questions, and the current survey results are included in Appendix 4 of this document.

Sterman theorized that orders were based upon an anchoring and adjustment heuristic and participants under-weighing the supply line. Does this heuristic explain the behavior of the participants in my study? In order to test this question, Sterman's data was obtained from the author. This data, along with the program Sterman used to simulate the beer distribution game, are included in Appendix 5 of this document. Sterman estimated four parameters to explain the behavior of his participants. I have the record of his results, published in 1989, along with his original data. I duplicated his estimation procedure in order to compare the results of my trials against his. This leads to my next hypothesis:

Hypothesis 4

Hypothesis 4 – *The estimated parameters of my trials without IT will be comparable to Sterman's parameter estimations*. It was assumed that players with similar knowledge and experience had similar results when exercising the same simulation under essentially unchanged conditions. In order to test this hypothesis I compared the results from my Control Group to Sterman's directly using the Mann-Whitney U test. In addition, I compared my data directly to the optimal parameters as identified by Sterman (1989b).

In his 1989 paper, Sterman estimated the parameters θ, α_s S', and β, using a grid search subject to a number of constraints. These constraints were:

$$0 \le \theta \le 1. \quad \alpha_s, S', \beta \ge 0.$$

Finally, he estimated θ to the nearest 0.1, α_s to the nearest 0.05, β to the nearest 0.05, and S' to the nearest 1.0 units (Sterman, 1989b). There were probably a number of reasons that Sterman limited his search to these parameters, not the least of which was the capability of computers and software in the late 1980s when he completed this research. In completing the research today, I was able to use more sophisticated computational tools than those available in 1989. In order to compare the data from my research to the data from Sterman's 1989 research accurately, I obtained the raw data from Sterman's research and used the same estimation techniques on Sterman's original data as I used on my data. The original data, as well as the results of this comparison, are available in Appendix 5. Table 4 is an illustration of the summary data for Sterman's Budweiser Team trial. From this data, I saw that by using the Standard Evolutionary Solver to minimize the variance between the actual orders from the data, and the predicted orders from the model, in noticeable improvements in the results were possible.

Table 5 Sterman Trial Budweiser

Trial	**Budweiser**			
Grid Search Estimates	*Retailer*	*Wholesaler*	*Distributor*	*Factory*
$\Sigma (AO\text{-}Ot)^2$	2529.500	2728.936	3521.890	444.373
Standard Evolutionary Solver	*Retailer*	*Wholesaler*	*Distributor*	*Factory*
$\Sigma (AO\text{-}Ot)^2$	544.223	237.734	355.402	182.536
Variance	1985.277	2491.201	3166.488	261.837
Percent Improvement	78%	91%	90%	59%

Table 6 summarizes the variance and percent improvement for all of the eleven trials from the original Sterman data. Overall, the improvement using the solver techniques is noticeable, and would certainly result in distortion of the results if I evaluated the outcome of my current trials using the advanced solver techniques against the solutions derived using the Grid Search technique.

Table 6 Sterman Comparison Summary

	Retailer	*Wholesaler*	*Distributor*	*Factory*
Average Variance	703.459	693.440	1008.150	252.528
Average Improvement	52%	47%	50%	27%

Hypothesis 5 – *The estimated parameters of my trials with IT will not be comparable to Sterman's estimation.* It was assumed that implementing information technology would stabilize the system and that the result would be improved performance. In order to test this hypothesis, I compared the estimated parameters of my Test Group to the estimated parameters from Sterman's data. As before, I tested the data for the entire 40 weeks, as well as tested the data for the first 20 weeks- that is, before information technology was implemented. I then compared the data for the final 20 weeks, after implementing information technology. This second test was done to determine if the difference could be attributed to the implementation of information technology. It was assumed that if the data is comparable for the first 20 weeks but not for the full 40 weeks, then the implementation of information technology is responsible for the difference. Table 7 illustrates the analysis of Hypothesis 4, Table 8 the analysis of Hypothesis 5.

Table 7 Hypothesis 4

Comparison	**Period of Comparison**	**Question being answered**	**Statistical Test**
Sterman's parameters *(α,θ,β,S')* vs. Control group parameters	40 weeks – 40 weeks	Are the results of my control groups' similar to Sterman's 1989 trials?	Mann-Whitney U Test

Table 8 Hypothesis 5

Comparison	**Period of Comparison**	**Question being answered**	**Statistical Test**
Sterman's parameters *(α,θ,β,S') vs. Test group parameters*	40 weeks – 40 weeks	Are the results of my test groups similar to Sterman's 1989 trials?	Mann-Whitney U Test

Comparison	**Period of Comparison**	**Question being answered**	**Statistical Test**
Sterman's parameters (*α,θ,β,S'*) *vs. Test group parameters*	40 weeks – 1st 20 weeks	Are the results of my test groups similar to Sterman's 1989 trials before implementation of IT?	Mann-Whitney U Test
Sterman's parameters (*α,θ,β,S'*) *vs. Test group parameters*	40 weeks – 2nd 20 weeks	Are the results of my test groups similar to Sterman's 1989 trials after implementation of IT?	Mann-Whitney U Test

CHAPTER 4: CASE STUDY RESEARCH DESIGN

There is support in the literature for the theory that there are several different factors that impact the performance of subjects managing a supply chain. These factors include behavioral aspects and operational factors. I have studied the performance of a simulated supply chain to understand if the implementation of information technology, a fundamental structural change, has improved performance of the simulated supply chain. A further question needs to be asked: what is the impact of the implementation of information technology in a real world organization? In order to answer this question, a different approach to the research was required. I proposed to take the lessons learned from the beer distribution game experiment to a real world organization where I would conduct a case study using system dynamics tools.

The organization selected for the case study was selected primarily for the availability of information as well as the willingness of the firm to participate in this research. In discussions with the Senior IT management of this firm, I have determined that implementing information technology has created numerous unanticipated effects. The firm is experiencing dynamic challenges in managing its information technology infrastructure in an era of growth and expansion, while at the same time being challenged by the owners to maintain costs at prior period levels, challenges that are shared by many firms today. Information technology is being used in many previously unanticipated ways creating some of the pressures felt by information technology managers.

The proposed plan was to work with the IT management and staff at the case study organization to evaluate the current information technology infrastructure and to develop an understanding of how the infrastructure developed over the past three to five years. This understanding of the current situation could then be developed using system dynamics modeling techniques. Upon developing models of the existing infrastructure, I simulate how the system reacts to various changes to both exogenous and endogenous variables. The plan is to use simulation to enable the researcher and the organization to understand where the leverage points lie in aligning the behavior and structure of the organization. Simulation allows the researcher to study performance and behavior by creating virtual worlds that provide a laboratory-like setting in order to study the effects of changes to variables on system performance and behavior (Sterman, 2000).

Supply chains are specialized types of organizations, or are they? The supply chain depicted by the beer distribution game is one that encompasses several different business models. If I consider the supply chain in terms of the MIT Business Model Archetypes Chapter 2, page 40, it appears obvious that there are at least two of the business models represented, i.e. the factory or brewery is the manufacturer, and it creates a physical asset that is then sold to its customers. The distributor, wholesaler, and retailer clearly fit in the wholesaler/retailer category; they distribute physical assets that are created by others. This simulated supply chain probably only exists in the virtual world. It is a good exercise in learning about organizational behavior, but most beer sold today is not sold through a retail arm of the brewery.

To extend the learning from the beer distribution game simulation, it is necessary to study information technology in a real organization. I will study the information technology at HTS, a professional services firm located in the greater Washington, DC area.[4]

ENTERPRISE BACKGROUND

HTS maintains dozens of offices and has nearly 2,000 employees. Services are provided in a number of practice fields, including program and project management as well as a variety of architectural and engineering services for clients in government, education, and industry.

A privately held firm, HTS was established in 1956 and has a five decade record of growth and success. In the mid 1960s, HTS began using computers for the first time, and in the early 1980s, HTS became one of the first design consultants to embrace widespread use of computer aided drafting and design.

Design-build has become a major practice area for HTS, with the firm's clients benefiting from the increased collaboration between the designer and contractor required in this evolving field. Design-build is typically faster than the traditional design-bid-

[4] The name of the firm has been changed to preserve confidentiality.

build process because it eliminates many of the lead times required in the traditional process. HTS is experienced in working with the building contractor, proceeding through concurrent design and construction phases, and expediting delivery of the final product to the client.

Successful land development requires a strong local knowledge of a regions political, regulatory, and economic conditions. HTS's success in this area is centered on a network of community-based offices that enable their clients to benefit from HTS's experience and local knowledge. Rigorous attention to their client's schedule and budget requirements has led to clients repeatedly turning to HTS for their land development needs.

HTS is using information technology in numerous, previously unanticipated ways. HTS no longer uses draftsmen to create drawings. In fact the first generation of information technology that supported this output, Computer Aided Design and Drafting (CADD), has largely been replaced by new Geographic Information System (GIS) technologies. These new technologies support new tools such as the Building Information Model (BIM). In a traditional architectural drawing, or even in a drawing created using CADD, a door is nothing more than a few lines, arcs, and perhaps a text description. The same door in a BIM can have far more information; it can have the fire rating of the door, information on its construction, even information on the wall the door resides in. All of this information "supports the continuous and immediate availability of high-quality, reliable, integrated, and fully coordinated design data" (T. Wilson, 2006, p. 8). HTS is using information technology to implement their spatial database that provides project members and partners simultaneous access to all project data, including digital imagery data, engineering data, framework data, and other project databases Access to this data is provided through the Internet, eliminating the geographic boundaries that previously restricted collaboration. Email is being used by HTS to communicate with others within the firm, and with professional contacts outside of the firm. These are but a few examples of how information technology is being used at HTS.

Problem Statement

HTS has a consistent record of leadership in the services the firm provides. and its management is determined to maintain that leadership. To maintain this position, HTS is continuing its expansion through acquisition and organic growth into new regional markets. HTS, a leader in innovation, is also continuing to embrace new technologies and business practices that will enable the firm to maintain its reputation for leadership in its markets. HTS is actively pursuing expansion into new geographic markets, and is applying new technologies to improve the service offered to clients while simultaneously aggressively managing costs to maintain the low operating ratios that have been the tradition of the firm.

The problem for the CIO is to effectively optimize the technology to enable dynamic changes in the breadth and depth of the services he provides the firm. HTS is expanding the firm in two dimensions: the services that it provides to its customers and the geographic locations from which it provides these services. The CIO must provide optimal levels of service to the organization, while maintaining existing budget levels.

Moreover, the technology that comprises HTS's infrastructure and that supports HTS's production functions has advanced rapidly over the past decade. At the level of the production employee, i.e. the designer, the surveyor, and even the administrators of projects, information technology has become an indispensable capability of the firm. Today much of the firm's production capacity is only available because of the information technology in place.

Despite this requirement, the mental models of the firm's owners have not evolved to recognize the importance of information technology. Information technology is still cast in a supporting role, one that is considered nice to have, but not essential for the survival of the firm. Rather than seeing information technology as a business enabler, one that is fundamental to the production function of the organization, information technology is still seen as a cost center, where the greatest benefit is achieved through cost reduction, or at the very least cost stabilization. This has led to policies within the firm that have failed to optimize the value of information technology. The CIO has been constrained in managing this resource by financial decisions that have not kept up with the growing importance of information technology.

Case Study Plan

The CIO of HTS provided me nearly universal access to his office for interviews and meetings, and participated actively in general discussions about the issues they face and about the research process. Over a period of several months, we met on numerous occasions, and had several telephone conversations. During these meetings, we discussed the problems faced by the information technology organization at HTS, as well as how the research could benefit the firm. The CIO fully supported the research with access to him and his staff for meetings, interviews, and working sessions.

I spent several months working with the IT organization at HTS to complete my research. The process that was followed is outlined in *Business Dynamics* (Sterman, 2000) and is an iterative process.

Problem Articulation

Sterman leads off his overview of the modeling process description with a number of “what questions” that he suggests are appropriate for defining the initial problem. “What is the issue the clients are most concerned with?” “What problem are they trying to address?” “What is the purpose of the model?” The answer to these questions helped to establish the plan for my research.

1. What is the issue the client is most concerned with? HTS is concerned with their ability to provide increasingly effective information technology services to a company expanding geographically, while at the same time maintaining costs on a per capita basis. Geographic expansion includes the expansion of the firm both organically and through acquisition of other professional service firms.

2. What problem are they trying to address? HTS is trying to address the problem of technology creep, along with the expansion of geographic locations, while maintaining costs. Ownership has a long held vision of keeping overhead costs low, maintaining them at a specific per capita amount. The CIO would like to better understand how they got to their current situation and what their leverage points are

in order to improve performance. One area that is a valuable measure of the information technology department's performance is the service ticket backlog, and the delivery delay or response time for service tickets.

One capability they are interested in is demonstrating to the owners how various investment and operational decisions impact the performance and cost of the information technology infrastructure.

3. What is the purpose of the model? The purpose of the proposed model is to understand the structure of the information technology infrastructure; to identify and clarify relationships among the many components of the infrastructure; to identify leverage points in managing the infrastructure; to communicate to stakeholders the expected impact of various decisions; and to illustrate to the senior management and ownership of the firm the full role and impact of the information technology infrastructure of the firm.

Next Steps

Meetings with the CIO and information technology staff proceeded as key variables, reference modes and time horizons of the problem were identified. These meetings were used to develop dynamic hypotheses explaining the problem behavior. The process of modeling the problem at HTS follows the iterative modeling process in *Business Dynamics*, Chapter 3 (Sterman, 2000). Table 9 highlights some of the questions that are asked as the researcher/consultant and client work through the modeling process.

Table 9 System Dynamics Modeling Process (Sterman, 2000)

Step	**Questions**
1. Problem Articulation	
• Problem identification	What is the problem? Why is this a problem? What is the impact of this problem on organizational performance?
• Key Variables	What are the key variables affecting this problem? Are there other concepts that must be considered? Behavior over time of the key variables?
• Time Horizon	How long has this been a problem? How far into the future must we plan for? Behavior over time of the problem?
• Dynamic Problem Definition	What is the issue? What problems are we trying to address? What is the purpose of the model? Are the proposed answers adequate?
2. Formulate Dynamic Hypothesis	
• Initial hypothesis	What are the initial theories which explain this problem? What are the relationships among the key variables? Are these relationships specified by experts? Supported by literature?

Step	Questions
• Endogenous focus	What are the endogenous factors that contribute to this problem?
• Boundary diagrams	Which variables are endogenous? Which variables are exogenous? Are they really exogenous factors, or is my model boundary too narrow? Which variables are excluded? Why?
• Subsystem diagrams	What are the subsystems? What is the structure of the problem?
• Causal loop diagrams	What is the feedback structure? What are the causal links among the variables?
• Stock and flow diagrams	What is the physical structure? What are the accumulations in the system? What are the delays in the system?
3. Formulation of simulation model	
Specification	What are the initial conditions? What are the relationships between variables? What are decision rules?
Estimation	What are the values of the parameters? What are the behavioral relationships between the variables?
Tests	Test the model for consistency with the purpose of the model, and the boundary conditions of the model.

Step	Questions
4. Testing	
Comparison to reference modes	Does the model reproduce the problem behavior?
Robustness under extreme conditions	When stressed by extreme conditions does the model behave appropriately?
Sensitivity	How does the model behave given uncertainty in variable estimation? Relationships of the variables? Other estimated/unknown values?
5. Policy Design and Evaluation	
Scenario Specifications	What scenarios might we use this model to explore?
Policy Design	What policies, strategies, or structural changes might improve the problem performance?
What if	What happens in the model if we implement these policies?
Sensitivity analysis	How robust are the new policies given uncertainties in the model conditions?
Policy interactions	Are there emergent properties when implementing the policies? Are they favorable? Unfavorable?

The five steps described in **Error! Reference source not found.** and Table 9 are the system dynamic modeling process. The value of models is that they create a virtual world, which enables a richer understanding of the underlying structure and assists in the development of policies that improve organizational performance. Modeling the problems experienced by HTS has two benefits. The first benefit is clearly to HTS developing a richer understanding of the system structure and behavior enables the management of HTS to manage the organization more effectively. The second benefit is to the researcher. Specifically, I hypothesized that the unanticipated behavior of organizations when implementing information technology is a result of the misalignment of the behavior (mental models) and structure of the organization. By studying the information technology at HTS through system dynamic models, I can deepen the understanding of this alignment, and contribute to the theory of introducing information technology in organizations.

The MIT Business Model Archetypes provide a taxonomy that categorizes organizations according to two dimensions: what type of asset is sold, and how much is the asset transformed by the organization. Weil, Malone, D'Urso, Herman and Woerner (Weill, 2004) concluded that this model was a useful taxonomy that enabled comparison of different business models. It was my plan to extend the usefulness of the taxonomy, by using it as a guide to generalizing my research. The MIT archetypes classify the organization based on its underlying structure. A final step in my modeling of HTS was to use the methodology developed at MIT to categorize the business model of HTS.

Generalizations

I have observed that when organizations implement information technology, they frequently don't get the desired or expected results. There is little in the literature to explain why these unanticipated results occur so frequently. I propose to study this phenomenon specifically with an experimental simulation of a supply chain using the beer distribution game. Further case study research at HTS will explore the dynamic structure of the information technology infrastructure. The information from this model will be most applicable to HTS as they develop new policies to deal with the problems of information technology implementation; however, the learning from this model will not be limited to HTS. Using the MIT taxonomy immediately reveals a direct comparison between HTS and other organizations with the same business structure. I don't propose that the model developed at HTS will predict the future behavior of HTS; rather the model will provide HTS management with a better understanding of the underlying structure of the information technology supporting the organization. The intention is not to develop a model that can be approximated to fit other organizations, but rather one that can provide a useful approach for managers to asses their own organization and develop strategies for their future implementation of information technology.

CHAPTER 5: EXPERIMENTAL RESEARCH RESULTS

BEER DISTRIBUTION GAME EXPERIMENT

The research described in the previous chapter was completed over several months. The initial studies using the modified beer distribution game were begun in September 2005 with the Fall Semester Engineering 5104 class at Virginia Tech. The standard beer distribution game protocol is normally used for playing this game in this class. However, the class instructor, Dr. Kostas Triantis, agreed to allow me to conduct the experiment in his class. Later, the game was played in additional classes at Virginia Tech, an additional session was played in Manassas, Virginia, and a final session was played as part of a course offering at Georgetown University for employees of the Food and Drug Administration.

The players in all sessions were informed that the results of the play were being used in this research. Each trial required a minimum of four subjects in order to accommodate all students. In some of the classroom settings an additional fifth participant was included in some of the trials. This fifth participant shared the duties of the person playing the factory position in that specific trial. A total of 19 trials were played over the course of four months in the autumn of 2005 and the spring of 2006. Of the 19 trials, 9 teams were the control group and played the game without the implementation of information technology. The other ten teams played the game with the modification of having information technology implemented at the end of week 20.

Initially, I expected that by implementing information technology in the game, I would see improved performance of the teams that had implemented information technology. Remember that the participants were all told that this was a competition and that the goal of each player was to optimize the performance of his or her team. Although I did not offer a financial incentive as prescribed by John Sterman in his 1989 paper(Sterman, 1989b), players were clearly engaged in the competition.

When the game play had proceeded to the end of the 20th week, game play was momentarily stopped and the announcement was made to all players that approximately half of the teams would be implementing information technology. The teams were randomly selected to implement information technology, with one exception which is discussed later in this dissertation. The players who were not selected to implement information technology in the game routinely objected to not being selected, saying that this wasn't fair and that the teams with IT would have an unfair advantage. This belief that information technology would provide performance improvement closely mirrored the hypothesis I was testing with the game.

The one exception to the random selection of teams implementing information technology was made in a class at the Virginia Tech Pamplin School of Business. By week 20 one team had clearly demonstrated that they had little understanding of the game. Normally the game is played with bingo chips, with one chip representing one case of beer. Frequently, this leads to large quantities of bingo chips in inventories and in shipping delays. In order to facilitate larger quantities of beer, pennies were used to represent 10 cases of beer, and nickels were used to represent 50 cases of beer. The team that was specifically excluded from implementing information technology had driven their inventory to unparalleled heights, and was forced to use additional Post-it® notes to record their inventory, as there were not enough nickels in the room to meet their demand. The results from this team were eliminated from the study in their entirety because they were such an obvious outlier. This study is based upon the results from 10 teams that implemented information technology, and 8 teams that did not.

Hypothesis 1

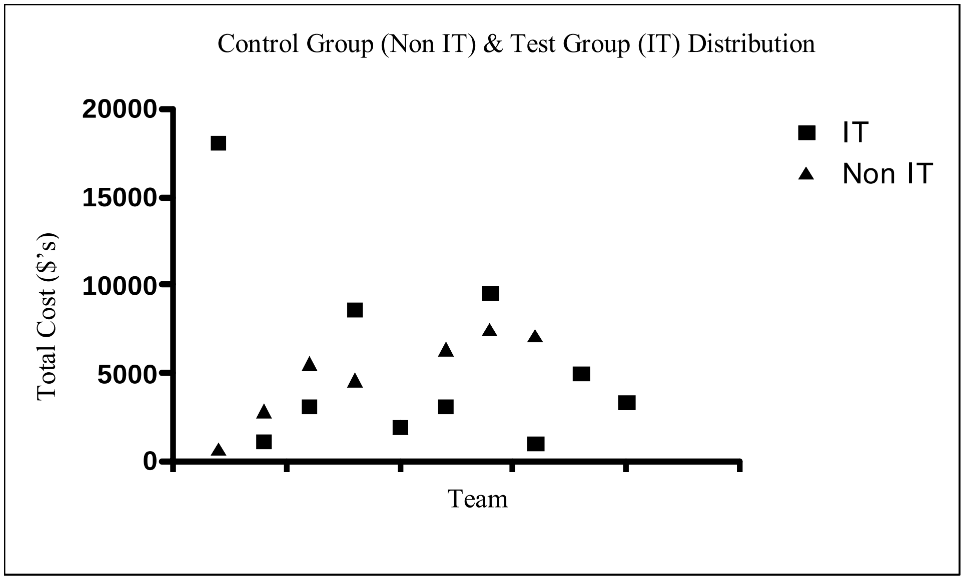
The experiment was conducted in order to research several specific hypotheses. The first hypothesis was that the performance of teams would improve with the implementation of information technology. This assumption mirrors the attitudes of many in the world today, that implementing information technology will automatically improve performance. This belief was reflected by the participants who objected when they were not selected to implement information technology. In analyzing the results of the play, I studied this hypothesis in several ways. The standard measure of performance in the beer distribution game is the total cost of the team, and I used this measure in my study. If implementing information technology improved performance, I should have seen an improvement in the overall score of the teams, with the teams implementing information technology having a lower overall cost than the teams without information technology. Summaries of team performance are shown in the next several tables. Table 10 summarizes the performance of each of the teams for the entire 40 weeks. The name of the team is listed, along with the total cost incurred by the team for the 40 week trial. Teams are grouped in columns by whether they implemented IT or not. Teams are listed alphabetically within the column.

Table 10 Test Group - Control Group 40 Weeks

40 weeks			
Test Group		Control Group	
Team Name	**IT**	**Non IT**	Team Name
Bira	18,020.00	707.50	#1
Black Label	1,160.50	2,888.00	Big Bass
Frosty 2	3,164.50	5,571.50	Frosty
Guinness	8,590.50	4,597.50	Hires root beer
Guinness 2	1,927.00	1,936.00	Napoly
Guzzlers	3,143.50	6,355.00	Northeast
Heineken	9,502.50	7,473.00	Root 66
Lonestar	1,055.00	7,126.50	Shiner
Lonestar 2	4,972.50		
Miller	3,391.00		

Figure 3 is a visual depiction of the team performance for the entire 40 weeks. This figure charts the distribution of the data The control groups are the teams that did not have IT, the test groups are the teams with IT. The control group teams are represented by solid triangles, and the test group teams are represented by solid squares. The y-axis represents the total cost of each of the teams, the teams are distributed evenly along the x-axis.

Figure 3 Control Group - Test Group 40 weeks



The following table, Table 11 is the summary of the data from the comparison of the control group and the test groups for the first 20 weeks, before information technology was implemented. Again, the chart displays the team name, and the teams are grouped by whether they implemented information technology or not. The teams and are listed alphabetically. The cost listed in this chart is the cost the teams incurred in the first 20 weeks of play, before any teams had implemented information technology.

Table 11 Test Group - Control Group 1st 20 weeks

1st 20 weeks			
Test Group		**Control Group**	
Team Name	**IT**	**Non IT**	Team Name
Bira	1,855.00	372.00	#1
Black Label	405.00	1,040.00	Big Bass
Frosty 2	1,277.00	1,765.50	Frosty
Guinness	2,059.00	810.50	Hires root beer
Guinness 2	778.00	1,078.00	Napoly
Guzzlers	1,433.50	862.00	Northeast
Heineken	2,055.50	766.00	Root 66
Lonestar	462.50	1,148.00	Shiner
Lonestar 2	1,819.00		
Miller	1,100.50		

Figure 4 is a visual depiction of the same data, test group vs. control group for the first 20 weeks. This figure charts the distribution of the data The control groups are the teams that didn't have IT, the test groups are the teams with IT. The control group teams are represented by solid triangles, and the test group teams are represented by solid squares. The y-axis represents the total cost of each of the teams, the teams are evenly distributed along the x-axis. The distribution is for the costs incurred during the first 20 weeks of play, prior to the implementation of information technology.

Figure 4 Test Group - Control Group 1st 20 weeks

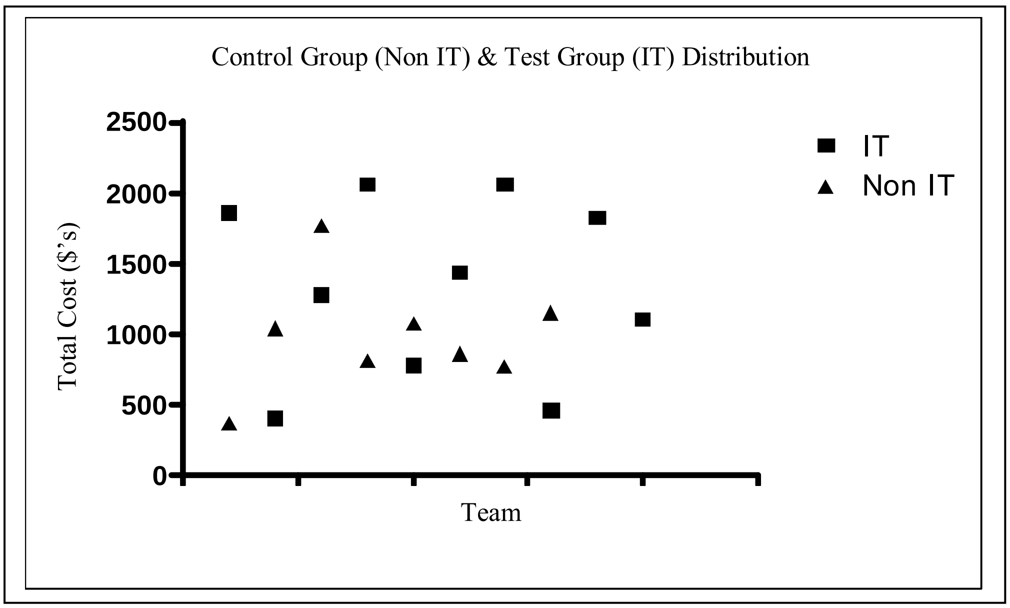


Table 12 is the summary data comparing the performance of the control group and the test group for the final 20 weeks of game play, after information technology was implemented.

Table 12 Test Group - Control Group 2nd 20 weeks

2nd 20 weeks			
Test Group		Control Group	
Team Name	**IT**	**Non IT**	Team Name
Bira	16,165.00	335.50	#1
Black Label	755.50	1,848.00	Big Bass
Frosty 2	1,887.50	3,806.00	Frosty
Guinness	6,531.50	3,787.00	Hires root beer
Guinness 2	1,149.00	858.00	Napoly
Guzzlers	1,710.00	5,493.00	Northeast
Heineken	7,447.00	6,707.00	Root 66
Lonestar	592.50	5,978.50	Shiner
Lonestar 2	3,153.50		
Miller	2,290.50		

Figure 5 is the graphical representation of the data for the final 20 weeks of the game.

Figure 5 Test Group - Control Group 2nd 20 Weeks

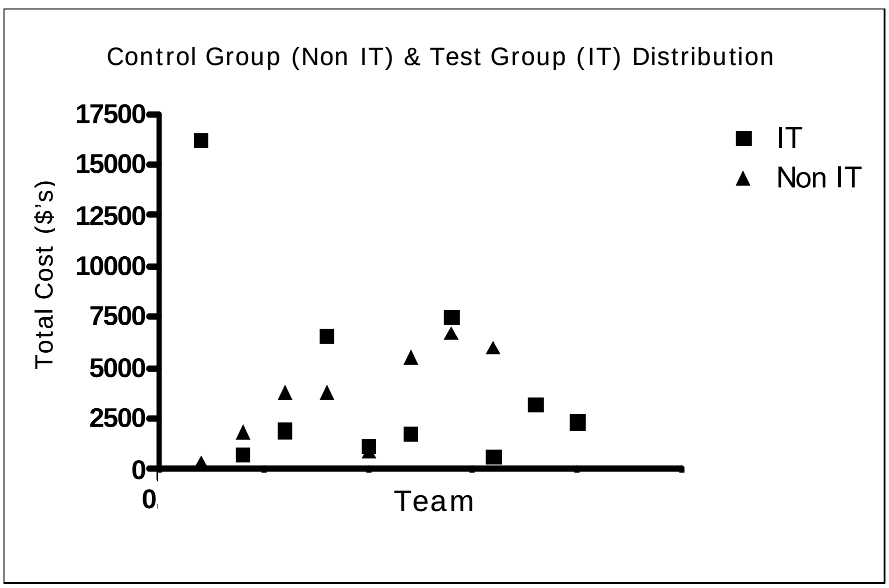


Table 13 lists the three comparisons made in studying the effect of information technology, along with the results.

Table 13 Hypothesis 1 Results

Comparison	Period of Comparison	Question being answered	Result of Statistical Test Mann- Whitney U Test
Control Group vs. Test Group	40 weeks – 40 weeks	Did IT improve Performance?	No statistically significant difference
Control Group vs. Test Group	1st 20 weeks – 1st 20 weeks	Is there a performance difference not explained by IT?	No statistically significant difference
Control Group vs. Test Group	2nd 20 weeks 2nd 20 weeks	Did IT improve performance?	No statistically significant difference

The results of Hypothesis 1 were surprising, but clear. In the experimental population, implementing information technology did not improve overall performance. Hypothesis 1 is rejected.

Hypothesis 2

The second hypothesis proposed was that implementing information technology would reduce the bullwhip effect. The bullwhip effect is described as an increase in order variance from node to node. I compared the variance from retailer to wholesaler, from wholesaler to distributor, and from distributor to factory to determine if the implementation of information technology reduced the bullwhip effect. I used the same statistical protocol that Croson and Donohue (2003) used when they tested for the bullwhip effect in some similar research using the beer distribution game as a research platform (Croson, 2003). The evaluation was done using the sign test as used by Croson and Donohue to test for a reduction in the bullwhip effect (Croson, 2003). The test is simple and has only one underlying assumption, which is that the variable under consideration has a continuous distribution. The results of these tests were compared across the Control and Test Groups using the Mann-Whitney U test as with Hypothesis 1. The results of research on Hypothesis 2 are documented in Table 14.

Table 14 Hypothesis 2

Comparison	Period of Comparison	Question to be answered	Result of Statistical Test: Sign Test Mann Whitney U Test
Control Group vs. Test Group	40 weeks - 40 weeks	Does the Implementation of IT reduce the bullwhip effect?	Yes, implementation of IT reduced the bullwhip effect.
Control Group vs. Test Group	1st 20 weeks - 1st 20 weeks	Is there a differnce in the bullwhip effect across groups not explained by IT?	No, statistically there is no difference in the two groups over the first 20 weeks.
Control Group vs. Test Group	2nd 20 weeks - 2nd 20 weeks	Does the Implementation of IT reduce the bullwhip effect?	Yes, implementation of IT reduced the bullwhip effect.

The results of Hypothesis 2 are somewhat counter to the results of Hypothesis 1. In the first hypothesis, I expected to see an overall performance improvement but did not. In the second hypothesis, I anticipated that one of the causes of the performance improvement would be a reduction in the bullwhip effect. Although I did not see an overall performance improvement, I did see a reduction in the bullwhip effect: teams that implemented information technology had less order variance from node to node when information technology was implemented. Previous research has shown that the bullwhip effect is robust even when players know the customer demand (R. Croson, Donohue, K., 2005; R. Croson, Donohue, K., Katok, E., Sterman, J., 2005), and that information sharing had little value in a two level supply chain simulation (H. Lee, Padmanabhan, V., Whang, S., 1997a).

My research showed that when IT was implemented, there was a statistically significant difference in the occurrence of the bullwhip effect between teams that had implemented information technology and teams that had not. Further review of the data shows that there was no difference in the occurrence of the bullwhip effect between the teams over the first 20 weeks, prior to the implementation of information technology. These results simply reinforce the complexity of the phenomenon being studied. The bullwhip effect was reduced; however, the information sharing had little effect on overall performance. Therefore, Hypothesis 2 is accepted, implementation of information technology reduced the bullwhip effect.

Hypothesis 3

The third hypothesis follows the second, in that Sterman demonstrated that the bullwhip effect was the result of two factors, the initial inventory and subjects under-weighing the supply line (Sterman, 1989b). The third hypothesis of this research was that subjects would no longer under-weigh the supply line with the implementation of information technology. In his research, Sterman developed an ordering rule which he demonstrated simulated the performance of the subjects in the beer distribution game. This rule is given as (Sterman, 1989b):

$$O_t = MAX[0, \hat{L}_t + \alpha_s(S' - S_t - \beta SL_t) + \varepsilon_t] \tag{0.6}$$

Sterman proposed that orders were a non-negative function of the expected sales plus adjustments for the stock in inventory and stock in the supply line. From Sterman's research, β can be interpreted as the fraction of the supply taken into account by the subjects (Sterman, 1989b). Table 15 lists all of the variables in this equation and defines each of them.

Table 15 Equation Variables Defined

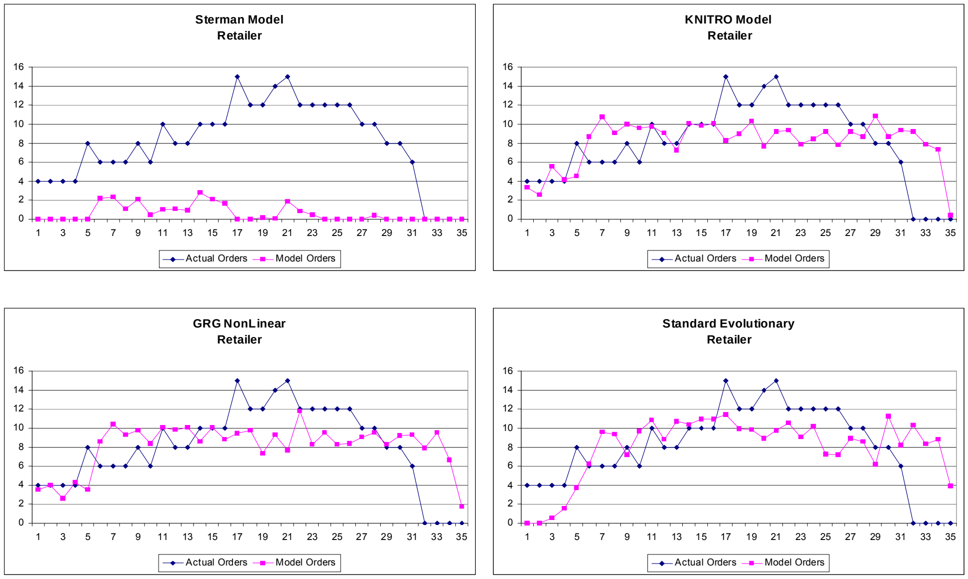
Variable	Meaning
α_s	Orders
$\hat{L}_t$	Expected loss (sales) rate
α_s	Stock adjustment factor, (estimated)fraction of the discrepancy order each period
S'	A function of the desired stock plus B times the desired supply line.

Variable	Meaning
S_t	Current Stock (inventory)
β	Fraction of the supply line taken into account by the subjects.
SL_t	Current Supply Line
ε_t	Additive Disturbance.

In order to test for hypothesis 3, I needed an estimate for β for each of the subjects playing the game. Sterman used a grid search estimation technique(Sterman, 1989b) in order to estimate the parameters of interest in the research. Advances in computer technology allowed the use of an estimation technique that proved to be a bit more powerful than the original. In order to test for Hypothesis 3, it was desirable to build upon Sterman's work; therefore, the data from his original research was obtained from Sterman to be used as a comparative tool.

In order to solve equation 1.1, I selected the GRG nonlinear Solver as implemented by Frontline Systems in their Premium Solver package. The Premium Solver package includes several nonlinear software algorithms. I ran the model using several different algorithms: KNITRO Solver, Standard Evolutionary Solver, and the Standard GRG (Generalized Reduced Gradient) nonlinear Solver but selected the GRG nonlinear package because it provided comparable results to the other solvers, and required significantly less time to process a solution. The following figures are graphical representations of the output from the various solver solutions I tested. Each of the graphs documents the actual orders placed, and the orders placed using the parameters estimated by either Sterman's grid search technique or one of the Solver techniques used. The first graph documents the actual orders compared to Sterman's grid search technique. The second graph compares the same data with the solution set using the KNITRO model to estimate the parameters. The third graph compares the actual data with the data developed using the GRG nonlinear Solver. The final graph represents the solution set developed by the Standard Evolutionary Solver compared to the actual data. The data for this came from Sterman's Budweiser Trial, and these all represent the retailer's position.

Figure 6 Solver Comparison



As can be seen from the graphs, each of the models clearly surpasses the estimates made using the grid search technique. The solution sets were developed by minimizing the square of the differences between the orders from the actual data, and the model orders using the estimated parameters from the model.

$$\sum (AO - O_t)^2 \tag{0.7}$$

The full model sets are included in Appendix 3 of this document. Table 16 is the full solution set for the Budweiser Trial highlighted graphically above. Each of the cells shows the sum of the difference squared, $\sum (AO - O_t)^2$, for the position indicated in the far left column, using the estimation technique indicated in the top row.

Table 16 Budweiser Solution Set all Estimation Techniques Used

Trial & Position	Estimation Technique			
Budweiser	Grid Search	KNITRO Solver	Standard Evolutionary	Standard GRG Non Linear
Retailer	2,529.50	490.35	544.22	473.62
Wholesaler	2,728.94	150.42	237.73	191.19
Distributor	520.95	406.95	355.40	350.17
Factory	444.37	192.79	182.54	204.12

The following table, Table 17, shows the estimates for the four parameters from the Budweiser beer trial for the Standard GRG nonlinear Solver and for the Grid Search estimates. The estimates are considerably different when comparing the two estimation techniques, and the Standard GRG estimates appear to be much more precise. This additional precision is because the grid search technique estimated the parameters θ, α_s, β, S' to the nearest 0.1, 0.05, 0.05, and 1 units respectively. (Sterman, 1989b)

Table 17 Budweiser Trial Standard GRG Comparison with Grid Search

	Standard GRG Non Linear Solver					Grid Search Parameter Estimates			
Trial & Position	θ	α_s	β	S'		θ	α_s	β	S'
Budweiser									
Retailer	0	0.489	0.027	20		0	0.4	0.1	7
Wholesaler	0.629	0	0	0		0	0.4	0.75	30
Distributor	0.464	0	0	0		0.15	0.05	0.35	14
Factory	0.769	0.322	0.013	9		0.25	0.25	0.1	9

In order to complete an analysis of the Hypothesis 3, it was first necessary to complete the regression estimates for each of the positions in each of the trials. I used the Standard GRG nonlinear model to develop these solutions. The following tables display the regression estimate, and the parameter estimates for all of the data trials for the entire 40 week test period. The first table is the estimates for the ten trials that implemented information technology. The second table is for the eight trials that did not implement information technology. All data was compiled using the Standard GRG nonlinear Solver.

Table 18 Regression Estimates - Teams w/IT

Trial & Position		***Standard GRG nonlinear Solver***			
	Σ (AO-Ot)2	**θ**	**α_s**	**β**	***S'***
Bira [IT]					
R	3,148.93	0.09	0.70	0.00	18.56
W	18,274.71	1.00	1.00	0.00	17.49

Trial & Position		*Standard GRG nonlinear Solver*			
	Σ (AO-Ot)2	**θ**	**α_s**	**β**	***S′***
D	78,660.57	1.00	1.00	0.00	24.31
F	30,472.35	0.76	0.10	1.00	0.00
Black Label [IT]					
R	406.40	0.00	0.56	0.13	19.98
W	883.92	0.71	0.08	0.75	22.76
D	458.75	0.87	0.11	0.12	21.43
F	1,434.11	0.00	0.26	0.00	38.39
Frosty 2 [IT]					
R	129.94	0.36	0.15	0.26	52.94
W	1,295.27	0.71	0.12	0.03	29.28
D	1,654.38	1.00	0.00	1.00	0.00
F	8,730.01	0.27	0.81	0.00	17.30
Guinness [IT]					
R	264.60	0.34	0.08	0.00	100.00
W	556.10	0.40	0.94	0.00	12.36
D	1,678.13	0.84	0.53	0.00	10.64
F	1,901.53	1.00	1.00	0.00	16.70
Guinness 2 [IT]					
R	1,363.80	0.01	0.49	0.10	21.00
W	3,229.75	0.00	0.52	0.06	21.00
D	2,937.35	1.00	0.56	0.00	18.00

Trial & Position		*Standard GRG nonlinear Solver*			
	Σ (AO-Ot)2	**θ**	**α_s**	**β**	***S′***
F	18,479.48	0.80	0.23	0.15	28.40
Guzzlers [IT]					
R	310.48	0.98	0.00	0.14	100.00
W	1,101.41	0.58	0.12	0.00	5.02
D	1,438.30	0.42	1.00	0.00	0.00
F	1,928.53	0.60	0.01	1.00	0.00
Heineken [IT]					
R	273.85	0.61	0.37	0.00	18.00
W	1,897.33	0.25	1.00	0.00	22.07
D	49,054.86	1.00	1.00	0.09	22.56
F	41,823.26	0.28	0.79	0.00	43.37
Lonestar [IT]					
R	138.14	0.00	0.31	0.00	27.00
W	238.04	0.00	0.09	0.00	88.24
D	370.02	0.00	0.09	0.00	82.54
F	298.14	0.82	0.45	0.87	18.06
Lonestar 2 [IT]					
R	671.79	0.01	0.99	0.17	17.36
W	1,294.88	0.55	0.11	0.22	4.37
D	15,030.85	0.27	1.00	0.11	50.61
F	14,000.40	0.97	1.00	0.87	0.00

Trial & Position	Σ (AO-Ot)2	Standard GRG nonlinear Solver θ	α_s	β	S′
Miller [IT]					
R	173.30	0.02	0.13	0.00	73.00
W	778.22	0.26	0.32	0.20	30.52
D	1,211.87	0.66	0.21	0.00	19.43
F	3,709.10	1.00	0.12	0.00	65.03

Table 19 Regression Estimates - Teams w/out IT

Trial & Position	Σ (AO-Ot)2	Standard GRG nonlinear Solver θ	α_s	β	S′
#1					
R	74.76	0.00	0.55	0.39	24.00
W	111.11	0.58	0.27	0.58	24.46
D	146.40	0.83	0.11	1.00	30.06
F	144.74	0.00	0.42	0.00	30.15
Big Bass Ale					
R	2,025.05	0.05	0.17	0.53	63.07
W	413.75	0.37	0.43	0.12	23.58
D	1,892.50	0.16	0.08	0.00	70.93
F	2,214.52	0.35	0.21	0.34	25.58
Frosty					
R	928.69	0.00	0.53	0.19	23.80

Trial & Position		*Standard GRG nonlinear Solver*			
	Σ (AO-Ot)2	**θ**	α_s	**β**	***S′***
W	465.94	0.00	1.00	0.06	20.59
D	2,371.48	1.00	0.41	0.12	11.37
F	2,545.26	1.00	1.00	0.00	21.22
Hires Root Beer					
R	764.39	0.00	0.11	0.00	66.43
W	753.80	0.08	1.00	0.00	15.89
D	14,887.73	0.53	10.00	0.08	14.42
F	3,200.07	0.19	0.22	0.00	49.23
Napoly					
R	873.17	0.00	0.23	0.14	37.92
W	233.84	0.65	0.37	0.04	14.14
D	962.46	0.01	0.57	0.00	21.07
F	1,214.41	0.62	1.00	0.00	1.56
Northeast					
R	1,770.68	0.10	0.44	0.01	22.06
W	5,217.61	0.79	0.51	0.08	10.62
D	2,121.05	0.94	0.02	0.00	0.00
F	18,038.81	0.52	0.81	0.24	35.39
Root 66					
R	165.72	0.00	0.52	0.00	23.00
W	296.32	0.79	0.08	0.00	12.13

Trial & Position		Standard GRG nonlinear Solver			
	Σ (AO-Ot)2	**θ**	α_s	**β**	***S′***
D	1,638.08	0.59	1.00	0.00	9.37
F	73,181.34	1.00	0.58	0.00	51.86
Shiner					
R	492.90	0.00	0.69	0.05	19.47
W	1,502.26	0.78	0.10	0.00	46.47
D	11,320.03	0.28	1.00	0.00	19.43
F	3,343.55	1.00	0.23	0.00	33.93

The next step in analyzing Hypothesis 3 was to use the Mann-Whitney U test to compare the groups, comparing the median estimate of β for each group to determine if there is a statistically significant difference between the groups. In order to complete the analysis, it was first necessary to compare the estimates of β for the test group, the group which implemented information technology, against the control group, the group which did not implement information technology, for the entire 40 week period. Next, the test group was compared against the control group for the first 20 weeks of the trial, the period before the test group implemented information technology. Then, the results of the test group were compared against the control group for the second 20 weeks. In comparing the data for the second 20 weeks, the regression estimate and the estimates of all parameters were recalculated. This calculation was done using the entire data set, the data for all 40 weeks. However, the regression estimate and the parameter estimates were only calculated using the second 20 weeks of data. The entire data set was used because the data for the second 20 week period was dependent on the data from the first 20 weeks. Table 20 is the printout from GraphPad Prism, the statistical analysis program that was used to conduct the Mann-Whitney U tests for this research, and it shows the results of the comparison between the test and control groups for the entire 40 week trial period.

Table 20 Mann-Whitney U Test 40 Weeks Test - Control

Parameter	Value
Table Analyzed	40 week
Column A	IT 40
vs	vs
Column B	Non IT 40
Mann Whitney test	
P value	0.8625
Exact or approximate P value?	Gaussian Approximation
P value summary	Not Significant
Are medians signif. different? (P < 0.05)	No
One- or two-tailed P value?	Two-tailed
Sum of ranks in column A,B	1557 , 1369
Mann-Whitney U	703

The results of the test indicate that there is no significant difference between the two groups. That is over the 40 week trial the group with IT did not improve their performance in terms of under-weighing the supply line. In order to complete the analysis of the data supporting Hypothesis 3, several different comparisons were completed. Table 21 is a listing of the comparison, as well as the analysis of that comparison for Hypothesis 3.

Table 21 Hypothesis 3 Under-weighing the Supply Line

Comparison	**Period of Comparison**	**Question to be answered**	**Result of Mann-Whitney U Test**
Control Group vs. Test Group	40 weeks – 40 weeks	Does the implementation of IT eliminate the under-weighing of the supply line?	No statistically significant difference
Control Group vs. Test Group	1st 20 weeks – 1st 20 weeks	Is there a difference in the under-weighing of the	No statistically significant difference

Comparison	**Period of Comparison**	**Question to be answered**	**Result of Mann-Whitney U Test**
		supply line not explained by IT?	
Control Group vs. Test Group	2nd 20 weeks – 2nd 20 weeks	Is there a difference in the under-weighing of the supply line not explained by IT?	No statistically significant difference

I compared the control group against the test group in three temporal dimensions. First, I compared the two groups for the entire 40 weeks of the game play. I used the Mann-Whitney U test to make this comparison and there was no statistically significant difference. Second, I compared the control group against the test group for the first 20 weeks, Again I used the Mann-Whitney U test, and again there was no statistically significant difference. Finally, I compared the performance of the control group and the test group over the last 20 weeks using the Mann-Whitney U test. Again, there was no statistically significant difference in the performance of the teams over this period. The results of this test clearly show that implementing information technology in this experiment did not have any effect on whether the players under-weigh the supply line in their ordering decisions. My hypothesis that subjects would no longer under-weigh the supply line upon implementation of information technology is rejected. Under-weighing the supply line appears to persist, even with the information sharing from implementing information technology.

Hypothesis 4

Much of this research was based on John Sterman's 1989 paper, *Modeling Managerial Behavior: Misperceptions of Feedback in a Dynamic Decision Making Experiment.* The final phase of the experiment was to compare my results with the results that Sterman published in his work. How would my test groups compare with his test groups? Given the history of the game, I proposed two final hypotheses. Hypothesis 4 held that the parameter estimates for the control group trials, the teams that did not implement information technology, would be similar to Sterman's parameter estimates for his trials. Hypothesis 5 postulated that the parameter estimates for the test group trials, the teams that implemented information technology would not be similar to the estimates of Sterman's trials.

In order to compare my parameter estimates against Sterman's estimates, one additional intermediary step needed to be completed. Sterman did his analysis using his grid search technique while I used a GRG nonlinear Solver solution. Earlier, I compared the results of my GRG nonlinear Solver with Sterman's grid search technique in order to demonstrate the variance between the two estimation methods when using the same data. In order to compare my trials with Sterman's for this hypothesis I needed to use the same estimating technique. The parameter estimates for Sterman's data were completed using the GRG nonlinear Solver, and Table 22 compares the results of the parameter estimates using the GRG nonlinear Solver with the original grid search techniques.

Table 22 Standard GRG - Grid Search Estimates

	Standard GRG nonlinear Solver					Grid Search Parameter Estimates			
Trial & Position	θ	α_s	β	S'		θ	α_s	β	S'
Bassbeer									
R	1.00	0.15	0.29	17.00		0.90	0.10	0.65	20.00
W	0.43	0.26	0.00	8.00		0.00	0.25	0.50	27.00
D	0.28	0.00	0.00	0.00		0.15	0.05	0.35	14.00
F	1.00	0.77	0.14	12.00		0.25	0.65	0.40	15.00
Budweiser									
R	0.00	0.49	0.03	20.00		0.00	0.40	0.10	7.00

	Standard GRG nonlinear Solver					Grid Search Parameter Estimates			
Trial & Position	θ	α_s	β	S'		θ	α_s	β	S'
W	0.63	0.00	0.00	0.00		0.00	0.40	0.75	30.00
D	0.46	0.00	0.00	0.00		0.00	0.30	0.10	10.00
F	0.77	0.32	0.01	9.00		0.25	0.25	0.10	9.00
Coors									
R	0.00	0.37	0.00	26.00		0.00	0.20	0.00	25.00
W	0.86	0.00	0.00	0.00		0.00	0.15	0.50	38.00
D	0.94	0.40	0.16	12.00		0.90	0.30	0.20	10.00
F	0.34	0.30	0.00	22.00		0.25	0.30	0.00	18.00
Freebeer									
R	0.34	0.45	0.13	14.00		0.40	0.35	0.45	15.00
W	0.23	0.13	0.00	30.00		0.30	0.05	0.00	30.00
D	0.41	0.03	0.00	4.00		0.05	0.35	1.00	18.00
F	0.46	0.25	0.00	25.00		0.25	0.25	0.00	19.00
Grin & Beer It									
R	0.00	0.43	0.00	21.00		0.10	0.35	0.65	13.00
W	0.85	0.13	0.00	10.00		0.95	0.15	0.55	14.00
D	0.40	0.29	0.00	13.00		0.20	0.20	0.30	19.00
F	0.69	0.00	0.00	0.00		0.25	0.35	355.00	24.00
Grizzly									
R	0.23	0.33	0.48	26.00		0.05	0.30	0.65	31.00
W	0.40	0.22	0.02	17.00		0.30	0.20	0.35	27.00

	Standard GRG nonlinear Solver					Grid Search Parameter Estimates			
Trial & Position	θ	α_s	β	S'		θ	α_s	β	S'
D	0.25	0.00	0.00	0.00		0.15	0.05	0.25	15.00
F	0.54	0.35	0.00	18.00		0.56	0.34	0.00	19.00
Heineken1									
R	0.42	0.22	0.08	21.00		0.95	0.15	0.00	9.00
W	0.59	0.00	0.00	0.00		0.50	0.00		
D	0.40	0.39	0.00	12.00		0.20	0.30	0.05	8.00
F	1.00	0.00	0.00	0.00		0.80	0.00		
Heineken2									
R	0.00	0.24	0.02	33.00		0.50	0.05	0.60	6.00
W	0.71	0.08	0.00	9.00		0.40	0.10	0.30	16.00
D	1.00	0.08	0.00	0.00		1.00	0.15	0.80	14.00
F	0.61	1.00	0.00	10.00		0.55	0.80	0.00	9.00
Heineken3									
R	0.14	0.05	0.00	59.00		0.05	0.30	0.45	5.00
W	0.77	0.07	0.89	5.00		0.20	0.00		
D	0.56	0.00	0.00	0.00		0.30	0.10	0.90	12.00
F	0.52	0.02	0.00	0.00		0.00	0.30	0.15	17.00
Suds									
R	0.01	0.53	0.19	21.00		1.00	0.00		
W	0.26	0.36	0.13	17.00		0.05	0.30	0.20	20.00
D	0.57	0.24	0.04	11.00		0.15	0.60	0.25	0.00

	Standard GRG nonlinear Solver					Grid Search Parameter Estimates			
Trial & Position	θ	α_s	β	*S′*		θ	α_s	β	*S′*
F	0.77	0.04	0.00	0.00		0.40	0.35	1.05	32.00
Twoborg									
R	0.01	0.48	0.00	21.00		0.75	0.35	0.00	4.00
W	0.33	0.21	0.04	12.00		0.00	0.25	0.05	18.00
D	0.23	0.21	0.00	33.00		0.05	0.50	0.00	15.00
F	1.00	0.03	0.00	0.00		0.95	0.30	0.20	26.00

The next step in the analysis of Hypothesis 4 was to compare the parameter estimates of the control group with the newly estimated parameters for Sterman's data. The first comparison was done for the parameter θ. Table 23 displays the results of the Mann-Whitney U test for Sterman's data against the control group.

Table 23 Sterman Group – Control Group θ

Parameter	Value
Table Analyzed	Sterman vs Non - IT "Theta"
Column A	Sterman
vs	vs
Column B	Non-IT
Mann Whitney test	
P value	0.3623
Exact or approximate P value?	Gaussian Approximation
P value summary	Not Significant
Are medians signif. different? (P < 0.05)	No
One- or two-tailed P value?	Two-tailed
Sum of ranks in column A,B	1628 , 1298
Mann-Whitney U	

The results of this test show that there is no significant statistical difference between the control group and Sterman's data for the parameter θ.

The next test for Hypothesis 4 is a comparison of the estimate of α_s for Sterman's data with the estimate of α_s for the control group. The results of that comparison are displayed in Table 24.

Table 24 Sterman Group αs - Control Group αs

Parameter	Value
Table Analyzed	Sterman vs Non IT "Alpha s"
Column A	Sterman
vs	vs
Column B	Non - IT
Mann Whitney test	
P value	0.5564
Exact or approximate P value?	Gaussian Approximation
P value summary	ns
Are medians signif. different? (P < 0.05)	No
One- or two-tailed P value?	Two-tailed
Sum of ranks in column A,B	1483 , 1443
Mann-Whitney U	663

This comparison shows that the teams that did not implement IT had no statistically significant difference in the estimated value of αs.

Following the comparison of αs, the estimated value of β for the control group was compared with the estimated value of β for the Sterman data. The results of this comparison are depicted in Table 25.

Table 25 Sterman Group β– Control Group β

Parameter	Value
Table Analyzed	Sterman vs Non - IT "Beta"
Column A	Sterman
vs	vs
Column B	Non IT
Mann Whitney test	
P value	0.1227
Exact or approximate P value?	Gaussian Approximation
P value summary	ns
Are medians signif. different? (P < 0.05)	No
One- or two-tailed P value?	Two-tailed
Sum of ranks in column A,B	1624 , 1617
Mann-Whitney U	633.5

Again we see there is no statistically significant difference between the control group and Sterman's groups from 1989. The final parameter estimation to be compared is the estimation for the parameter S'. The comparison of the Sterman Group against the control group is displayed in Table 26.

Table 26 Sterman Group - Control Group S'

Parameter	Value
Table Analyzed	Sterman vs Non - IT S'
Column A	Sterman
vs	vs
Column B	Non - IT
Mann Whitney test	
P value	0.3105
Exact or approximate P value?	Gaussian Approximation
P value summary	ns
Are medians signif. different? (P < 0.05)	No
One- or two-tailed P value?	Two-tailed
Sum of ranks in column A,B	1442 , 1484
Mann-Whitney U	622

The next table, Table 27, summarizes the comparison of the contemporary trials with Sterman's trials There is no statistically significant difference between the estimates for the Sterman data and the parameter estimates for the control group data. Therefore, Hypothesis 4 is accepted.

Table 27 Hypothesis 4 Results

Comparison	Period of Comparison	Question Being Answered	Statistical Test: Mann Whitney U
Sterman's Θ vs. Control Group Θ	40 weeks - 40 weeks	Are the Results of our control groups similar to Sterman's 1989 trials?	Statistically the results of the test group are similar to Sterman's 1989 trials.
Sterman's β vs. Control Group β	40 weeks - 40 weeks	Are the Results of our control groups similar to Sterman's 1989 trials?	Statistically the results of the test group are similar to Sterman's 1989 trials.
Sterman's α vs. Control Group α	40 weeks - 40 weeks	Are the Results of our control groups similar to Sterman's 1989 trials?	Statistically the results of the test group are similar to Sterman's 1989 trials.
Sterman's S' vs. Control Group S'	40 weeks - 40 weeks	Are the Results of our control groups similar to Sterman's 1989 trials?	Statistically the results of the test group are similar to Sterman's 1989 trials.

Hypothesis 5

Hypothesis 5 is similar to Hypothesis 4, in that it compares the results of the contemporary trials with the results of Sterman's research. Recall that in order to compare the groups I had to estimate the values of the parameters for Sterman's data using contemporary techniques. This data is shown in Table 22 in the section on Hypothesis 4, and is not repeated here. Hypothesis 4 compared the control group trials with the Sterman trials. Hypothesis 5 compares the test group trials with the Sterman data. Underlying these hypotheses is the assumption that the results of the contemporary trials where information technology was not implemented would be similar to the results of Sterman's trials. Additionally it was assumed that the results of the trials where information technology was implemented would not be similar to the results of Sterman's trials.

In comparing the test group against the Sterman data I again began with the comparison of the parameter θ. In comparing the test group against the Sterman data, there is no significant statistical difference between the two groups for the estimate of this parameter. Table 28 displays the results of this test.

Table 28 Sterman Group – Test Group θ

Parameter	Value
Table Analyzed	Sterman vs IT "Theta"
Column A	Sterman
vs	vs
Column B	IT
Mann Whitney test	
P value	0.4396
Exact or approximate P value?	Gaussian Approximation
P value summary	Not Significant
Are medians signif. different? (P < 0.05)	No
One- or two-tailed P value?	Two-tailed
Sum of ranks in column A,B	4313 , 2474
Mann-Whitney U	1387

The second comparison was the comparison of the Sterman data against the test group data for the parameter α_s Table 29 displays this comparison. From this analysis it can be seen that the estimated value of α_s for the teams with information technology implemented was significantly different from the estimated value for Sterman's data. Recall that α_s represents the Stock Adjustment Factor, the fraction of the discrepancy ordered each period. This test demonstrates that the teams that implemented IT ordered a different fraction of the discrepancy each period than did the original teams in Sterman's research.

Table 29 Sterman Group - Test Group α_s

Parameter	Value
Table Analyzed	Sterman vs IT "Alpha s"
Column A	Sterman
vs	vs
Column B	IT
Mann Whitney test	
P value	0.0044
Exact or approximate P value?	Gaussian Approximation
P value summary	Significant
Are medians signif. different? (P < 0.05)	Yes
One- or two-tailed P value?	Two-tailed
Sum of ranks in column A,B	1552 , 2019
Mann-Whitney U	561.5

The next comparison is the comparison for values of β, for the Sterman trials to the values for the teams with information technology. Table 30 displays the results of this analysis. There is not a significant difference between the estimate of β for the Sterman trials and the teams that implemented information technology.

Table 30 Sterman Group - Test Group β

Parameter	Value
Table Analyzed	Sterman vs IT "Beta"
Column A	Sterman
vs	vs
Column B	IT
Mann Whitney test	
P value	0.1148
Exact or approximate P value?	Gaussian Approximation
P value summary	ns
Are medians signif. different? (P < 0.05)	No
One- or two-tailed P value?	Two-tailed
Sum of ranks in column A,B	1696 , 1875
Mann-Whitney U	705.5

The final parameter estimation to be completed was the estimation for the parameter S’. The comparison of the Sterman group against the control group is displayed in Table 31.

Table 31 Sterman Group - Test Group S'

Parameter	Value
Table Analyzed	Sterman vs IT S'
Column A	Sterman
vs	vs
Column B	IT
Mann Whitney test	
P value	0.0007
Exact or approximate P value?	Gaussian Approximation
P value summary	***
Are medians signif. different? (P < 0.05)	Yes
One- or two-tailed P value?	Two-tailed
Sum of ranks in column A,B	1493 , 2078
Mann-Whitney U	502.5

Table 32 summarizes the results of the comparisons between Sterman's trials and the Test Group trials, those subjects who did implement IT.

Table 32 Hypothesis 5 Results

Comparison	Period of Comparison	Question Being Answered	Statistical Test: Mann Whitney U
Sterman's Θ vs. Test Group Θ	40 weeks - 40 weeks	Are the Results of our control groups similar to Sterman's 1989 trials?	Statistically the results of the test group are similar to Sterman's 1989 trials.
Sterman's β vs. Test Group β	40 weeks - 40 weeks	Are the Results of our control groups similar to Sterman's 1989 trials?	Statistically the results of the test group are similar to Sterman's 1989 trials.
Sterman's α vs. Test Group α	40 weeks - 40 weeks	Are the Results of our control groups similar to Sterman's 1989 trials?	Statistically the results of the test group are not similar to Sterman's 1989 trials.
Sterman's S' vs. Test Group S'	40 weeks - 40 weeks	Are the Results of our control groups similar to Sterman's 1989 trials?	Statistically the results of the test group are not similar to Sterman's 1989 trials.

Hypothesis 5 is rooted in a similar comparison as Hypothesis 4. In Hypothesis 4 it was expected that the groups that did not implement information technology would have parameter estimates comparable to the subjects in Sterman's research. However, in Hypothesis 5 it was expected that the estimated parameters for the test group trials, the subjects that implemented information technology would be significantly different from the trials of the Sterman data. The results of this test, shown in Table 32, are much less clear. For two of the estimated parameters, θ, (Adjustment Factor for Expected Losses) and β (The Fraction of the Supply Line Taken Into Account), the results showed that there was not a statistically significant difference between the Sterman data trials and the test group trials. Therefore, even with IT, the test groups did not improve their performance in estimating their weekly sales, nor did their performance improve in terms of taking the supply line into account.

For two of the parameters, α_s and S', there was a statistically significant difference in the data. Recall that α_S represents the Stock Adjustment Factor, the fraction of the discrepancy ordered by the subject each week. Also, S' is a function of the desired stock plus β times the desired supply line. The subjects in the test group did show a difference in the fraction of the stock discrepancy ordered each week. Additionally the test group showed a difference in estimating the desired stock. Although there are statistically significant differences between the test group and the Sterman data for two of the estimated parameters, two of the parameters are statistically equivalent. Therefore, Hypothesis 5 must be rejected.

EXPERIMENTAL RESULTS SUMMARY

When preparing for this research it was assumed that the implementation of information technology would improve the performance of the teams. Five hypotheses were designed to test this assumption. The first hypothesis that teams with IT would perform better was rejected. Teams that implemented information technology did not perform any better. The second hypothesis, implementing information technology would reduce the bullwhip effect was accepted. The third hypothesis that teams with information technology would not under-weigh the supply line, was rejected. The fourth hypothesis essentially compared teams today with the trials done in the 1980s. It was accepted that my control group trials were similar to the trials from the 1980s. I rejected the fifth hypothesis that said that my test group trials would not be similar to the earlier trials.

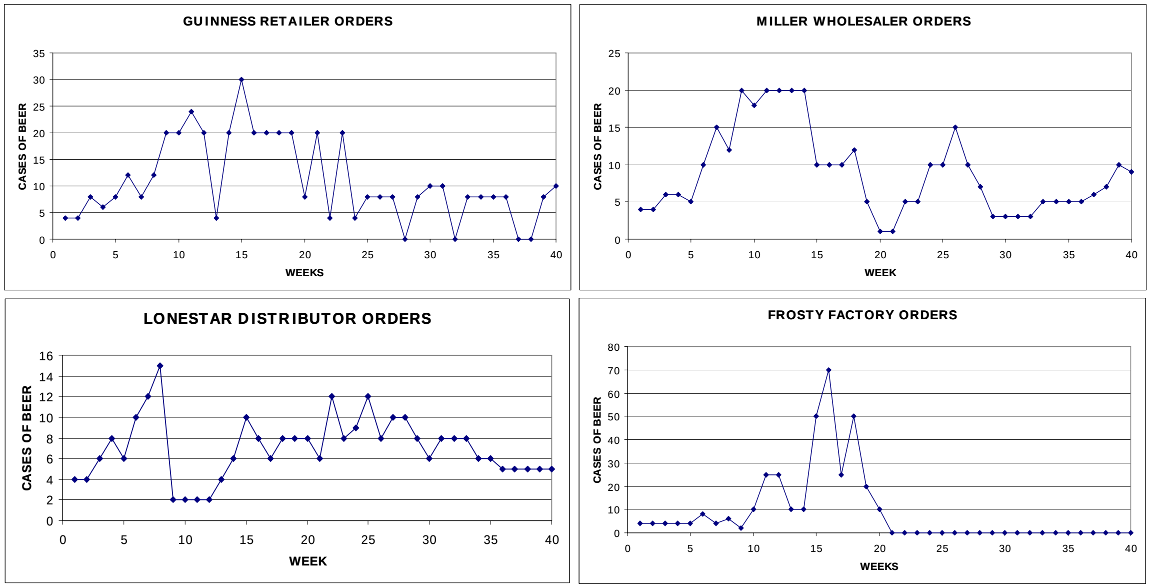
The results of the experiment did little to shed light on the subject. Although there was some reduction in the bullwhip effect, there was no evidence of the clear performance improvement that had been expected. Understanding these unexpected results was challenging. There were a number of questions to consider. What, if anything, could be learned from the surveys of the students? What could be surmised from the observation of game play? Did the literature on the beer distribution game shed any light on the results?

THE MOMENT OF DISCOVERY

During preparation for an early progress meeting with the faculty committee, an "aha moment" was experienced. The survey information, included in Appendix 4, while not compelling, did provide some insight. The survey was not conducted immediately after the play of the game, because permission to survey the participants was delayed from the university. When permission was granted, the survey was conducted, but this was at the end of the semester, several weeks after the students had played the game, and most had been debriefed the week following the game. The survey information is certainly tainted by both the time lag and the debriefing, but it was still useful in understanding the results. Those participants who answered generally expected the teams with IT to perform better, and generally said that they had in fact used the information to improve their ordering process.

When observing the play of the game it was apparent that there was a lag between the time when information technology was implemented, and there was clear evidence of the results. The following graph, Figure 7 Test Group Orders, displays the orders placed by four of the subjects playing the game with IT.

Figure 7 Test Group Orders



Although it had already been shown that overall performance of the trials was not improved with the implementation of IT, there appeared to be a reduction in the order variance over the last 10 weeks or so of the game. As an observer of the game, it appeared to me that performance was indeed improving with the play of the game it simply did not improve immediately after the implementation of information technology. This suggests that if the game play were continued, one would see improvement in the results. In considering the results of the game the literature on the beer distribution game was also revisited. Sterman concluded in his research that the performance of the subjects was a result of misperceptions of feedback and demand information; a conclusion that can be characterized as a behavioral explanation. Recall that Lee, Padmanabhan and Whang (H. Lee, Padmanabhan, V., Whang, S., 1997a) identified four operational causes of the bullwhip effect. Their conclusion was that the phenomenon is the result of operational or structural causes, as opposed to behavioral causes.

The breakthrough came when I compared the results of the game play, the observations of the game play, and the literature on the beer distribution game. Perhaps the reason why implementing information technology did not improve performance was an alignment issue. I had made no effort to change the behavior of the players in the beer distribution game, even though I had changed the structure of the game. Players had developed their own ordering heuristics, which they were using to place their orders in the first 20 weeks of play. The results of studying our hypotheses showed that there was no statistically significant difference in the overall performance of players who had information technology from those who did not. Furthermore, two of the contributors to less than optimal performance, the bullwhip effect and under-weighing the supply line, were persistent factors even with information technology. Despite the survey results, it appeared that players continued to use the same ordering heuristics immediately after the implementation of information technology as they had used prior to the implementation.

After several weeks of continued play there is anecdotal evidence that players began to align their ordering behavior with the new structure of the game. The moment of discovery came when I understood that the change in the structure of the game was not accompanied by any attempt to align the behavior of the players with the new structure.

Behavioral Alignment

Although I now had some insight into the results, I also had a new avenue of research to review. This breakthrough drove me to revisit the relevant literature in information technology, organizational psychology, and science to see if I could find relevant theories on the alignment of behavior and structure. The literature review proved fruitful. A number of researchers and authors have looked at this phenomenon from several different perspectives. Barki and Pinsonneault (2005) recently studied this from a perspective of organizational performance. Robey and Boudreau (1999) studied the contradictory consequences of information technology. Armstrong and Sambamurthy (1999) researched the influence of senior leadership and the quality of the information technology infrastructure on the success of information technology. Orlikowski (1996) proposed that organizational transformation is endemic to the practice of organizations, and implementing information technology is a common basis of organizational change. Markus (2004) identified an organizational practice of using information technology to drive organizational change. She proposed that this change requires a more robust set of strategies and tools than the simple project management tools that are pervasive in IT organizations.

Research has shown that organizational integration, the extent to which the organizational components constitute an organizational whole, is positively correlated with organizational performance. From the perspective of information technology, organizational integration is defined through two perspectives. The first is the technical perspective, and through this lens, integration refers to how well the various systems within the infrastructure can communicate with each other. The second perspective describes how well the various components of the organization communicate with each other using computers and telecommunication facilities (Barki, 2005). It is this second perspective that is of particular interest.

The successful integration of information technology within the organization requires assimilation of the systems and underlying processes. This assimilation refers to how well the firm utilizes the capabilities of the technology to enhance the business; the more information technology is infused into the daily activities of the firm the greater the assimilation. The success of this assimilation/integration is strongly correlated to two factors. The first factor influencing success is the partnership between IT management and the business executives of the firm. The second factor is the quality of the IT infrastructure. The IT infrastructure is defined as including the platform and network technologies as well as the applications running in the infrastructure. Research demonstrates that a strong relationship between IT management and business management along with a robust IT infrastructure, strongly contribute to the success of IT integration (Armstrong, 1999).

The focus of this research has been on understanding the unintended consequences of implementing information technology. Robey and Boudreau (1999) have proposed that implementing information technology as an organizational change agent often leads to contradictory results. They categorize these results as implementations where the expected consequences of information technology do not occur; implementations where different consequences occur; implementations where contradictory consequences occur; and finally, implementations where unanticipated adaptations of the technology, usually driven by the users, occur.

Robey and Boudreau (1999) study a number of different theories to understand the causes of inconsistent results from introducing information technology. They go on to conclude that there is every reason to believe that as organizations continue to change, and new generations of information technology are implemented, the results will continue to be inconsistent. Perhaps more importantly, Robey and Boudreau (1999) identify that managers must understand that they are not in position to unilaterally determine outcomes.

From the system dynamics literature, it is clear that failures to perform as expected in dynamic situations are often the result of inadequate mental models that fail to understand adequately the highly complex interrelationships that comprise organizations. Furthermore, these models fail to incorporate the dynamics of these relationships in all but the simplest systems (Sterman, 2000). These feedback structures and incomplete mental models are typically embedded in the culture of the organization. They are the drivers of institutional persistence, and Robey and Boudreau (1999) conclude that this persistence and culture often cannot be overcome by new technologies.

In this paper, Robey and Boudreau (1999) cite a 1994 publication by Markus on a study of electronic media. Markus found that users often find electronic media to be useful for storing and organizing the documentation that is used to justify decisions. Ironically, Markus also discovered that this compulsion to document decisions erodes much of the improved productivity from the new technology (Robey, 1999). Markus identified two categories of information technology change. The first is the simple upgrade or technology substitution. This change requires little effort on the part of users, and might go completely unnoticed. Success in these projects is measured in terms of functionality and reliability of the technology or in cost of operations. Although this change may have a significant payoff, changes of this type rarely impact how the organization works (Markus, 2004).

Markus coined a term, “technochange”, which she uses to identify the high risk, high reward organizational change that is driven by information technology. This is the situation when management uses information technology to change the way the organization works. Using IT to drive change is fundamentally different from either IT projects, or organizational change programs. It is different from IT projects in that this change requires significant effort on the part of users. It is different from organizational change efforts because of the unique aspects of driving the change through technology.

There are a number of reasons why management would drive organizational change with information technology. Some changes cannot happen without information technology – the new structure of the organization can only be supported through new information technology. The culture of some organizations simply will not allow the change to take place without the catalytic effect of information technology – without the coercive effect of the new technology users will simply revert to the old ways of doing business. It is important to note that the literature shows that sometimes even with the new technology cultural values and mental models resist change. A final explanation for driving change through the implementation of information technology is the belief that IT alone will create improvements. Markus refers to this as the “magic bullet” explanation (Markus, 2004).

Many people in information technology management positions appear to believe that good project management practices are the answer to successfully driving organizational change with information technology. Markus (2004) notes that despite reasonably robust project management practices, upwards of 75% of organizational change efforts driven by information technology fail. This appears to be because even when the technology performs as expected, the project management tools do not effectively manage the users’ reactions to the new technology. Good IT project management ensures that organizations implement the technology correctly. Good IT portfolio management ensures that the technology that is implemented is aligned with the existing technologies within the infrastructure, that the IT organization has the capabilities to implement the technology, and that the implementation of the technology does not create unacceptable level of risk to the organization. Neither project management, doing things right, or portfolio management, doing the right things, addresses the organizational changes inherent in technochange projects.

Conner Partners, an Atlanta based consulting firm, have written on the subject of information technology project success. In their paper, *The Leader’s Challenge:*

Installation or Realization (Connerpartners, 2004) they recognize that change requires investment and that managers have a responsibility to their stakeholders to obtain the highest return on investment possible. Connor Partners say that many change initiatives fail because mangers don't begin with an appropriate perspective on this ROI. In order to be successful, change must address four key elements. Do the sponsors of the project have sufficient resolve to see the project through to success? Will the targets (users) of the technology resist the new technology? Is the culture of the organization aligned with the new technology? Is there sufficient capacity within the organization to deliver the desired changes (Connerpartners, 2004)?

Markus (2004) identifies several important dynamics of technochange as well. Besides the cultural fit, the sponsors' resolve, and the resistance of users, Markus also identifies an issue of aligning the project direction with the authority and reward system of the organization. Failure to address each of the questions will impact the success of the initiative.

The literature seems to support the idea that alignment is an important, even critical, issue to consider in the implementation of information technology. In *Technochange Management: Using IT To Drive Organizational Change* Markus (Markus, 2004) makes a strong case for alignment. "Misaligned technochange solutions may or may not be complete, but they conflict so seriously with the existing organization that they are likely to be rejected" (Markus, 2004, p. 6).

Misalignment Is a Critical Factor

Earlier in this paper, it was established that implementing information technology was not enough to improve organizational performance when playing the beer distribution game. Contemplation of these results, along with observation of the game play, led to a consideration of alignment as a critical factor in the success or failure of information technology. Review of the literature supports this hypothesis. Systems thinking must consider how mental models interplay with the structure of the organization. In *The Leader's Challenge*, Conner Partners (2004) describe the work environment as having two major building blocks: the inert structure of the organization, including its policies, technologies, and strategies, and the human factors of the organization, including the perceptions, assumptions, fears, beliefs, and values of the people within the organization. It is the interplay between these two blocks, the relationship between the inert structure and the human elements, the alignment of the organizational structures with mental models, which breathes life into the organization. When the mental models are not aligned with the organizational structure there is a risk of failure in the implementation of information technology.

CHAPTER 6: CASE STUDY RESEARCH RESULTS

CASE STUDY INTRODUCTION

Meetings with the CIO of HTS Systems were held regularly for a period of approximately eight months. During this time, I studied the information technology organization at HTS using the iterative process described in the research design. The initial focus of these meetings was to understand the structure of the organization, specifically from an information technology perspective, and to understand what mental models existed in the organization. There are several questions to be addressed by the case study:

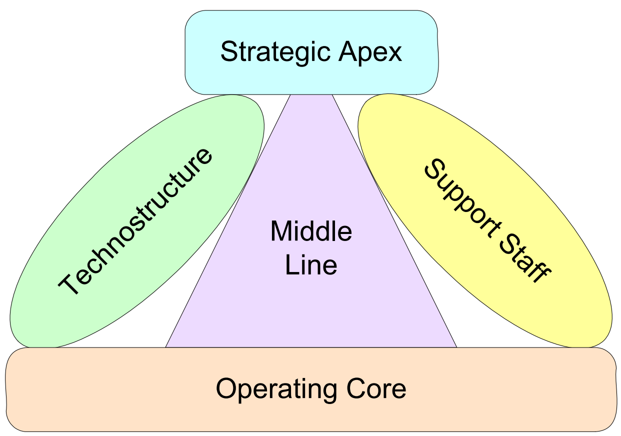
1. What is the problem the client is most concerned with?
2. Why is this a problem?
3. What is the impact of this problem on organizational performance?
4. What is the purpose of the model?
5. What are the initial theories or hypotheses that explain this problem?

Problem Articulation

What is the Problem? HTS is concerned with their ability to provide expanding information technology services to a company expanding geographically, while at the same time maintaining costs on a per capita basis. Geographic expansion includes the expansion of the firm both organically and through acquisition of other professional service firms. HTS is trying to address both the problem of technology creep, and the expansion of geographic locations while maintaining costs. Ownership has a long-held vision of keeping overhead costs low, maintaining them at a specific per capita level. The CIO would like to be able to better understand how they got into their current situation and what strategies they can use to manage the information technology effectively in the future. The CIO might describe the current situation as tenuous: performance currently meets acceptable standards, yet many possible scenarios keep him awake at night. The information technology organization has seen an increase in the services provided to the organization, without any real growth in the budget to provide these services.

Writing in Management Science, Henry Mintzberg (1980) described the five basic parts of the organization. These five parts include the operating core, the strategic apex, the middle line, the technostructure, and the support staff. Mintzberg defined technostructure as consisting of "those analysts, out of the formal 'line' structure, who apply analytic techniques to the design and maintenance of the structure and to the adaptation of the organization to its environments (e.g., accountants, work schedulers, long range planners)" (Mintzberg, 1980, p. 323). He further defined the support staff to include "those groups that provide indirect support to the rest of the organization (e.g., in the typical manufacturing firm, legal counsel, public relations, payroll, cafeteria)" (Mintzberg, 1980, p. 324). Figure 8 is a graphical depiction of Mintzberg's structure.

Figure 8 Mintzberg's Organizational Structure



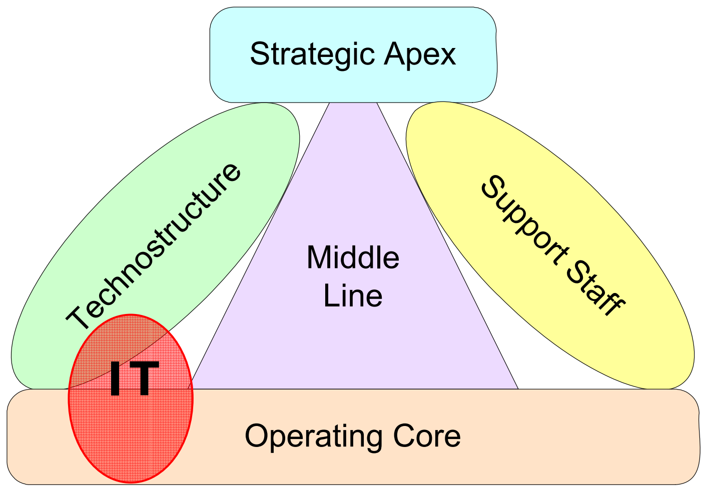
Mintzberg doesn't specifically address information technology and the information technology support organizations as belonging in either the technostructure or support staff of this representation, and arguments could be made that information technology support belongs to either of these two regions. Accountants are described as belonging to the technostructure of the organization, yet payroll is described as support staff. It appears that the primary difference between technostructure and support staff is the influence the staff exerts over the operations of the operating core. Accountants prescribe how transactions will be handled; payroll staff simply record the transactions in support of the operating core. In an organization today, information technology probably belongs in both structures. Many information technology projects and implementations have the effect of prescribing how activities will be completed as well as simply processing the transaction. For example, the “Fairfax County Virginia Department of Information Technology: Mission and Goals” identifies “10 IT Fundamental Principles,” and the third principle is: “Evaluate business processes for redesign opportunities before automating them. Use new technologies to make new business methods a reality. Exploit functional commonality across organizational boundaries” ("Fairfax County Department of Information Technology: Mission and Goals", 2006). Following this principle, information technology belongs within the technostructure of the organization. In either case, the important issue is that information technology is not considered a part of the operating core, but is part of a support or technostructure function.

For the purpose of this research, information technology at HTS is classified as being technostructure as opposed to being part of the HTS Support structure. This does not imply that information technology is not used by the HTS support structure. Information technology prescribes how work will be done, a technostructure function as well as supporting doing the work, a support function. At HTS the corporate Enterprise Resource Planning (ERP) system prescribes how transactions are done: they must be done in compliance with the previously established system rules and policies, a technostructure function. The ERP system also supports the staff who actually enter the data and compile reports from the system for management, a support function. The root of the problem lies not in whether information technology is a technostructure function, or simply a support function; the root of the problem lies in whether information technology is considered a support function, or a support and production function. During a brief hallway encounter at HTS, the author was told by a manager that HTS was not an IT firm, and IT was therefore not critical to the daily operations of the firm. When questioned about this assertion, this manager replied that they could continue to provide services to their customers without using information technology. They could go back to using draftsmen to create the drawings for their customers, as draftsmen didn’t require information technology to deliver their service[5]. Information technology is considered a business cost, not an enabler. In fact, most of what is produced by HTS is produced

[5] This encounter was an isolated incident, but didn’t seem to differ greatly from the prevailing culture within the organization.

using various information technology services and systems throughout all phases of the project. Modifying Mintzberg's earlier model results in a slightly different picture of how IT fits within the organization. Figure 9 Modified Organizational Structure, depicts this modified model.

Figure 9 Modified Organizational Structure



This new diagram illustrates that IT crosses from the technostructure into the operating core of the organization. At HTS, information technology is a fundamental production function. Without IT, many of the ongoing projects couldn't be completed at all; others could be completed, although at great competitive disadvantage and with some degree of difficulty. Plans could be drafted using Mylar® sheets, pencils, and draftsmen, but where would HTS get the experienced draftsmen, or even the drafting tables? And how many of their customers would be satisfied receiving their designs on two dimensional sheets? How much longer would it take to complete this work?

The problem at HTS is that information technology is a critical production function, but it is considered by many in the firm to be simply a cost that should be minimized. The critical nature of information technology is not understood or recognized by the ownership of the firm, and this has resulted in information technology budgets and policies that do not adequately address the needs of the firm.

Why Is This A Problem?

HTS is a privately held firm and the equity ownership of the firm is entirely held by a small group of investors. There is, however, a somewhat larger group of individuals who have invested all, or significant portions, of their professional careers at HTS. These men and women have long term relationships with the owners of the firm, and in fact, many of them have a longer tenure at the firm than the current CEO, a professional engineer who has been with the firm only five or six years. These senior managers might not have equity ownership in the firm, but the investment of their careers, as well as their long time relationship with the equity owners gives them a sense of ownership. For the purposes of this research, ownership refers not just to the equity owners of the firm, but rather to that larger group of stakeholders that includes the equity owners, and many people in management roles with long work histories at HTS.

We all have our own filters, experiences, expectations, and generalizations that influence how we understand the world. These “mental models” are deeply ingrained in us, and we may not even be aware of many of them (P. Senge, 1990). The ownership of HTS doesn’t see information technology as a critical production function of the firm, but rather as a support function: not a business enabler, but as a cost to be driven out of the organization. This is a problem because although IT does play a role in providing both support and technostructure capabilities, it also plays a significant role in the operating core.

As is the case for many professional services firms, HTS operates on a project basis, with most customer engagements defined by projects. In the past, project managers were measured on total revenue, and more specifically, on how they met their total revenue goals. Although the firm was successful using total revenue as a measure, current strategic plans call for financial expectations to be measured in terms of net revenues and profitability, not just in total revenues. At HTS, the mental models of the ownership of the firm were developed and established over many years. The specific mental models regarding information technology perceive it as a support or technostructure function.

There is an often held maxim in management, "be careful what you measure for that's what you'll get." It refers to any number of different phenomena. If you measure temperature, you will get some measure of temperature, depending on what measurement device you use, what scale you choose, and other variables. If you measure performance based on total revenues you will get total revenues. This outcome is dependent on both the measurement device, and the fact that people who are being measured will try to optimize their performance in the area that is being measured. If managers are being measured in units of total revenues, their focus will be on performing well in terms of total revenues. Changing the measure of their success from total revenues to net revenues will naturally force them to focus more attention on expenses.

At HTS, information technology has historically been considered a support function, and therefore a shared expense, one that has been shared on a per capita basis among all projects equally. IT is a requirement for nearly all projects at HTS, but the level of IT required varies from business unit to business unit, from engagement to engagement, from project to project, depending on the specific work being done. The cost for information technology is allocated on a strict per capita basis and is not aligned with the amount used, or the costs to provide this IT support to a specific project, engagement, or business unit. The effect of this misalignment is that projects that are IT intensive are being subsidized by projects that do not require IT at the same level.

This might not be an issue when managers and executives are measured on, and compensated for, performance against total revenues. When the measurement shifts to net revenues, this subsidization is going to become more of an issue for managers, especially those who are working on projects and engagements with lean margins. Figure 10 is a diagram of the primary business units at HTS and shows how the information technology expenses are allocated to the various business units. The next figure, Figure 11 depicts the burden of information technology. This figure summarizes the expenses and the labor costs associated with supporting information technology for each of the business units. As you can see by comparing these diagrams there is considerable variance between the allocations and the burdens for some of the business units.

Figure 10 HTS IT Expense Allocation by Business Unit

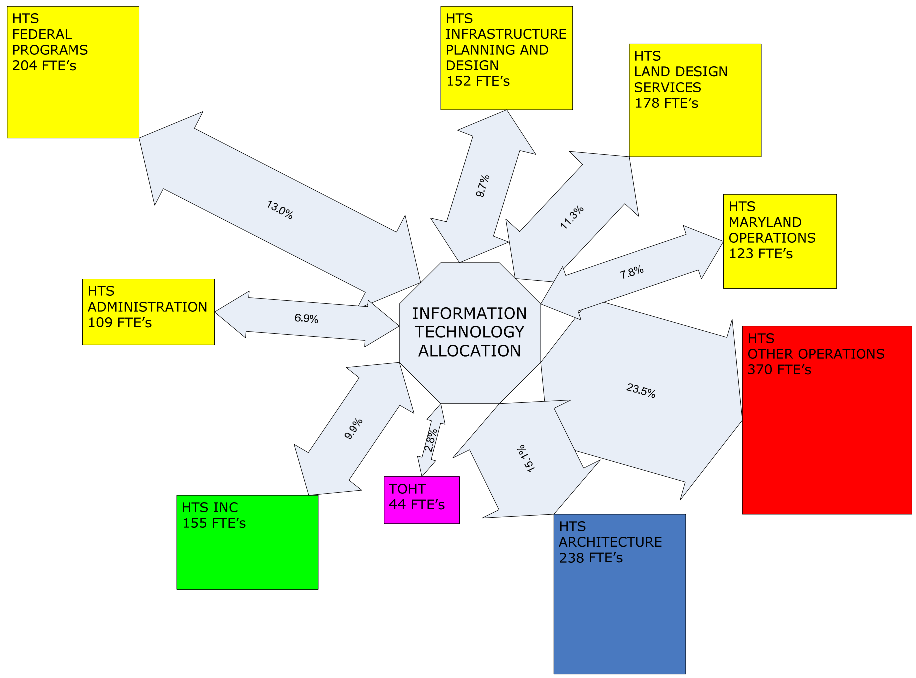
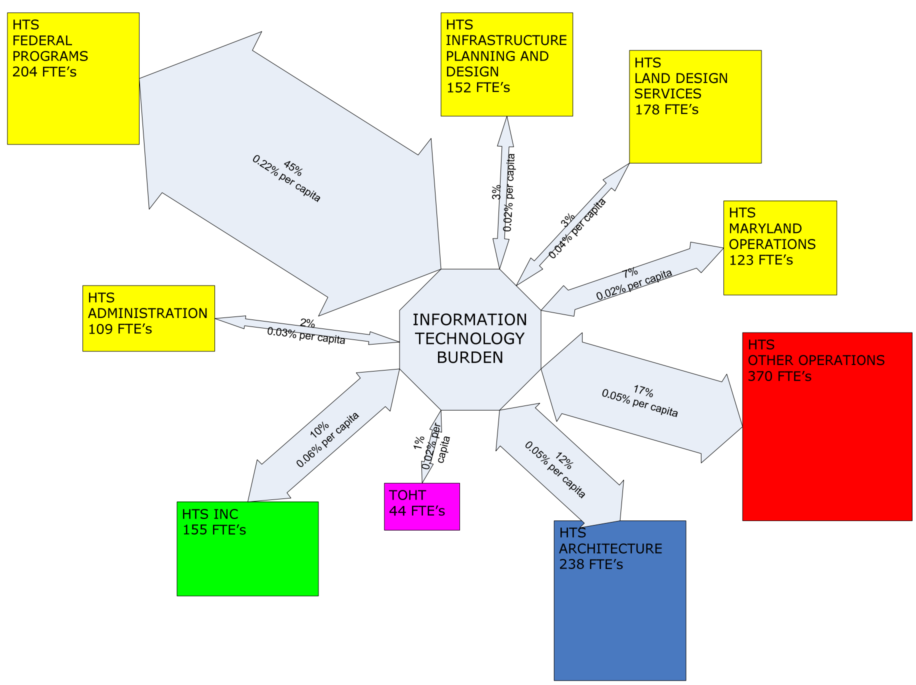


Figure 11 HTS IT Burden by Business Unit



This misalignment is causing problems for several reasons. First, costs of production associated with information technology are not allocated to the appropriate business unit. Second, because information technology is perceived as a support function, and not a production function, the funding for IT resources is falling behind the IT requirements. Over the past several years, the requirements for IT have grown across the board. Both new production technologies and new business technologies have been implemented. For the purposes of this dissertation, production technologies or production applications are defined as those technologies directly tied to the production of deliverables for a client. Business technologies or applications are defined as those systems which are primarily part of the technostructure and in fact are used to run the business.

Although several information technology initiatives have been approved and deployed, other initiatives, even those with quantifiable benefits have been dismissed because of resource constraints. An ERP system has been deployed, and use of it has been mandated throughout much the organization. Recall from the discussion of the Fairfax County Department of IT's fundamental principles, that their third principle was to evaluate business processes before automating them, and to use information technology to make new business practices a reality. This principle guided HTS in their deployment of the new ERP system. There is, however, anecdotal evidence that many of the people tasked with using the new technology are still completing their work doing business the way they always did.

What Is The Impact Of This Problem On Organizational Performance?

The CIO of HTS believes that information technology is critical for the ongoing success of the firm. HTS is an engineering and design firm and over the years since it first opened its doors HTS has implemented many information technology systems, both in support of its core production functions and in support of business operations. HTS is in fact a professional services firm. The product they sell is created by the application of the intellectual capital of the professional services staff. Much of what they sell is delivered to the clients in the form of documents, either paper documents or electronic documents. These documents include detailed designs, engineering analysis, recommendations for engineering solutions, detailed maps, and other products of the firm's intellectual capital. Although the paper may be the final deliverable, it is not really what the client is purchasing; rather, they are purchasing the effort and expertise that went into developing the design, recommendations, or other products.

When the firm was first founded, information technology was not a factor in the creation of the products and services of the firm, nor was information technology required to support the business operations of the firm. Today the environment is quite different. Most of the deliverables of the firm require information technology for their creation, their delivery, or both; the business operations of the firm are fully supported by information technology. Despite this new reality, the ownership of the firm still perceives that information technology plays a supporting role in the organization.

It is important to note that not all of the people who are described as owners perceive IT as solely a support function and a cost to be managed. Some of them understand the value of IT, especially when it comes to their projects and engagements. The problem is that when the owners or senior management meet to establish policies, budgets, and priorities for the coming years, even these enlightened supporters become complacent and accept the same old policies and priorities in establishing budgets. The mental models of the ownership of the firm are not aligned with the reality of the structure of the organization.

Information technology is not a support function but provides both support functions and production functions. The corporate priorities, policies, and budgets are not aligned with this reality. Therefore production costs are not allocated correctly, and technology budgets are falling short of the business demand. The information technology support organization is stretched to its capacity; current resources are taxed simply to provide adequate support for current operations. Implementations of new initiatives that may be required to support new or ongoing client engagements are jeopardized by resource constraints.

What Are the Key Variables Affecting This Problem?

In meeting with the management and staff of HTS, a number of key variables were identified. As with any system dynamics model, the key drivers of the model are the levels or stocks and the rates at which those stocks change. Table 33 briefly lists and describes the primary level variables in the model. It is desirable to maintain an endogenous perspective as much as is possible or practical, and for this model, the endogenous perspective has largely been maintained. However, there are several important variables that are exogenous to the model. Table 34 lists these variables with a brief description of what they represent and why they are exogenous to the model.

Table 33 Level Variables

Variable	**What it represents**
HTS Contracts -	This variable represents the current active contracts in the HTS organization.
HTS Non IT Staff -	This variable represents the total number of non IT Staff in the organization.
IT Staff - Service -	This variable represents the IT service staff, those people regularly performing service functions.
IT Staff - Other -	This variable represents the rest of the IT staff, other then those people regularly performing service functions, that is closing service tickets. The total staff includes, developers, project managers, management staff.
Available IT Budget -	This variable is the available IT budget. Budget is allocated annually, used monthly, and refreshed at the end of 52 weeks. (Money not spent in one year does not carry over to the next year.)
Available IT Staff Budget -	This variable is the available IT budget. Budget is allocated annually, used monthly, and refreshed at the end of 52 weeks. (Money not spent in one year does not carry over to the next year.)
Operational IT Systems -	This is the number of systems in the information technology infrastructure that are operational at any given moment
Tickets Backlog -	This variable represents the number of tickets in the IT service Queue, and is used to represent the workload demanded of the IT organization in support of the rest of the company.
Data Storage -	This variable represents the total amount of data storage in the system at any given time. Measured in Gigabytes, initial value is 30000 Gigabytes
Processor Power -	This variable represents the total amount of processor power in the system at any given time. Measured in Gigahertz the initial Value = 386000 GHZ
IT Hardware Software -	This variable represents the IT hardware and software in the system and is used to represent the fact that IT HW & SW is replaced on a regular schedule

Table 34 Exogenous Variables

Variable	What it represents
New Contract Proposals	This variable represents the growth of the firm, with new contracts driving HTS Corporate Growth.
Annual IT Staff Budget	This is the annual budget allocated to staffing the IT Organization at HTS. This is developed by the ownership of the firm with input from the CIO, is largely based on historical staff costs with cost of living raises. IT staff levels have not increased in 7 years.
Per Capita Allocation	This is the annual per capita allocation, it is set as a percentage of the firms net revenue. It has not increased in several years.

The following graphs, Figure 12, Figure 13, and Figure 14 illustrate the behavior over time of several of the key variables. The data was obtained from HTS sources. Some of the historical data was not captured and was approximated by HTS staff for the purpose of this case study.

Figure 12 HTS Staff

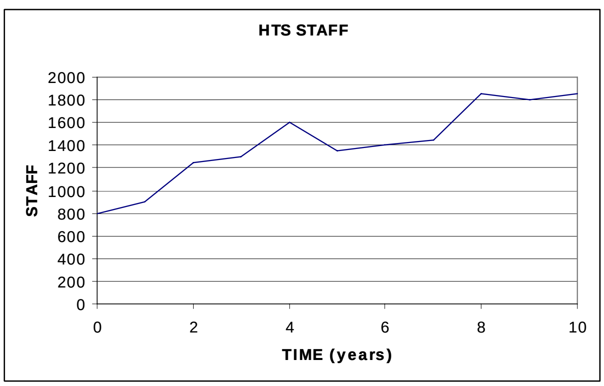


Figure 13 HTS IT Staff

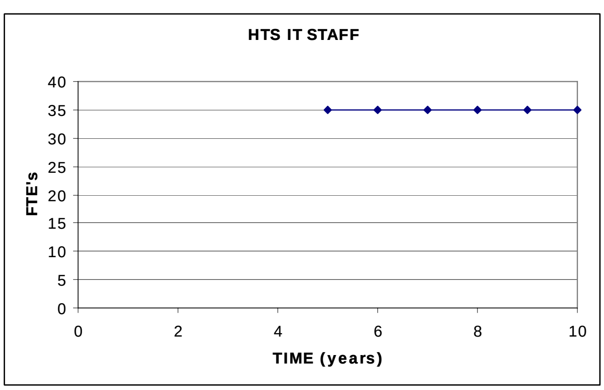
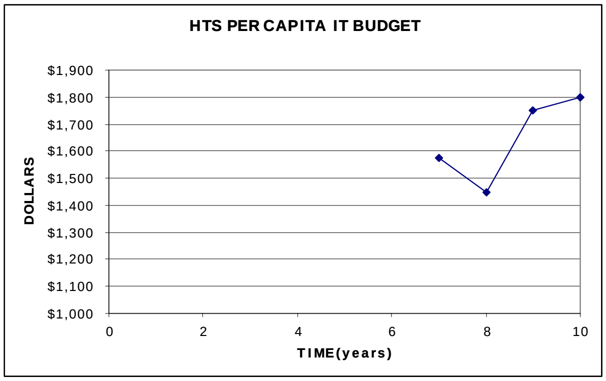


Figure 14 HTS Per Capita IT Budget



What Is The Purpose Of The Model?

The purpose of the proposed model is to understand the structure of the information technology infrastructure; to identify and clarify relationships among the many components of the infrastructure; to identify leverage points in managing the infrastructure, such as lengthy delays to acquire infrastructure components like data storage and or processor power, and to use this information to communicate to stakeholders the expected impact of various decisions; and to illustrate to the senior management and ownership of the firm the realities of the information technology infrastructure of the firm.

Two areas that are valuable measures of the information technology department's performance are the service ticket backlog and the delivery delay or response time for service tickets. One capability that the CIO is interested in is demonstrating to the ownership how various investment and operational decisions impact the performance and cost of the information technology infrastructure.

Formulate the Dynamic Hypothesis

What are the initial theories which explain this problem?

Ownership doesn't understand or accept that information technology has become a core production requirement of the firm. As a result of the migration of information technology from being purely technostructure/support structure, to technostructure/support structure *and* operating core requirement, the policies of the past are no longer effective in managing this critical resource. Continued growth of the firm requires adequate information technology services and support. The policies that currently govern the acquisition and management of the information technology resources are inadequate to support the growth of the firm. The mental models of the ownership of the firm have not changed with the structure of the firm. This misalignment prevents the firm from adequately supporting and financing the mission critical information technology services of the organization.

What are the endogenous factors that contribute to this problem?

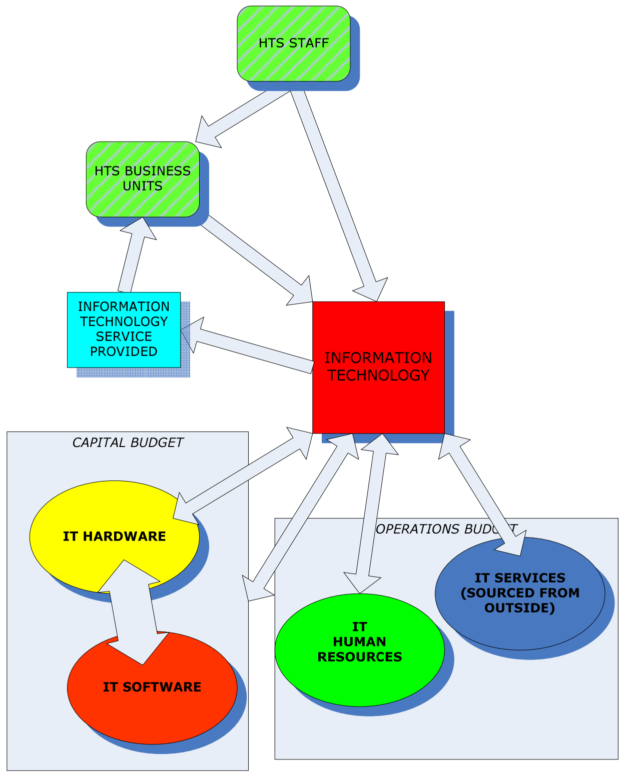
It is a generally accepted principle of system dynamics modeling that it is desirable for models to be broad enough that the behavior of the model is explained by endogenous variables. "Exogenous explanations are really no explanation at all; they simply beg the question" (Sterman, 2000, p. 95). Clearly, understanding the problem requires broad enough model boundaries to generate the behaviors endogenously. Fortunately, the CIO of HTS has a holistic viewpoint, and over the course of several meetings, we were able to develop model boundaries which are narrow enough to allow modeling the problem, yet broad enough to consist almost entirely of endogenous variables.

What are the subsystems?

Modeling is used to understand the structure of the organization and the relationship of the various subsystems that interact with each other. As this is an iterative process, a number of different subsystem structures were considered. Some were abandoned, others were modified as the causal loop diagrams, and later, the stock and flow structure, of the model began to come into focus. There were several subsystems that arose early in the analysis of the structure of the enterprise.

One of the first subsystems to arise in the modeling process is pictured in Figure 15. This diagram is a very high level diagram of how the information technology organization fits into the larger structure of HTS.

Figure 15 Subsystem Model



This diagram illustrates that the HTS staff and business units drive the information technology requirements of the firm. The information technology provides a service which is provided to the business units and, of course, to the staff of the firm. The information technology services provided can be considered as belonging to one of four fundamental cost categories. All of the expenses in the IT organization fit into one of these categories. These four categories are:

1. IT Hardware, which includes many different types of equipment: laptops and PCs, servers, network printers, routers, switches, SAN equipment, and any other IT product that is fundamentally hardware.

2. IT Software, which includes software licenses for operating systems, office suites, and specialized software, such as the ERP system.

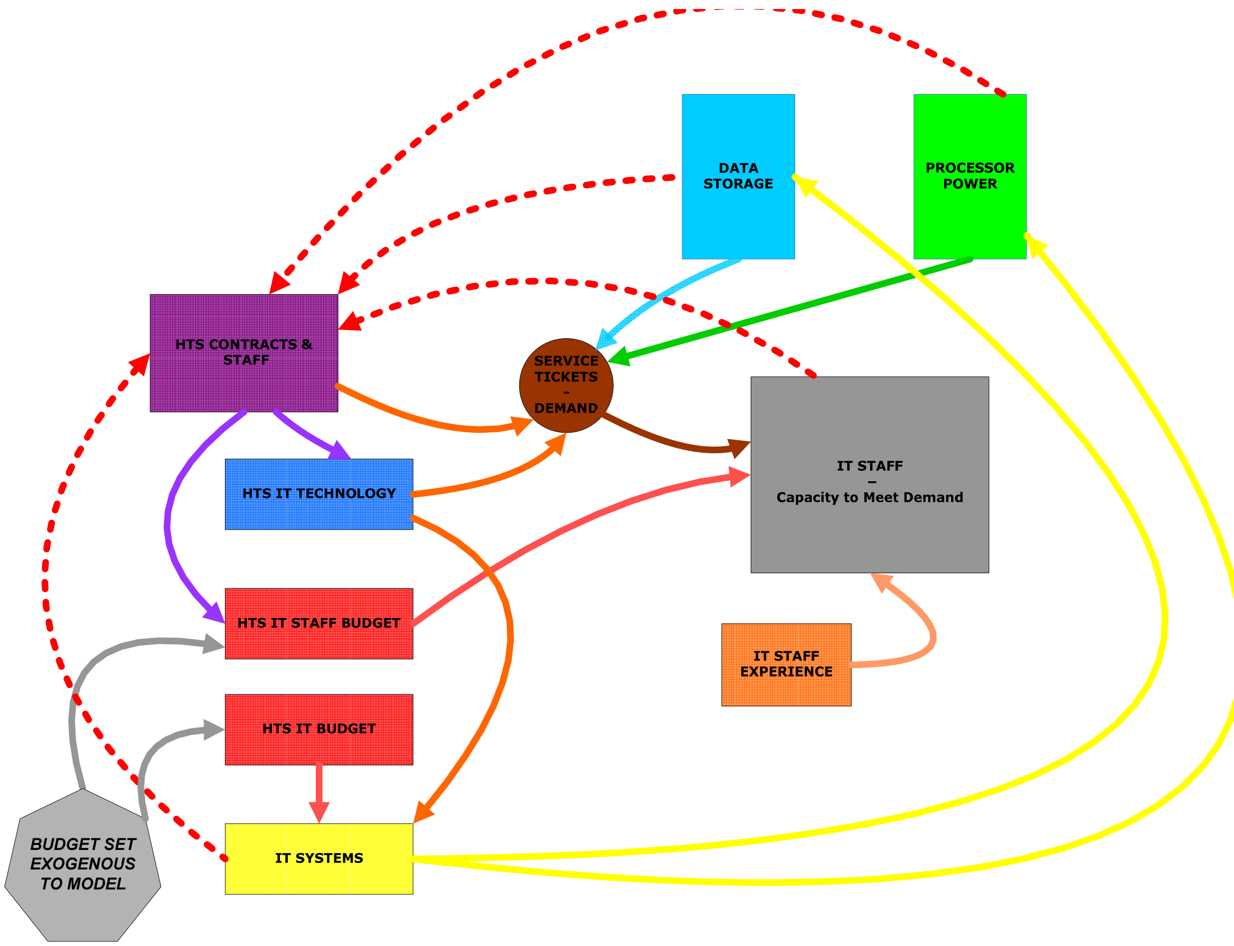
3. IT Services (Sourced from Outside) which includes telecommunications services and outside consultants or temporary employees who provide information technology services.

4. IT Human Resources, which includes the salary expenses for the staff working in information technology.

In the HTS budget, these four categories of expenses are addressed by two different IT budgets. The first IT budget is the operations budget, and it contains the budget for the IT human resources. The annual budget for this area is currently $2,000,000 and covers the direct salary expenses for 35 people. Benefits and other indirect costs are not allocated to the IT organization. The operations budget also covers the cost of paying for services that are sourced from outside providers. This includes paying for the telecommunication costs and any IT consultants who were used to support the infrastructure.

Several iterations of subsystem diagrams were explored, and while some of them were useful in constructing early models, they were discarded as the model progressed. The subsystem diagram that represents the final model is shown in Figure 16. This diagram shows the placement of the various subsystems in the final Causal Loop/Stock and Flow Diagram.

Figure 16 Subsystem Model



In this subsystem diagram, several subsystems have been added to the earlier four subsystems. However, these subsystems are essentially more specific representations of the original subsystems, defined with greater precision. The subsystem HTS Contracts and Staff is equivalent to the earlier subsystems of HTS Staff and HTS Business Units. The change in organizing and naming this subsystem was done to reflect more accurately the role it plays in the model. Information technology at HTS is both a support and a production system, but in either case, it is simply a tool that is used either to support production activities or to support business activities.

Growth of IT systems is the result of providing greater support for the firm. Real growth in IT systems is the result of growth in the firm. The subsystem HTS Contracts and Staff represents the staff and non-IT business units of the firm, and is the driver of growth. The subsystems HTS IT Technology, IT Systems, Data Storage and Processor

Power all represent IT Hardware and IT Software and are all funded through the capital budget. The IT Staff subsystem represents the IT Human Resources and is funded through the IT Staff budget. The subsystem HTS IT Budget represents the operations budget.

The IT Staff Experience subsystem is really a subsystem of the IT Staff subsystem. The IT Experience subsystem is separated out as a separate subsystem because of the complexity of modeling it in the simulation model. A number of factors are considered and modeled in this subsystem. These factors include the average experience of the HTS IT staff, the average experience of new hires, the effect of new technology on staff experience, the effect of training on staff experience, and the effect of time on the job on staff experience. All of these effects are modeled in this subsystem, and the output of the IT Experience subsystem is a factor in modeling the average time per ticket. Finally, in this diagram, the exogenous variables that establish the budget for the IT organization are explicitly identified.

CAUSAL LOOP/STOCK AND FLOW DIAGRAMS

The full Vensim model is included in Appendix 7 of this document. The size of the model makes it impractical to include the sketch of the entire model within the text. The model is very complex with over 200 variables used. In order to explain the model, it will be disaggregated into each of its several component subsystems, and each will be presented here as a different section.

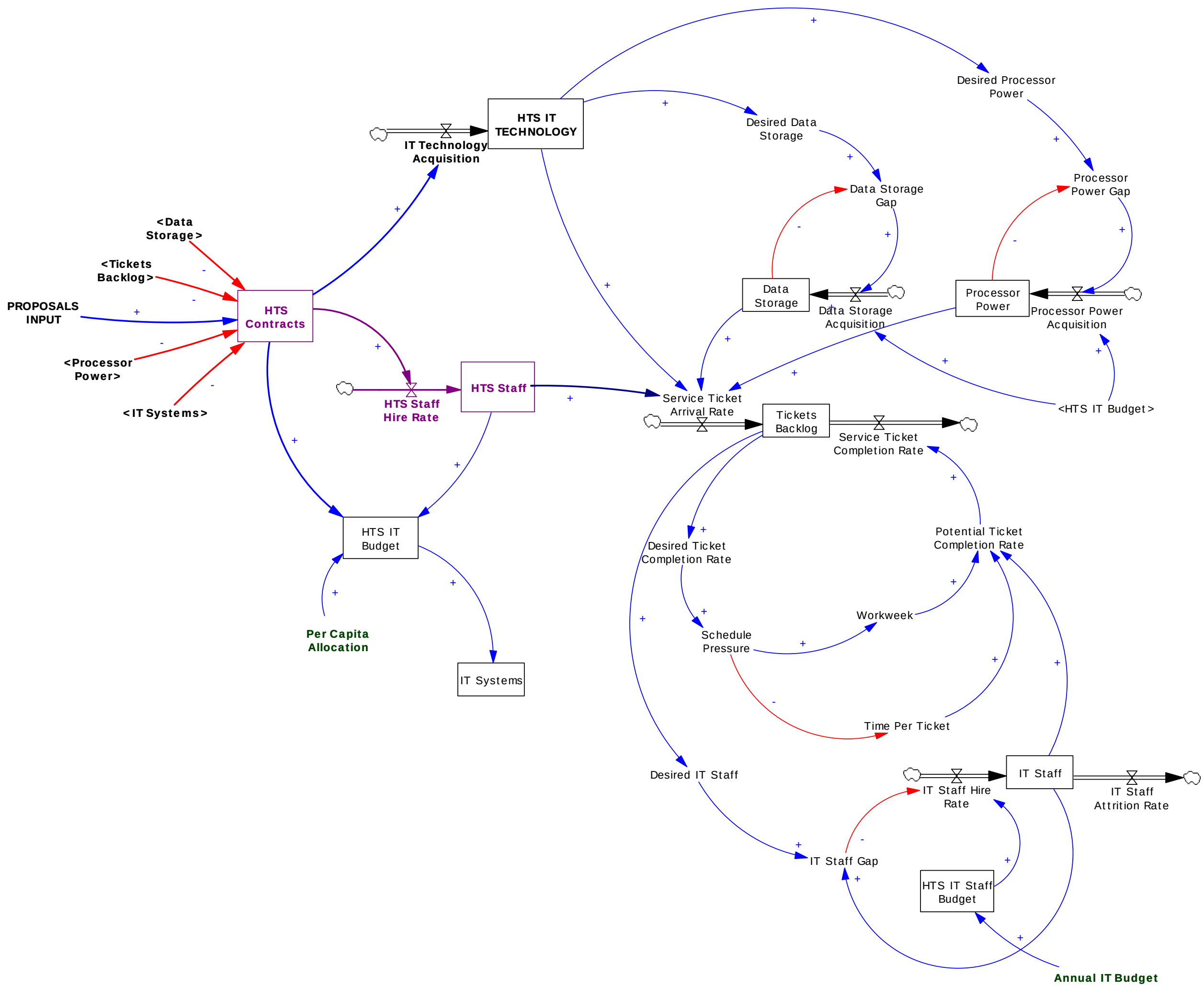
First a vastly simplified diagram is presented that is used to explain the overall model. Although this diagram is developed using Vensim, it does not follow all of the conventions of system dynamics modeling. This diagram is not intended to be a simulation model, but is rather a simplified version of the overall model, intended to help understand the simulation model. This model was developed after the simulation model was finalized and is used here to as a tool communicate the structure of the completed simulation model. A high-level explanation of the overall model will follow this simplified diagram. A model diagram of each of the major subsystems will follow with a detailed explanation of each subsystem.

Overall Model

Figure 17 presented here is the simplified diagram of the overall model. This diagram is intended to communicate the overall structure and operation of the detailed model. The overall structure of the simulation model is built upon the subsystems discussed in the previous section. Company growth and performance are modeled in the HTS Contracts and Staff subsystem. The growth is driven exogenously using an input created by a test input generator. The input generator allows the model to be tested using a number of different input behaviors. The growth of the firm drives the implementation of additional IT technology initiatives though HTS IT Technology. Growth of the firm also controls the HTS IT budgets. In the simulation model, as in the actual organization, growth in either the IT systems (modeled by the IT Systems subsystem. the Data Storage subsystem, and Processor Power subsystem), or in the IT Human Resources (modeled by the IT Staff subsystem) is controlled by the HTS IT budgets.

The subsystem HTS IT Technology drives growth in the IT Systems, the Data Storage, and the Processor Power subsystems. Growth in any of these subsystems – HTS Staff, IT Technology, Data Storage, or Processor Power – drives the service ticket arrival rate. The service ticket arrival rate drives the IT Staff subsystem. Each of the IT subsystems – IT Technology, Data Storage, Processor Power and HTS IT Staff – feeds back to the HTS Contracts subsystem. None of these are modeled as reinforcing loops back to the growth of the firm, but rather are modeled as balancing loops that constrain the growth of the firm. This approach was used because the problem being studied is the perceived misalignment of the ownerships mental models with the structure of the organization.

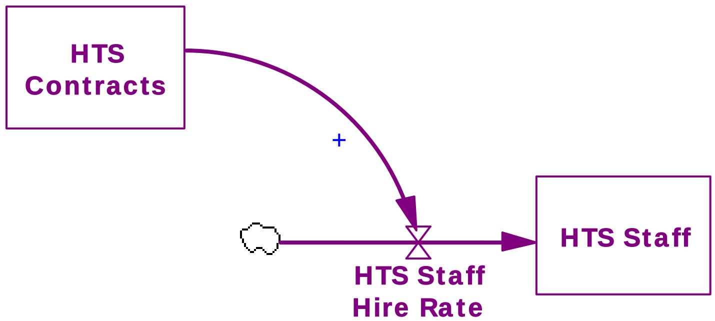
Figure 17 Simplified Causal Diagram of HTS Information Technology.



HTS Contracts & Staff Subsystem

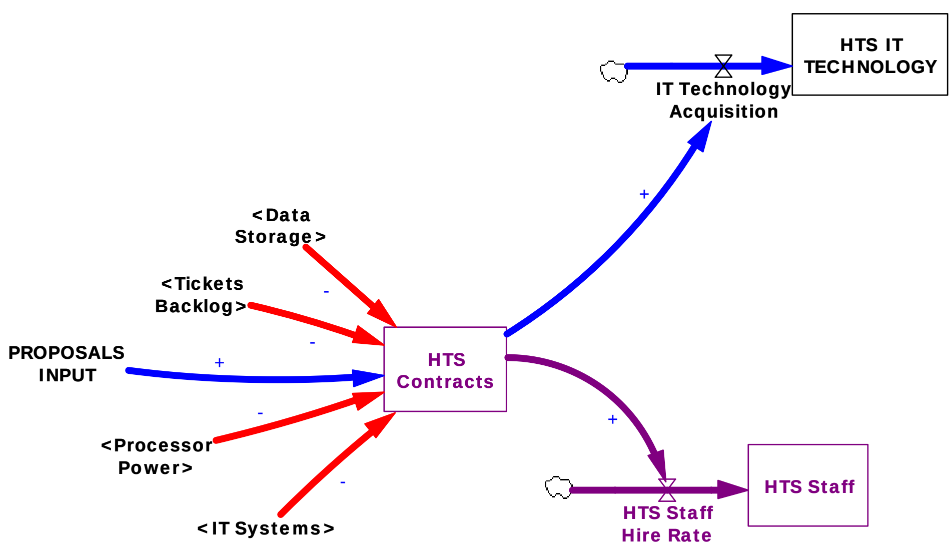
The subsystem HTS contracts and staff is represented by the stocks HTS Contracts and HTS Staff, as well at the rate variable HTS Staff Hire Rate. This subsystem is pictured in Figure 18. This subsystem models the growth of the firm generated by both increases in staff and increases in the number of contracts.

Figure 18 HTS Contracts & Staff Subsystem



Some very important feedbacks are introduced in this subsystem. These feedbacks are the effects that IT performance has on the growth of the firm. In Figure 19 these new variables are introduced to the subsystem.

Figure 19 HTS Contracts Subsystem With External Feedback Loops Identified



This feedback represents the importance of four primary functions of the IT organization/infrastructure in the performance of business at HTS. The first function is the requirement for data storage. In the past five years data storage requirements have been growing exponentially at HTS, and currently there are 30 terabytes of data storage media available. The CIO estimates that data storage requirements will continue to grow exponentially, with the total requirements doubling every 18 months for the foreseeable future. It is believed that these data storage requirements directly affect the production capabilities of the firm and therefore have a direct effect on the performance of the firm.

It is easier to understand the effect of data storage on the performance of the firm if one considers the extreme condition effect. What would happen to the performance of the firm if the required data storage facilities failed? It is clear that much of the production work at HTS would be constrained by a lack of data storage facilities.

In modeling this behavior in the simulation model, a ratio of desired data storage facilities to actual data storage facilities is used to model this feedback. The desired data storage facilities are developed in the simulation model from the implementation of new IT technology, which drives the need for more data storage. This diagram also introduced the relationship between the growth of the firm and the growth of information technology through the link between HTS Contracts and IT Technology Acquisition. In the simulation model, growth of IT Technology is a function of the HTS Contracts.

The second important feedback in this diagram is the feedback from the service tickets backlog to the performance of the firm. In this case, the feedback represents the effect on performance of the firm if IT service tickets are not addressed in a timely manner. The extreme condition test is valuable in understanding this feedback as well.

Currently, service tickets are cleared generally within one business day, with some variance for the priority of the problem and the status of the employee who is experiencing the problem. Considering the extreme condition, what if tickets were not cleared, on average for five business days? What about 30 days? 90 days? It is clear that these delays would have an effect on the overall performance of the firm. However, experience suggests that these extreme delays will not stop the performance of the core business of HTS; it will simply reduce the capabilities. Even if the IT staff doesn't clear the tickets, generally someone from the business units will eventually take matters into their own hand and address the issues, or a workaround will be developed. Nevertheless delays in closing the tickets will have an impact on the performance of the firm.

The feedback from processor power is developed similarly to the structure of the data storage requirements. Overall processor power is currently measured at 386,000 GHz in the infrastructure. Growth is not as rapid as with data storage, and the growth is not expected to approach rate of data storage. In the model the feedback from the processor power requirements to the performance of the firm is calculated using a ratio of desired processor power to actual processor power. As with desired data storage, desired processor power is a function of the simulation. The desired processor power is driven by the growth of information technology.

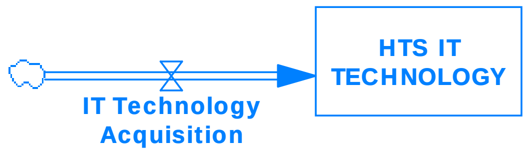
The last feedback from IT to the performance of the firm is IT Systems, and this represents the impact of operational versus non-operational systems in the infrastructure. In order to model the effect of an IT failure, these complimentary variables, operational and non-operational systems, are introduced in the model. In the simulation model, these variables are summed and this creates the variable Total IT Systems. When simulating the model, it becomes clear that a failure of IT has a profound effect on the overall performance of the firm.

Finally one additional variable is introduced into this diagram. This variable is the proposals input, and represents the exogenous growth of the firm. In the simulation model, it is simulated using a test input generator that allows various simulated input behaviors to be tested to understand the impact of growth of the firm.

HTS IT Technology Subsystem

The subsystem HTS IT Technology is specifically represented by the level variable HTS IT Technology and the rate variable IT Technology acquisition. Figure 20 depicts this subsystem. In the simulation model, this subsystem represents the growth of information technology through the acquisition of new technology as well as the growth of existing technology. The previous section showed that the rate variable "IT Technology Acquisition" was driven by the level variable "HTS contracts." As HTS grows through the acquisition of new contracts, the IT infrastructure grows with new initiatives and systems.

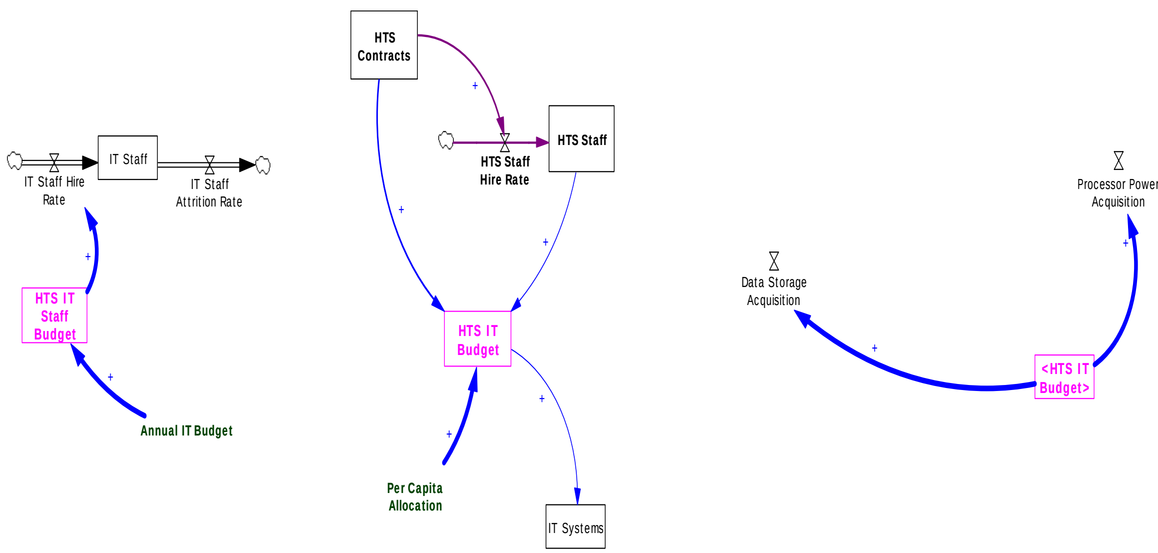
Figure 20 HTS IT Technology Subsystem



HTS IT Staff Budget and HTS IT Budget

Although these are two separate subsystems, they are closely related and are addressed together. Figure 21 depicts the two budget subsystems.

Figure 21 HTS Budgets



This figure shows that HTS IT Staff Budget is driven by the exogenous variable Annual IT Budget; likewise the HTS IT Budget is driven by the exogenous variable Per Capita Allocation. The HTS Staff budget acts to control the IT Staff Hiring Rate, and the HTS Budget controls the acquisition of data storage, the acquisition of processor power, and the IT Systems variable. The IT budgets at HTS do not allow a carry-over from year to year. Therefore, in the simulation model, the budget is cleared at the end of each fiscal year.

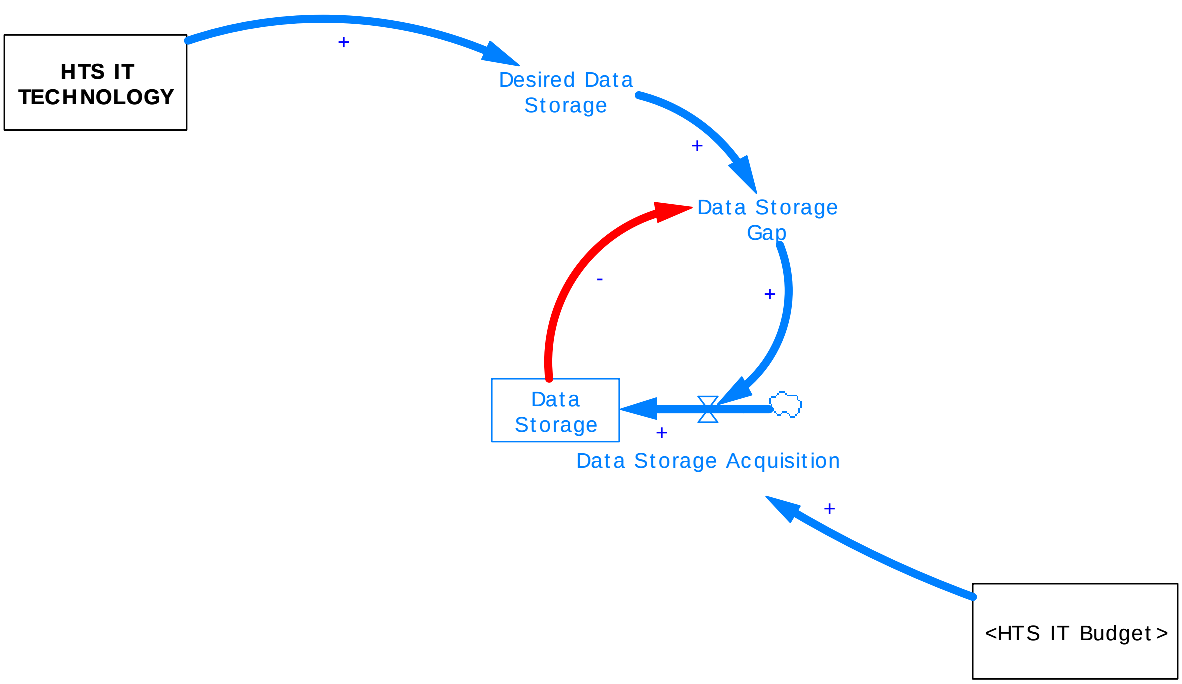
IT Systems Subsystem

This subsystem is represented very succinctly in the simplified diagram. The representation is a single additional level variable, IT Systems. This variable can be seen at the bottom of the HTS IT Budgets subsystem diagram in Figure 21. In the simulation model the IT Systems subsystem is used to simulate the replacement of equipment as it ages. This is primarily done to account for the impact on the IT budget from the replacement of systems.

Data Storage Subsystem

In the Data Storage subsystem, it is shown that the desired data storage is driven by the level variable HTS Technology. This represents the relationship between the Technology in the firm and the data storage requirements. This subsystem is pictured in Figure 22.

Figure 22 Data Storage Subsystem



This diagram also depicts two other important relationships. First, the data storage gap is shown, which represents the difference between the actual and desired data storage. Closing the gap and acquiring data storage media is controlled by the HTS IT Budget. If there is no money in the budget to acquire additional data storage facilities, the gap will remain. In addition to the control function of the budget, there is a delay that represents the time it takes to specify, approve, order, receive, configure, and deploy the new data storage equipment. This delay is modeled in the simulation with the variable, Time to Close Data Storage Gap, and is a constant of 12 weeks, which is the currently the average time it takes to upgrade data storage facilities.

The relationship between the desired and actual data storage is further developed in the simulation model. It is this ratio, Desired Data Storage/Data Storage, that is fed back to HTS Contracts and that constrains the overall performance of the firm when the ratio is less than one. For when the ratio is less than one, there is a gap between desired and actual data storage facilities. This gap means that data storage facilities are not at the optimal or desirable level.

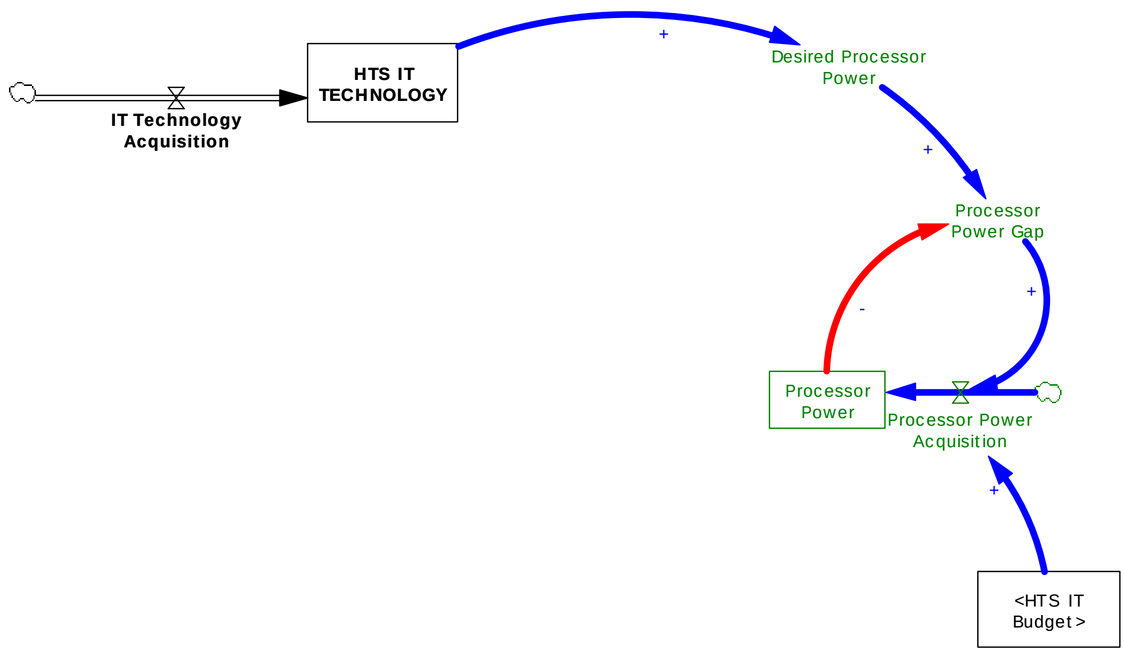
It is useful to note that the level variable Data Storage is modeled as having an inflow into the stock, but no outflow from the stock. This is done intentionally and represents the belief that data storage capabilities are never eliminated: once in the infrastructure, it is there forever. This is important, because the growth of data storage impacts the organization in many subtle ways.

For instance, more data storage capacity means more data is stored. Without sophisticated record management systems, this can impact the ability of individuals to obtain the information that is necessary. More data can impact the speed at which useful data can be obtained, and it also increases the resources, both in time and dollars, required to back up and archive the stored data. It is recognized that data storage facilities will fail from time to time, and perhaps an outflow from the data storage would have been appropriate to capture this dynamic. However, it was felt that failure of storage facilities doesn’t really change the total storage requirements. Replacement of data storage equipment as it ages or fails is addressed in the IT Systems subsystem.

Processor Power Subsystem

The processor power subsystem is very nearly identical to the data storage subsystem. Growth of processor power is a result of growth of the firm, which drives growth of IT technologies, which drives growth of processor power. Figure 23 depicts the Processor Power subsystem.

Figure 23 Processor Power Subsystem



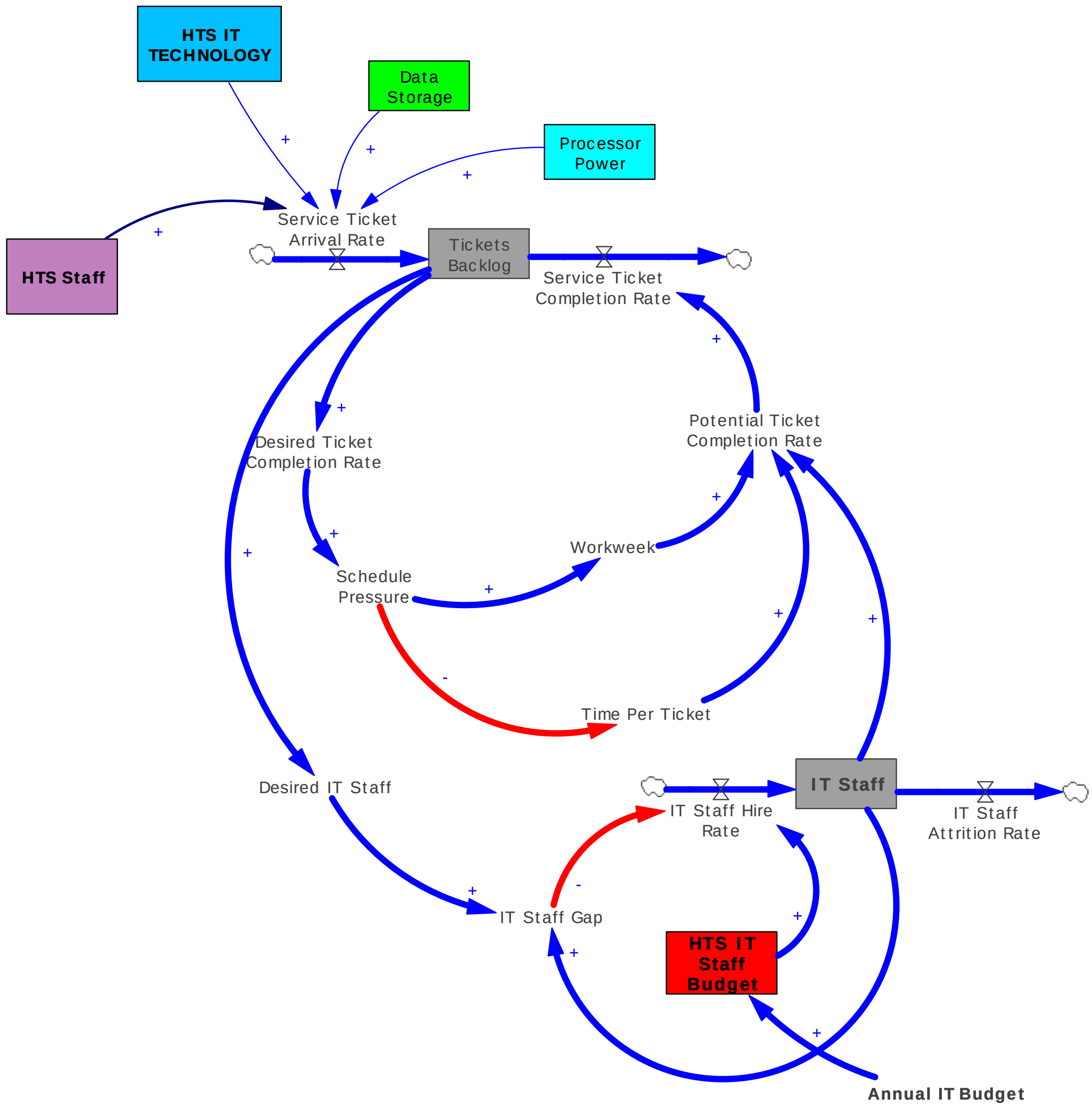
As with the data storage subsystem, the processor power subsystem shows the relationship between HTS Technology and Processor Power. As HTS technology grows, as a result of the growth of HTS, the desired processor power grows. Closing the gap between actual processor power and desired processor power is controlled by the HTS IT Budget. There is a delay in the simulation, as it can take several weeks to select the appropriate hardware and software, order it, receive it in house, properly configure the systems, and deploy the new equipment. Like the data storage subsystem, processor power is modeled as a level that has no outflow from the stock. Again this is modeled intentionally as a level that only accumulates and does not decrease. The ratio of desired processor power to actual processor power is the feedback to the performance of the firm and acts as a constraint on the growth of the firm.

IT Staff Subsystem

The IT staff subsystem models the workload of the IT support organization. The workload of the organization is represented by the service tickets backlog. It is acknowledged that not all work arrives in the IT organization through service tickets. However, it was generally accepted by the CIO and the IT management team that the ratio of work that arrives at the department via the service ticket queues, and work that comes in through other methods, is generally constant, and therefore the IT service ticket queue is an acceptable proxy for the workload of the organization. This was important to establish since there is good data within the organization on the tickets that arrive in the service department and there is little data to track other methods of receiving work requests.

Figure 24 diagrams the IT Staff subsystem. The ticket backlog represents the current outstanding service tickets within the organization. Tickets arrive in the queue at some normal arrival rate. For HTS, the normal arrival rate was estimated to be .123 tickets per HTS Staff person/week. This arrival rate is impacted by three additional variables, these variable are: HTS IT Technology, Data Storage, and Processor Power. HTS IT technology impacts the ticket arrival rate by increasing the number of tickets that arrive when new technologies are deployed in the organization. This increase in ticket arrival is the result of new technologies being unfamiliar to the user community and by new technologies adding to the complexity of the information technology workplace, which causes interactions with other existing technologies. Data Storage increases the ticket arrival rate less directly. The increase in data storage means there is more equipment to manage, and more equipment to fail. The additional data storage equipment also increases the workload requirements for backups and the restoration of data.

Figure 24 HTS IT Staff Subsystem



The effect of processor power is similar to the effect of data storage, in that it increases the complexity of the infrastructure, and there are more processors and servers in the infrastructure to fail. None of these effects is assumed to be linear, and all are simulated using nonlinear table functions that were developed, modified, and accepted through meetings and discussions with the CIO and IT staff.

Ticket Backlog is increased by the ticket arrival rate, and decreased by Service Ticket Completion Rate. The ratio of Service Tickets Arrival Rate to Service Ticket

Completion Rate is not shown in the overview model, but is used in the simulation model. This ratio describes the average time it takes the information technology organization to close a ticket. In the simulation model this delay time is compared to the target ticket completion time, which is the IT Management team's target for closing service tickets. In the simulation model, this is a constant of 100 minutes. This ratio is the feedback from the IT Staff subsystem to the performance of the firm.

It is desirable for the service ticket backlog to remain roughly at equilibrium. That is, the service ticket arrival rate and the service ticket completion rate should be equal in any given period. If the ticket backlog grows too high, it obviously means that service tickets are not being closed in a timely manner. As the firm expands, the rate of service tickets is likely to increase, as a function of one or all of the drivers increasing.

In order to maintain the backlog at equilibrium, there are three possible interventions that can be taken. The organization can 1.) increase the workweek of the current staff, 2.) reduce the time spent on each ticket, or 3.) increase the staff. Each of these interventions forms a separate loop in the IT Staff Model subsystem. As the ticket backlog grows, the desired ticket completion rate grows. As the desired ticket completion rate grows, schedule pressure also grows. As schedule pressure grows, so too does the work week; however, as schedule pressure goes up, the time per ticket goes down. With either less time spent per ticket or the staff working longer hours, the potential ticket completion rate is increased. In the simulation model, the growth of the workweek is constrained by the IT Staff budget, as working additional hours requires overtime, and working overtime increases the weekly cost for IT Staff.

Alternately, as the ticket backlog goes up and the desired ticket completion rate rises, so does the desired IT staff. The variance between Desired IT Staff, which is driven by the increased backlog of tickets, and IT Staff forms a gap that is closed by increasing the number of IT staff people. Closing this gap is controlled by the HTS IT Staff Budget, because hiring additional IT staff requires funds from the IT Budget.

Additionally, there is a delay modeled in the simulation, because it requires time to hire additional staff. This delay has several constituent parts, including the management decision to hire additional staff and the time to advertise the position. Also, once a person has been selected, there is generally a minimum of two weeks before that person can start. In the simulation model, this delay is modeled as two distinct delays. The first delay is the management decision delay. This delay is the more complex of the delays and includes the effect of recent tickets backlog and the effect of recent workweeks in the process. In brief, the delay is modeled after the actual process in which the management of the IT organization would not hire additional people immediately simply because either the recent workweek or the previous weeks' ticket backlog had reached some predetermined level. The simulation model uses information delays to ensure that the both the recent workweek and the recent ticket backlogs are longer term trends, and not simply anomalies.

The other delay, which models the post decision delay is much simpler, and is done using a single variable, Time to Hire Staff. This variable is a modeled as a constant five weeks and is the CIO's best estimate of how long it takes him on average to hire new people, once the decision has been made to hire.

The model is described beginning with the variable HTS Contracts. Conceptually, this represents the contracts of the firm, and as the firm grows, the stock of contracts grows. The firm grows as a result of receiving, responding to, and winning more proposals. As the number of contracts the firm is working on grows, the number of people required to work on these contracts grows, and therefore, as HTS Contracts grows, HTS Staff grows. Additionally, new contracts causes growth in the IT infrastructure of the firm, both in terms of new initiatives required to support the contracts and in terms of size of the infrastructure required to support the larger firm.

The model includes three components of the infrastructure. These three components are modeled as separate subsystems and are briefly described above. As the firm grows, the requirements for new information technology grows. As the new technology requirements grow, the desired data storage and the desired processor power grow. As the firm grows in terms of staff and information technology, the number of service tickets arriving in the information technology organization grows. The acquisition of new data storage and new processors, as well as the hiring of staff, are governed by the budget and by delays in hiring new staff and by delays in implementing new technologies. Because of the delays, and more importantly because of the budget constraint, gaps develop between desired data storage and actual data storage, between desired processor power and actual processor power, and between desired average service ticket completion time and actual service ticket completion time. Each of these gaps between desired and actual constrains the ability of the firm to perform at desired levels, and each of these gaps feeds back to the core business performance of the firm and constrains both the performance and growth of the firm.

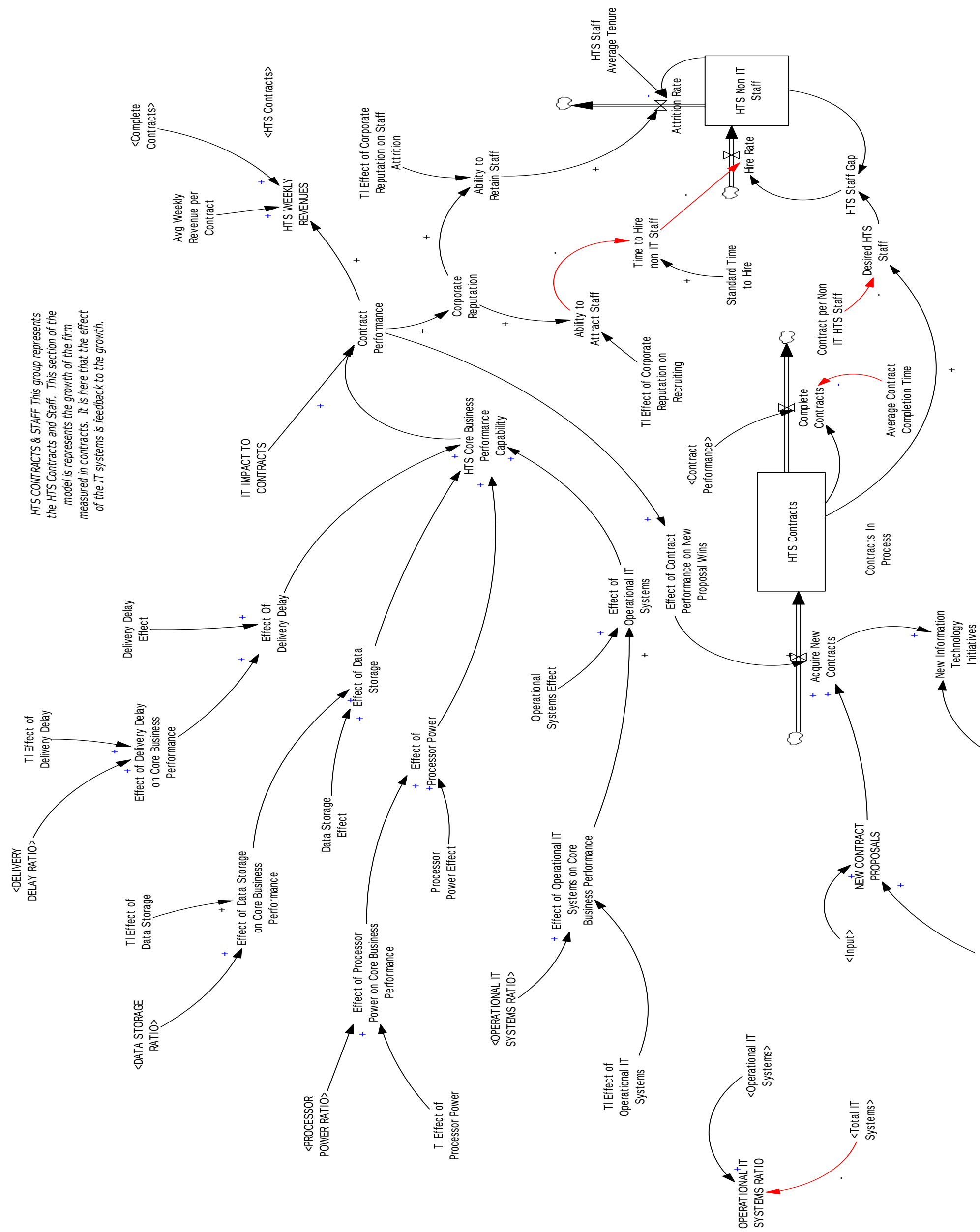
There are those who would argue that information technology enhances the firm's production capability. That may be true, but this model takes the approach that information technology simply enables the core performance capability of the firm. If information technology is performing at desired levels, the firm is free to grow and perform unconstrained by information technology. If, however, information technology is not performing at desired levels, it has the effect of constraining performance and growth of the firm.

DETAILED MODEL DESCRIPTION

HTS Contracts and Staff Subsystem

The first section of the model to be described in detail is the HTS Contracts and Staff section. Figure 25 is the detailed diagram of this section.

Figure 25 HTS Contracts & Staff Detailed Subsection Model



It is in this section that the model simulates growth of the firm. It is also in this section that the very important feedbacks from information technology are found. Several of the important variables and relationships will be detailed in this section of the chapter. The detailed documentation of the model is found in Appendix 6, and the reader is invited to explore the documentation for further information on the remaining variables.

The first variable to be considered is the auxiliary variable Contract Performance. This variable is one of the most important variables in the model. Under normal conditions this variable is equal to 1, and has no effect on the rest of the model. Mathematically this is done by limiting Contract Performance to a range of values from 0 to 1, and by using Contract Performance as a multiplier; other variables are multiplied by Contract Performance. When performance in the information technology sections of this model is not at desired levels, Contract Performance is reduced to some level below 1, this then reduces the value of the other variable. The variable contract performance has as its input two variables. The first variable is HTS Core Business Performance Capability, and this variable is where the model aggregates the feedback from the information technology sections of the model. The second variable is IT Impact To Contracts. This variable is used only in testing/demonstrating the model. It is used to turn off the effect of the feedbacks from the information technology sections. It is accomplished with the following equation:

Contract Performance =

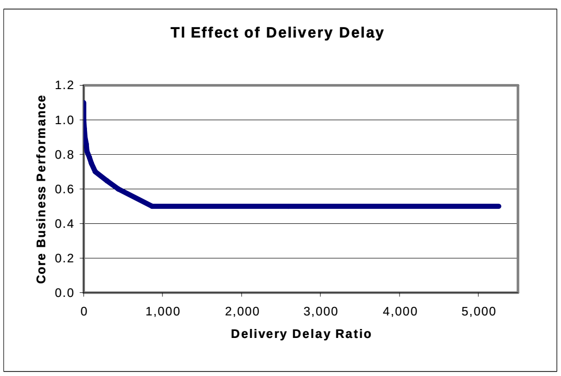
(HTS Core Business Performance Capability*IT IMPACT TO CONTRACTS)+

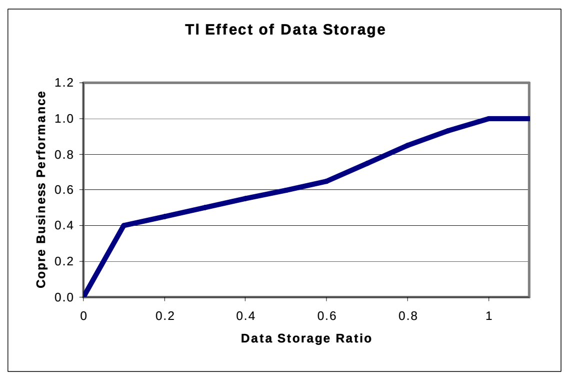
(1-IT IMPACT TO CONTRACTS) (0.8)

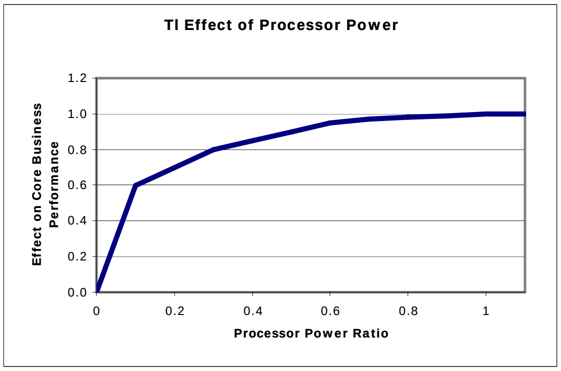
This equation demonstrates that when IT Impact To Contracts = 1, then Contract Performance = HTS Core Business Performance Capability; that when IT Impacts To Contracts = 0, then Contract Performance is equal to 1; and that Contract Performance has no effect on the subsequent variables HTS Weekly Revenues and Corporate Reputation. HTS Weekly Revenues is a function of the average weekly revenues per contract times the number of completed contracts each week. When IT Impact To Contracts is equal to 1, then Contract Performance is equal to HTS Core Business Performance Capability, which varies between 0 and 1. When all IT functions are operating at their desired levels, then HTS Core Business Performance Capability is equal to 1, and the IT functions have no effect on the weekly revenues or the corporate reputation. However, when the ratio of Desired Performance/Actual Performance is less than 1, there is an impact on the core performance capabilities of the firm, which is captured here.

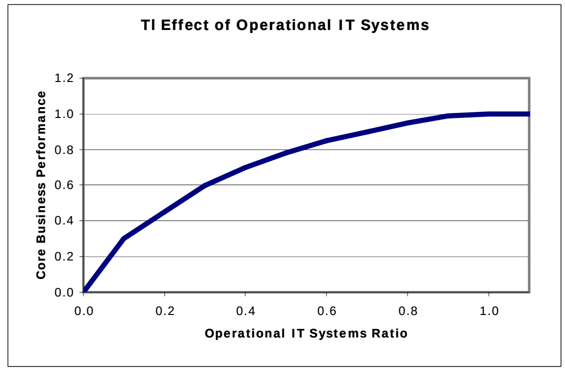
Recall that each of four IT subsystems has a feedback to the core business capabilities. Each of these feedbacks is captured using a separate nonlinear table function. The non linear functions were developed with the assistance of the CIO to capture the client's belief in how the various information technology functions impacted the firm's capabilities. In addition, there are four additional variables incorporated into the feedback structure. These four variables Delivery Delay Effect, Data Storage Effect, Processor Power Effect, and Operational Systems Effect are used in testing and presenting the model. Each of them is set up at equilibrium to be equal to 1. During testing they can be adjusted from .75 to 1.25, and they have the effect of strengthening or weakening the table variables. This was done recognizing the value of sensitivity analysis in such a key feedback structure. If a client felt that the table functions do not accurately reflect the effect of one of these structures, the effect can be modified 25% up or down during SyntheSim operations to capture the client's mental models. Figure 26 is the Table Variables for the four feedback ratios.

Figure 26 Table Variables Governing Primary Feedback Loops









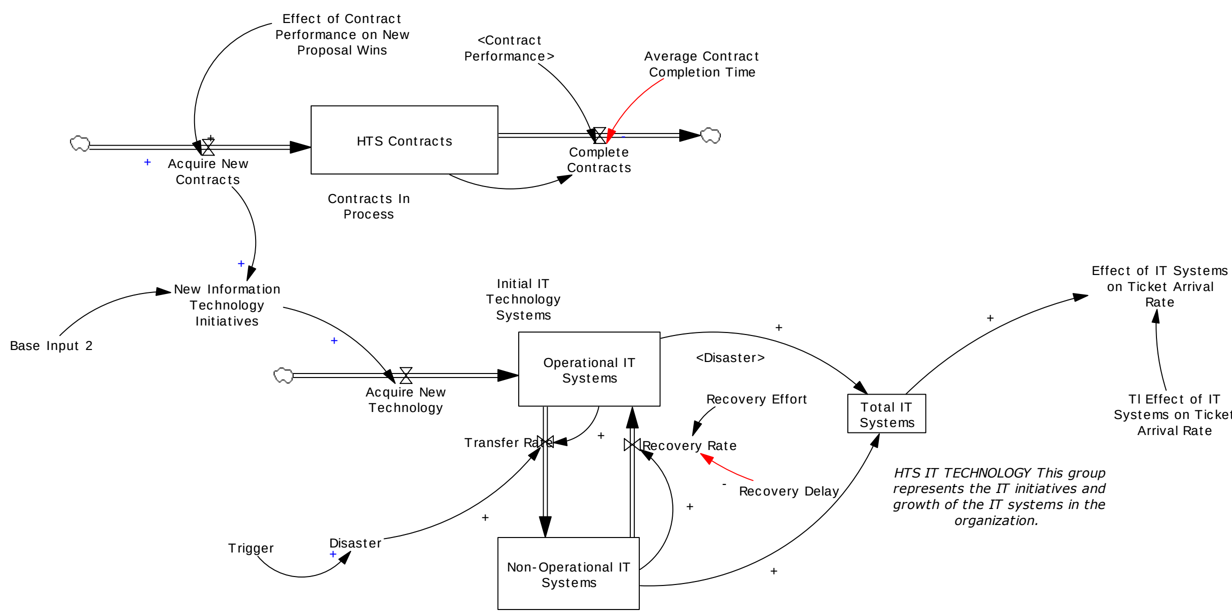
The next variable to be considered is the level variable HTS Contracts. This variable is the stock of current active contracts in the firm. It represents the core activity of the firm. The initial value is the variable Contracts in Process, and is initially equal to 5,000. This value was provided by the management of the firm as the number of current open contracts. The input to the stock HTS Contracts is the rate variable Acquire New Contracts, and the outflow of this stock is the rate variable Complete Contracts. Both the input and the output rate variables of this level are affected by the auxiliary variable Contract Performance. The input, Acquire New Contracts, is affected through an intermediary variable, Effect of Contract Performance on New Proposal Wins. The output Complete Contracts is affected directly by the variable Contract Performance. Conceptually, contract performance impacts the firms ability to win new contracts, which is modeled through the input to the stock; at the same time, the firm's performance also impacts the ability of the firm to complete contracts, which is modeled through the output of the stock.

The other level variable in this section of the model is the level HTS Non IT Staff. This represents the number of people employed by the firm to complete contracts, to do the work of the firm. This variable is also affected by the variable Contract Performance through some intermediary variables. In this case, the intermediary variables model the effect of contract performance on the firm's reputation, and the subsequent ability to retain staff and attract new staff. These relationships are modeled as nonlinear relationships, and the table functions used to represent the relationships were developed in meetings with the CIO. This variable has a direct effect on the other sections of the model because it is one of the key drivers of the Service Ticket Arrival Rate, which drives the work demand into the information technology organization.

HTS IT Technology

The subsystem HTS IT Technology is where the growth of information technology is modeled. For clarity, and to show the connection back to the HTS Contracts and Staff subsystem, the level variable HTS Contracts is included in the diagram of this section. Figure 27 depicts this section of the model.

Figure 27 Detailed HTS IT Technology Subsystem Diagram



There are two important level variables in this section of the model. The first is Operational IT Systems, and the second is the alternate variable Non-Operational IT Systems. Under normal operations, all IT Systems are operational and therefore are modeled by the variable Operations IT Systems. There are two inflows into and one outflow out of the stock of operational IT systems. The first inflow is governed by the rate variable Acquire New Technology. This rate variable is in turn governed by the auxiliary variable New Information Technology Initiatives, which is a function of the acquisition of new contracts. As the firm grows (measured by the acquisition of new contracts), the information technology infrastructure grows through the acquisition of new technology. This in turn grows the number of Operational IT Systems. The single outflow from Operational IT Systems represents the flow of systems from operational status to non-operational status. This flow is controlled by the rate variable Transfer Rate, which is in turn controlled by the variable Disaster. The flow back from Non-Operational IT Systems to Operational IT Systems is controlled by the rate variable Recovery Rate. Recovery Rate is controlled by two variables, Recovery Effort and Recovery Delay.

Fundamentally what is being modeled here is that, first, the growth of IT Systems comes about as a function of growth of the firm. Second, the Disaster variable is used in testing and presenting the model, and enables the modeler to demonstrate the impact of a disaster that causes the IT infrastructure to fail. This disaster causes all of the IT systems to move from operational status to non-operational status and the recovery of these systems is controlled by the level of effort and the recovery delay. Currently, Recovery Effort is assumed to be 100%, and Recovery Delay is assumed to take 20 weeks for full recovery. A disaster can be modeled in the system using the Trigger variable, which is a slider on the Control panel, and can vary anywhere from week 0 to week 520. The initial value of the trigger variable is -10. The only use of the variable is as the start time for a pulse function in Vensim, and since the model settings begin at time 0, the trigger at its initial value is not a factor.

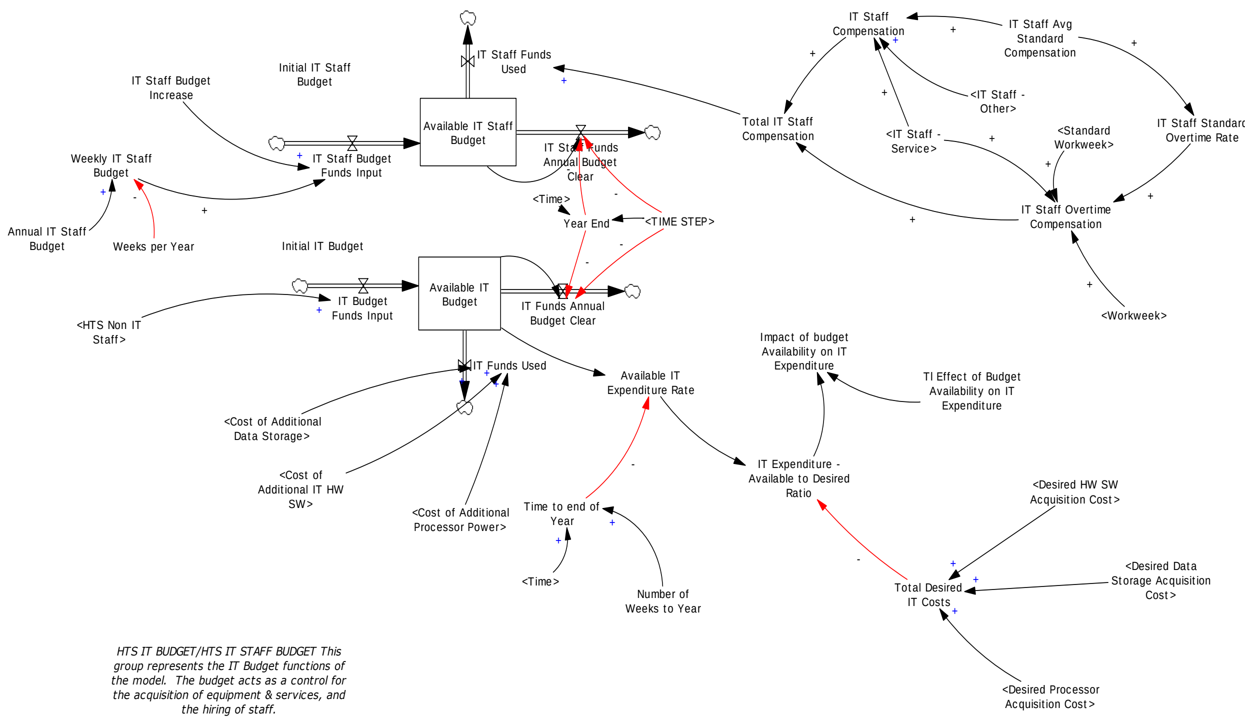
HTS IT Budget/HTS IT Staff Budget

The information technology budgets, both the capital budget and the operational budget, are represented in this section of the model. A number of very important concepts are presented here. One of the most important revolves around the two level variables in this section of the model. These two level variables, Available IT Staff Budget, and Available IT Budget, are used to model the fundamental principle at HTS that these are separate budgets. The principle behind how each of these variables is modeled is similar, with a few distinctions. Both variables are modeled with one input rate, and two outflow rates. The inflow to the Available IT Staff Budget is an exogenous variable, Annual IT Staff Budget. This is divided by the variable Weeks Per Year, which converts the annual budget into a weekly budget for the simulation.

The additional variable, IT Staff Budget Increase is used to account for growth in this budget over the ten year simulation period. This growth is modeled as an annual increase of 4%, which is based on historical budget data from the firm. Budgets are generally developed as annual or monthly budget figures, and rarely are weekly budgets considered. The simulation model uses a weekly budget to account for the incremental cost of overtime compensation. In general, the IT staff at HTS are hourly employees, and when they work more than the standard 40-hour workweek, they receive overtime compensation at the rate of 1½ times their normal hourly compensation. The simulation model is using a unit of time that equals Week in order to simplify the calculation of IT Staff compensation.

The inflow into the Available IT Budget is the exogenous variable Per Capita Allocation, multiplied by the HTS Non IT Staff. The per capita allocation is actually determined on an annual basis by the management of the firm, but in the simulation model, it is converted to a weekly number. No exogenous growth variable is required in this inflow, as the variance in the size of the firm is endogenous to the model, measured by the HTS Non IT Staff, which will cause the appropriate variance in the Available IT Budget. The detailed diagram for this subsystem is Figure 28.

Figure 28 Detailed HTS IT Budget/HTS IT Staff Budget Subsection Models



Both available budget stocks have an outflow rate called IT Staff Funds Annual Budget Clear, and IT Funds Annual Budget Clear, respectively. These rate flows are controlled by identical equations. The equation for IT Funds Annual Budget Clear is as follows:

$$\text{IT Funds Annual Budget Clear}=\text{Available IT Budget}/\text{TIME STEP}*\text{Year End} \tag{0.9}$$

The equation for the variable Year End is:

$$\text{Year End} = \text{IF THEN ELSE}(\text{modulo}(\text{Time},52)<\text{TIME STEP},1,0) \tag{0.10}$$

Time Step is the time increment being used in the simulation. For this model, the time step being used is 0.007812, which is in fact the smallest time step available in Vensim. It will become clear why this time step was used in the section discussing the HTS IT Staff subsystem.

Reviewing the equation for year end, there is a nested function within an "if then else" statement. The Modulo function returns the remainder when A is divided by B, or in this case when Time is divided by 52. If time is equal to 52, then it is the end of the year, and the remainder is equal to 0. At all other times, the equation will generate some positive remainder greater than Time Step. Therefore, if the time is at the end of the year, there is a remainder less than the time step, and the variable Year End = 1. At all other times, the variable Year End = 0.

Returning to the equation for the rate variable IT Funds Annual Budget Clear, this equals the Available IT Budget divided by Time Step. This quotient is then multiplied by the Year End indicator of 0 or 1. If it is the end of the year, it is multiplied by 1, and the entire budget is cleared out. If it is not the end of the year, the IT Funds Annual Budget Clear is equal to 0, and all of the funds remain in the stock. This function is repeated exactly for the Available IT Staff Budget. In both cases, it models the reality that the budget doesn't carry over from year to year.

The two level variables each have an additional outflow, IT Staff Funds Used and IT Funds Used. These outflows represent the real expense of paying staff salaries and acquiring equipment, software, and services. For the Available IT Staff Budget, the rate of outflow is equal to the IT Staff Compensation, which is calculated by multiplying the IT staff times the average standard compensation, plus the IT Staff Overtime Compensation. IT Staff Overtime Compensation is calculated by comparing the actual workweek with the standard workweek, and multiplying the difference times the standard overtime rate.

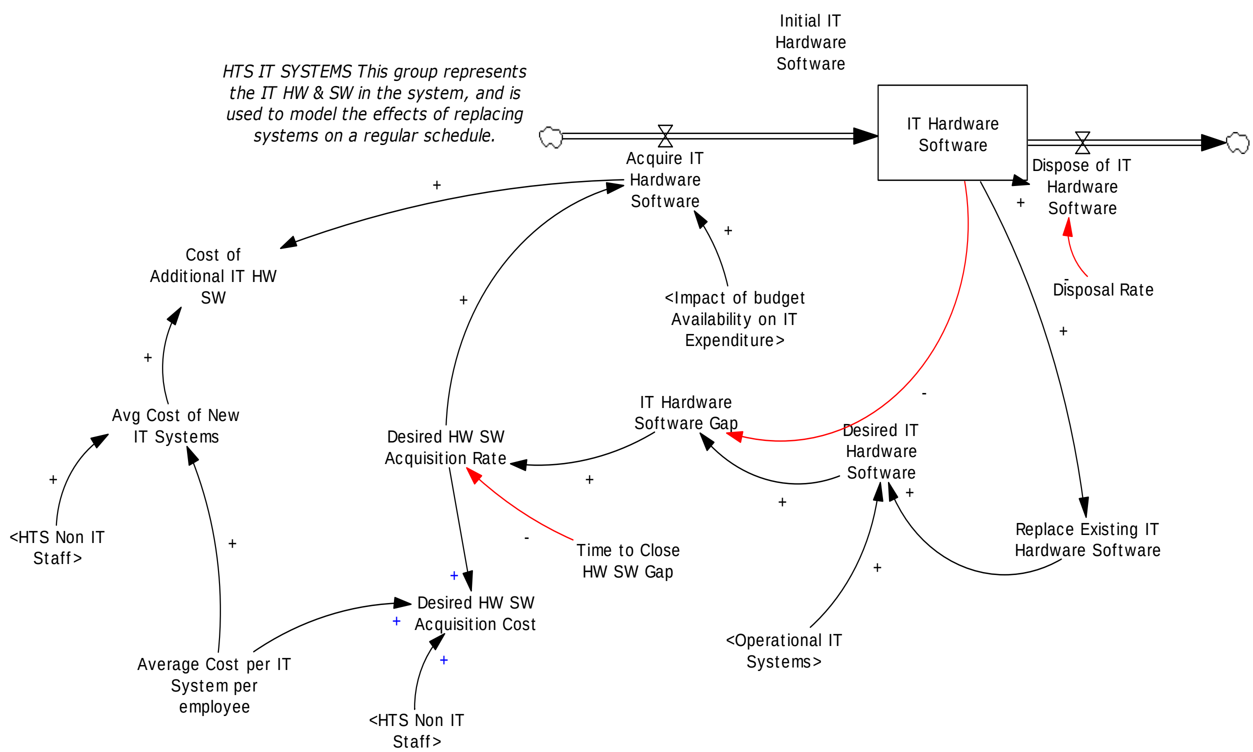
The rate variable IT Funds Used is a bit more complex in its calculation. First, consider the variables Desired HW SW Acquisition Cost, Desired Data Storage Acquisition Cost, and Desired Processor Cost, which are outputs of other subsystems of the model. Essentially, these three variables represent the cost of acquiring desired hardware and software in the HTS IT Systems subsystem, the cost of acquiring desired data storage equipment in the Data Storage subsystem, and the cost of acquiring desired processor power in the Processor Power subsystem. These three variables are summed to create the Total Desired IT Costs. This variable then represents the total desired IT costs for a period. Total Desired IT Costs is compared to the Available IT Expenditure Rate to calculate the IT Expenditure Available To Desired Ratio. The output of this ratio is then compared to a table function and used to determine how much of each desired acquisition can be purchased. Next, the impact of budget availability on the acquisition of equipment is used to compute the actual equipment acquired. The result of this calculation is subsequently multiplied times the average cost of the desired equipment and fed back to the budget variable IT Funds Used as the cost of Additional Data Storage, Cost Of Additional IT HW SW, and Cost Of Additional Processor Power, which are summed as the input to the rate variable IT Funds Used, which reduces the available IT Budget.

The HTS IT Budget and the HTS IT Staff Budget act in the simulation to limit the growth of either the acquisition of equipment and systems or the hiring of additional staff to support the organization. This correctly models the behavior of the firm, where the acquisition of equipment or the hiring of personnel is governed by the available budget. In addition, budgets are not carried over from year to year in real life, and therefore the model correctly simulates reality by clearing the budget each year. Finally, both of these budgets are established exogenously of the information technology organization, and this is established within the model with the two exogenous variables Annual IT Staff Budget and Per Capita Allocation. Of interest is the perceived misalignment of the firm's ownerships mental models with the actual structure of the organization. As previously noted, the ownership establishes the budgets for IT with the belief that IT is not a critical production function. In order to test the model, each of these variables have been placed in the Control Panel as Sliders, which enables on the fly changing of the budgets; this budget change translates into real time changes in the core business capabilities of the firm. These changes also affect the staff of the firm and the staff of the IT organization, and these changes clearly demonstrate how an investment in the IT budget has an impact on the weekly revenues of the firm.

HTS IT Systems

The HTS IT Systems subsystem is relatively simple, and has the primary purpose of modeling the replacement of IT systems on a regular schedule. Figure 29 is the detailed model diagram for this subsystem.

Figure 29 Detailed HTS IT Systems Subsystem Model



IT systems at HTS are replaced on a regular basis with user equipment like PCs and laptops replaced on a three year schedule and back office systems like servers and network equipment replaced on a five year schedule. The CIO of HTS estimates that 25% of the total equipment in the infrastructure is replaced each year. The replacement of existing systems is relevant to this research because of the impact it has on the IT budget. From the budget of HTS, the average cost to replace systems was determined to be $1,889 per person. This price is amortized over a five year period and works out to $7.26 per week per person. Resources, both staff time and budget funds, that are spent on replacing existing systems are not available for improvement initiatives.

There is only one level variable in this subsystem IT Hardware Software, and it represents the existing IT systems, a percentage of which must be replaced each period. The acquisition of replacement systems is done by closing the gap that exists between Desired IT Hardware Software and IT Hardware Software. Closing the gap is delayed by Time To Close HW SW Gap. Desired HW SW Acquisition Cost, which is used in the

HTS IT Budget to control how much of the requested expenditure is allowed for each subsystem is calculated here. The equation for this variable is:

$$\begin{gathered}\text{Desired HW SW Acquisition Cost=Desired HW SW Acquisition Rate}\\ \text{*Average Cost per IT System per employee*HTS Non IT Staff}\end{gathered} \tag{0.11}$$

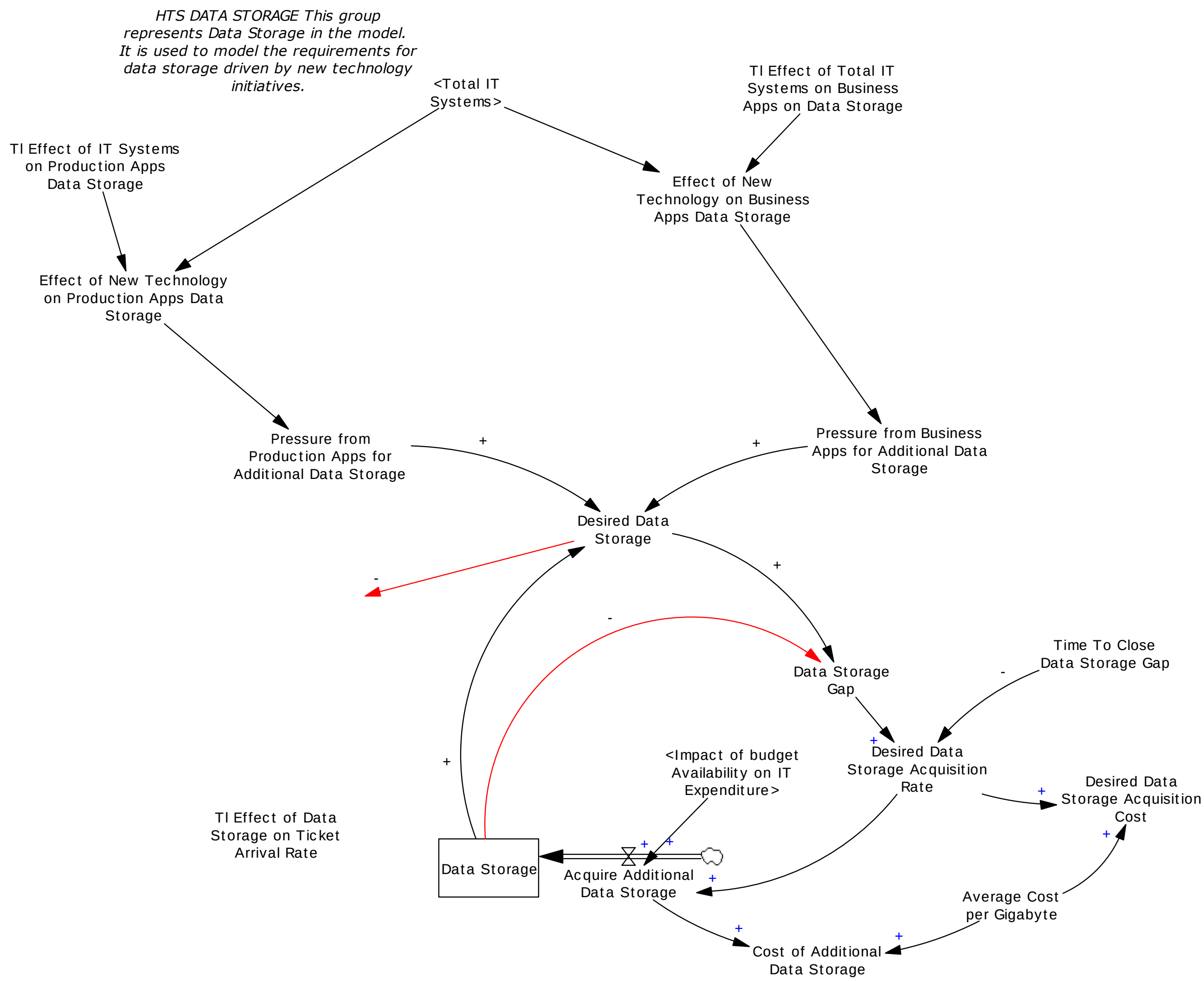
The HTS IT Budget controls the actual acquisition of hardware and software through the variable <Impact Of Budget Availability Of IT Expenditures>. Note that it is a shadow variable in this subsystem because it is calculated in the HTS IT Budget subsystem. Shadow variables are simply a tool in Vensim which enables the modeler to connect variables without presenting a long causal loop in the diagram. They are denoted as shadow variables by the "<" before and the ">" after the variable. Shadow variables are used extensively in the HTS Model to connect the various subsystems of the model and simplify reading of the diagram.

The final variable of significance in this subsystem is the Cost of Additional IT HW SW. The variable Desired HW SW Acquisition Cost was used by the IT Budget subsystem to determine how much funding was available to each of the subsystems. The variable Cost Of Additional IT HW SW is the actual expense, and is used by the HTS IT Budget to reduce the Available IT Budget.

HTS Data Storage

The subsystem HTS Data Storage represents data storage in the infrastructure. The variable <Total IT Systems> drives this subsystem. Recall that <Total IT Systems> is a variable which represents the total information technology systems in the infrastructure. This variable was discussed in the HTS IT Technology section and is the sum of the Operational IT Systems and the Non-Operational IT Systems. Operational IT Systems is a level variable with the inflow rate variable, Acquire New Technology. Acquire New Technology is a function of the size of the firm, measured in the acquisition of new contracts. Figure 30 is the detailed subsystem diagram of the HTS Data Storage subsystem.

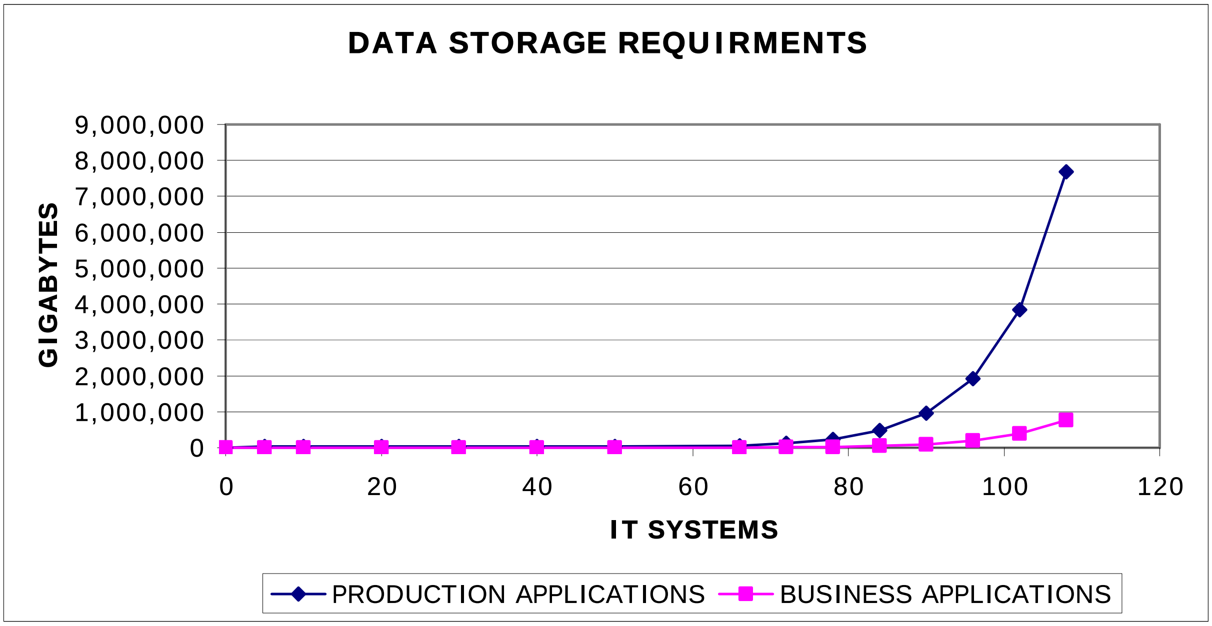
Figure 30 Detailed HTS Data Storage Subsystem Model



As the firm grows through the acquisition of new contracts, Operational IT Systems grows, and Total IT Systems grows. Total IT Systems impacts Desired Data Storage through two "pressure" variables. These variables, Pressure From Production Apps For Additional Data Storage and Pressure From Business Apps For Additional Data Storage, represent the pressure to increase data storage because of the new technologies.

A very important issue is modeled here by disaggregating the business applications from the production applications. The CIO of HTS believes that both production applications and business applications are generating exponential growth in the requirements for data storage. However, the growth in production applications requirements is many times greater than the growth requirements for business applications. This is a result of the way the two applications are deployed. Production applications will be used to service many different clients, and each client engagement or project will generate demand for data storage. Business applications on the other hand are used internally to HTS and only require data storage for a single client. The relationships are described using two table variables. For clarity the two table variables are combined in a single table, Figure 31.

Figure 31 Data Storage Requirements For Production and Business Applications



There is only a single level variable in this subsystem, Data Storage. Data Storage is modeled as a stock with no outflow as was discussed earlier in the overview section. Data Storage is acquired by closing the gap between Desired Data Storage and Data Storage. The acquisition is controlled by the budget variable <Impact Of Budget Availability Of IT Expenditure>. The equation for the variable Desired Data Storage Acquisition Rate is as follows:

$$\text{Desired Data Storage Acquisition Rate} = \text{Data Storage Gap} / \text{Time To Close Data Storage Gap} \tag{0.12}$$

This simply means that the desired acquisition rate is the ratio of the gap and the time to close the gap. The time to close the gap is a constant, is based on the experience of the firm, and is equal to 12 weeks. The variable Desired Data Storage Acquisition Rate feeds the variable Desired Data Storage Acquisition Cost which is used by the HTS IT Budget subsystem to control spending in the other subsystems of the model. The variable Acquire Additional Data Storage drives the Cost Of Additional Data Storage variable. The equation for this variable is:

$$\begin{aligned}&\text{Cost of Additional Data Storage=}\\&\quad\text{Acquire Additional Data Storage*Average Cost per Gigabyte}\end{aligned} \tag{0.13}$$

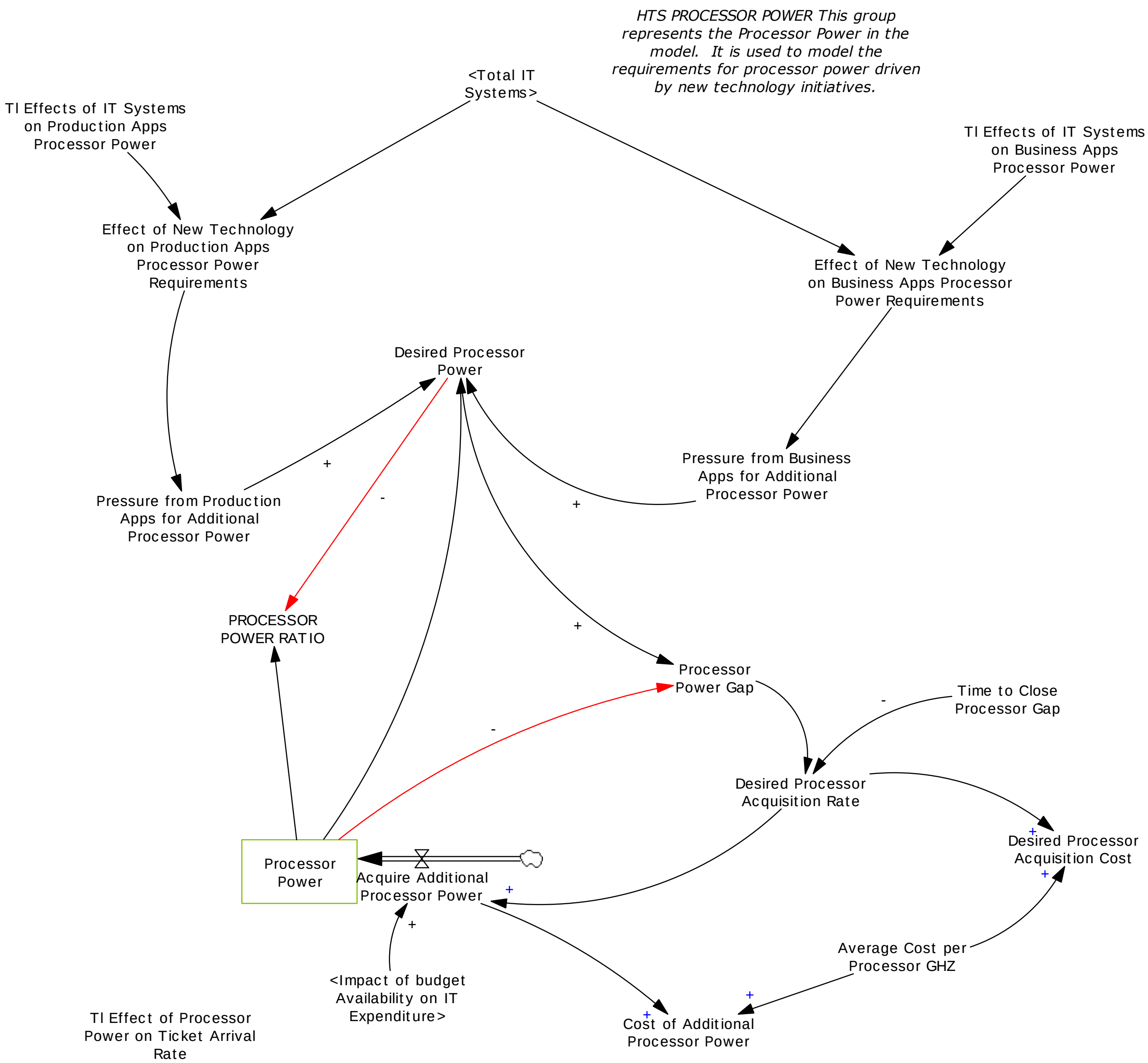
This equation simply calculates the cost of the acquisition of the additional data storage by multiplying the data storage acquired by the average cost per gigabyte. This cost is then used to reduce the level variable Available IT Budget in the HTS IT Budget subsystem. The average cost per gigabyte is estimated based on current historical costs at HTS. This is assumed to be a somewhat volatile number, and the variable Average Cost Per Gigabyte is set as a slider on the Control Panel so it can be easily changed to consider the impact on the simulation with different costs.

The final variable to be reviewed is Data Storage Ratio. This is the ratio of Data Storage to Desired Data Storage. This ratio feeds back to the HTS Contracts & Staff subsystem and impacts HTS Core Business Performance Capability. Conceptually, when the data storage in the infrastructure equals the desired data storage, this ratio is equal to 1, and when fed back to HTS Core Business Performance Capability, it does not negatively impact the firm's performance. However, when the actual data storage is less than desired data storage, this ratio falls below 1. The greater the discrepancy between the actual and desired data storage, the smaller this ratio, and the greater the impact it has on the performance of the firm. The explanation is that when the ratio does not equal 1, some production applications; or some business application does not have enough data storage available, and therefore, performance is inhibited. This directly impacts the core business performance capability of the firm. This impact is assumed to be non-linear in its effect and is governed by a table variable, which is pictured in the HTS Contracts and Staff subsystem of the model.

HTS Processor Power

Figure 32 depicts the HTS Processor Power subsystem. Fundamentally, this subsystem is structured nearly identically to the Data Storage subsystem. The obvious difference is that the characteristic being modeled here is the processor power in the infrastructure, and not the data storage.

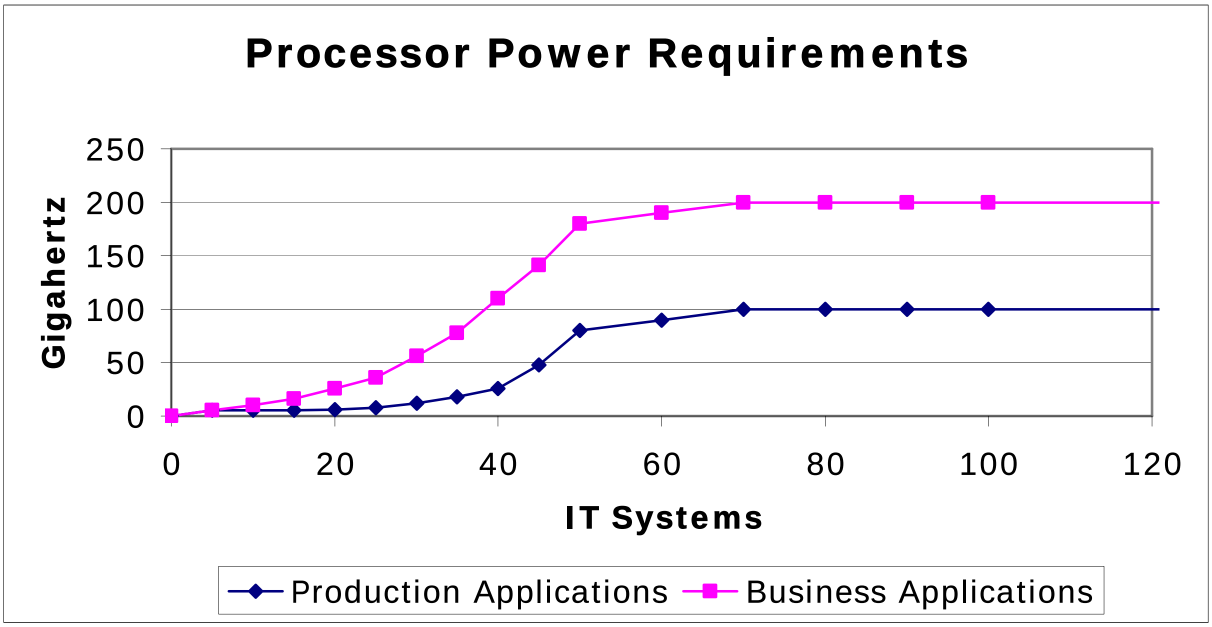
Figure 32 Detailed HTS Processor Power Subsystem Model



There is one significant difference in the structure of this subsystem. Recall that in the data storage subsystem, the effects of production applications were many times greater than the effect of business applications. In the HTS Processor Power subsystem, the opposite effect is true. The evidence suggests that business applications have a greater effect on processor power than production applications. The CIO believes that this is due to the nature of how production applications and business applications are used in the firm. Once a production application is implemented, there is little additional processor power required to support many clients, engagements, or projects. Business applications on the other hand are implemented entirely for use within the firm, and each business application will require additional processor power. Simply put, multiple clients using a single application require less processor power than multiple applications for a single client.

The table variables representing these relationships have again been combined for clarity and are shown in Figure 33.

Figure 33 Processor Power Requirements For Production and Business Applications



Finally, there is the variable Processor Power Ratio. This ratio is the ratio of the Processor Power to Desired Processor Power. As with the data storage ratio this ratio represents the discrepancy between desired and actual processor power. The variable is fed back to the HTS Contracts and Staff subsystem and models the effect that the discrepancy between desired and actual processor power has on the performance of the firm. This impact is assumed to be non-linear and is governed by a table function which is pictured in the HTS Contracts and Staff section of this chapter.

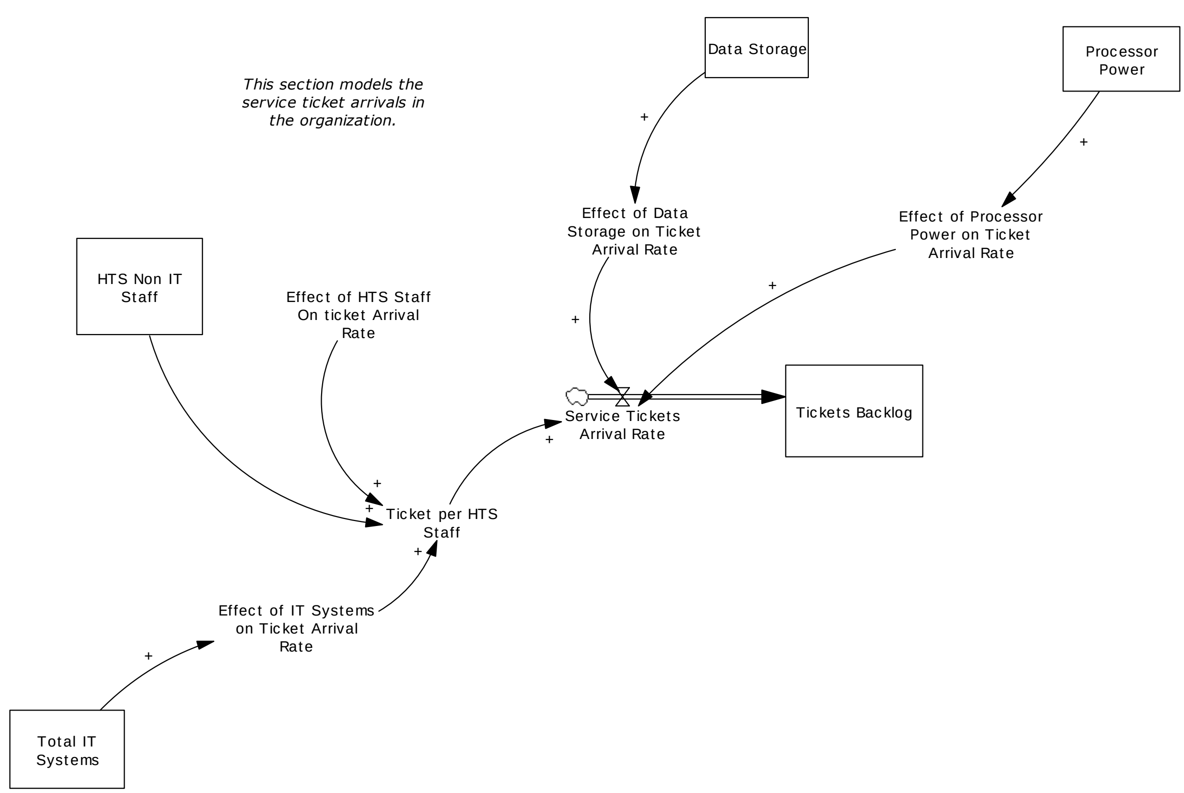
HTS IT Staff

This subsystem represents the IT staff workload from the organization. The central variable in this subsystem is the level variable Tickets Backlog. This subsystem was discussed in some detail in the earlier overview of the model. Recall that Tickets Backlog is used as a proxy of the entire workload of the organization. Also recall that Service Tickets Arrival Rate represents the workload being demanded of the IT Staff, and the Service Tickets Completion Rate represents how well the IT Staff has met that demand.

Service Ticket Arrival Rate

The Service Ticket Arrival Rate variable is driven by four stocks in the model. Figure 34 depicts the stocks that drive the rate variable and subsequently the ticket backlog.

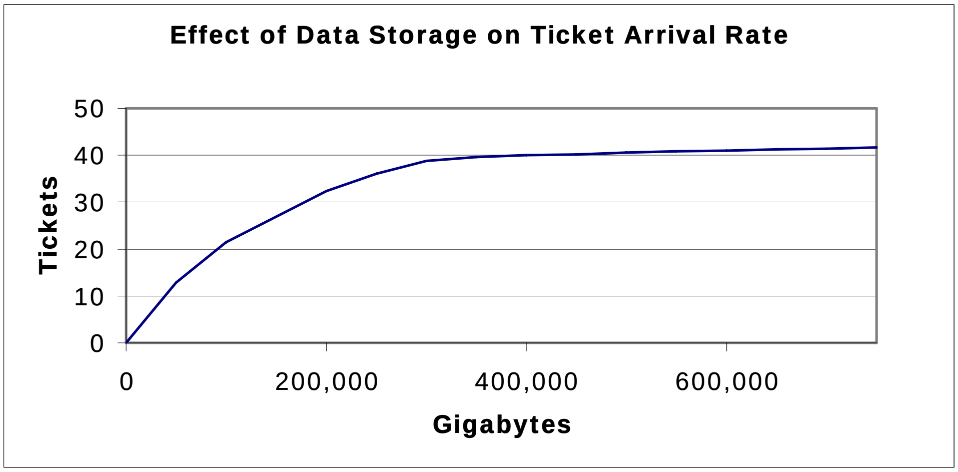
Figure 34 Detail of Service Ticket Arrival Rate



A brief overview of the four factors follows:

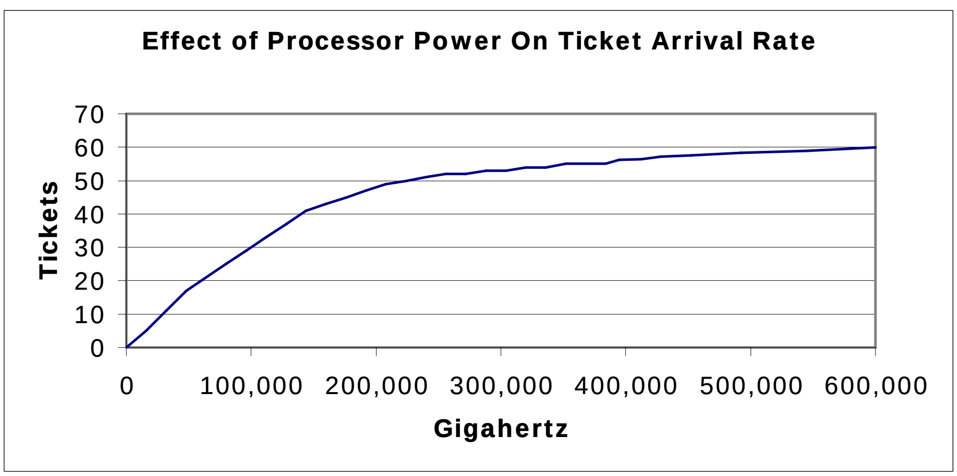
1. HTS Non IT Staff – the relationship between the total staff of the firm and service ticket arrival rate is fairly straightforward and easily understood. As more total staff are being supported, there are a greater number of service tickets being generated. At HTS, the historical ratio of tickets to staff person is 0.123 tickets per week per staff person.
2. Total IT Systems – the relationship between the total IT Systems and the ticket arrival rate is governed by a table function. This table function is used because the IT management of the firm originally believed that this relationship was non linear. In working through the model the CIO elected to represent this relationship as being linear, with one additional ticket per week being generated by each IT system in the infrastructure.
3. Data Storage – the relationship between data storage and the ticket arrival rate was estimated by the CIO and is believed to be a nonlinear relationship. This relationship suggests that the more data storage in the infrastructure, the greater the number of tickets generated as a result of the data storage. However, this also assumes that there is some economy of scale: when the amount of data storage reaches a certain tipping point, there is a benefit from better technology, redundancy, and data management capabilities. The growth of tickets levels off at this point, even though the data storage capacity continues to grow. This relationship is governed by the table function shown in Figure 35.

Figure 35 Effect of Data Storage on Ticket Arrival Rate



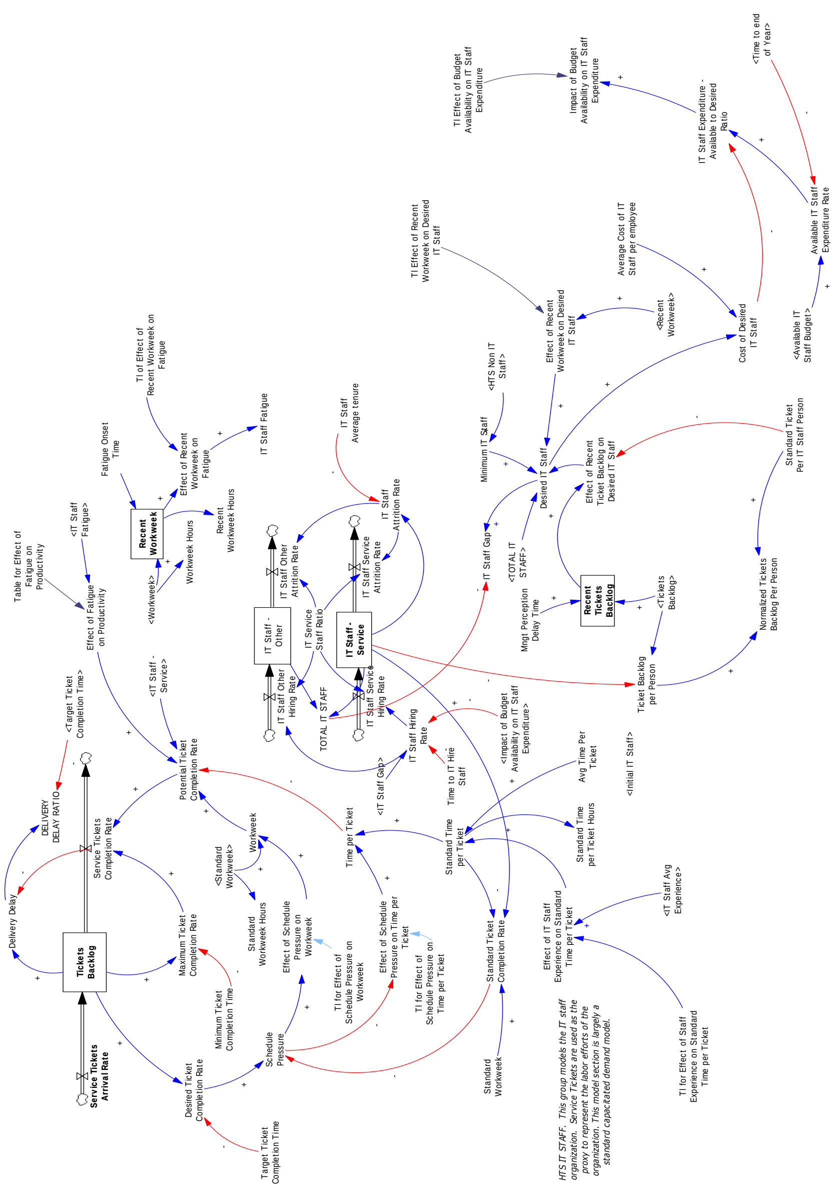
4. Processor Power – the relationship between the processor power and the ticket arrival rate was also estimated by the CIO, and is believed to be nonlinear as well. Just as the effect of data storage is assumed to have a tipping point, the effect of processor power is also assumed to have a tipping point at which there is a benefit from improved technology, management tools, and system redundancy. This relationship is governed by the table function shown in Figure 36.

Figure 36 Effect of Processor Power on Ticket Arrival Rate



To recap, the Service Ticket Arrival Rate is driven by four factors: the number of people in the firm, the number of systems in the infrastructure, the amount of data storage in the infrastructure, and the amount of processor power in the infrastructure. Figure 37 illustrates the subsystem HTS IT Staff.

Figure 37Detailed HTS IT Staff Subsystem Model



The Service Ticket Arrival Rate is the inflow to the level variable, Tickets Backlog, and the Service Ticket Completion Rate is the outflow from this level. Ideally it would be desirable for the Tickets Backlog to stay at equilibrium. Therefore, Service Ticket Arrival Rate and Service Ticket Completion Rate should be equal. When the firm is experiencing growth, the Service Ticket Arrival Rate will increase. The equation for the Service Ticket Completion Rate is as follows:

$$\text{Service Tickets Completion Rate} = \text{MIN}(\text{Maximum Ticket Completion Rate, Potential Ticket Completion Rate}) \quad (0.14)$$

Assuming that the IT organization has excess capacity, the Service Ticket Completion Rate will be controlled by the Maximum Ticket Completion Rate. The Maximum Ticket Completion Rate is simply the ratio of the Tickets Backlog to the Minimum Tickets Completion Time. The maximum tickets completion rate is the physical maximum that can be completed in any time period. One simply cannot complete more tickets than are in the backlog. If capacity is reached, then the Potential Ticket Completion Rate variable will govern Service Ticket Completion Rate. If capacity is reached, it is desirable to increase capacity. This increase in capacity can be achieved through one of the three interventions discussed in the high level discussion of the model: the time per ticket can be reduced, the workweek can be increased, or the number of staff can be increased. Each of these interventions is modeled within this subsystem.

Time Per Ticket

Fundamentally, what is modeled in this loop is that as the tickets backlog increases, the desired ticket completion rate increases. As the Desired Ticket Completion Rate increases, the Schedule Pressure increases. As Schedule Pressure increases, Effect Of Schedule Pressure On The Time Per Ticket decreases, and Time Per Ticket decreases. This may seem confusing: Schedule Pressure has a positive effect on the Effect Of Schedule Pressure On Workweek, but it has a negative effect on the Effect Of Schedule Pressure On Time Per Ticket. Consider briefly what is really happening: as schedule pressure increases, the organization experiences greater pressure to complete tickets. Increasing the hours worked per week will allow more tickets to be completed in a week. Decreasing the amount of time spent on each ticket will also allow more tickets to be completed in a week. As Time Per Ticket decreases Potential Ticket Completion Rate increases. When Potential Ticket Completion Rate exceeds Maximum Ticket

Completion Rate then Maximum Ticket Completion Rate again governs the number of tickets that can be completed.

The time per ticket loop begins with Desired Ticket Completion Rate, which is expressed in the flowing equation:

$$\text{Desired Ticket Completion Rate} = \text{Tickets Backlog}/\text{Target Ticket Completion Time} \tag{0.15}$$

Desired Ticket Completion Rate is the ratio of Tickets Backlog and the constant Target Ticket Completion Rate. The target ticket completion rate is the organization's target and, for this model, is set at 0.01 weeks. This converts to a target ticket completion time of 100 minutes at HTS. Desired Ticket Completion Rate is one of two inputs into the Schedule Pressure variable:

$$\text{Schedule Pressure}=\text{Desired Ticket Completion Rate}/\text{Standard Ticket Completion Rate} \tag{0.16}$$

The other input into Schedule Pressure is Standard Ticket Completion Rate. The equation for Standard Ticket Completion Rate is:

$$\begin{aligned}&\text{Standard Ticket Completion Rate}=\\&\quad\text{"IT Staff - Service"}*\text{Standard Workweek}/\text{Standard Time per Ticket}\end{aligned} \tag{0.17}$$

This means that the standard ticket completion rate is equal to the IT staff who are handling service tickets times the standard workweek, divided by the standard time per ticket.

Two very important concepts are introduced here. First is the concept of "IT Staff – Service." All of the people in the IT department do not complete service tickets. There are a number of other important positions in the IT organization, including project managers, developers, supervisors, data base analysts, and others. In order to model the organization accurately, the stock of IT staff had to be disaggregated into those who work on service tickets and the rest of the staff. The second concept introduced here is the Standard Time Per Ticket variable. The standard time per ticket is a variable that feeds both Time Per Ticket and Standard Ticket Completion Rate. The equation for Standard Time Per Ticket is:

Standard Time per Ticket =

Effect of IT Staff Experience on Standard Time per Ticket*Avg Time Per Ticket (0.18)

The average time per ticket is simply a constant, which is estimated based on historical data as equal to .0074 weeks or approximately 74 minutes per ticket. Effect Of IT Staff Experience On Standard Time Per Ticket is the output from the final subsystem, HTS Staff Experience. Conceptually, what is being modeled with this input is the effect that the experience or training of the service person has on the standard time per ticket. People with greater experience and training are able to clear tickets faster because of their experience and training. On average, the more experience that the IT staff have, the better their performance will be in closing tickets.

Workweek

The workweek loop models the second possible intervention, an increase in the workweek. As Tickets Backlog increases, Desired Ticket Completion Rate increases. As Desired Ticket Completion Rate increases, Effect Of Schedule Pressure On Workweek also increases. As Workweek increases, Potential Ticket Completion Rate increases and, just as with Time Per Ticket, when Potential Ticket Completion Rate is greater than Maximum Ticket Completion Rate, Maximum Ticket Completion Rate again governs Service Ticket Completion Rate. This loop has an important feedback to the IT Staff loop. The feedback to this loop is created in the equation for the Potential Ticket Completion Rate. That equation is:

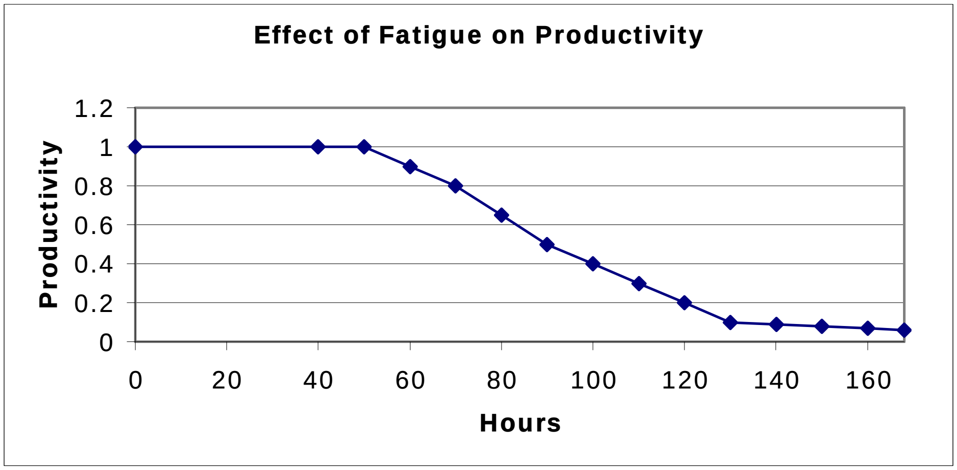
Potential Ticket Completion Rate =

"IT Staff - Service"*Workweek*Effect of Fatigue on Productivity/Time per Ticket

(0.19)

Thus, the potential ticket completion rate is equal to the number of people working on closing service tickets (IT Staff – Service) times the average hours worked that week (Workweek) times some function that represents the effect fatigue has on the employees' productivity, divided by the time per ticket. The function Effect Of Fatigue On Productivity is governed by a nonlinear table function which is shown in Figure 38.

Figure 38 Effect of Fatigue on Productivity



Fundamentally, this table represents that employees in the IT organization are at 100% productivity until they have worked 50 hours in a week. At this point, there is a fairly linear decline in their productivity which reaches its low of about 10% productivity when they work 130 hours in any week. This function was estimated by the management of the information technology organization. The workweek loop is balanced by the effect of fatigue on productivity. If the workweek is extended from 40 hours to 50 hours, there is no negative impact on the productivity of the people. Extending the workweek beyond 50 hours impacts the productivity of the IT staff, and ultimately there is a point at which increasing the workweek will reduce overall productivity so that the intervention has the negative effect of not increasing Service Ticket Completion Rate, but rather decreasing the Service Ticket Completion Rate.

There is an additional effect of increasing the workweek, and that is the effect it has on the IT staff budget. This effect was previously discussed in the IT Staff Budget subsystem. Recall that IT employees are paid 1½ times their normal rate for overtime, and that overtime is limited by the IT staff budget.

IT Staff Loop

The third intervention possible is to increase the number of employees, IT Staff – Service. Increasing the number of employees closing service tickets will increase Standard Ticket Completion Rate, shown previously in equation 1.10. Increasing Standard Ticket Completion Rate will reduce Schedule Pressure, which in turn will reduce The Effect Of Schedule Pressure On The Workweek, effectively reducing the workweek. At the same time a decrease in Schedule Pressure will increase Effect Of Schedule Pressure On The Time Per Ticket, effectively increasing Time Per Ticket. Changing the variable Time Per Ticket or the variable Workweek both impact the variable Potential Ticket Completion Rate, which of course is the input into the Service Ticket Completion Rate.

Increasing the IT staff will also have the effect of increasing the IT staff compensation, which again was discussed in the IT Staff Budget subsystem section.

IT Staff Hiring

The model is designed to replicate the actual decision process used by management in dealing with the ticket backlog through these interventions. The first intervention that the CIO believes is likely to happen is the reduction in time spent on each ticket. This is simply done at the level of the staff person doing the tickets they will begin to take shortcuts, and will solve symptoms, rather than determining the root cause of a problem, in order to reduce the ticket backlog. If the backlog does not reduce with this intervention, management will assign some staff to work overtime to work through the backlog. Hiring additional staff is the intervention that requires the most time, for several reasons. Ultimately, hiring additional staff is modeled by the variables IT Staff Hiring Rate, IT Staff Other Hiring Rate, and IT Staff – Service Hiring Rate. IT Staff Hiring Rate is increased by closing the gap between Desired IT Staff, and Total IT Staff.

Establishing the Desired IT Staff variable is somewhat complex and requires several intermediate steps and variables. First, the CIO wouldn't hire people based on a single week's backlog. The backlog would need to extend for several weeks before the decision would be made to hire additional staff. In addition to ensuring that the increase in Ticket Backlog was not a single-week phenomenon, the CIO would want to ensure that other measures had been taken to reduce Ticket Backlog. This would mean reviewing the workweek and ensuring that not only is Ticket Backlog not a one-week phenomenon, but also that staff have worked overtime for several weeks to try to reduce the ticket backlog.

In order to model this decision process a number of steps had to be taken. The first step is to create a variable, Tickets Backlog Per Person. This variable is simply the ratio of the level variable Tickets Backlog to the level variable IT Staff – Service. This variable is required because the value of the level variable Tickets Backlog needs to be normalized on a per person basis. The second step is to create a variable Recent Tickets Backlog. This variable serves to represent the average ticket backlog over an extended period of time. The equation for this variable is:

$$\text{Recent Tickets Backlog}= \text{SMOOTH(Tickets Backlog, Mngt Perception Delay Time)} \tag{0.20}$$

The smooth function returns an exponential smoothing of the input (Tickets Backlog), over the delay time (Mngt Perception Delay Time). The variable Mngt Perception Delay Time is a constant which, in this case, reflects how long before management makes the decision to hire additional staff. Currently, this variable is set at 8 weeks.

An additional variable must be created to return a similar function of the input Workweek. Again, the smooth function is used to model this variable, Recent Workweek. The equation for this variable is:

$$\text{Recent Workweek} = \text{SMOOTH(Workweek, Fatigue Onset Time)} \tag{0.21}$$

Fatigue Onset Time is the delay in this function, and represents the number of weeks the CIO believes the staff can work overtime before they reach fatigue levels that are detrimental to their performance. Fatigue Onset Time is modeled as 6 weeks at HTS.

Both of these variables, Recent Ticket Backlog and Recent Workweek feed additional variables, Effect Of Recent Ticket Backlog On Desired IT Staff and Effect Of Recent Workweek On Desired IT Staff, respectively. These two functions drive Desired IT Staff, and IT Staff Hiring Rate is a function of closing the gap (IT Staff Gap) between Desired IT Staff and Total IT Staff. Total IT Staff is the sum of IT Staff – Service and IT Staff Other. The ratio of IT Staff Other to IT Staff Service is kept constant to simplify the modeling process. The actual hiring rate for the stock, IT Staff – Other is provided by the following equation:

$$\text{IT Staff Other Hiring Rate} = \text{IT Staff Hiring Rate}*(1-\text{IT Service Staff Ratio}) \tag{0.22}$$

And the actual hiring rate for the stock, IT Staff – Service is provided by the following equation:

$$\text{IT Staff Service Hiring Rate} = \text{IT Staff Hiring Rate}*\text{IT Service Staff Ratio} \tag{0.23}$$

The IT Staff Service Ratio is a fixed ratio of IT Staff - Other to IT Staff -Service, is modeled on the current ratio, and is equal to .333. Essentially this ratio models hiring in such a way as to maintain the current ratio of IT Staff – Other to IT Staff – Service.

IT Staff Attrition

The second part of the IT Staff loop is the attrition of IT staff. So far, this dissertation has described how the model accounts for staff hiring, using a number of variables to model the impact of the budget on hiring; how it accounts for the requirement that the backlog be a genuine problem, and not simply an anomaly; and how it accounts for management's need to determine that overtime has been tried to reduce the backlog of tickets.

Modeling the attrition, or the voluntary quitting of employees, is much more difficult than modeling the hiring of employees. The hiring decision is generally a decision that follows a well defined process, and as in my model, it has some checkpoints which are used to determine if the time is right to hire additional staff. However, consider the attrition rate. The potential for variance is far greater, since there are so many more decision makers. The firm has limited control over many possible variables that can go into a person's decision to leave the organization. In discussions with the management of HTS as this model was developed, the decision was made to use simply the classic formulation for attrition. This formulation is shown in the following equation:

$$\text{IT Staff Attrition Rate}=\text{TOTAL IT STAFF}/\text{IT Staff Average tenure} \tag{0.24}$$

This equation simply says that the attrition rate is the ratio of staff to the average tenure of staff. Average tenure is modeled as a constant and is estimated, based on the data for the current IT Staff, to be five years or 260 weeks. There is one more step in modeling the attrition rate: because the IT Staff is disaggregated into two stocks, IT Staff – Other and IT Staff – Service , IT Staff Attrition Rate must be converted with IT Service Staff Ratio to create the actual rate variables for the two stocks. The equations are similar to the equations for the hiring rate variables. The equation for IT Staff Other Attrition Rate is as follows:

IT Staff Other Attrition Rate=IT Staff Attrition Rate*(1-IT Service Staff Ratio) (0.25)

And the equation for the IT Staff Service Attrition Rate is:

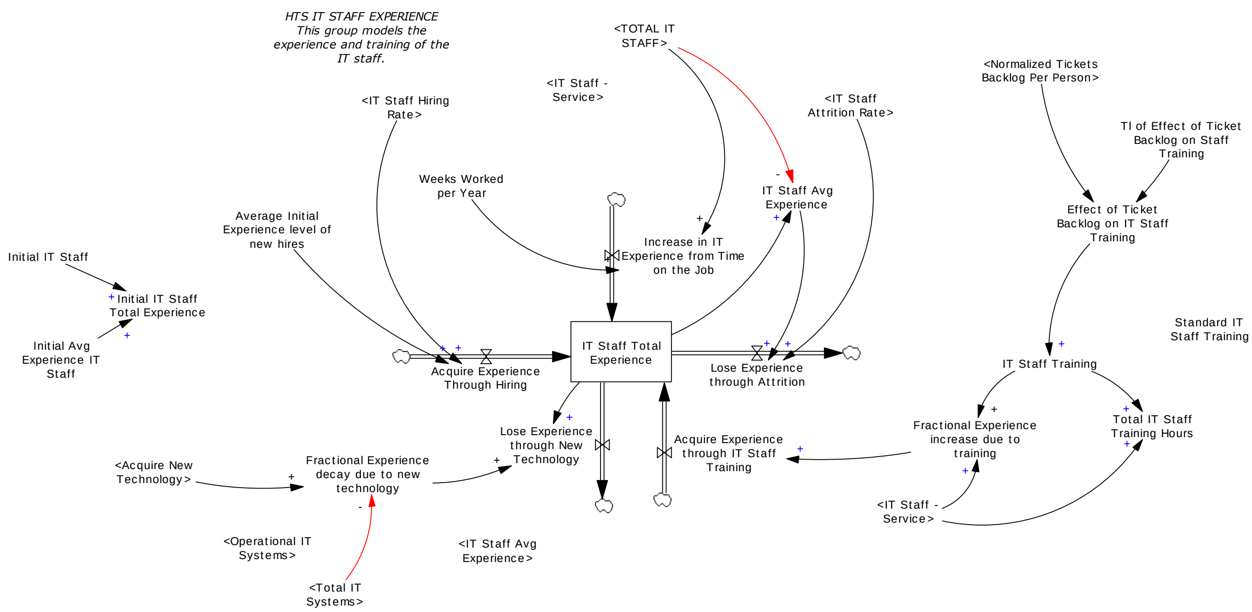
IT Staff Service Attrition Rate=IT Staff Attrition Rate*IT Service Staff Ratio (0.26)

Recall that the IT Service Staff ratio is the ratio of IT Service Staff to IT Staff Other and is constant at 0.333.

HTS IT Staff Experience

The final subsystem is the model of HTS IT staff experience. The primary function of the HTS IT Staff Experience subsystem is to model the effect of experience and training on the standard time per ticket. Both experience and training are expected to increase the number of service tickets an individual can complete in a week. IT Staff Experience is modeled with a single level variable, IT Staff Total Experience. This level variable has three input flows and two output flows. Reviewing the inflows and outflows of this variable is especially instructive in understanding the subsystem. Figure 39 is a diagram of this subsystem.

Figure 39 Detail of HTS IT Staff Experience



The first inflow into this level is controlled by the Acquire Experience Through Hiring rate variable. The total experience of the workforce is going to be increased by hiring additional people, although this might not increase the average experience. The equation for the rate variable Acquire Experience Through Hiring is as follows:

$$\begin{aligned}&\text{Acquire Experience Through Hiring} =\\&\quad\text{Average Initial Experience level of new hires*IT Staff Hiring Rate}\end{aligned} \tag{0.27}$$

Explicitly, this means that new experience is acquired through hiring at the IT staff hiring rate multiplied by the average experience of the new hires. Average Initial Experience Of New Hires is estimated at 104 weeks, or two years.

The second inflow into IT Staff Total Experience is controlled by the rate variable Increase in IT Experience from Time on the Job. The function being modeled by this inflow is simply the growth of experience that is the result of working at HTS. The equation for this function is:

$$\begin{aligned}&\text{Increase in IT Experience from Time on the Job=}\\&\quad\text{TOTAL IT STAFF*Weeks Worked per Year}\end{aligned} \tag{0.28}$$

This function says that each person gains one week of experience for every week they work at the firm. The variable Weeks Worked per Year is set at 0.88 weeks per person.

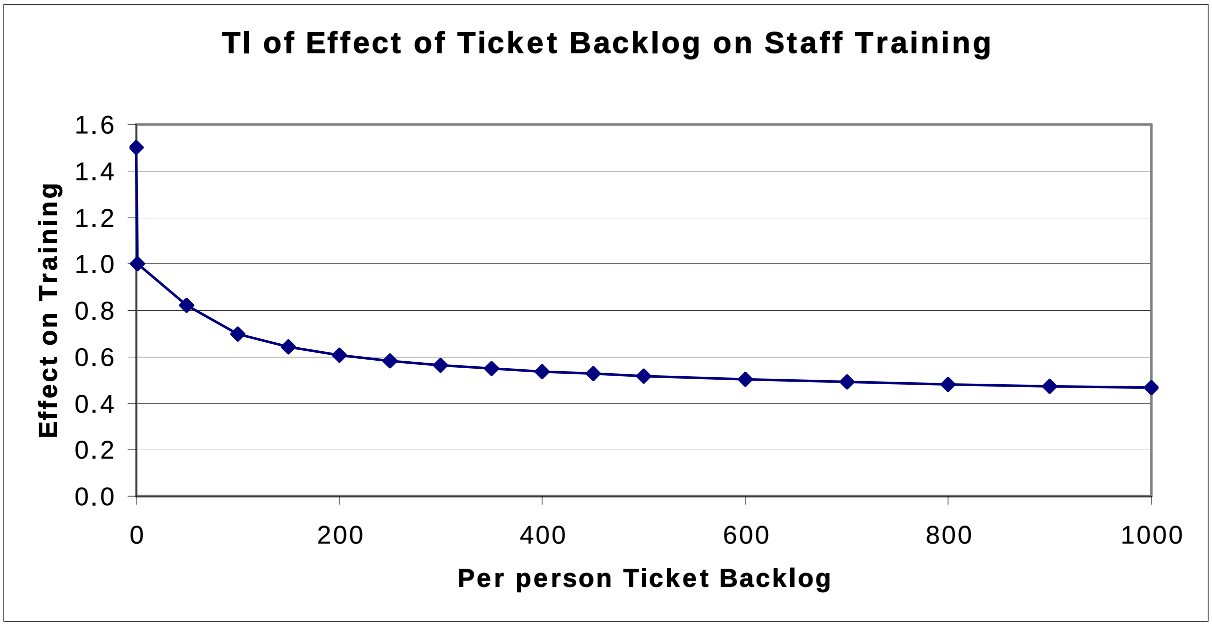
This was estimated based on the following formula: There are 52 weeks per year, less an average of two weeks of vacation per year, less two weeks of training, less one week of personal time, less one week of sick leave per year, all of which equals 46 weeks worked per year. This 46 weeks converts to 0.88 weeks per person per week.

The third inflow to the level is the Acquire Experience through IT Staff Training. In this model, training is being modeled as a characteristic of experience. Training effectively increases the rate at which staff gains experience. An understanding of how training increases the experience of IT staff requires an analysis of how the model estimates training. The CIO of HTS recognizes the value of training and has a goal of providing every employee two weeks of training per year. Since each employee only works, on average, 46 weeks per year, two weeks of training converts to 1.75 hours per week. Converting this from hours to weeks results in a Standard IT Staff Training of 0.01041 weeks of training per week of work per person. This is the goal of the organization, but if the workload is too large, training is reduced to ensure that enough people are working on the ticket backlog. To model training it is necessary to start with the Normalized Tickets Backlog Per Person variable, which drives the function Effect of Ticket Backlog on IT Staff Training. This function is nonlinear and is modeled by the following equation:

$$\begin{aligned}&\text{Effect of Ticket Backlog on IT Staff Training}=\\&\quad\text{Tl of Effect of Ticket Backlog on Staff Training(Normalized Tickets Backlog Per Person)}\end{aligned} \tag{0.29}$$

Thus, Effect of the Ticket Backlog is governed by the table function Tl of Effect of Ticket Backlog on Staff Training. The table function is shown in Figure 40. It shows that as the per person ticket backlog increases, the percentage of training decreases.

Figure 40 Table of Effect of Ticket Backlog on Training



IT Staff Training is a function of the effect of the function Effect of IT Staff Training on Standard IT Staff Training. The equation for IT Staff Training is:

IT Staff Training=
Standard IT Staff Training*Effect of Ticket Backlog on IT Staff Training (0.30)

IT staff training is the normal staff training of 1.75 hours per person per week multiplied by the effect of ticket backlog. When the ticket backlog is greater than one per staff person, this function reduces the training by some specified percentage.

As IT Staff Training increases, Fractional Experience Due to Training also increases. This variable, Fractional Experience Due to Training, establishes how much experience a person gains from training. The CIO of HTS felt that one week of training was equivalent to 13 weeks of experience. The equation for Fractional Experience increase due to training is:

Fractional Experience increase due to training=
"IT Staff - Service"*IT Staff Training*13 (0.31)

The rate variable, Acquire Experience Through IT Staff Training, which actually increases the stock of IT Staff Total Experience, is equal to the fractional increase rate.

Reviewing the three inflows to the stock of IT Staff Total Experience, experience is gained through the addition of new staff, and it increases at a rate that equals the average experience of new hires times the new hires. There is a gain of experience at a rate of one week per person for each IT staff person that works each week, and there is a gain of experience at the rate of 13 weeks for each week that someone spends in training. There are two outflows from the IT Staff Total Experience. The first outflow is the obvious outflow, the loss of experience through attrition. This is modeled by the variable Lose Experience Through Attrition, and is a function of IT Staff Average Experience multiplied by IT Staff Attrition Rate.

The second outflow from IT Staff Total Experience is the loss of experience because of new technology. As a result of new technology, the IT Staff Total Experience is reduced. This is simply a function of new technology not being something with which they have experience because it is new. In order to model this function, the variable Fractional Experience Decay Due To New Technology is created. This variable is simply the ratio of Acquire New Technology to Total IT Systems. Since the acquisition of new technology each week is normally a very small number relative to the total number of systems in the infrastructure, this ratio is also going to be a very small number. This variable drives the rate variable Lose Experience through New Technology. The equation for this rate variable is:

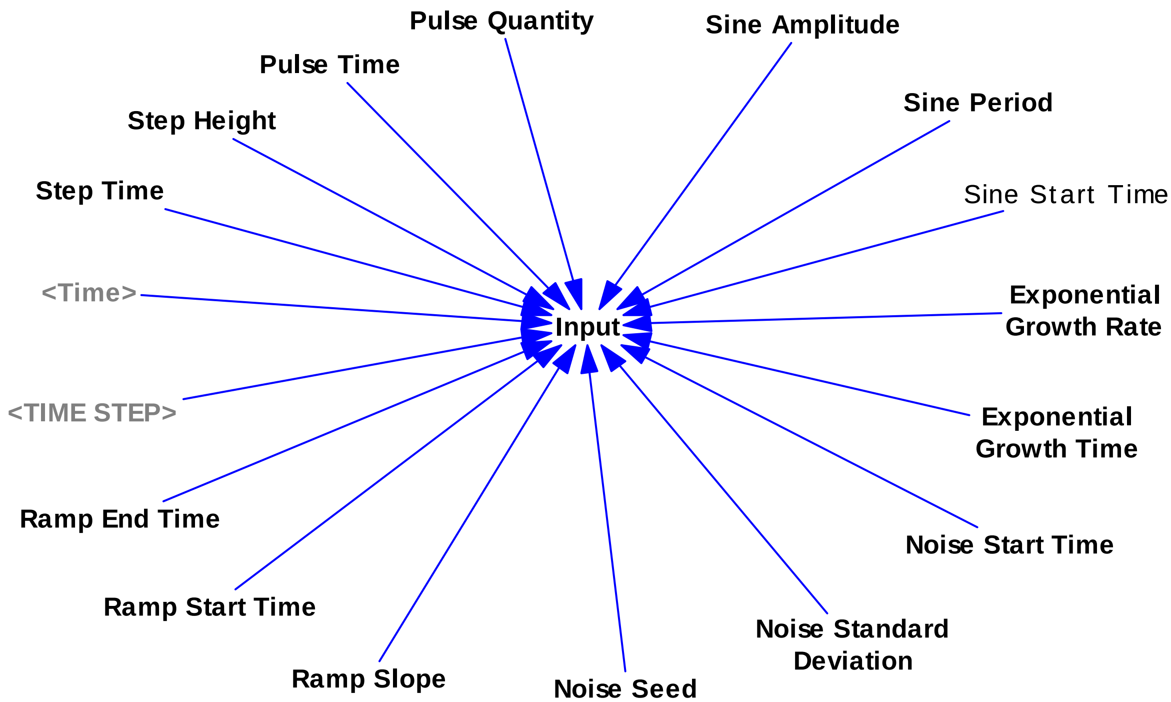
$$\begin{aligned}&\text{Lose Experience through New Technology}= \\ &\quad \text{IT Staff Total Experience*Fractional Experience decay due to new technology}\end{aligned} \tag{0.32}$$

Under normal circumstances, the loss of experience due to new technology is very small. This is the result of a relatively low rate of new technology acquisition when compared to the overall infrastructure. However, if a large number of systems, relative to the total number of systems, were added to the infrastructure, total experience would be impacted.

Test Input Generator

The Input Test Generator is used to generate different patterns of input into the system. It does not appear in the model diagram, but is saved in a different view. The Test Input Generator is shown in Figure 41.

Figure 41 Test Input Generator



By using the input generator, it is possible to simulate various patterns of growth for the firm, not in an attempt to replicate the historical data, but to test and understand the dynamics of the system. This model was developed by John Sterman as a supplement to his system dynamics text book: *Business Dynamics: Systems Thinking and Modeling for a Complex World* (Sterman, 2000). It is used here with the author's permission.

THE PROBLEM REDUX

The problem being examined at HTS is a misalignment between the mental models of the ownership of the firm and the structure of the firm as it relates to information technology. The model building phase of this project revealed some very important feedback loops from the information technology infrastructure back to the growth of the firm. These loops are the effect of delivery delay the effect of processor power, the effect of data storage, and the effect of operational IT systems. Together, they offer some understanding of how the structure of information technology affects the organization's performance. These loops help to communicate the structure of the organization. Hopefully, they will help to align the ownership's mental models.

MODEL TESTING

Model testing is not something that is completed once the model is built, nor is there any single test that can be used to validate a model. The value of the model is developed slowly, as the client and the modeler challenge their assumptions and try and understand the dynamics at play. Much of the last 100 pages has been dedicated to describing and analyzing the model that was developed at HTS over the past year. To be certain, this is not the first model that was developed nor is it the second or even the tenth.

Over the past year, I have developed dozens of models as I tried to understand the organization and the problem. Many of the early models were discarded in the discussion of the causal loop diagrams; they simply didn't hold up under careful scrutiny. Later, I developed a causal loop diagram that appeared to explain the major behaviors that I was interested in analyzing. This model fell apart when I tried to move from a very theoretical description of variable interactions to one that was operational in nature. I had developed a number of variables that made sense in an abstract discussion, but when I tried to formulate actual variables and relationships, and when I tried to develop measures and metrics of these variables, they fell short.

Each of these efforts added considerably to my learning, and from each of these failures I developed a better understanding of the dynamic relationships and the physical measurements of the variables and characteristics that I was studying. Along the way, I developed some insights into the modeling process that were useful in the project and in developing and testing my model. One of the early insights into this process was developed as I tried to convert causal loop diagrams into stock and flow diagrams. It was my experience that it was essential to have an understanding of the stocks in the model in order to develop an effective simulation model.

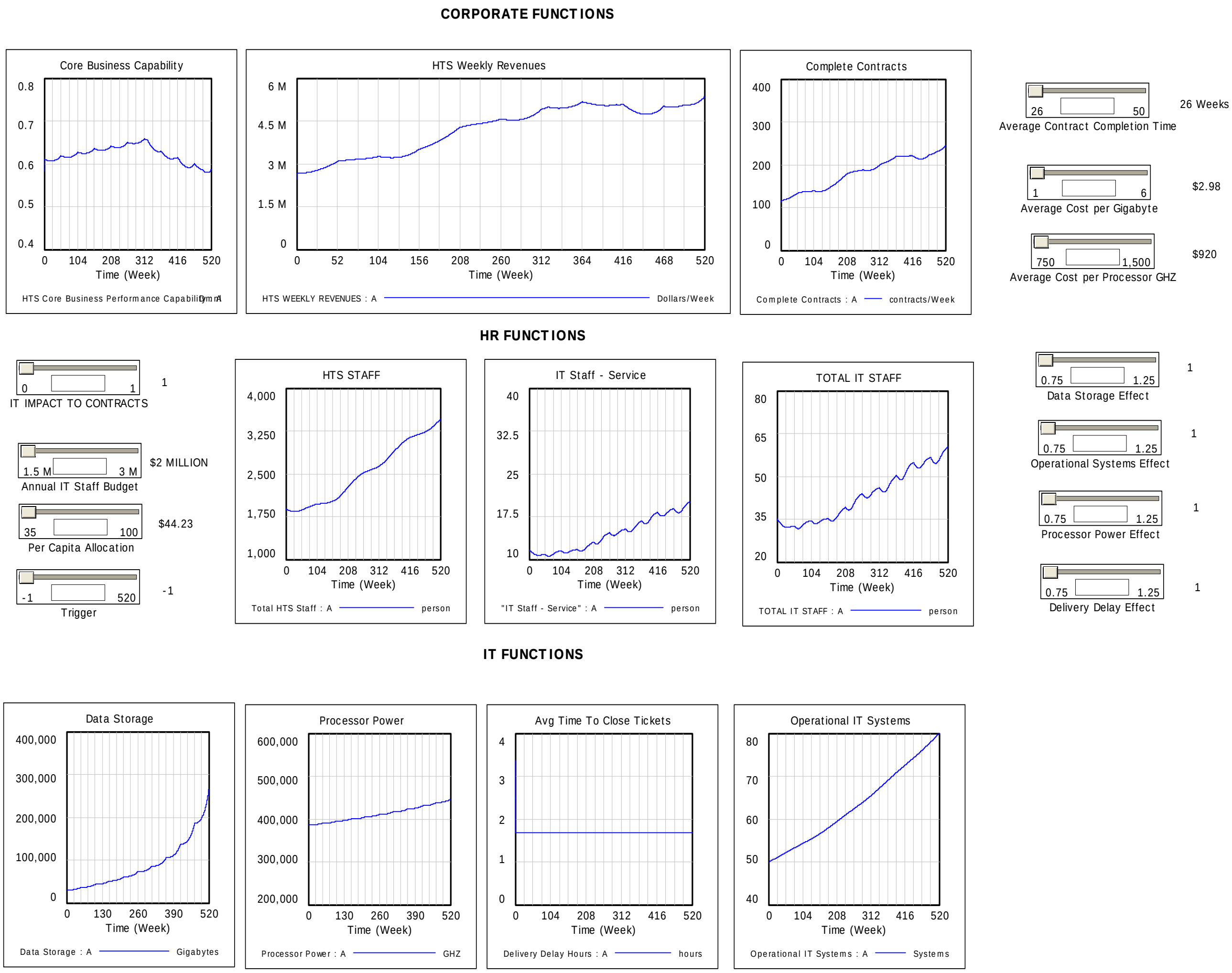
As the model grew, it became necessary to develop the model in subsystems. By considering the subsystems, and by using various test inputs, I was able to test pieces of the model and ensure that the building blocks worked. As the modeling progressed, I was able to link the subsystems together and test larger portions of the model. In developing an understanding of the model, I would break links and predict the effects that the broken loop had on the system. Using a sine wave input to see how a section of the model behaved dynamically was especially useful, and the sine wave is readily apparent as it traverses through the loops.

Control Panel

During the testing I learned a great deal about the Vensim Input Output Object tool along with Vensim's Synthesim both of which I later used to test the model. The input output object tool allows the modeler to put various input or output objects directly into the sketch of the model. Synthesim allows the modeler to make changes to the model "on the fly," that is, to make a change to the model and see the impact directly. By putting the model into Synthesim mode and changing constants, I was able to test various parameters and understand the behavior quickly.

I developed a Model Control Panel that allowed me to capture and understand the behaviors much more quickly than running repeated simulations. This Control Panel became an important attribute of my testing of the final model. Figure 42 depicts the Control Panel that was developed and used in this process.

Figure 42 Control Panel



There are a number of graphs and sliders in this Control Panel. Understanding what each represents is important, as the Control Panel was used repeatedly in testing the model. There are two types of object on the Control Panel: the first is a graph, and the second is a slider. The graphs display the dynamic behavior of a variable, whereas the sliders are used to change the value of a constant. There are three rows of graphs in the Control Panel, and each of these rows has several graphs that are related. The top row has three graphs that display variables that are described as a corporate functions. From left to right, the first variable displayed is Core Business Capability. Recall from the earlier discussion of the HTS Contracts and Staff subsystem that this variable serves as the aggregation point for the four information technology feedback loops: delivery delay, processor power, data storage, and operational systems.

The second variable graphed is the HTS Weekly Revenues. This variable represents the weekly revenues of the firm and was selected for such a prominent position in the Control Panel because of its obvious interest to the ownership of the firm. The third variable displayed is the variable Complete Contracts. This variable represents the number of contracts that are completed each week.

Following the “Corporate Functions” row is a row that displays three variables which are referred to as HR functions. These three functions are from left to right, HTS Staff, IT Staff – Service, and Total IT Staff. All of these are level variables, and the graph displays the weekly level of each of these stocks.

The final row of graphs displays four prominent IT functions, the level of Data Storage, the level of Processor Power, Average Time To Close Service Tickets (Delivery Delay), and the level of Operational IT Systems.

There are two columns of sliders on this Control Panel. In the left column, the sliders from top to bottom are as follows. The first slider controls IT Impact to Contracts. This slider is set to vary from 0 to 1 with an increment of 1. Effectively, this variable turns off the feedback loops from IT to the performance of the company. It can be used to completely remove the feedback from IT and demonstrate the potential growth of the firm without the constraint of IT. The initial value of this slider is 1, which connects the feedback loops from IT.

The next slider controls IT Annual Staff Budget. This slider is set to vary from $1.5 million to $3 million dollars, with increments of $50,000. The initial value of this variable is $2 million. The IT Annual Staff budget is set exogenously by the firm’s ownership, and this slider is used to test policy changes to the budget process.

The third slider controls Per Capita Allocation of the IT Capital Budget. This slider is set to vary from $35 to $100 with increments of $5. The initial value of this variable is $44.23. As with the previous variable, the per capita allocation is set exogenously by ownership, and this slider is used to test policy interventions.

The final variable with a slider in this column is the Trigger variable. Trigger is used to generate a pulse that simulates a disaster. This value establishes when the disaster takes place. The initial value of the trigger is at -10, which is before the simulation's initial time. Thus in its initial stage, this variable has no effect on the model. It can be varied from -1 to 520, triggering a disaster anytime during the ten year simulation.

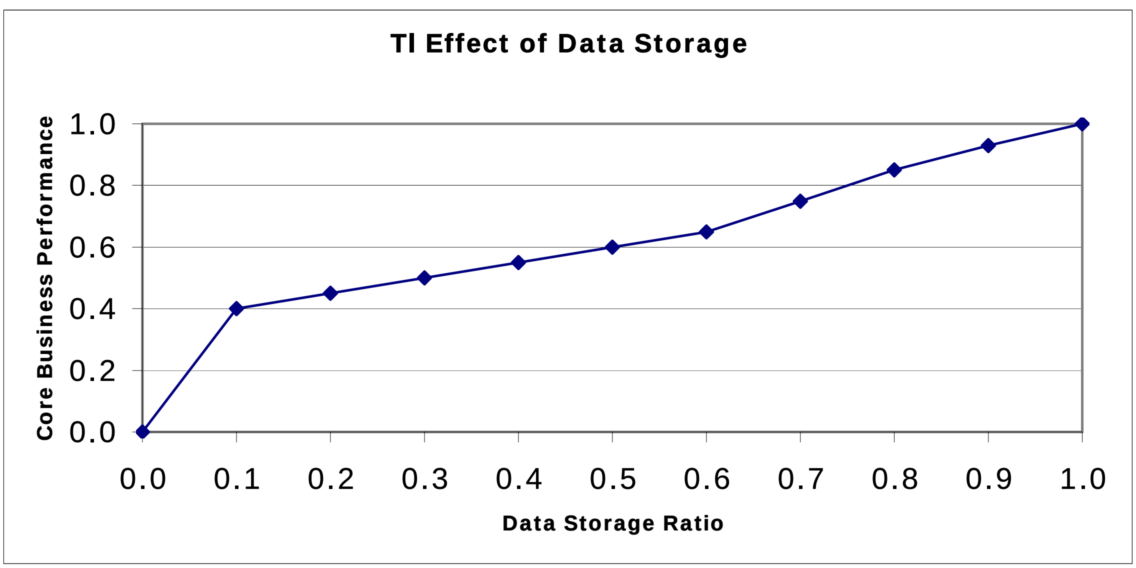
There are seven additional sliders on the Control Panel that govern other variables. These seven sliders are located on the right side of the panel, and the first variable from top to bottom controls Average Contract Completion Time. This variable has an initial value of 26 weeks and can vary from 26 weeks to 50 weeks. This slider was added to the Control Panel to address the issue of average contract length. The value of 26 was estimated based on data provided by HTS's office of the controller. It is mathematically correct but it might not be the best representation of the length of time for contracts. HTS considers many different orders to be contracts. A $1,000 change order on one engagement that might take two hours to complete is considered a contract, as is a multi-year federal development contract worth $90 million that might take five years to complete.

The next slider controls the variable Average Cost Per Gigabyte. This slider has an initial value of $2.98 and can vary from $1.00 to $6.00 with an increment of $0.10. The average cost per gigabyte was estimated based on historical purchasing records of the firm. The slider adjusts the sensitivity of the model to the price of data storage. The simulation operates over ten years, and it is likely that over that period, one or more technology changes in data storage and pricing will occur.

The Average Cost per Processor GHz is the next slider, and it controls the variable Average Cost per Processor. This slider has an initial value of $919.86, which was calculated based on invoices obtained from HTS. The Slider is set to change from $750 to $1,500 with an increment of $1. Like the previous slider, this allows a view of how sensitive the model is to price changes in processor acquisition, a price that is likely to change several times over the ten year run of the simulation.

The last four sliders are designed to test the assumptions for the table variables that control the feedback from information technology to the performance and growth of the company. Each slider varies the effect of one of the feedback loops. Recall that these feedback loops are all governed by table variables. These table variables were presented in Figure 26 Table Variables. The table variables were developed with the assistance of the HTS CIO, based on his experience and expectations. These variables were added to enable the client to specifically change the effect that any feedback might have on the performance of the organization. For example the effect of the Data Storage Ratio on core business performance is illustrated here in Figure 43. Looking at several points on the graph, it says that if the data storage ratio, which is Data Storage divided by Desired Data Storage, is equal to one, then the core business performance will be equal to one. Since the Core Business Performance under normal conditions is equal to one, this supports the idea that when there is no gap between desired and actual data storage, data storage will not have an effect on the business performance capabilities of the firm.

Figure 43 Table Effect of Data Storage on Core Business Performance



The next point to examine is the point where the data storage ratio is equal to zero. At this point, the actual data storage in the infrastructure must be equal to zero. Since data storage is a requirement of virtually all production and business applications at

HTS, having zero data storage available is going to have the effect of completely disabling the performance capability of the firm, and the core business capabilities are therefore equal to zero.

The point where the data storage ratio is equal to .one, or where there is 10 % of the required storage, is a tipping point. At this point, the business performance is significantly impacted, but at least some work can be done. From this point to the point where the ratio is equal to 1, there is a smoothly increasing curve, implying that the closer the data storage ratio comes to unity, the better the performance of the firm.

This ratio is based on the client's belief about the impact of information technology on the firm, but others could argue that while the data storage ratio might indeed have an effect on the firm, they may consider this relationship too strong or too weak. In order to accommodate this discussion and to improve the opportunities for learning from the model, these variables were created and the sliders were developed to enable real-time changes to these assumptions.

Figure 43 showed the table variable for the data storage effect. The slider Data Storage Effect has an initial value of one, and can be varied from .75 to 1.25. Figure 44 is the graph of the variable Data Storage Effect that shows the variable for three different runs. The first run is DSEFFCT1, and for this run the Data Storage Effect slider was set equal to one. The second run DSEFFECT75, and the third run DSEFFECT125, the variable Data Storage Effect was set at the extreme conditions of .75 and 1.25 respectively. Figure 45 shows the variable Effect of Data Storage with all three runs on the same graph. From this graph you can see that varying the slider from 1 to .75 strengthens the effect of the variable, while varying the slider from 1 to 1.25 has the effect of weakening the effect of the variable.

Figure 44 Data Storage Effect

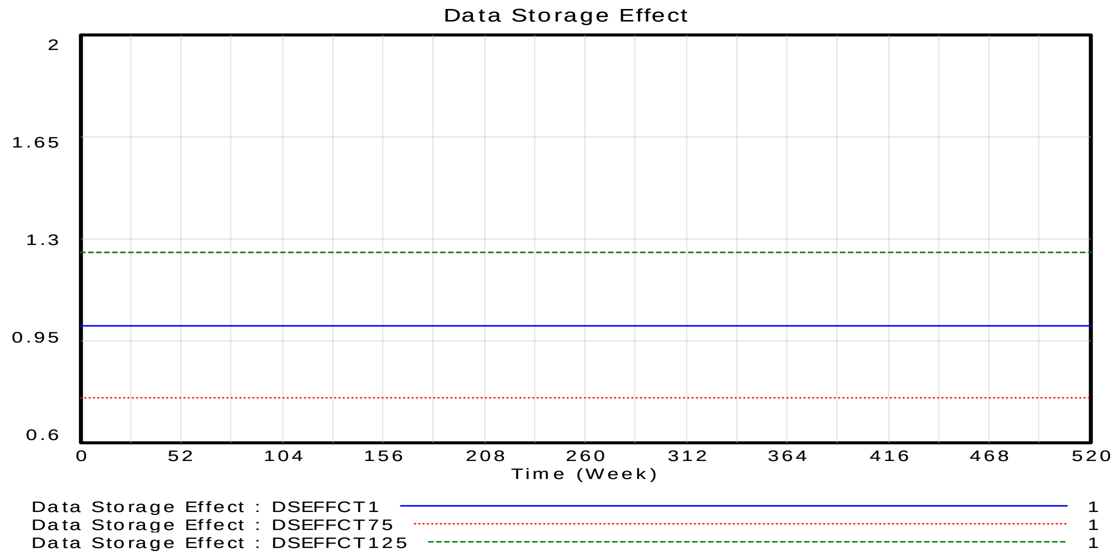


Figure 45 Effect of Data Storage

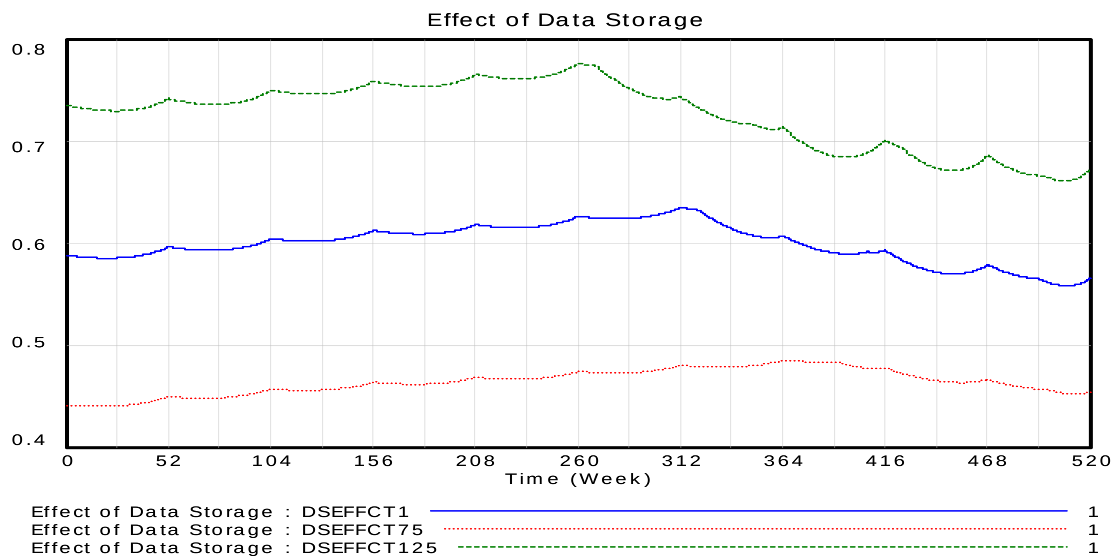
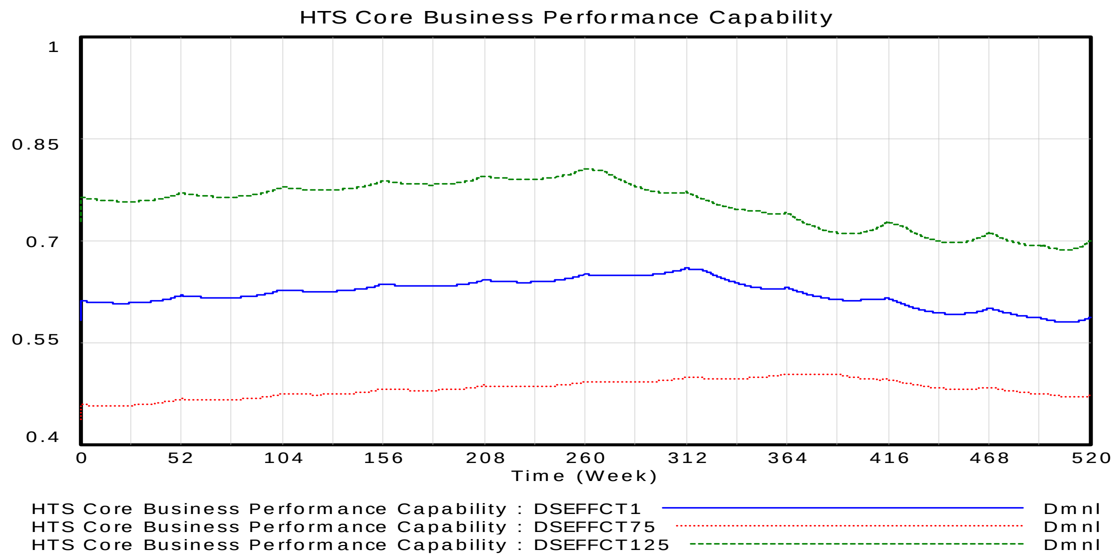


Figure 46 shows the next variable in the loop, the HTS Core Business Performance Capability. From this graph it is clear that varying the Data Storage Effect from .75 to 1.25 impacts the HTS Core Business Performance Capability.

Figure 46 HTS Core Business Performance Capability



Each of the other three sliders, Operational Systems Effect, Processor Power Effect, and Delivery Delay Effect operate under the same principle, that each varies the effect of the ratio of the same name.

Reference Modes

The question of whether the model reproduces the problem behavior is not one that is easily answered. The problem being explored with this model reflects the ownership's failure to understand the very real effect that information technology has on the organization. Modeling requires a relationship between the client and the modeler, one in which the client is involved in the development of the model from its early phases, has an interest in the model and in the process, and perhaps most importantly, is prepared to question every parameter, every link, and every relationship. The CIO at HTS has a very holistic world view, and although he did not have experience with system dynamics modeling, he was familiar with the concepts. The model was developed entirely collaboratively, in that every relationship was subject to dissection during our meetings. As the model progressed to the simulation stage, the CIO was involved in reviewing the results and in confirming that the behavior was consistent with his experience and his expectations.

For the purpose of writing up the research, the model has been described as being composed of several interconnected subsystems, but the model was not actually constructed as separate subsystems. Model construction began with simple causal loop diagrams that represented relationships that the client felt were the most important in understanding the problem. These causal loop diagrams evolved into stock and flow diagrams, and ultimately, this model evolved into a single large model with over a hundred variables. In order to develop the appropriate equations to model the variables and their relationships, the model was disaggregated into several subsystems, or molecules, which could be easily modeled and simulated. As the simulation progressed the client was involved in validating that the behavior of each section reproduced the reference behavior. As the subsystems were integrated together into the current model, testing continued for behaviors that were consistent with our reference modes and our expectations.

Estimation

There are 68 constants in the model. Most of these constants reflect some variable, some value which had to be estimated for the model. The process of estimating the variables differed depending upon the variable and the purpose of the variable. Some are simply variables that govern specific behavior of the model. For example, this includes variables such as Final Time, which dictates the final time for the simulation, Savper, which dictates the frequency that the output from the model is stored, and Base Input, which has the value of one, and is used simply for dimensional consistency in converting the output of the test generator to the acquisition of new contracts. These variables were generally estimated as part of the modeling process and were not estimated based on meetings with the client.

The next class of variable to be estimated included the variables that had some real physical value. This includes variables such as Annual IT Staff Budget, Average Cost Per Gigabyte, and HTS Non IT Staff. These variables were estimated by combing through the various records available to the modeler during the research process. The Annual IT Staff Budget was developed by exploring the data for all of the various IT staff budgets for the past 3 years. It was necessary to obtain information from several sources and combine this information, because some of the IT staff are funded in budgets outside of the IT organization. The Average Cost Per Gigabyte was estimated by averaging the cost for all data storage purchases made over the last three years. This information was developed by going through all IT purchase requests for the past three years, identifying any that were for data storage, and extracting the per unit cost. The HTS Non IT Staff Information was obtained from the firm's human resource records. As the values for these variables were developed, each variable and the estimated value for that variable were reviewed by mangers within the IT organization and, ultimately, by the CIO himself.

Other variables which were estimated were of a class for which there were no physical records available. These were estimated in discussions between the researcher and the CIO. This class of variable included such variables as Fatigue Onset Time, Fractional Experience Increase Due To Training, and Mngt Perception Delay Time.

Fatigue Onset Time describes how many weeks of extended work the average IT employee can work before the cumulative effect of working overtime affects his or her productivity. This is different from the effect of working 80, 90, or 100 hours in any given week. This variable describes the effect that working 50 to 60 hours a week for several weeks in a row has on an employee's performance and morale. This was estimated by the CIO to be six weeks.

Fractional Experience Increase Due To Training is actually modeled as an auxiliary variable and not a constant. However, it has a constant component entered directly in the equation. This constant represents the equivalent experience of one week of training. Initially, the researcher proposed 26 weeks for this variable, but the CIO was adamant that this was not an accurate projection, and proposed 13 weeks as more realistic.

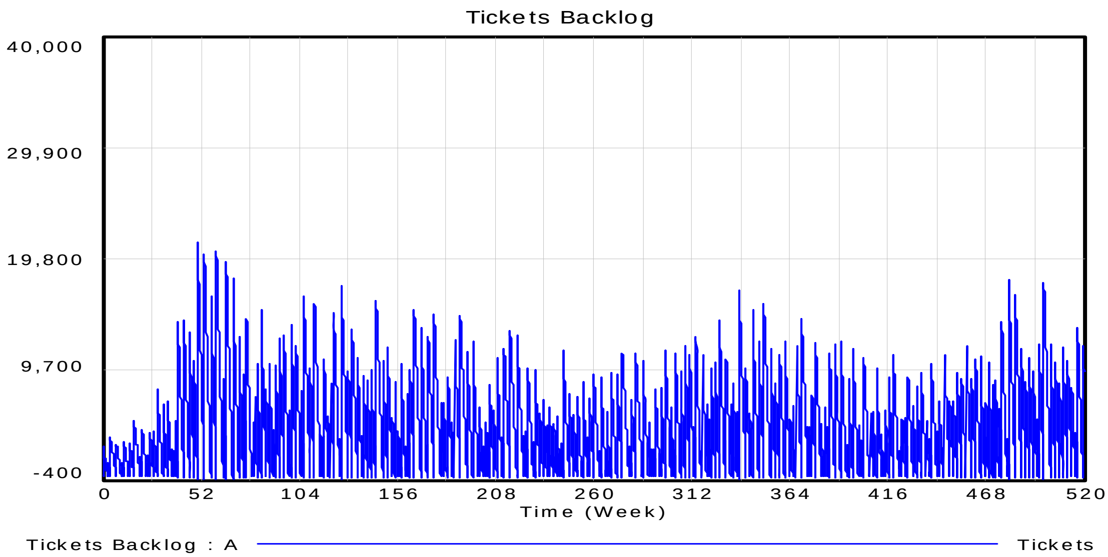
Mngt Perception Delay Time represents the number of weeks of delay between an upturn in the ticket backlog and the acceptance that this is a real change in the system, and not simply a temporally localized event. This value was estimated at eight weeks; meaning that management would seek to hire a new person if the ticket backlog remained high after eight weeks.

Table variables are a final class of variable that had to be estimated for the model. There are 22 table functions in the model. Some of these variables were estimated from the system dynamics literature such as Tl for effect of Schedule Pressure on Workweek. Most table variables were developed in a series of workshops with the researcher and the CIO. The process involved drawing graphs that represented the effect the CIO believed accurately described the relationship between the variables. This was followed by the researcher creating actual table variables that had scales on each of the axes, and then confirming with the CIO that this table represented the relationship as he saw it. Additional work was done to identify reference points for these variables. A final step was to compare tables that affected the relationship between one variable, and more than one other variable. For example, Total IT Systems affects Production Applications and Business Applications. Early tables had the effect on Production Applications 100 times greater than the effect on business applications. By reviewing these paired tables together, the estimation process was completed.

MODEL PROBLEM DISCOVERED

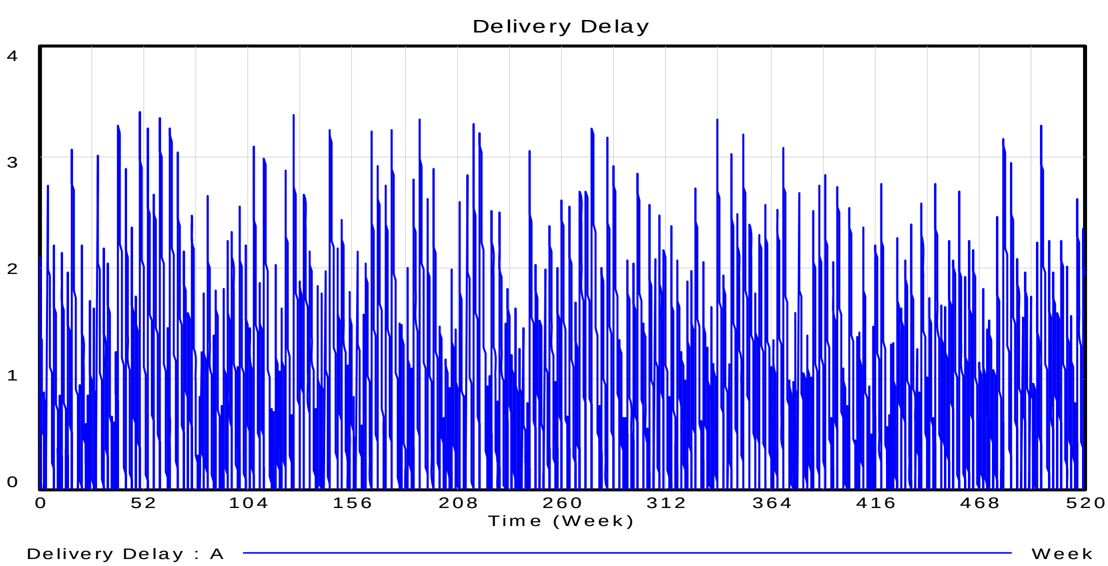
The model was finally coming together when, during testing, a problem was discovered that threatened the project. The stock of *Ticket Backlog*, a central variable in what is now described in the IT Staff subsystem was going negative, and was oscillating wildly. After consulting with an expert in system dynamics modeling, Dr. Hazhir Rahmandad, it was determined that the time step for the model, which was 0.0625, was greater than the shortest time constant in the model. The graph of this oscillation is shown in Figure 47.

Figure 47 Ticket Backlog Oscillation



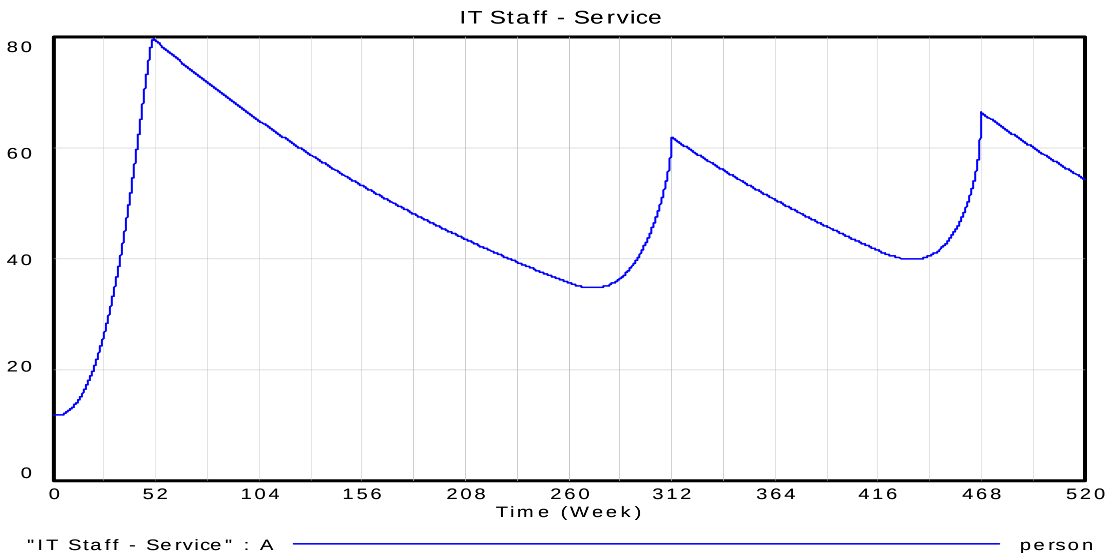
In addition to Tickets Backlog behaving in this fashion, Delivery Delay, which is an important feedback for the performance of the firm, and which is a ratio of the variable Ticket Backlog to Service Ticket Completion Rate was also oscillating. Figure 48 is a graph of the delivery delay.

Figure 48 Delivery Delay



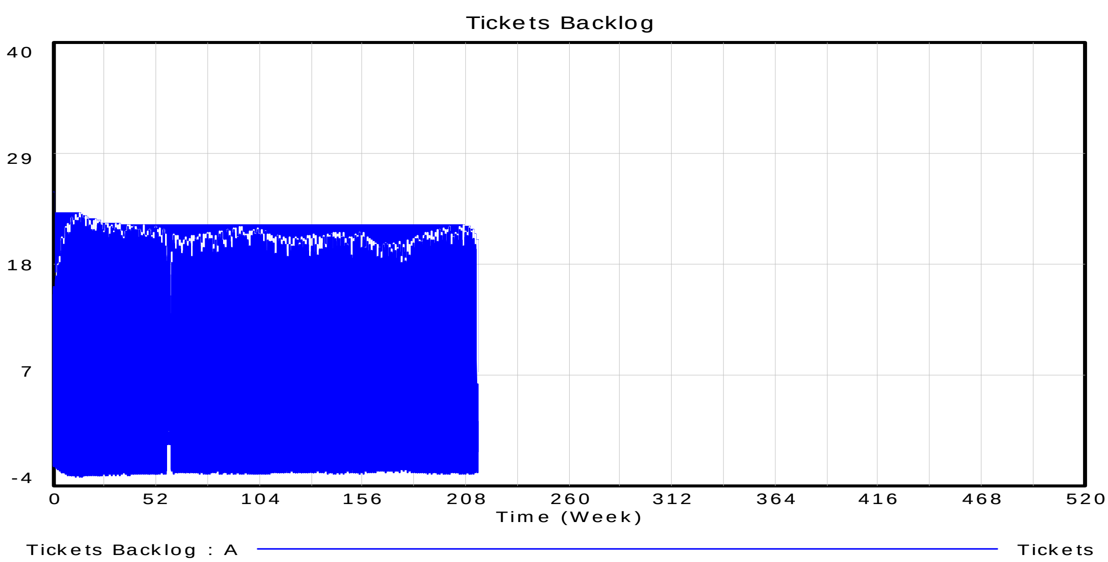
Other variables that were also affected by this oscillation included IT Staff – Service which is depicted in Figure 49.

Figure 49 IT Staff - Service



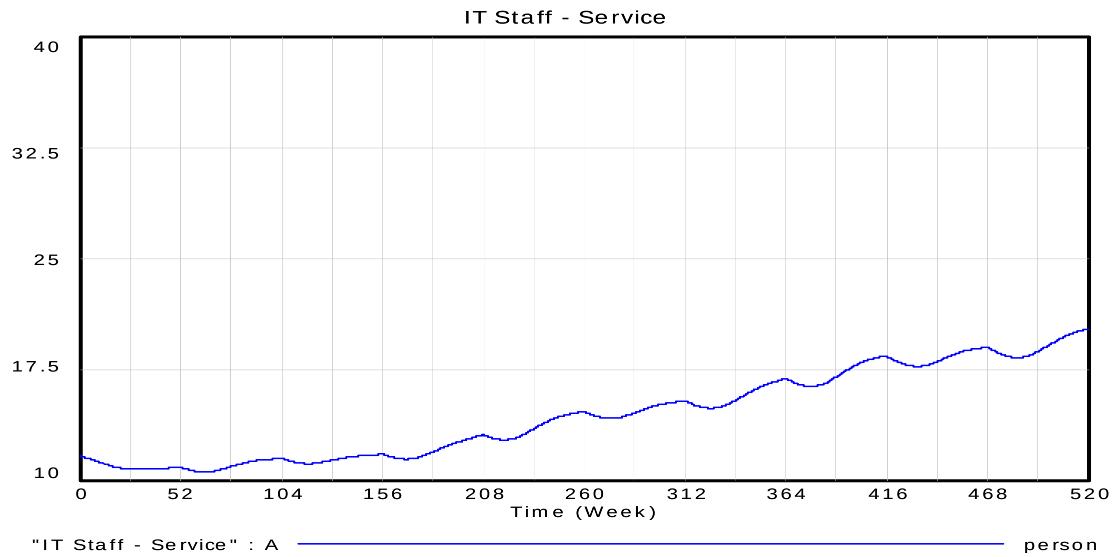
Clearly, the model was not behaving as expected. By changing the time step in the model from 0.625 to 0.007812 the magnitude of the problem was changed, but the problem was still there. Figure 50 depicts the ticket backlog when the time step is changed to 0.007812.

Figure 50 Ticket Backlog at Time Step 0.007812



The behavior of IT Staff – Service had changed dramatically, it was no longer oscillating wildly. Figure 51 depicts the IT Staff Service at the new time step.

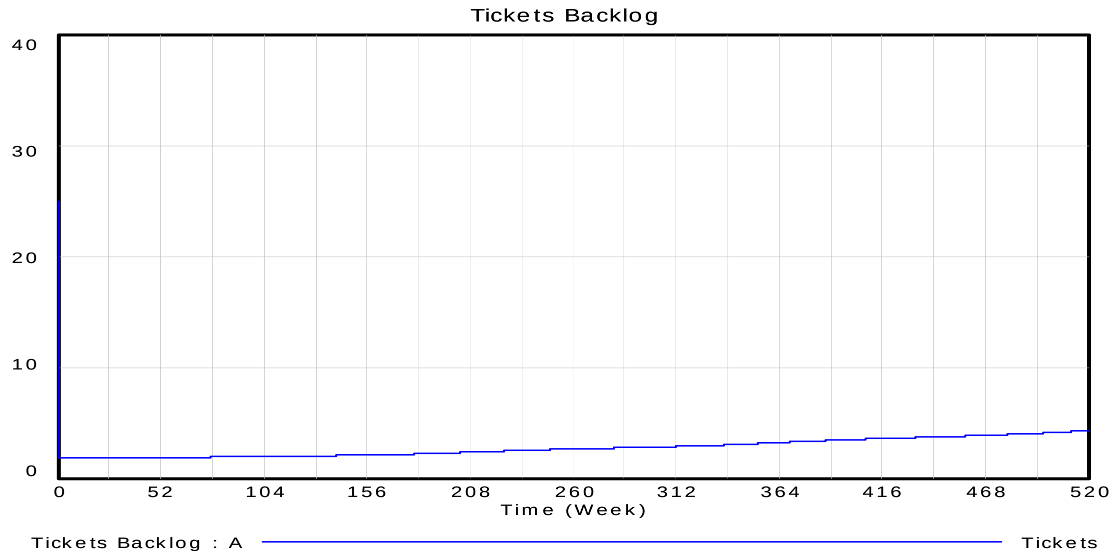
Figure 51 IT Staff Service



Identifying and understanding the problem was challenging. Consider the first time step, 0.0625. Given that the units for time in the model were weeks, the time step of 0.0625 translated to 630 minutes, or just over 10 hours. The new time step is 0.0078125 which is equal to 78.75 minutes, or 1.3 hours. The problem was that two variables had estimated values of less than 78 minutes. These two variables were Minimum Ticket Completion Time and Target Ticket Completion Time. Minimum Ticket Completion Time represented the physical minimum time in which a service technician could close a ticket. This value was estimated at 10 minutes. The second variable, Target Ticket Completion Time, represented the goal for the length of time in which tickets would be completed. The goal was 30 minutes. These two seemingly innocuous variables were disrupting the model performance in a major way.

Vensim is limited to a minimum time step of 0.0078125, and the integration time could therefore not be reduced any further. In order to make the model functional, the two variables had to be changed to a value that would not cause an integration error. The variables were both changed to a value of 100 minutes. Figure 52 is the graph of the tickets backlog with the new values for the two variables. The oscillation was gone, and the ticket backlog was no longer going negative.

Figure 52 Tickets Backlog at 100 minutes



The other variables were no longer demonstrating unexplained variation. The problem appeared to be fixed, with no major impact to the model. It was now clear what had caused the problem. The minimum time constant in the system had to be greater than 78.75 minutes, but both of the variables, Minimum Ticket Completion Time and Target Ticket Completion Time, had been set to 100 minutes. What would be the impact of changing these two variables to 79 minutes? Figure 53 is the graph of the Ticket backlog at 100 minutes (Run A) and at 79 minutes (Run B). There is little difference in the effect on ticket backlog. Looking at other major variables in the model provided the same results. Figure 54 HTS Contracts at 79 Minutes and Figure 55 HTS Weekly Revenues at 79 Minutes are depicted below.

Figure 53 Ticket Backlog at 79 Minutes

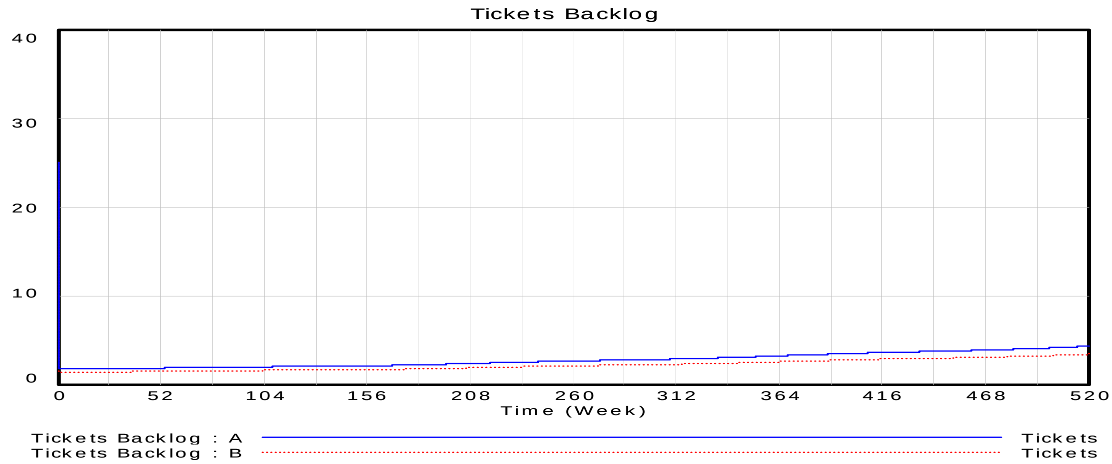


Figure 54 HTS Contracts at 79 Minutes

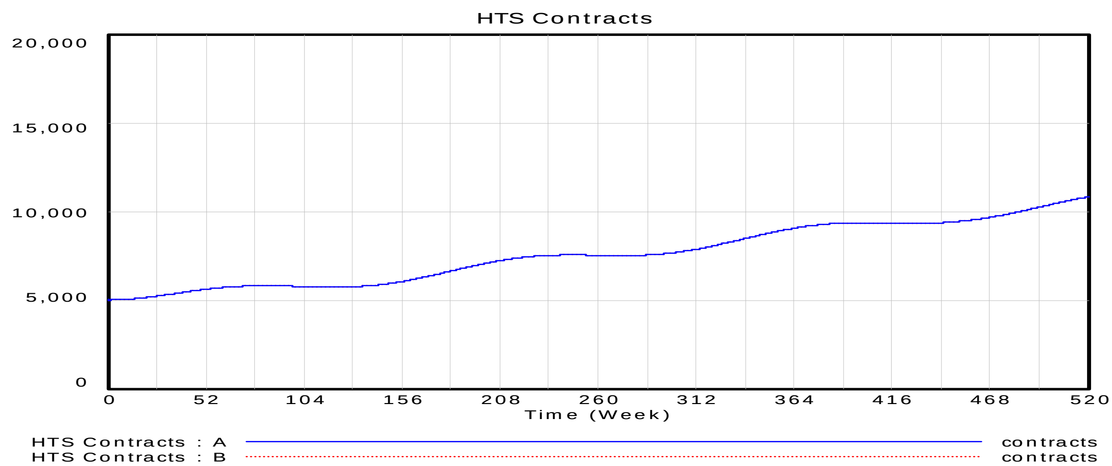
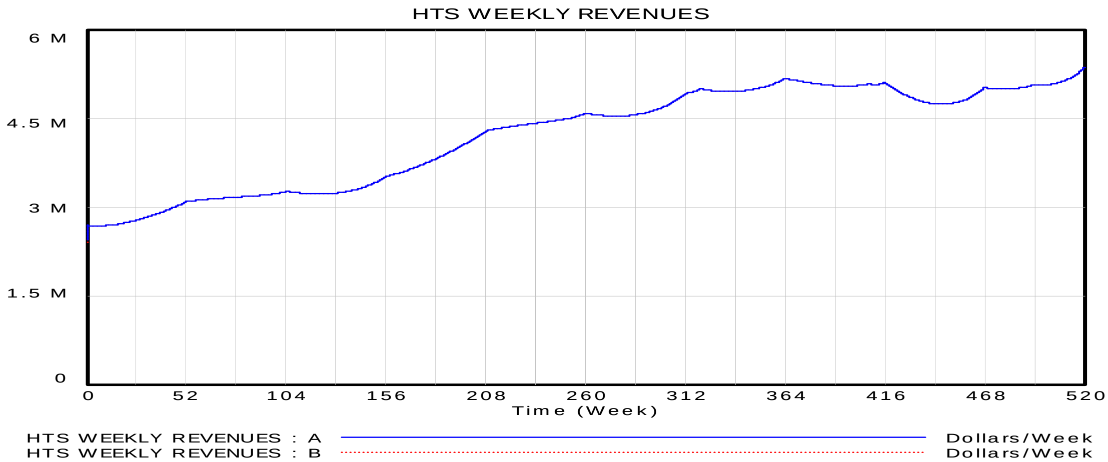


Figure 55 HTS Weekly Revenues at 79 Minutes



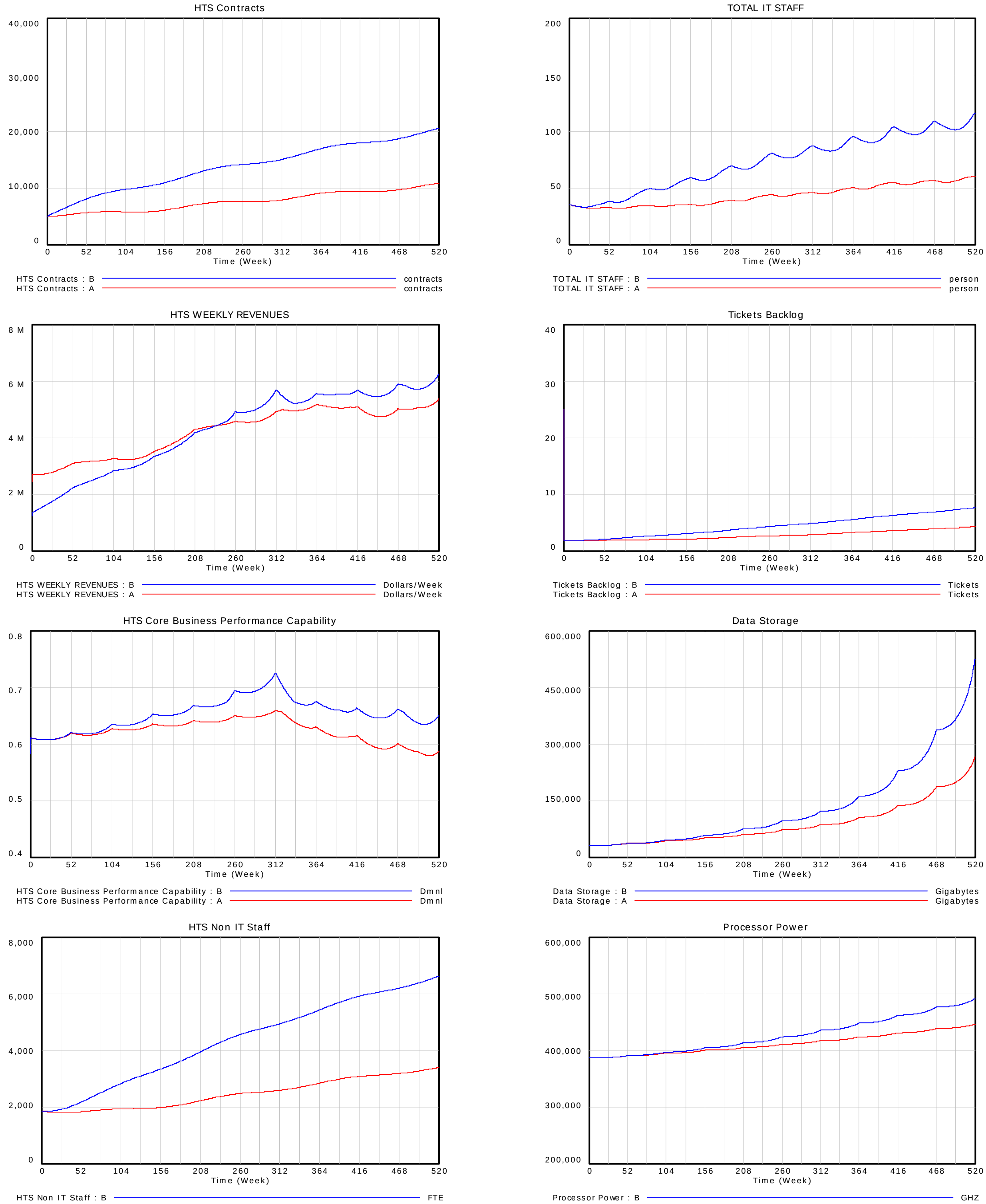
The problem was resolved, or at least the oscillation was no longer a problem. Studying the system a little further, it became clear that there was an unintended consequence of changing these variables. Four central functions of IT had been identified, all of which fed back to the Core Business Capability of the firm. These four functions were: Data Storage, Processor Power, Deliver Delay, and Operational IT Systems. The fix for the integration problem was causing the Delivery Delay and subsequently, the HTS IT Staff subsystem to have no effect on the Core Business Capability of the firm.

Time was running out for the research, and I met with the CIO of HTS and explained the problem. Although the delivery delay impact was not working in the simulation, the model still had an impact on learning and understanding. The client agreed that the model was acceptable despite the problem in this one area. It isn't too difficult to understand why there would be an impact, since the time constant had changed from 10 minutes to 100 minutes, an order of magnitude change, but unfortunately, one that couldn't be avoided. If there had been unlimited resources, the model could be formulated using a different time unit, one shorter than a week. The model could be done with a time unit of a day instead of a week. This would eliminate the integration problem present with the current model. Changing the model was briefly considered but discarded, because the resources were not available to go through the modeling processes and validate all of the variables. Additionally the CEO of the HTS had been scheduled for a briefing, and there simply wasn't time for a major model rewrite. The purpose of the model was not to predict the future. The purpose of the model was to develop understanding, and that purpose has largely been fulfilled. In fact, the problem enhanced the understanding by forcing an investigation of the structure.

SENSITIVITY TESTING

In addition to the obvious sensitivity testing that was undertaken while testing and understanding the problem described in the last section, sensitivity analysis has been done on other variables in the model. In doing the sensitivity testing, a number of key variables were selected to be observed in terms of the effect that changes on these variables had on the model. These key variables are: HTS Contracts, HTS Weekly Revenues, HTS Core Business Performance Capability, HTS Non IT Staff, Total IT Staff, Tickets Backlog, Data Storage, and Processor Power. Figure 56 Sensitivity Testing Run 1 depicts the graphs of two simulations of the model. The Simulations are labeled Run A and Run B. Run A was the simulation completed with base levels of all variables. Run B is the test for a change in the Average Contract Completions Time. The reader may recall that this variable is one of the sliders on the Control Panel. The contract completion time was changed from 26 weeks to 52 weeks for this test.

Figure 56 Sensitivity Testing Run 1 – Average Contract Completion Time

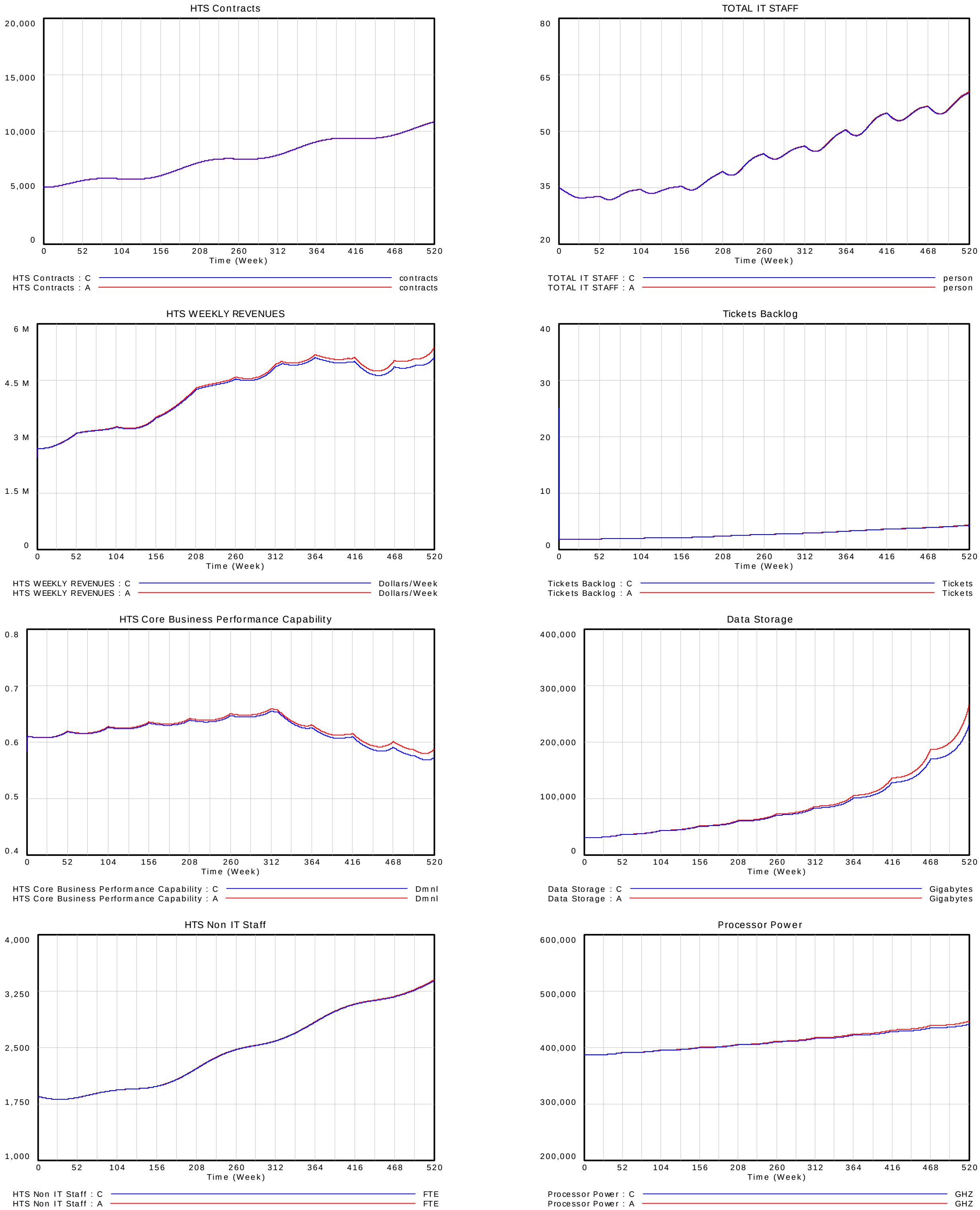


The first variable considered is the stock of HTS Contracts. By changing the average time it takes to complete a contract, the outflow rate variable of that stock was effectively reduced. Therefore, an increase in the stock is the expected and actual behavior. The behavior of HTS Weekly Revenue is a bit more interesting. Initially, the weekly revenue is lower than the base level, but it increases at a faster rate and eventually exceeds the revenues of the base rate. In the model, weekly revenues are a function of completed contracts. Since contracts are completed at a slower rate, it makes sense that revenues would initially be lower. Because the rate of acquisition of contracts is not reduced, the stock of contracts builds in the system over time, and because there are more contracts, the completion rate of contracts must increase. When the completion rate of contracts increases, the weekly revenue must also increase. The behavior is appropriate for the change made.

HTS Core Business Performance Capability has an interesting variance. Generally this capability is greater when the average contract length is longer. The performance capability displays sharp variances at the end of each year. The shape of the curve can be traced back to the effect of data storage on performance. The slope changes in the curve at the end of each year can be attributed to year-end budget clearing. The performance improvement can be attributed to an increase in the contracts in process because each contract takes longer. Also, HTS Non IT Staff is a function of contracts; therefore, an increase in contracts means an increase in HTS Non IT Staff. This, in turn, results in a budget increase to close the gap between desired and actual data storage. Since that gap is closed faster, overall performance is improved. Total IT Staff is a function of tickets backlog and or a minimum ratio of Total HTS Staff to Total IT Staff. Since Total Staff has increased, it is to be expected that IT Staff should also increase. Since there is an increase in the Total Non IT Staff, there is an increase in the budget, enabling the purchase of more data storage equipment and more processor power. This explains the increase in both data storage and processor power. Tickets Backlog is a function of a number of drivers, including Effect Of Non IT Staff, Effect Of Processor Power, and Effect Of Data Storage. Since all three of these variables have increased, it is to be expected that Tickets Backlog would also increase. The model behaves correctly and is not sensitive to a doubling of contract completion time from 26 weeks to 52 weeks.

A second variable that was tested is the Average Cost Per Gigabyte for data storage equipment. Figure 57 Sensitivity Testing Run 2 depicts the results of this testing. The variable, Average Cost Per Gigabyte was increased from $2.98 by a factor of 10, to $29.80. The model doesn't appear to be sensitive to this change, but there are some interesting results which are noted here. As before, Run A is the base line run, and for this graph, Run C is the simulation with the variable change.

Figure 57 Sensitivity Testing Run 2 – Average Cost Per Gigabyte



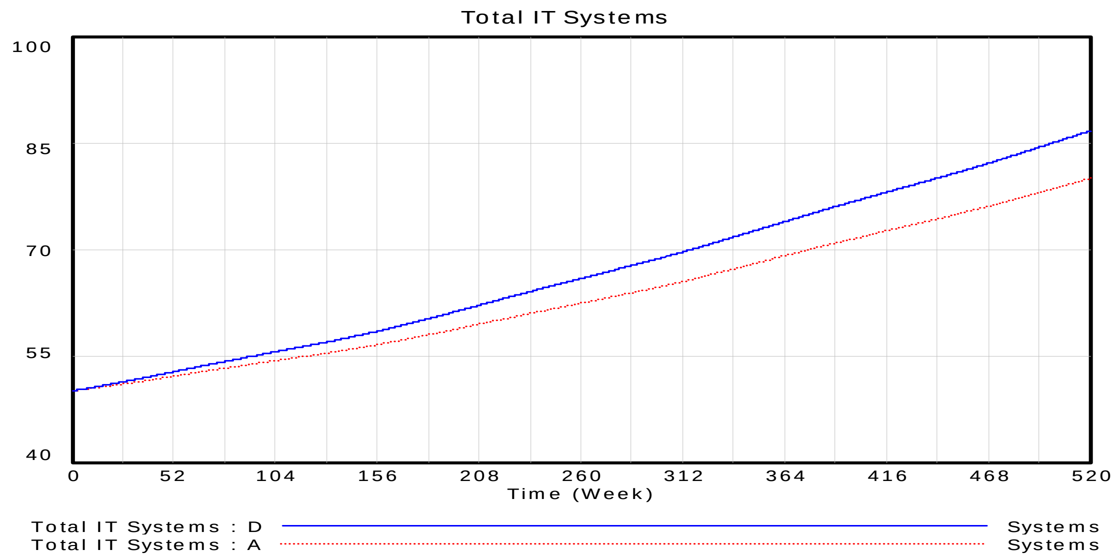
The first observed variable is HTS Contracts. There is no change in this variable. HTS Contracts is not sensitive to a change in Average Cost Per Gigabyte. This insensitivity is because both the input to Contracts, Acquire New Contracts, and the output from Contracts, Complete Contracts, are affected by the variable Contract Performance.

HTS Weekly Revenues is sensitive to a change in this variable over the course of the 10 year simulation. Weekly revenues grow at a slightly slower rate with the change in the cost per gigabyte. This sensitivity can be traced to the next variable in the graph, HTS Core Business Performance Capability, which, over the course of the simulation falls slightly below the former level. This can be traced back to Data Storage which has also fallen slightly behind the level of the previous run. This can be attributed to simple economics since Desired Data Storage has not been changed in the model, nor has Available IT Budget. The result is that less data storage capability can be acquired with the same budget, so Data Storage falls further and further behind Desired Data Storage. This causes Data Storage Ratio to shrink, which in turn causes HTS Core Business Performance Capability to fall. Additionally, the final variable in the analysis, Processor Power, also falls slightly behind the previous run. This is understandable because the acquisition of processor power is funded through the same budget as data storage.

An interesting analysis is testing the sensitivity of the system for an increase in the ratio of new contracts to new information technology systems. There is no ratio variable that can be changed to test this sensitivity. However, there is a variable called Base Input 2, which is used to provide dimensional consistency in the conversion process between the input to the growth of the firm, measured in contracts per week, to the growth of the information technology infrastructure, measured in systems per week. Since this variable is only there to provide dimensional consistency, it has a base value of 1. Changing that variable to 1.3 effectively increases growth of the information technology by 30%.

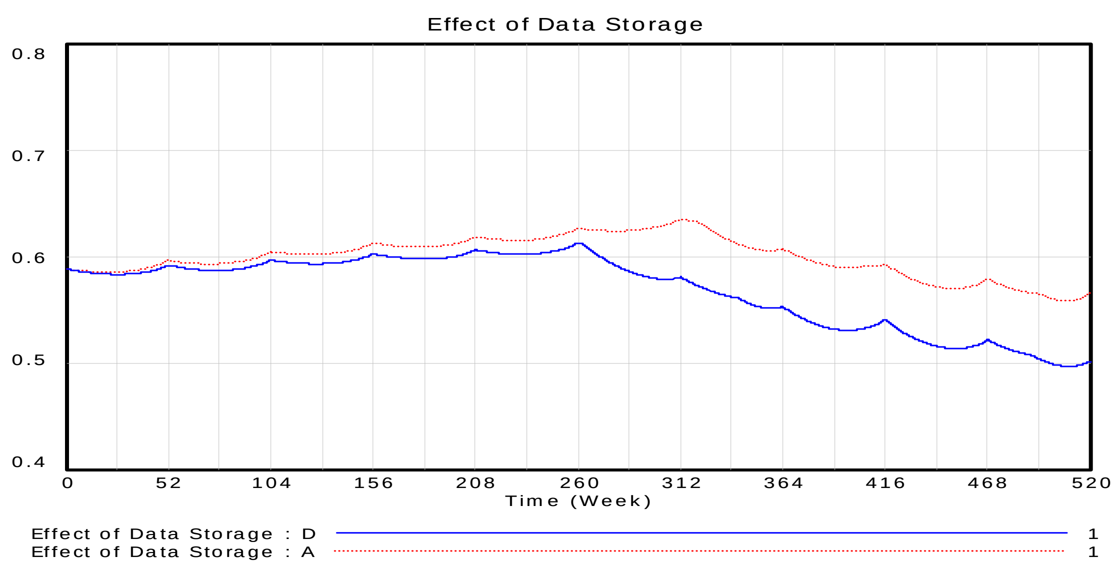
After performing this analysis, the first variable examined is Total IT Systems. Figure 58 depicts the comparative runs for this variable. As expected, Total IT Systems increases at a faster rate.

Figure 58 Total IT Systems At 1.3 Growth Factor



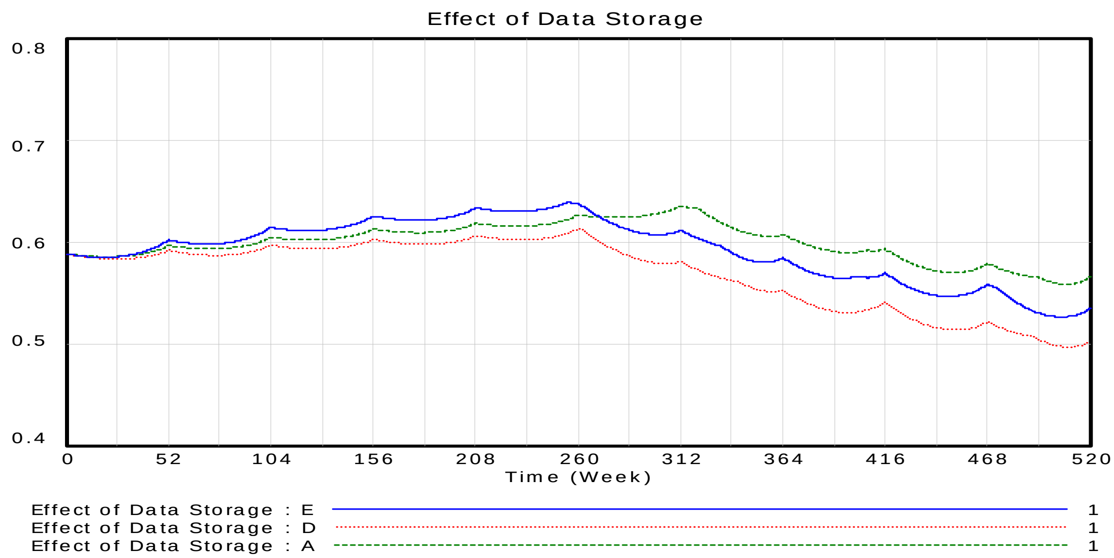
The next variable reflects the effect of data storage on the performance of the firm. Figure 59 shows the effect of this increased growth on the firm. Not surprisingly, growing the information technology infrastructure faster simply causes the requirement for data storage to grow faster. This coupled with the restrictive budget constraint, causes the negative effect of this misalignment to appear more rapidly.

Figure 59 Effect Of Data Storage At 1.3 Growth Factor



Changing a second variable verifies this performance. The following graph, Figure 60, depicts Effect of Data Storage when the growth factor is increased by 30% and the per capita allocation is simultaneously increased by 50%. Run A represents the base run with the standard variables. Run D represents the increase in the growth factor by 30%. Run E represents the effect of data storage when both the IT growth factor has been increased and the per capita budget has been increased.

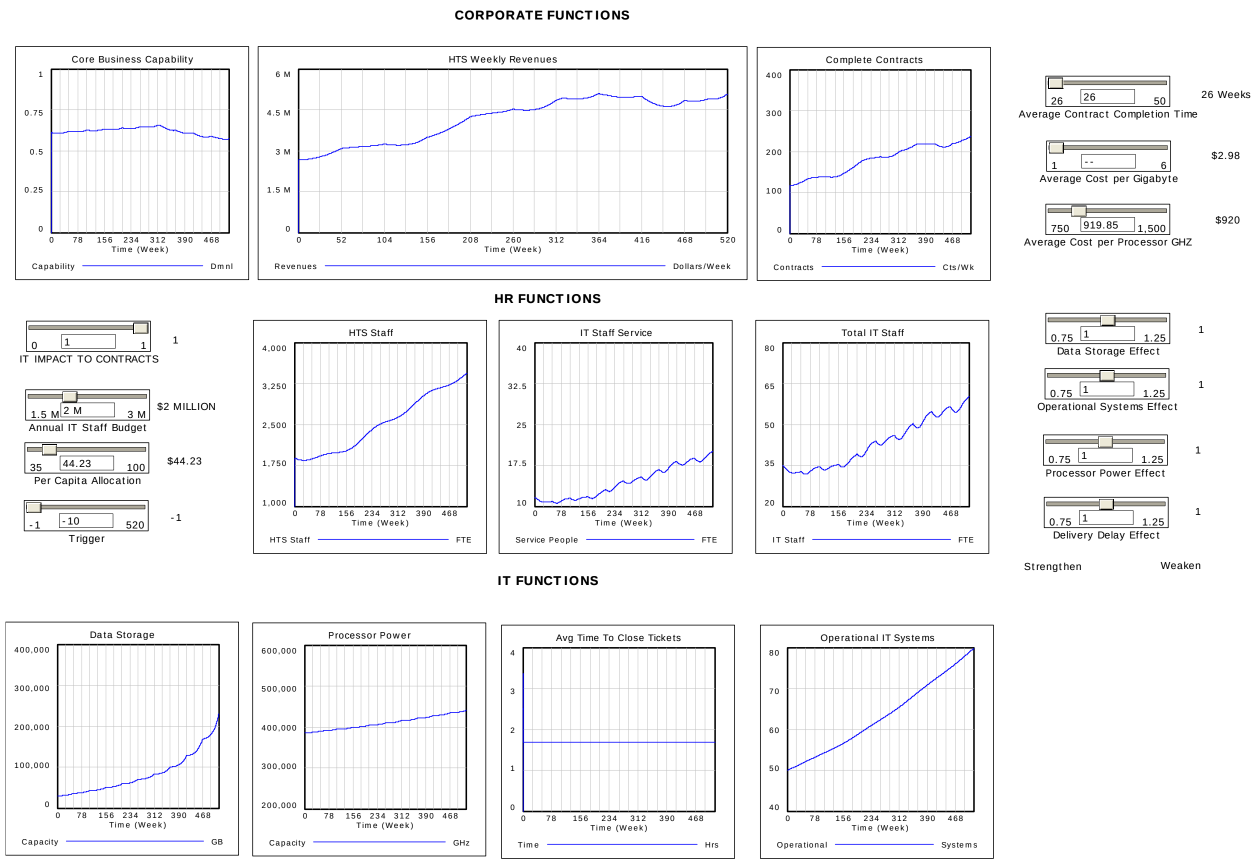
Figure 60 Effect Of Data Storage With 30% Growth And 50% Budget Growth



As can be seen, Run E, when the budget has been increased along with the growth factor, exceeds the performance of the system when only growth has been increased. After week 260, the performance of both runs begins to decrease, falling below the performance of the original run.

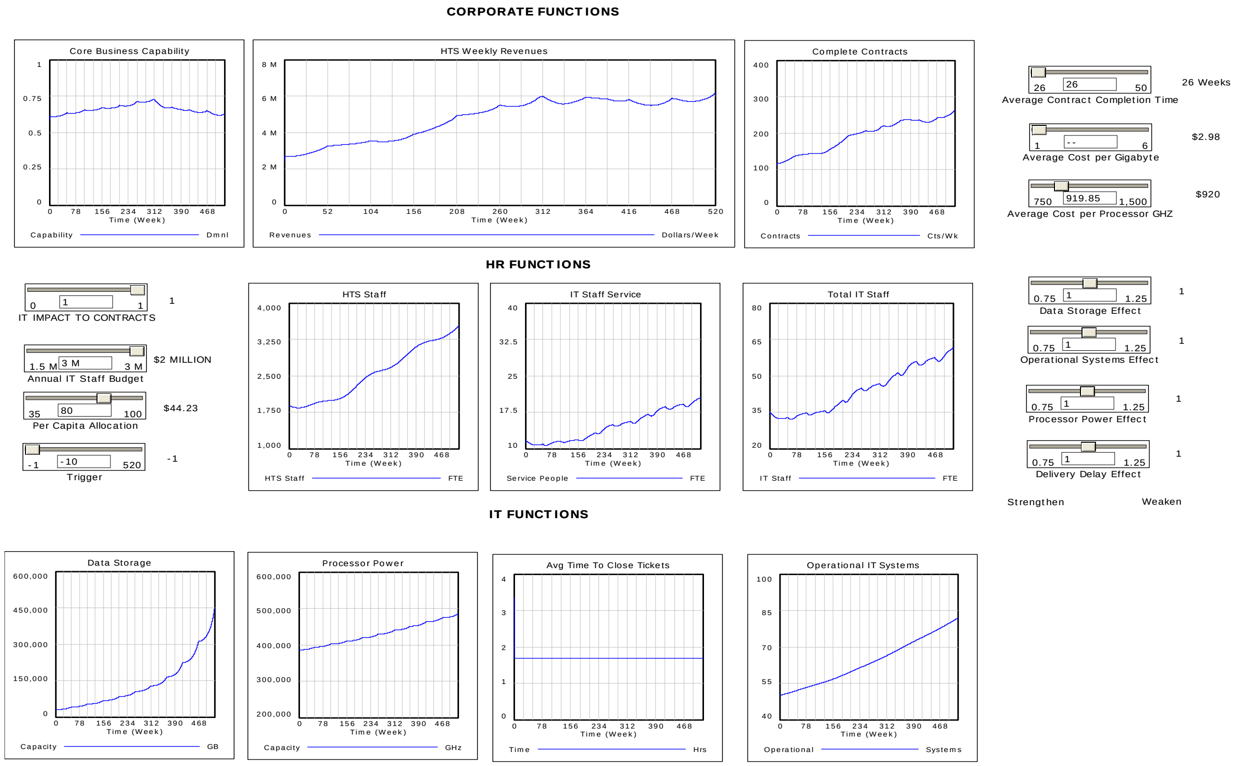
Two of the variables that would be most interesting to follow are the effect of the Per Capita Budget and the Annual IT Budget. Using the Control Panel, the effects that these variables have on the system are easily recognized. The Control Panel is especially useful when working with the client for this analysis, as it can be done using Synthesim in a real time fashion. Figure 61 is a screen depiction of the Control Panel with the all variables at their base values. The Core Business Capability is varying between approximately 60% and 65% with a decline noted at about week 312. Weekly revenues follow a pattern of growth over the entire 10 year simulation peaking at week 520 at about $5 million per week.

Figure 61 Control Panel - Base Values



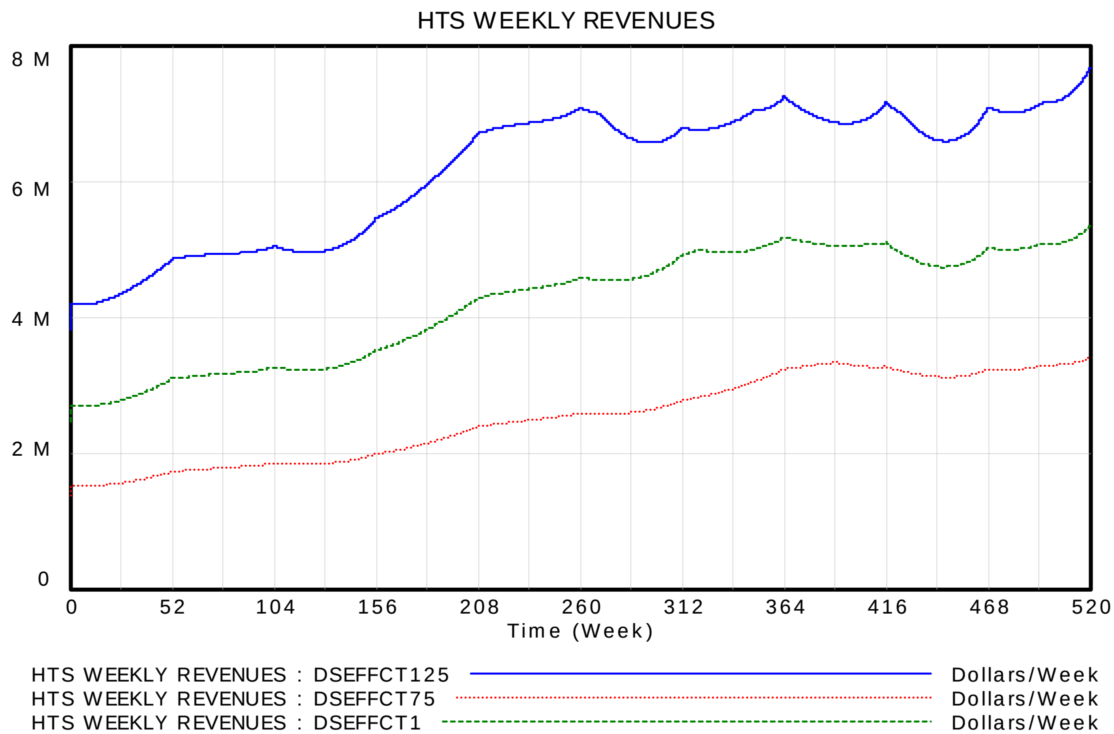
The second screen shot shows a similar pattern, however, Core Business Capability varies between 60%and 75%. Weekly revenues follow a similar pattern of growth but they now peak at slightly over $6 million per week, at week 520. This suggests that increasing the budget for information technology will have a positive effect on the corporate growth and revenues.

Figure 62 Control Panel With Budget Increase



There are several other sliders on the Control Panel that should be discussed in this section. The effect of IT on corporate performance and growth is based on the expert opinion of the CIO. However, others might feel that he has overestimated or underestimated this effect. For integration modeling reasons that were covered earlier in this chapter, the effect of delivery delay has no impact on the performance of the system. Processor power has little effect because the variance between desired and actual is relatively small, and the growth of desired processor power is slower than the growth of desired data storage. For these reasons, the following analysis will simply examine the effect of data storage on the weekly revenues of the firm. Figure 63 displays the effect of changing the strength of the data storage effect on weekly revenues. The figure illustrates that if the effect is weakened, weekly revenues are higher for the entire run of the simulation.

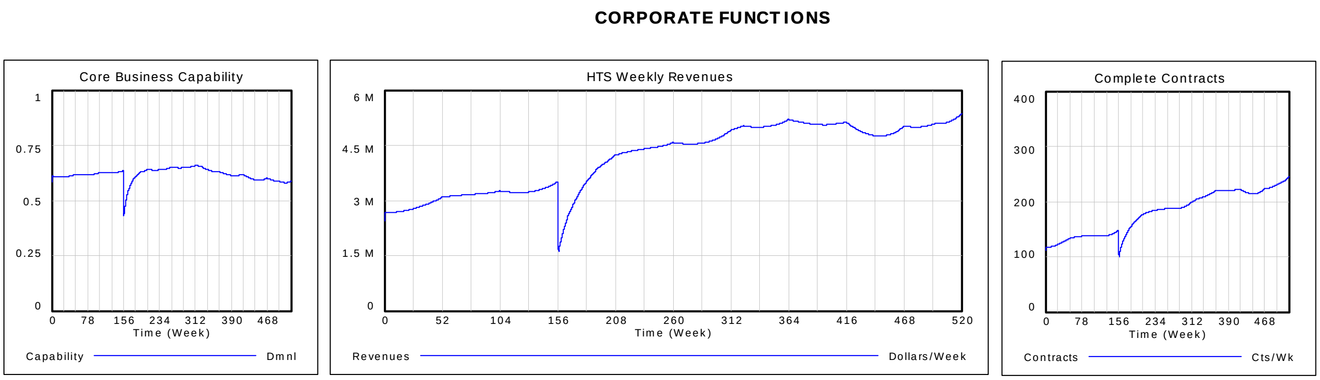
Figure 63 Effect of Data Storage On Weekly Revenues



If the effect is strengthened, weekly revenues are considerably lower. There are sliders built into the model Control Panel that enable the client to vary these effects on a real-time basis.

There is one final test that should be documented, and this is the test of the effect of a disaster on the system. Recall that there is a slider on the Control Panel called Trigger, and that slider is used to initiate a total failure of the information technology system and the subsequent recovery. The model has been simulated with a disaster triggered at week 156. A review of the Control Panel graphs shows the dramatic effect this has on performance across the board. Figure 64 depicts the effect on the three corporate functions on the Control Panel.

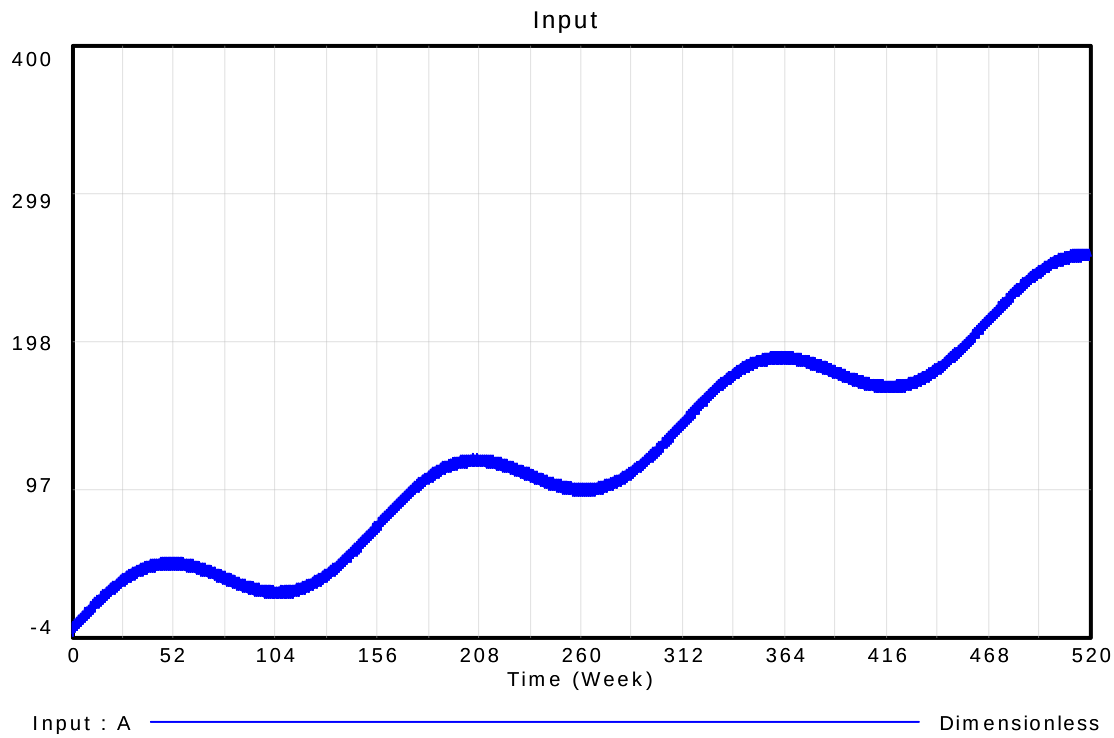
Figure 64 Corporate Functions In The Case Of A Disaster



It is obvious from the above figure that weekly revenues take a huge fall with full recovery taking nearly a year to complete. Reviewing Complete Contracts, it appears that contracts recover back to a level greater than before the disaster and then, after a period, they return to the lower normal level. This is consistent with the structure of the model; although a disaster is simulated, it does not immediately affect incoming proposals, so the stock of contracts that are no longer being completed continues to rise. Once the system has recovered from the disaster, this additional stock of contracts must be reduced until returning to the original rate of growth.

The input to this system has been generated by the Test Input Generator which was developed by John Sterman. The input that was used was developed with the client's assistance and was a ramp with a growth rate of approximately 10% per year. Superimposed on top of this ramp was a sine wave with an amplitude of 25 and a period of three years. Superimposed on top of this was a noise factor with a standard deviation of four. The graph of the input appears in Figure 65. The model is designed to allow the modeler and client to model different inputs as desired. Various combinations of growth rates and sine waves were tested as part of the development of the model.

Figure 65 Input



POLICY DESIGN AND EVALUATION

George Box is attributed with originating the statement, “all models are wrong, but some are useful.” Regardless of who first said this, it succinctly summarizes the problem with models. The model created for HTS is wrong, but it has proven to be useful. The model was developed through a close collaboration between the researcher and the client, there were many iterations of the model developed and at each step of the process the client gained confidence in the model, and understanding of the interactions. Early versions of the model were printed on letter sized paper, 8.5” x 11”. As the model grew in complexity and size the model was printed on legal paper, 8.5” x 14” in size. One day, the model was simply too large to force on the legal sheet, it was printed out full size on multiple sheets, which were then taped together to create one large printout. When the CIO of HTS saw this, he made available the plotter which was used thereafter to print out the model. Regular meetings were held in which the model was studied to ensure that the client accepted the model structure. As the simulation became operative, these meetings began to include a review and criticism of the various assumptions and the results of the tests. This criticism made the model more useful and made the client more confident in the model. Eventually, the client and the researcher accepted that it was time to declare the model complete. At this time, I scheduled a meeting with the CEO of the firm to brief him on the problem I was studying, the modeling effort, the model, and the results.

SCENARIOS

Models can take many different forms, from simple diagrams that express relationships, to complicated simulation models. System dynamics models can take both forms. A simple causal loop diagram can be used to communicate the relationships between variables that may represent a range of concepts from simple to complex. Many of these simple diagrams stand on their own and are never developed into simulation models. There are consultants who use system dynamics in their practice, yet never take the models beyond this phase. These simple diagrams can be useful in communicating, and they are certainly easier to construct than a full-scale simulation model. The value of simulating models is the ability to explore policies in a virtual world and see what happens if changes are made to individual variables. Conceptual models enable communication, but simulation models enable us to study policy changes. There are times when the complex system of feedbacks and interactions are not intuitively understood by the client or owners of the system being modeled. It is these situations, in which the mental models of the decision makers are misaligned with the structure of the enterprise, that benefit most from simulation.

The model at HTS has been developed into a simulation model, which permits exploration of the effects of various policy changes to understand what possible outcomes might occur as a result of these policy changes. There are two policies that have risen to a level of concern for the client. The first policy is the policy of expanding the depth and breadth of services required from information technology without concurrently expanding the budget to acquire and support the new information technology. The model has shown the impact that information technology can have on the performance of the firm as a whole. The effect of an IT disaster on the firm would seem to be relatively simple to understand and accept. However the ownership of the firm has been unwilling to invest in disaster recovery or business continuity for a number of reasons. First, they have a fairly high risk tolerance, at least in this area. They seem to think that since they have not yet experienced a disaster, there is little reason to expect one now. Additionally, the ownership of the firm has only just begun to understand that IT is a production function of the firm and that if IT fails, many people working at the firm will no longer be able to do their jobs. Finally, investing in Disaster Recovery and Business Continuity services can be expensive. For a privately held firm like HTS, this expense can be seen as a simply a reduction of the owners' profit.

The effect on the performance of the firm of data storage, processor power, and the time required to close service tickets are even more difficult to conceptualize. These important feedback loops did not become clear until later iterations of the model were developed. It was only as the model was developed into its final form did these loops become obvious. These loops clarified the effect of budget changes on the performance of the firm, and not only on the performance of the IT department. Increasing the per capita allocation has a positive effect on the performance of the firm. This was covered in the section on sensitivity analysis. Increasing the annual IT budget has an impact on the number of people in the IT department.

It was previously noted that there is a problem in the model because of the Vensim integration limitations that restrict the impact of time constants in my model. Therefore, increasing the annual IT budget does not have the anticipated impact on the performance of the firm. Yet despite this apparent failure, fruitful discussion regarding this policy change is still possible because of the model. Since the loops for processor power, operational systems, and data storage have such a clear impact of the budget performance, it didn't require much effort to understand the impact of increasing the IT staff budget. The discussion simply required that the client accept that the loop for delivery delay had the same structure as the other loops and understand why this loop was not behaving similarly. The problem with the model did not negatively impact the discussion and might have actually improved the client's confidence in the model. In order to accept the problem, the client had to be briefed in great detail on how the loops worked and why the delivery delay section of the model was not working.

A simulation model allows an exploration of the effect of policy changes in the model. In this case, the simulation model forced an examination of the effect of this policy change in a discussion, and not through a report from the modeling software.

CEO MEETING

The CIO of HTS systems requested that the research be presented to the CEO of the firm. The meeting with the CEO of HTS scheduled for October 31, 2006. The CEO was familiar with the system dynamics principles and had previously been shown some small diagrams, although none that were simulation models. In addition, he had observed the maturation of the model as it grew from single sheets of letter paper left on the CIO's conference table, to several full-scale drawings that were taped to the wall of the CIO's office. The model was presented by first discussing the purpose of the research and the problem that was being studied. The second step of the presentation was a detailed presentation of the model and the purpose of each of the subsystems in the model. This discussion was done with a large scale drawing of the model printout that was pinned to the wall of the conference room. After the model was described, the meeting moved to a live presentation of the model, primarily driven by the Control Panel. Once the client was comfortable with the structure of the model, the Control Panel became a very effective tool to communicate and understand the impact of policy changes. The CEO was able to see the interactions of the various systems and to see the impact of changing variable values on system performance.

The presentation took about 40 minutes, and when it concluded, the CEO asked a few questions. We discussed the limitation of the model, especially as it related to the problem with the integration error and the IT Staff subsystem. The value of the model was clear. He didn't hesitate to question some of the assumptions. Most importantly, he saw the value of the model, not in it being a great predictor of the future, but in it being a tool that could stimulate thinking about the problem in different ways.

CHAPTER 7: CONCLUSION

INITIAL RESEARCH

This research initially arose from a phone call from a colleague at work. He called and asked, “Why haven’t you responded to the email I sent you an hour ago?” It was this initial phone call that generated some observations and questions.

I had observed that information technology isn’t implemented simply because an organization has money to burn, but rather that organizations initiate new technologies, or changes to existing technologies, or both, because they anticipate performance improvement in some dimension. I further observed that organizations frequently don’t get the improvement that they expect, sometimes recognize no measurable improvement at all, and sometimes get entirely unintended effects.

The call from my colleague started me thinking about the unintended consequences of information technology. When companies implemented email, they enabled people to communicate more quickly. Did they plan for this implementation to create an environment where they expect people to respond more quickly? Should they have reasonably foreseen that users would expect real-time or near real-time response to a message? Information technology has been, and will continue to be, a powerful enabler of communication; it is likely that implementing new information technology will continue to create unintended consequences.

Information technology does not exist in a vacuum. IT is a part of the organization: it plays either a supporting role, or as seen at HTS, it can be a factor in production. For most organizations, however, information technology is simply a tool to enable the organization to perform better, faster, cheaper. Many people who work in information technology lose sight of this fact. Implementing information technology has become the goal by itself, rather than implementing information technology as a resource to improve some dimension of the organization’s performance.

In preparing for this research, studying information technology became a focus. The effect of information technology doesn’t exist outside of the context of the organization. Information technology is difficult to isolate from the many other factors that constitute the structure of the organization. These factors make isolating the impact of information technology difficult to accomplish, and therefore make it difficult to study. The beer distribution game was selected as an experimental platform, because it could be used to isolate the effect of information technology in a well known virtual world.

THE BEER DISTRIBUTION GAME

The results of the beer distribution game experiment were surprising, since they were not at all what had been expected. In retrospect, the unexpected results proved much more valuable to the research process than the expected results ever could have been. If implementing information technology in the beer distribution game had resulted in the expected performance improvement, it would have done little to advance an understanding of the problem. Because it did not show the expected performance improvement, it was necessary to develop some understanding of why the expected improvement had not been detected. This led to a theory that one possible explanation of this failure was the lack of alignment between the mental models of the subjects and the new structure of the organization (beer distribution game). A further consideration of this explanation required a re-examination of the literature on alignment. Revisiting this literature resulted in a conclusion that there were both sufficient support to build on this theory and sufficient room to move forward with the research.

The beer distribution game had provided a theoretical research platform. This platform enabled a study of the effect of implementing information technology and provided the necessary research breakthrough, leading to a theory that explained the phenomenon. The theory is that the misalignment between the mental models of the users of IT and the structure of the organization was a cause of the unintended results. In the beer distribution game, although IT was implemented, nothing was done to train the users or to change their mental models. The structure of the game had been changed, but the mental models of the subjects were still aligned with the previous structure. The performance of the players with IT did not statistically improve over the players without IT. One explanation for this is that the players did not align their mental models, and therefore their behaviors, to the new structure with IT; specifically they did not change their ordering decisions to align with the new structure.

The beer distribution game research is limited by a number of factors. In Sterman's (Sterman, 1989) research he discarded the results of trials that had not calculated their inventory position correctly. None of my trials calculated all of the positions correctly. Also, the data set for my beer distribution game experiment was limited. There were only a total of 19 trials, and only 18 trials with valid data. Of those trials, 10 implemented information technology, and 8 did not. The Mann-Whitney U test was used to compare the results of the groups, largely because it was the test used by others in previous beer distribution game experiments (R. Croson, Donohue, K., Katok, E., Sterman, J., 2005) where groups were compared. The Mann-Whitney U test is considered unreliable for samples of 7 and under, the larger the sample the more reliable the results are expected to be. My sample was above the minimum threshold, but was still considered a very small sample. The results of the tests might be different if there had been additional trials. Additionally, several trials were done at distant campus locations. This made control of the game play very difficult and may have influenced the outcome of the trials. Finally, a number of the trial subjects were not native English speakers. This clearly had an impact on their understanding of the instructions and of the game play and may have had an impact on the outcome of the trials as well.

THE CASE STUDY

I began working with HTS on the case study prior to completing the beer distribution game experiments. I had identified the initial problems and concerns of the CIO and had begun the data collection process. The research really began to gel after completion of the experiments with the beer distribution game and development of the theory of misalignment. Initially, the plan was simply to use two different research techniques to develop insight into the problem, but it quickly became clear that the misalignment theory that was developed to explain the results of the beer distribution game fit the problems at HTS equally well. The mental models of the ownership of the firm were not aligned with the structure of the firm.

An early model of the variance between the allocation of expenses to the various business units, shown here in Figure 10 on page 162 and the allocation of the support burden, shown in Figure 11 on page 162 illuminated this misalignment. It became clear that the mental models that were responsible for the allocation of these costs had not been aligned with the new organizational structure. Furthermore, as the firm moves from measuring the performance of business units on a total revenues basis, to a net revenues basis, I believe that this misalignment is going to create additional problems.

GENERALIZATIONS

The case study research at HTS has been successful in many ways. First, it helped the CIO of HTS explain some of the problems that were keeping him awake at night. Presenting the model to the CEO may result in an opportunity to align the mental models of some of the ownership, which might in fact result in reducing some of the problems being experienced in the organization. It certainly had the effect of providing data that supported the research on misalignment. The question is whether the model developed at HTS translates into something useable for other organizations.

My initial intention was not to develop a model that can be approximated to fit other organizations, but rather one that can be a useful approach for managers to assess their own organizations and to develop strategies for the future implementation of information technology. Although the model will not transfer directly to other firms, I think the research, combined with the model provides an approach that can be useful in helping others understand the challenges they face when implementing IT. I have had the opportunity over the past several weeks to share the model with others in the IT industry, and they have universally demonstrated an understanding of the underlying structure, and an acceptance of the important feedback loops from IT to the performance of the organization. The feedback loops at HTS are specific to HTS, and other firms would have different loops. Furthermore, other firms would probably feel that the nonlinear relationships specified in this model do not accurately depict the relationships that govern operations in their organization. This is an acceptable position.

The model is best used as a tool to understand the dynamic complexity of the issue of successfully implementing information technology. The primary feedback loops from the information technology subsystems – Data Storage, Processor Power, and Delivery Delay – were not apparent until late in the development of the model. These feedback loops were not initially evident because they are the result of the number of variables and the dynamic complexity associated with their interactions. In fact the insight that led to this understanding was the result of a casual discussion about the model.

The effect from these loops on HTS may be different from the effect of the same loops on another firm. This difference is due to the complexity of the interaction IT has on the organization.

PROBLEMS WITH THE RESEARCH

The Beer Distribution Game Research

There are some problems with the research using the beer distribution game. The first problem is with the limited number of trials that were used in conducting the research. A second problem is that none of the players had a perfect record in keeping their scores. The research would be more valuable if I had been able to capture a greater number of trials. Additionally the research could be flawed simply because the subjects were unable to accurately record their inventory position and orders placed each week. All of these problems could be corrected by extending the research until a larger sample of trials with accurate record keeping could be obtained. The results of the experimental research might be different with these problems corrected.

The Case Study Research

The CIO of HTS was extraordinary in his help with this research. He was patient in explaining the complexity of the organization. He provided me with a cubicle on site where I spent much of the workweek for the past year. He gave me access to the budget and other organizational documents for the information technology department. He gave me access to his staff and directed them to provide me support and assistance. He reviewed the model at every step, offered criticism, and provided support. He asked questions and directed me to data sources that were useful in trying to complete the model. I estimate that he spent a minimum of 80 to 100 hours working directly with me, either in meetings or responding to my inquiries for information.

One of the challenges with doing the research at HTS was that they are not publicly traded. Some of the data that would have been useful in understanding the performance of the firm was not readily available, if it was available at all. Financial data was especially difficult to obtain, as was specific performance data. This meant that I had to estimate some of the information based on other data that was available and on the CIO's experience.

Research Bias

Researcher bias is a concern when using a system dynamics approach, or for that matter when invoking any modeling approach. In any qualitative research process, the researcher is going to be part of the process, and therefore will contribute some bias into the process; this is unavoidable. This may be especially unavoidable within a system dynamics approach, for several reasons. First, the system dynamics modeling process is designed to facilitate learning so as to understand key interactions, feedback loops, delays, nonlinearities and their impact on system performance. System dynamics is used to model the perceptions and mental models of the model client. Capturing these perceptions and mental models is certain to introduce the bias of both the modeler and the client.

The purpose of a system dynamics model is to learn about a specific problem, developing a deeper understanding of the problem of interest. An effective system dynamics model does not attempt to model a system; rather, it focuses on a specific problem that is of interest to the client. Defining the purpose of the model in the problem definition stage clearly begins with some bias. Developing the initial theories that explain the problem is one of the initial steps of the modeling process, and is another opportunity for the researcher and the client to introduce their collective bias into the process,

There are a number of approaches that can be taken to mitigate the effect of this bias. The first approach is to ensure that interactions between variables as well as key feedback structures within the model are consistent with the literature. It is important that the literature support the dynamic hypothesis of the modeling process. As much as possible I used relationships and interactions that were already substantiated within the literature. The primary subsystem in the model is based upon a standard capacitated demand model which is well documented and is accepted within the literature (Sterman, 2000). Key premises about the effect of introducing information technology were also taken into account.

A second approach to mitigate the effect of bias is to ensure that the behaviors associated with each loop are reasonable. When the behavior of a loop is inconsistent with reality, for instance when a physical stock goes negative, it is incumbent upon the researcher to adjust the model to ensure reasonable behavior. The modeling process is iterative, and frequently adjustments must be made to ensure that the model accurately represents the behavior of the system. Sharing the model with other experienced modelers who are not involved in the modeling process can be a useful means of validating behavior. I faithfully followed this process and made many adjustments to the model in order to ensure accuracy in the model behaviors. One of the problems I describe at length in the dissertation is a problem with the model which was never corrected. This problem had to do with an oscillating behavior which was not consistent with reality. This behavior was identified when I presented an earlier working version of the model to Dr. Rahmandad for his comments.

Finally, the system dynamics modeling process typically is not designed to predict future outcomes, but is rather a process designed to understand complex interactions of variables in a system with many spatial and temporal interactions and feedback loops. Simulation is an important key to improving the learning process. Without simulation, the system dynamics process is simply a consultative effort to capture the clients perceptions on the various interactions of variables in the system. These causal relationships are sharpened by moving from a simple causal loop diagram or stock and flow diagram to a functioning simulation model. By quantifying both the values of the variables and the relationships between variables, the modeler and the client are forced to carefully examine their preconceived notions. Simulation forces the modeler to eliminate bias from the model simply because the values and relationships must be examined carefully in order to provide quantitative values for the simulation.

FUTURE RESEARCH

Beer Distribution Game

There are a number of avenues of future research that could be pursued based on this research. The beer distribution game is always a fruitful research platform. As discussed previously, it would be useful to obtain a larger data sample for the comparisons between teams with IT and teams without IT. It is difficult to obtain this data because of the amount of time required to play the game. Essentially, it requires an entire class period to complete the game. Because of the requirement to have two comparable periods of play, it is important to have adequate time to complete all 40 weeks.

There are a number of electronic versions of the beer distribution game available. Perhaps modifying one of these games to implement IT would be a useful endeavor. This might mitigate the time issue and also the problem with calculating inventory positions.

One other direction for future research would be to study the effect on performance when specific steps are taken to align the mental models of the participants with the implementation of information technology. The subjects could be given additional information explaining that the implementation of IT was designed to improve their performance, and suggesting that they now had considerably more information at their disposal in order to manage the ordering process more effectively. Comparing the results from these teams with both my control groups and my test groups would be useful.

There are two very real drawbacks to playing the beer distribution game on the playing board. They include the time it takes to complete the game, and the difficulty subjects have in calculating their inventory positions quickly and correctly. Both of these problems are addressed by using an electronic version of the game. Playing the game electronically would be a more optimal solution for the studying the effect of misalignment, but as mentioned before, this would require some modification to current games in order to replicate the implementation of IT.

Another research avenue that might be useful is playing the game for a different number of weeks. I told the players that they were playing for a full year, but I stopped the game at 40 weeks. I terminated the game early in order to get two equal periods to compare, the first 20 weeks and the second 20 weeks, and to avoid the effect of players trying to manipulate their inventories when the end of the game is near. Since the first 4 weeks are played under the direction of the facilitator, it might be useful to compare the results of the weeks 4 – 20 against weeks 21 – 36. This should reduce the game play by several minutes, and might actually provide better data, since the weeks where the data is identical would be eliminated from the research. It might also be useful to play the game for an additional 10 – 12 weeks to see if subjects align their behavior with structure after a few weeks of learning.

Case Study

There are a number of opportunities to expand and improve the case study research as well. Probably the first area would be to improve the model and correct the problems with the HTS IT Staff subsystem. The model would have to be run using a time unit of days instead of weeks in order to capture the dynamics of that section. If the primary time unit of the model were days instead of weeks, the smallest time constant that could be used would be 11 minutes. 11 minutes is still longer than my estimated time constant of 10 minutes, but is much closer and is likely to correct the granularity problem that I experienced. Changing the model to days would mean reviewing every single variable and reconsidering it in the context of a daily unit instead of a weekly unit. Weeks were chosen because they were the largest unit that could effectively capture the overtime issue.

The model simulation was run for 10 years to see the long term effect on the organization. However, information technology changes so rapidly that using a ten year time horizon may not be necessary. At the integration level required, the model runs 128 time steps per time unit. If the model was run in days, a 10 year run would require 128 time steps per day, over 10 years that would mean 467,200 time steps for the 10 year period. It might be appropriate to use a model time frame of 3 -5 years.

One change to the model was considered to enable more effective policy analysis. It is clear from the model performance that the gap between desired data storage and actual data storage creates problems for the performance of the firm. It would be useful to test a change to the model in which the policy of adding additional data storage could be tested to see if it might mitigate the performance effects of the desired data storage ratio. Currently it is not possible to simulate this policy change in the model. By adding a variable that increases the Data Storage Gap, the difference between *Desired Data Storage* and *Data Storage,* the model could be designed to acquire additional data storage proactively.

One of the difficulties at HTS was measuring performance at a privately held firm. It would be a useful exercise to take this model to another firm and see if it can be adapted to a different environment. This would be useful in validating the structure of the model, and it would also be useful in dealing with the real challenges of defining and capturing performance measures in the model.

CONTRIBUTION

This work contributes to the literature in several ways. The beer distribution game has been used as a research platform many times before. Various studies have been completed that have used the beer distribution game to understand behavior (Croson, 2003; R. Croson, Donohue, K., Katok, E., Sterman, J., 2005; Sterman, 1989a). Studies have been done that used the beer distribution game to understand how structure impacts a locally rational decision (H. Lee, Padmanabhan, V., Whang, S., 1997b). This study is the first where the beer distribution game has been used to study the implementation of information technology. It was from this foundational work that I identified the theory of misalignment that extended the theory on why IT implementations do not always get the anticipated results.

The case study extends the theory developed from the beer distribution game into an organizational setting. The literature in information technology implementation is sparse, and none was found that used system dynamics as a modeling tool.

RESEARCH QUESTION

The focus of the research was to understand why organizations encounter unanticipated results when they implement IT. When I initially proposed the beer distribution game as a research platform, I expected that implementing IT would result in improvements in every dimension. Because I did not find the expected improvements, I was forced to focus on why these improvements were not manifested. The resulting theory, that the misalignment of subjects' mental models is one cause of unintended consequences, is supported by the case study research. Additional research is required to understand how to properly align users' mental models in order to eliminate this causal factor.

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APPENDICES