Theory, Design and Evaluation of a Learning Object Game Immersed in Complex Systems

"LOGICS"

By

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ABSTRACT

Simple economic systems are capable of generating highly nonlinear dynamic phenomena. The counter intuitive nature of these systems makes them difficult to understand and manage, thus resulting in suboptimal economic performance. Effective information system methods for improving economic performance are often underutilized. This dissertation uses design science research to examine the ability of a game to teach the value of information systems in dealing with problematic complex system behavior. A general design cycle framework uses participatory agent-based modeling and simulation (PABMS) to examine a novel information system design theory (ISDT). The purpose of this design theory is to create learning object games immersed in complex systems (LOGICS).

LOGICS initial complex system problem is the Sterman Beer Game (SBG), a classic four-tier supply chain management (SCM) problem. A multi-disciplinary approach draws from five contributing kernel theories in cybernetics, complex business dynamics, simulation, learning objects and online gaming. The pedagogical purpose of the initial SBG was to demonstrate the need for systems thinking in understanding the behavior of complex systems. LOGICS pedagogical purpose is to motivate the use of information systems to improve the economic performance of the SBG.

The SBG problem is well grounded in SCM research. Related ABMS research found the SBG problem to be highly resistant to reinforced learning.

A series of rapid prototype learning object game designs were tested by students from a variety of academic levels and majors. LOGICS prototypes were evaluated based on their ability to quickly achieve the economic learning objective of optimal system performance. Theatrical human computer interface (HCI) techniques were used to manipulate player actions. Five designs were required to obtain the learning objective of optimal economic performance. Every player of the successful design quickly abandoned intuition in favor of investing in the increased rationality provided by an information system. Non-parametric testing was used to analyze LOGICS unique statistical requirements.

The LOGICS ISDT provides a scalable platform for the creation of an online game immersed in a broad range of realistic complex system problems. The research has implications for increasing the understanding and adoption of modern complex system theories.

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1. Introduction

Jay W. Forrester was an early advocate for the use of computer models for social systems. He testified before the U.S. Congress that social systems are far more complex and harder to understand than technological systems (Forrester,1971). He argued that all decisions, laws and executive actions are based on models. The problem is that all too often the models are instinctive, fuzzy, incomplete and imprecise mental models. His first insight came from working with corporations. Corporations have several common characteristics. They know what they are trying to accomplish, that crisis forces action, they operate under power sensitive structures and traditions and they are primarily focused on dealing with external threats. He felt the computer modeling and simulation would lead to far better social systems, laws and programs.

In his Noble Prize winning work, Daniel Kahneman explored the psychology of intuitive beliefs, choices and bounded rationality. He shared Simon's concerns about strategic simplifications that reduce the perceived complexities of judgment (Simon,1955). He wanted a map of bounded rationality that compared people's actual beliefs and choices to the optimal beliefs and choices of rational agent models. The concept of the rational agent became the focal point for Kahneman's research. He concluded that most judgments and choices are based on intuition, not statistics. Humans substitute effortless intuition, called heuristics, for actual probabilities. Reasoning, on the other hand, requires effort. People are often content to trust a plausible judgment that quickly comes to mind rather than take the time to develop statistical skill or calculate actual risks. He discovered that out-of-pocket costs are valued more than opportunity costs. This lack of symmetry leads to loss aversion, which generates a bias towards the status quo. This bias manifests itself in "anchor and adjust" type behavior. These discoveries led him to conclude that intuition improvement required prolonged and extensive effort (Kahneman, 2003; Tversky & Kahneman, 1974).

1.1 Sterman Beer Game (SBG)

Deterministic Chaos can arise in extremely simple economic structures when heuristics are applied by people (Mosekilde, Larsen, & Sterman, 1991). The SBG is a noncomputerized board game designed to demonstrate the dynamic complexity generated when a hierarchy of decentralized inventories are organized in cascade fashion across a simple four-tier single product supply chain. Often players generated unstable production flows with large oscillations and various forms of highly nonlinear dynamic phenomena.

Sterman collected research data from the SBG to create a four-parameter mathematical model capable of reproducing the heuristics people used to generate various solutions (Mosekilde et al., 1991). As anticipated, the model confirmed the anchor and adjust heuristics described in various research publications (Davis, Hoch, & Ragsdale, 1986; Hogarth, 1987).

Players anchor their rationale to some imaginary expected demand and then adjust, based on the discrepancy between actual stocks versus some imaginary desired stocks. Further adjustments were made to resolve the discrepancy between actual stocks on hand and desired product in the supply line. These changes at the margin can produce a completely different system behavior (Mosekilde et al., 1991, p. 199). This discovery revisits Simon's concerns about simplifications disguising the complexity of judgment.

The SBG is widely used in supply chain research and establishes a basis for comparison of traditional modeling approaches with agent-based modeling and simulation (Sterman, 1992). SBG is a simplified supply chain model well-grounded in supply chain thinking and modeling (North & Macal, 2007).

1.2 Research Motivation

The original SBG non-computerized board game used a simple pedagogy to expose groups of players to a single business cycle of a simple system. A single exposure provides a limited learning experience. The stated pedagogical purpose of the game was to demonstrate the need for systems thinking when it comes to understanding the behavior of complex systems (North & Macal, 2007). There is scant published evidence that any instructional design methodology was used in the design of the board game.

Owen Densmore (Densmore, 2004) used traditional deterministic agent-based modeling and simulation (ABMS) techniques to create a PC based demonstration of the SBG. A simple set of buttons, faders and switches allowed players to interactively explore the parametric space of the SBG model. Traces of player's performance were not captured for future analysis. There is no published evidence that any instructional design methodology was used in the creation of the simulation.

Valluri, North, Macal and other researchers agree that ABMS multi-stage supply chains are highly resistant to reinforced learning techniques. They defined reinforced learning as the ability to achieve "online learning" with no prior knowledge. This involves trial and error search processes where positive outcomes are reinforced and negative outcomes are deemphasized. The ABMS reinforced learning techniques often require several thousand interactions to demonstrate progress towards the learning objective (Valluri, North, & Macal, 2009).

The research motivation for this dissertation is to use a design research approach to create an online game that quickly moves players from heuristic solutions to rational solutions, in pursuit of the learning objective of optimal economic game performance.

1.3 Research Question

The general research question is:

"Can an online game player learn to abandon intuitive reactions to local events in favor of investing in system solutions provided by information technology?"

1.4 Research Objectives

The primary objective is to create an Information System Design Theory (ISDT) consisting of a testable design process and a testable design product (Walls, Widmeyer, & El Sawy, 1992). The testable design process consists of an integrated development environment (IDE) for designing, building and evaluating of learning object games immersed in complex systems “LOGICS.” The testable design product is an online game artifact.

A secondary objective is to make contributions to the complementing kernel theories of cybernetics, complex business dynamics, simulation, learning objects and online games.

1.5 Outline

Chapter 1 introduces the project, the problem and the research question. Chapter 2 is a literature survey of the concepts abducted from complementing research kernel publications. Chapter 3 discusses the Information System Design Theory (ISDT) framework used in this research. Chapter 4 deals with methodology. It explores each of the individual design elements and how they conform to the meta-requirements and link to the hypotheses. Chapter 5 deals with the results, hardware architecture, artifacts, use of feedback and agent details. Chapter 6 provides the design analysis and evaluation details. Chapter 7 discusses the conclusion derived from the analysis of the results. Chapter 8 discusses the potential implications of the research including implications for practice and academic publication potential.

2. Review of Contributing Theory

The ISDT framework developed in this design research project uses a collection of research kernel theories to develop a learning object environment. The specific complex system addressed is the well-known SBG supply chain management (SCM) problem. There is a wide variety of published research in complementing research disciplines that document several decades of struggle with the control issues of a defiant complex system problem. The overview is illustrated in the Figure 1.

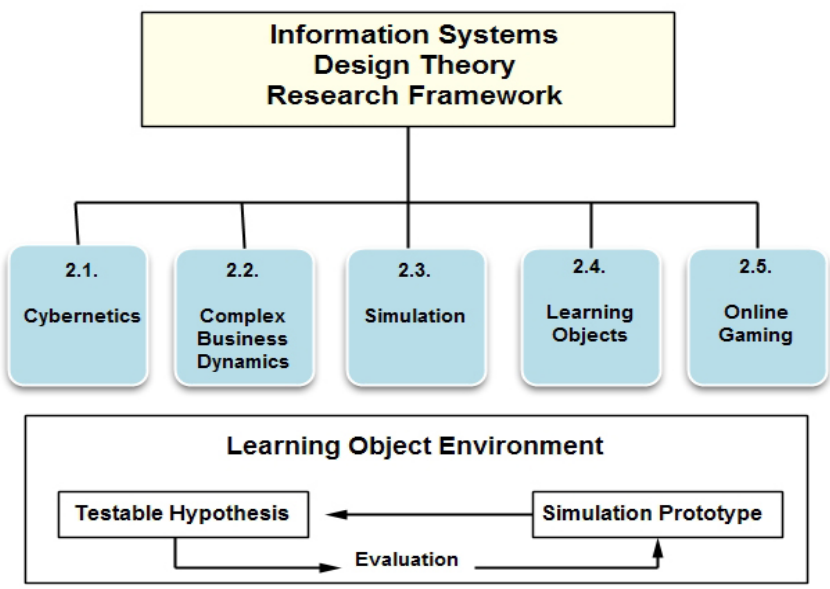

Figure 1. Information Systems Design Theory Research Framework

2.1 Cybernetics

Over eighty years ago, an MIT mathematician named Norbert Wiener used a multi-paradigm design research approach to examine control and communication in human and mechanical systems. His research transformed control engineering into communication engineering and created the modern definition of feedback. His multi paradigm exploration into purpose-seeking systems created new perspectives that have increased in influence for almost a century. The depth and breadth of his work inspired some to call him the father of the information Age and the creator of the first American Scientific revolution (Conway & Siegelman, 2006).

Before World War II, Wiener built and demonstrated an optical computer prototype that provided MIT with the five essential components for a digital computer: 1) a central calculating unit, 2) electronic switching devices, 3) a binary number system, 4) internal storage, 5) a sequence of operations with no human intervention. During World War II MIT assigned Weiner the problem of improving anti-aircraft artillery fire. The speed of German aircraft exceeded the performance capabilities of human controlled artillery. Weiner felt that a computer could use his equations to convert radar data into anti-aircraft firing solutions. This would usurp the need for human observation and calculation. The aiming problem required a human computer interface.

His solution used information output messages from one stage of a device as input information and controlling messages for another stage of the device. He used circular communication paths between internal devices to resolve the discrepancy between actual and desired positions. He discovered that humans introduced information entropy when they were introduced into feedback loops. The aiming problem revealed a paradoxical challenge: the more accurate the firing solution the more sensitive it was to error. This work produced the modern definition of messaging and feedback by merging control computer and communication engineering. Weiner had found a way for engineers to design and create artifacts that could process human intent or purpose and obtain a solution without human interference. He named this new teleological science Cybernetics.

Weiner expanded his work to simulate brain wave enzyme connections, information organization, information entropy and thermodynamic systems in an attempt to develop human cybernetic artifacts (Weiner, 1961). The study of Cybernetics advanced the study of systems that seem to be capable of self-organizing in near chaotic environments.

MIT neurophysiologist Warren McCulloch used his pioneering work in cognitive science to explore human cybernetic barriers. He called his form of design research experimental epistemology. His first work focused on message distortion created by the human sense of vision. The human eye sends highly organized and interpreted messages to the brain (Lettvin, Maturana, McCulloch, & Pitts, 1959). His pioneering work revealed that human messaging is entropically coupled to the physical world. He extended this work to the study of messaging entropy introduced by brain pattern matching. This resulted in a logical model of the nature of human mental activity, and in particular the computational behavior of the neuron (McCulloch & Pitts, 1943). Human messaging information is always distorted due to the entropy-generating nature of human beings. People are entropy-generating entities that have messaging, rationality and trust issues (McCulloch, 1965).

Psychiatrist W. Ross Ashby developed cybernetic insight into the stability and adaption of the brain. He used general systems theory and mathematics to define cybernetics as a transformational theory seeking to resolve the difference between two system states. He felt that cybernetics could bring into exact alignment various sets of possibilities. He was able to correlate the possibility states of servo mechanical systems and cerebral reflex systems.

He established the justification for modeling human behavior using servo mechanical models (Ashby, 1952).

2.2 Complex Business Dynamics

Jay W. Forrester (1961, p. 8) wrote “Management education and practice are, I believe, on the verge of a major breakthrough in understanding how industrial company success depends on the interactions between the flows of information, orders, materials, money, personnel and capital equipment.” Forrester was an MIT engineer with a background in servo mechanical systems and digital computers. He is credited with pioneering the field of industrial dynamics (ID). ID was primarily a byproduct of military systems research used to demonstrate that carefully selected formal rules could be automated into operational policies that exceed those made by human judgment. ID was constructed on four foundations: information feedback control theory, decision making processes, experimental approach to system analysis and digital computers.

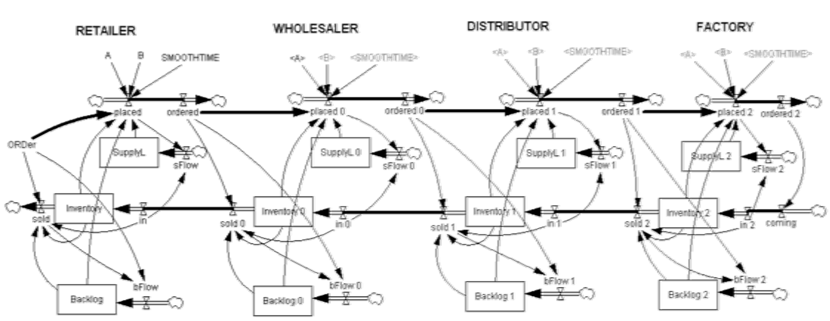

Figure 2. Servo Mechanical Model of Four Tier Supply Chain

Forrester used mechanical loop diagram techniques to generate differential equation models of production distribution systems. Figure 2 demonstrates the mechanical loop diagram for a four tier supply chain (A. T. Kearney, 2000). MIT's mainframe computers were used to compare the negative feedback mechanisms of servo mechanical systems and complex social systems. Both systems were found to use similar techniques to resolve the discrepancies between actual and desired output states. The insight influenced the complete transformation of modern military operations. But, Forrester's approach failed to resonate with industrial management.

Industry, academics and economic governing bodies did not readily accept his servo mechanical modeling of human behavior. They felt his system models were over simplified and idealistic. Forrester's harsh criticism of traditional operations research and management science was ignored during the U.S. post World War II economic boom. In his testimony to for the Subcommittee on Urban Growth of the Committee on Currency, U.S. House of Representatives, on October 7, 1970 Forrester said:

> "The human mind is not adapted to interpreting how social systems behave. Social systems belong to the class called multi-loop nonlinear feedback systems. In the long history of evolution it has not been necessary until very recent historical times for people to understand complex feedback systems. Evolutionary processes have not given us the mental ability to interpret properly the dynamic behavior of those complex systems in which we are now imbedded.

The social sciences, which should be dealing with the great challenges of society, have instead retreated into small corners of research. Various mistaken practices compound our natural mental shortcomings. Computers are often being used for what computers do poorly and the human mind does well. At the same time the human mind is being used for what it does poorly and computers do well. Furthermore, impossible tasks are attempted while achievable and important goals are ignored." (Forrester, 1975, p. 3)

When John D. Sterman became the Jay W. Forrester Professor of Management and Director of MIT's System Dynamics Group he refined Forrester's industrial mechanics approach. He is best known for his work in supply chain management (SCM). He used a non-computerized production-distribution board game to gather data on how people used heuristic techniques to manage the complex dynamics of this simple system. This data was used to create a reductionist model of SCM human behavior (Sterman, 1989). Using only four parameters, he was able to model managerial behavior and the misperceptions of dynamic feedback in a four-tier supply chain. He used a Monte Carlo style simulation to determine the four parameters that described the optimal solution to his simple SCM problem. He determined that, on average, intuitive SCM underperformed the optimal solution by a factor of ten. The SBG is illustrated in Figure 3 (Sterman,1992).

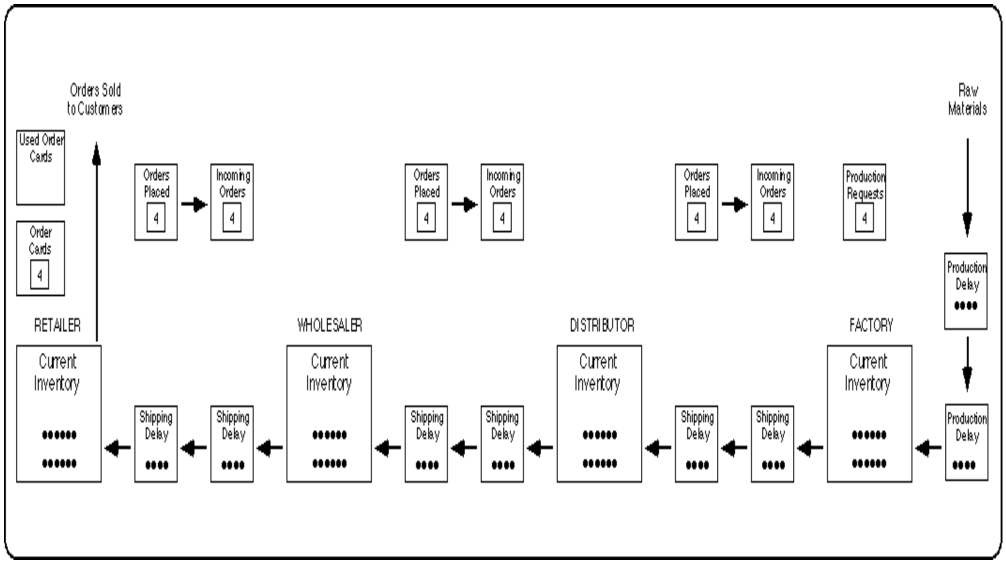

Figure 3. Sterman Board Game

His seminal work (Sterman, 1989) confirmed there were several cognitive barriers to optimal SCM performance. The primary barrier was dependence on common sense “rules of thumb” he labeled heuristics. People substitute heuristics derived from personal experience for rational statistical analysis of the feedback structure of a supply chain. This misalignment between mental models and rational models leads to suboptimal economic performance of the entire supply chain system. The experiment confirmed the existence of the predicted “Bull Whip” effect (Lee, Padmanabhan, & Whang, 1997). Sterman confirmed that demand distortions are amplified as they proceed down the chain from Retailer to Factory. He also confirmed that anchor and adjust heuristics (Tversky & Kahneman, 1974) reduced business model flexibility.

Peter Senge, the Director of Organizational Learning at the MIT Sloan School of Management; published a bestselling book “The Fifth Discipline” (Senge, 1994). This popular book generated a lot interest in complex dynamics. Many organizations used his books teamed with the SBG to increase their awareness of the learning disabilities of organizations (Rao & Babu, 2000).

Senge’s approach, while engaging, lacked the rigor necessary to enable the adoption or implementation of new SCM theories and practices. Immersed in a metaphorical context he called the learning organization, Senge used simple diagrams and linguistics to explain the behavior of complex systems and their state of continuous adaptation and improvement. Spring metaphors were used to illustrate the negative feedback resistance to change. Snowball metaphors illustrated the positive feedback accelerating momentum that tends to reinforce status quo. His intent was to develop a set of simple archetype templates to assist in modeling and understanding counterintuitive business systems.

In his third chapter “Prisoners of the System, or Prisoners of our Own Thinking,” Senge engaged in extensive anecdotal level discussions of Sterman’s “Beer Game.” He was impressed that the game had been played extensively on five continents; among people of all ages, nationalities, cultural origins, and with vastly varied business backgrounds. The lessons Senge cited from the game were: structure influences behavior, human systems structures are subtle and leverage often comes from new ways of thinking (Senge, 1994). Senge was widely published in professional journals and popular books. Some feel his work had no real impact on the management of complex systems for two reasons. First, there was oversimplification of system thinking skills. Second, the role of technology in the solutions was largely ignored (Rao & Babu, 2000).

Colin Camerer advocated the use of design research to explore how limited computational ability forces people to use simplified procedures or "heuristics" resulting in systematic mistakes (biases) in problem solving, judgment and choice. Camerer further speculates that management's irrational overconfidence results in underinvestment in computational flexibility. This lack of flexibility can be fatal in manufacturing and financial planning (Camerer, 1995). It is ironic that this underinvestment in flexibility comes at a time when information systems, high performance computing, object-oriented software and broadband connectivity are becoming more affordable every day.

2.3 Simulation

In the 1950's, Forrester used mainframe computers to examine mathematical models and simulations of production and distribution systems. In the 1970's, mini computers expanded simulation capabilities to research laboratories on a global scale. In the 1980's personal computing simulation software introduced object-oriented and semiotic functional modeling. Operating systems became interactive and graphical user interfaces allowed the extensive use of graphics. Large dynamic system problems were still too complex to be tractable on the desktop. Thus, reductionist methods were used to build simple models that could be simulated using desktop computing. Many practitioners and academics found these models difficult to create and validate.

In the 1990's, a second generation of desktop computer-based simulations emerged. Forrester's system dynamics modeling approach and many other forms of simulation became available to those with limited access to mainframe computers. Discrete event modeling and simulations like the Monte Carlo Method simulation (Metropolis & Ulam, 1948) moved theoretical construct to modeling technique. Combinations of probabilities that were too numerous and complicated for manual calculation were now widely available. Participatory simulation dates back to Aristotle's (Aristotle, 350 B.C.E) ancient Greek dramas. Sterman used this approach in his SBG (Sterman,1989). Optimization simulations began to explore the parameter space introduced by the SBG. Statistical simulations began using regression analysis to explore correlations between and among variables in quality control (Deming, 1982).

Risk analysis simulations examined the direct and indirect loss resulting from inadequate or failed internal process or external events.

Densmore used a PC-based ABMS environment called NetLogo to demonstrate the parametric behavior of the SBG (Sterman, 1989). NetLogo supports a participatory feature called" Hubnet" that allows people to interact with a running simulation. NetLogo has been used to successfully model the Sterman Beer Game (Densmore, 2004). The Graphical User Interface of the object-oriented four-tier supply chain simulation artifact is easy to understand and provides a good starting point for learning object games. Figure 4 illustrates Densmore's ABMS demonstration user interface.

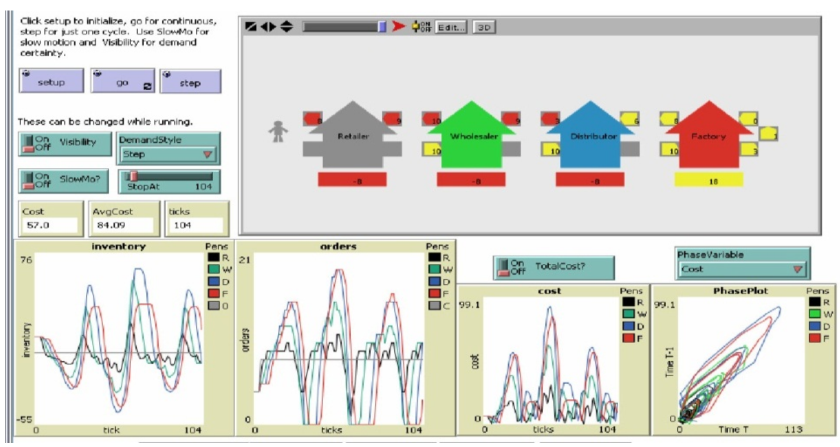

Figure 4. Densmore's NetLogo Demonstration of Sterman's Human Behavior Model

Developing agent-based models is not trivial. The simulation language shell is a syntax variant on a semiotic programming language called LISP. Semiotic programming languages use nontraditional flow-control structures. This approach provides great flexibility for the modeled agents but requires a significant programming effort. There is little formal documentation or support for tools such as NetLogo. Debugging tools are nonexistent or primitive. High startup costs provide a barrier to managers with little coding experience.

Blended model simulation allows many of the assumptions used in classic micro-economic theory to be relaxed (Simon, 1969). Agents are considered to be computational objects and have been used extensively to demonstrate the experimental findings in the emerging research field of behavioral economics. Behavioral economics incorporates experimental findings on psychology and cognition into theories of economic behavior (Smith, 1989). Agents have been used to simulate exponential growth that moves quickly and dramatically on trajectories away from their initial state (Arthur, 1988). The end points of these trajectories are referred to as system attractors (Casti, 1994). There are several advantages to using agent-based modeling. First, it is easy to limit the rationality of the agent. Second, it is easy to extend the rational agent to a heterogeneous population. Third, the model generates an entire dynamic history. This allows agents to be farsighted and operate far from equilibrium (Axtell, 2000).

2.4 Learning Objects

The learning technology standards committee (LTSC) was established in 1996 by the Institute of Electrical Electronics Engineers (IEEE) to develop and promote instructional and technology standards. The LTSC defined a "learning object" to be: "any entity digital or non-digital, which can be used, re-used or referenced during technology supported learning" (LTSC, 2012, p. 1).

Wiley proposed narrowing the definition to a reasonable homogenous set of digital things. He changed the definition to: "any digital resource that can be reused to support learning" (Wiley, 2000a, p. 7). He was concerned that the focus on technology and financial opportunities was overlooking the importance of instructional design. Reigeluth (Reigeluth, 1983) and others preferred an instructional design theory approach that closely follows Simon's prescriptive approach (Simon,1969). They felt that the modular approach favored by the commercial sector had sequencing and granularity issues.

To address these concerns Wiley developed a learning object design and sequencing theory (LODAS). Sequencing was defined as the combining of objects in a way that made instructional sense. He developed a LODAS taxonomy that used eight characteristics to define five learning object categories: fundamental (picture), combined-closed (video), combined-open (web page), generative-presentation (java applet), generative-instructional (game) (Wiley, 2000b).

2.5 Online Games

John Seely Brown stated that a large portion of the emerging workforce is already heavily engaged in this new digital vernacular and already learning and socializing in new digital ways (Brown, 2005). Gaming seems to have bypassed many of the socialization problems experienced by real world business organizations. He felt the lack of new learning and social interaction was causing a rift between instructional institutions and their students. He felt there was a real opportunity to create a new engaging instructional experience.

Online games are difficult to master. The gamers are constantly asked to make exploratory decisions in confusing environments that require constantly expanding knowledge. Gamers expect to be immersed in information-rich dynamic situations where they are asked to infer, decide and act quickly based on decisions made with high degrees of uncertainty.

The gamers are metric oriented and prefer constant feedback on performance improvement. They are accustomed to catastrophic setbacks that require them to start over in the creation of their personal power and influence. They are obsessed with “layering up” their challenges by solving new problems with ever increasing levels of difficulty. This obsession with advancing their performance score through many hours of dedicated effort has come to be known as “stickiness” (Brown, 2005)

Online games are a constantly evolving persistent ecosystem. Gamers are actively engaged in exploring complex creative dynamic environments in an augmented global economy. A persistent global society without knowledge gate keepers stimulates gamers to expand their creative skills to develop capabilities and solutions (Boellstorff, 2008). Games create an enriching experience through an expanded sense of control. The element of worry or failure anxiety typical in normal life is eliminated. This creates an enriching and engaging experience that is often referred to as "flow" (Csikszentmihalyi, 1991). The challenge is to create a gaming experience that is engaging and academically accurate (Kelly et al., 2007).

Practitioners have resisted the adoption of innovative theories and practices. A new pedagogy is needed to overcome the resistance. Young people may be leading the way. On a daily basis, young people participate in massive multiplayer online game economic cultures. They eagerly struggle with overwhelming challenges. Many of these cultures are created using ABMS (CCP, 2003).

There is speculation that one reason for the delay in the adoption of new management practices is the lack of simple usable models (Krugman, 1995). A recent survey of university faculty, hints that a similar dynamic may be suppressing academic and practitioner interest in virtual organizations (Burkhard & Horan, 2006).

2.5.1 Game Theory

Game theory is designed to address situations where the outcome depends on a player's behavior in interactive environments. Easley and Kleinberg (2010) defined a network centric game theory model that has three basic ingredients: players, strategies and payoffs. They describe a game by defining the number of players, their roles, how many strategies they must master, and how a payoff is calculated. Game outcomes are often dependent on the interaction between multiple agents. Managing this interaction adds a strategic dimension to the game. Game theory is broader than how people reason about their interaction with others. It also examines what trends persist in large populations. The perceived value of the outcome needs to be viewed from the group as well as the individual perspective. Players should not be constrained to a zero-sum context where they are only concerned about their payoff, because zero-sum games often have the paradoxical property that the optimal solution cannot be achieved rationally, players should be allowed to seek an altruistic payoff where they care both about their payoff and the payoff of others (Easley & Kleinberg, 2010).

2.5.2 Human Computer Interaction

In 1962, MIT hackers invented the first computer game, called "Space War." "The designers identified action as the key ingredient in blending thinking and doing for its players" (Laurel, 1992, p. 1). Brenda Laurel used a multi-disciplinary design research approach in order to better understand the nature of human computer interaction. She established that computers are a new kind of medium, not just a tool. Her computer interface metaphor defined an agent as one who initiates and performs action consistent with Aristotle's concept in the *Poetics.* Like a play, computer interaction is confined to an artificial world and all agents are situated in the same context, access the same objects and share the same language. Theatre, film and narrative can be profound and intimate sources of knowledge that generate actions with serious consequences. She divided human computer activity into two broad categories: productive (i.e. word processors) and experimental (i.e., games). She argued that a dramatic approach was more like a game and was capable of supporting serious activities and creating surprise and delight.

Steven Gabel used Aristotle's *Poetics* to assist in understanding agent-based simulations. Like poets, the simulation function is to describe things not as they are but how they might be. Computer activities can be defined as representations of actions with agents of both human and computer origin (Gabel, 2003).

2.5.3 Related Work

Valluri, North and Macal (2007) used an ABMS approach to examine the value of reinforced learning in a SCM multi-stage problem. They tested three simple reinforced learning algorithms and determined that it required several thousand periods for agents to learn in this multi-agent setting. Giannoccaro and Pontrandolfo (2000) examined a three-stage ABMS supply chain and found that reinforced learning required over 100,000 periods to demonstrate learning. Zhao and Sun (2006) applied reinforced learning to an ABMS supply chain similar to the SBG. They determined reinforced learning improved supply chain performance after a very large number of repetitions. Kimbrough et al. (2002) found that agents could use genetic algorithms to solve the Beer Game inventory problem if the agents were not independent and completely shared information in a centralized environment. LOGICS Design 5 solved the SBG inventory problem without information sharing. Sterman did not solve the SBG inventory problem; he used a Monte Carlo method to determine an optimal value.

Chaharsooghi, Heydari, and Zegordi (2008) used a four-stage Beer Game to examine the effectiveness of reinforced learning on an agent-based model. They found that learning occurred after 35 periods if the agents did not operate independently and inventory information was shared universally. This collective body of work suggests the ABMS SBG is highly resistive to reinforced learning.

3. Design Framework

In the late 1960's, Herbert A. Simon began to argue for a new kind of research that could meet the new intellectual challenges of the artificial. He labeled the course of action aimed at changing existing situations to preferred ones, design (Simon,1969). Hideaki Takeda favored a reasoning design cycle that used adductive and deductive loops (Takeda, Veerkamp, Tomiyama, & Yoshikawa, 1990). Others mapped this design cycle framework onto knowledge flows, process steps and logical formations (Vaishnavi & Kuechler, 2008). Information system design theory (ISDT) blends multi-paradigm research kernels into distilled discipline-specific processes and product artifacts (Walls et al., 1992).

Simon was concerned that natural science research methods filter out the investigation of the artificial/synthetic, favored the descriptive and excluded the normative. The result was an investigation into how things are, rather than how they ought to be. He wanted to explore the ability of symbolic manipulation to extend the range of abstract imitation. He called this capability simulation. He felt that simulation could contribute to the expansion of knowledge in two ways. First, simulations could tease out the consequences of assumptions. The workings of individual inner system components may have been well understood, predicting the behavior of their collective interaction was not. The second contribution would be to expand our knowledge of poorly understood systems (Simon1969).

Thomas Kuhn warned scientific textbooks were little more than a tourist brochure for science. He felt new scientific generations were being persuaded to become an enduring group of adherents to a minimal set of out-of-date and inaccurate ideas. This bias was leading to the premature promotion of a few popular ideas to the status of scientific law. The collective effect was to create a fundamental unit of scientific development he called the "paradigm." Consensus building in a paradigm is facilitated due to pedagogy-induced agreement on a set of fundamentals. His concern was novel ideas and multiple paradigms ideas would find it almost impossible to obtain the prerequisite consensus necessary to be considered normal science (Kuhn, 1962, 1970).

Vijay Vaishnavi and William Kuechler determined that artifact-based design research achieved legitimacy less than 30 years ago. Up until then IS had been restricted to a paradigmatic approach with a dominant set of research questions, methods and knowledge disseminating outlets. When IS shifted to multi-paradigmatic exploration, a new community of questions, methodologies and philosophies were created. This new community was united by their interest in the understanding of how human computer systems are developed, produced, process information, and influence organizations (Vaishnavi & Kuechler, 2008).

3.1 General Design Cycle (GDC)

Charles Owen wanted to use design to extend understanding beyond the analytic constraints of classic research. He found that knowledge generated by circumscriptive reflective cycles develops its own set of purposes, values, measures, and procedures. This approach allows systematic inquiry in fields where the work is primarily synthetic. The reflective cycles should be constrained and judged by the conventions and the rules of a knowledge discipline, but abduction from other disciplines should be allowed. The final results however, should be evaluated from the constraining discipline (Owen, 1997).

A general design cycle generates knowledge flows using logical deduction formalisms abducted from complementing natural and social science kernel theories. Cyclic feedback loops generate new knowledge and increase understanding of operational problems. Innovations emerge when diverse contributing kernel theories overlap. The discrepancy between suggested solutions and actual performance is evaluated during circumscriptive minor cycles. Goal bounded minor cycles deepen the understanding of discrepancies and trigger deductive conclusions. Deducted conclusions generate new problem perspectives. The new perspectives generate altered artifact expectations. New expectations influence the design of a new artifact. The new artifact is evaluated to determine its influence on the discrepancy gap. The interaction between process steps and logical formalisms creates new contexts and values (Dasgupta, 1996; Purao, 2002; Vaishnavi & Kuechler, 2008). Figure 5 illustrates the general design cycle.

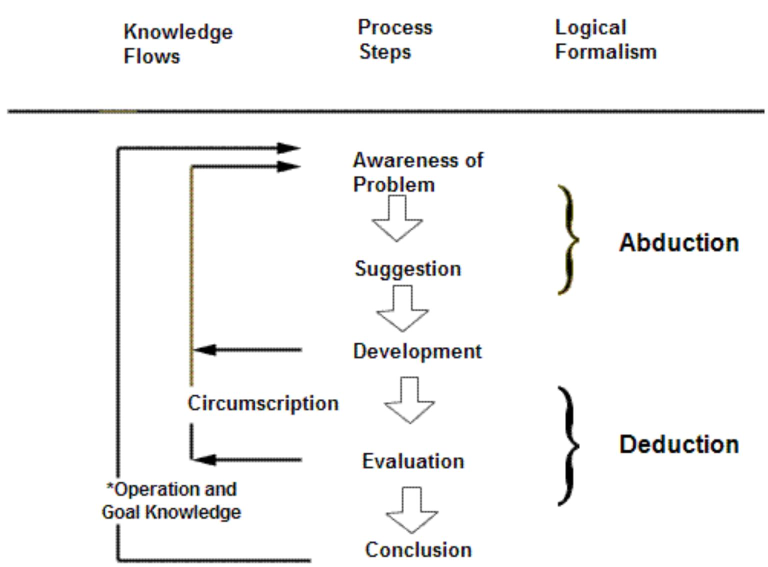

Figure 5. General Design Cycle (Vaishnavi & Kuechler, 2008, p. 33)

"An operational principle can be defined as “any technique or frame of reference about a class or artifacts or its characteristics that facilitate creation, manipulation, and modification of artifactual forms” (Dasgupta, 1996; Purao, 2002).

3.2 Design Science Research Methodology

Vaishnavi and Kuechler created a research perspective for a multi-discipline socio-technology enabled research community united by their class of outputs. Shared research values provided the strong binding force necessary to replace the empirical binding force of traditional science. This approach allowed viewpoints to shift during circumscription research cycles. A design research epistemology and its use of factual artifacts more closely resemble natural science research than positivist or interpretive research.

Hevner and others (2004) stated that the end result of design research may be poorly understood and still be considered a success due to an artifact’s ability to provide a basis for further exploration. Carroll and Kellogg (1989, p. 7) suggested that Human Computer Interaction (HCI) artifacts are perhaps the most effective medium for HCI theory development. Their objective was to produce a qualitative description of an HCI artifact that was limited to a category of user activity. Their approach provides a means for “exposing psychological overdetermination of HCI artifacts” (Carroll & Kellogg, 1989, p. 8).

March and Smith (March & Smith, 1995) restricted design research to two activities: build and evaluate. Design researchers build artifacts to demonstrate they can be constructed. Next, design researchers evaluate those artifacts to determine how well they work based on a predefined criterion. This is a very different approach than that used by traditional scientists who theorize and justify. For example the dynamic interaction of ABMS artifacts is often intractable. Simulations often generate complex counter intuitive behavior patterns with novel parameter spaces. Examination of these parameter spaces often lead to novel explanations and predictive capabilities.

Rittel and Webber (Rittel & Webber, 1984) added their support to the claim that a social system problem is different than a natural science problem. Scientists and engineers typically focus on tame problems where the mission is clear. Many social problems are intractable. Often it is not possible to know if the observed condition is the desired condition. They posited that an ideal planning system would be cybernetic in nature. A simulated model would run concurrently with an actual system on a cooperative goal seeking mission. Purao (Purao, 2002) recommended a semiotic approach that would enhance the ability of design research to increase understanding of phenomena and artifacts simultaneously.

Design science research communities generate a broad range of outputs that are used to identify the research discipline. March and Smith proposed four general outputs for design science research: (1) constructs, (2) models, (3) methods and (4) instantiations. Constructs create a conceptual vocabulary of a problem solution domain. Models are a set of propositions that create relationships between constructs that affect the models' behavior. Methods are goal directed plans that define a solution to the problem stated using construct vocabulary. An instantiation "operationalizes the constructs, models and methods." (March & Smith, 1995, p. 258)

Purao (Purao, 2002) shared the concern, with Walls and others (Walls et al., 1992), that design research was under developed. He made it clear that in his view the goal of design research was not the pursuit of truth, it was for those daring enough to invent virtual artifacts to support and improve real phenomena. This made invention the primary purpose of design research. He grouped outputs into various levels of abstraction. The highest level of abstraction consisted of emergent theories and embedded phenomena. The outputs for this level of abstraction are: constructs, better theories, and models.

He believed that his version of design science enhanced theory building in two ways: experimental exploration of method, experimental proof of method or both. Figure 6 shows the relationship between knowledge flows, process steps and outputs.

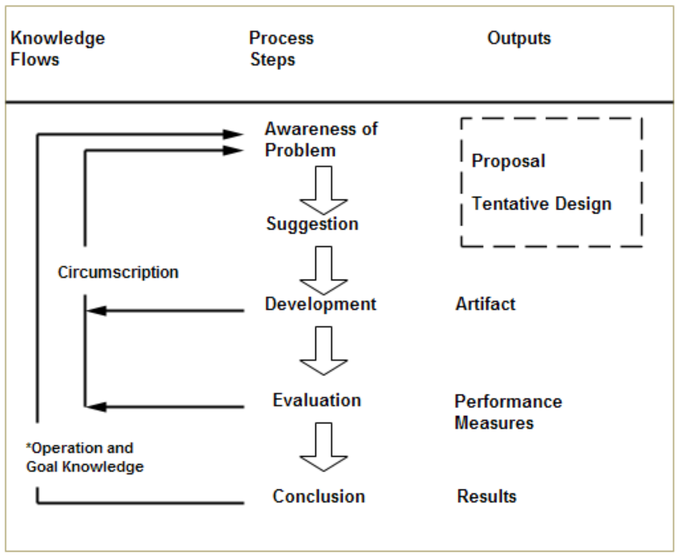

Figure 6. General Design Research (Vaishnavi & Kuechler, 2008, p. 20)

An operational principle can be defined as "any technique or frame of reference about a class or artifacts or its characteristics that facilitate creation, manipulation, and modification of artifactual forms" (Dasgupta, 1996; Purao, 2002).

The introduction of the output construct allowed design research reasoning to generate a general methodology with practice-specific variants. Logical formalisms are defined and labeled using constructs or patterns familiar to a specific design science research discipline (Vaishnavi & Kuechler, 2008, p. 59).

3.3 Information Systems Design Theory (ISDT)

Walls and others (Walls et al., 1992) posited that an information system design theory (ISDT) should be prescriptive and focus on intrinsic goals. The theory should expand on Simon's ideas of the artificial and procedural rationality (Simon,1982); and draw from kernel theories in natural science, social science and mathematics. Since design can be viewed as a verb and a noun, the outputs should be a testable set of product and process hypotheses.

In their approach, abductions from kernel theories generate a set of propositions that can be recast into prescriptive meta-requirements. Meta-requirements are used to generate a meta-design and a design method. The meta-design consists of a list of product artifact features. The features must be empirically tested for requirements conformation using a set of product hypotheses. The design method is heavily influenced by the ability to generate testable products. The design method requires a set of hypotheses to test their effectiveness. Figure 7 shows the general components and relationships of their ISDT approach.

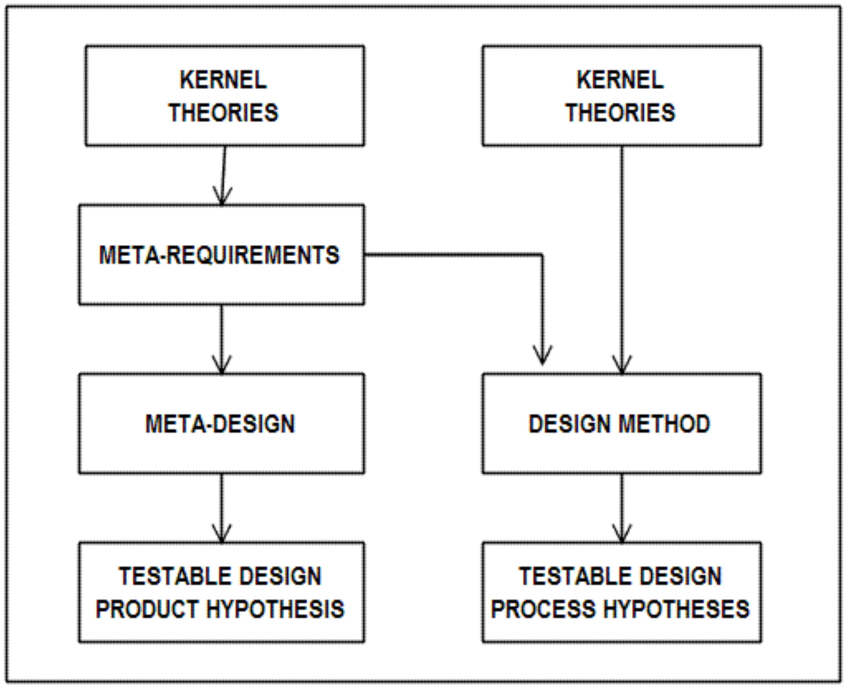

Figure 7. Components of an Information Systems Design Theory (Walls et al., 1992)

Others have used this approach to create artifact instantiations and design methods (Burkhard, 2006; Markus, Majchrzak, & Glasser, 2002). Gregor and Jones (Gregor & Jones, 2007) provided a refinement of this model. Their work influenced the LOGICS methodology. The emphasis on the instantiation or material artifact as the phenomena of interest for both a process and product added clarity to the approach. This allowed the testable hypotheses of the Walls (1992) approach to be replaced by research questions for the LOGICS process and product approach.

4. Methodology

Contributing theories covered in Chapter 2 are used to make the ISDT covered in Chapter 3 specific to learning object games immersed in complex system (LOGICS). Cybernetics, complex business dynamics, learning objects and online games are the dominant kernel theories for the product artifact. The simulation is the dominant theory for the design process. The product and process instantiations are evaluated against a set of research questions. Expository instantiations of working simulation designs will evidence of completion. Figure 8 shows how the kernel theories used in this research are allocated relative to the general template developed by Walls and others (Gregor & Jones, 2007; Walls et al., 1992).

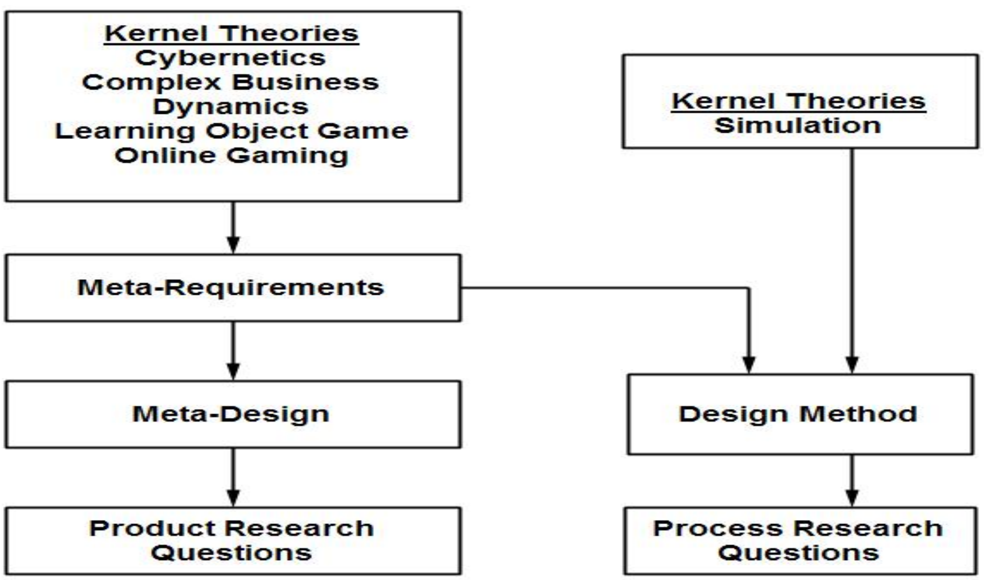

Figure 8. Components of LOGICS Methodology

4.1 Element Overview

These elements are used to keep the product and process artifact designs consistent during the multiple circumscriptive design cycles. The use of research questions is more appropriate than hypotheses in this type of design research.

Table 1. Design Elements

Design Process Elements - Plan a Structure That Satisfies All Requirements		
Kernel Theories Section 2.0 Section 4.2	Social science theories governing design processes themselves.	• Simulation: NetLogo with "Hubnet" features A behavior space generator, a PABMS space, and an Analysis space.
Design Method Section 4.6	A description for procedures and goals for a testable process artifact.	1. Accurately capture all performance parameters in a data file. 2. Confirm each product design accurately demonstrates the proper relationship between the SBG inputs and outputs. 3. Confirm stochastic PABMS accommodates player interaction. 4. Confirm that the instructor console properly monitors and manages the PABMS experiment. 5. Confirm that the Web based Public Scoreboard properly displays player performance. 6. Examine the results of the experiment for anomalies produced by erratic results. These results could be generated by human agent rule violation game play or simulation coding errors. 7. Use captured data to recreate the game experience. 8. Determine the best information system architecture for the selected PABMS problem. 9. Create a process that can accommodate future complex system problems.
Process Research Questions Section 4.7.3	Used to verify whether the design method results in an artifact that is consistent with the meta-requirements.	1. Can a Behavior Space Generator (BSG) be used to evaluate the deterministic properties of an ABMS complex system model? 2. Can the PABMS functional space be used to introduce stochastic player behavior into the SBG? 3. Can an immersive PABMS be used to move the gaming environment to a stochastic parameter space? 4. Can a PABMS accurately capture all relevant data, use it to examine erratic game play and generate animations? 5. Can the analysis space accommodate assumption-free statistics?

Table 1 (continued). Design Elements

Design Product Elements - Plan of Something to be Produced		
Element	Definition	
Kernel Theories Section 2.0 Section 4.2	Social science theories governing design requirements.	• Cybernetics: Closed Loop Negative Feedback. • Complex Business Dynamics: Sterman Behavior Model. • Learning Object: Design and Sequencing Theory. • Online Games: Immersive Interaction.
Meta-Requirements Section 4.3	Describes class of intrinsic goals to which the theory applies.	1. The human computer interface (HCI) should create a dramatic experience that directs human action by stimulating the imagination and emotion through crafted uncertainty. 2. The game HCI should use theatrical techniques to immerse a single player into a supply chain Retailer storefront context. 3. Form and structure allows the player to always have the option of using heuristics in managing the inventory. 4. The game should implement instructional techniques to influence player actions through slight adjustments in the gaming experience. 5. Dramatic instructional techniques in all designs should attempt to move the player to a new solution neighborhood.
Meta-Design Section 4.4	Describes a class of artifacts hypothesized to meet the meta-requirements.	• Retail theatrical storefront GUI. • Immersive retail storefront to provide game status, rules, hints and a variety of product ordering methods. • Instructor console to manage and monitor a real-time PABMS SBG experiment. • Web site public scoreboard.
Product Research Questions Section 4.7.4	Used to test whether the Meta-designs satisfy meta-requirements.	**1.** Can a PABMS use theatrical techniques to create a human computer interface (HCI)? **2.** Can PABMS be used to create and manipulate a dynamic version of the SBG? **3.** Can a PABMS accommodate the use of heuristics? **4.** Can a PABMS be structured to alter player behavior? **5.** Can a PABMS convince a player to abandon heuristics and invest in an I- enabled purpose-seeking system? **6.** Can a LOGICS product artifact quickly change player behavior?

4.2 Linking Kernel Theories to Meta-Requirements

Cybernetics is about control and communication in the animal and machine (Weiner, 1961). Closed feedback loops pass messages between various sensors, mathematical manipulators and actuators to produce a desired result. These systems are self-regulating and are able to evaluate the discrepancy between the ideal and actual result. This works well in mechanical systems. When human information processing is inserted in the messaging loops, communication entropy is introduced. Research shows the human brain behaves like a mechanical device with multiple layers of high entropy feedback loops that distort communication resulting in mindless hunting behavior in counter-intuitive complex system environments (McCulloch, 1965). This research transforms the deterministic ABMS into a stochastic PABMS by introducing a human agent into the counter-intuitive complex system environment. The goal is to isolate the human agent behavior in order to study the ability of various manipulations to move the human away from a neighborhood of heuristics to a neighborhood of rational IS investments.

Complex Business Dynamics research has determined that reactionary intuitive mental models, called heuristics, dominate reasoned rationality (Forrester, 1961) The learning object game developed in this research is designed to influence the struggle between intuition and rationality. Research has established that the SBG accurately models SCM performance in this complex dynamic economic space. Analysis of the parameter space has revealed an extremely complex structure (Mosekilde et al., 1991). Sterman restricted his analysis to a set of participants that knew, understood and played the game well. This LOGICS design research project uses a set of participants more in keeping with reinforced learning. No previous knowledge of the problem is assumed. The goal is to create an online game experience that can be evaluated from a learning object instructional design research perspective.

Simulation research has demonstrated that autonomous agents can interact with human agents in a dynamic concurrent environment (North & Macal, 2007). What is needed is an IDE that accommodates the use of traditional ABMS, automatically generates and accepts experimental data, accommodates PABMS interaction, and allows a flexible analysis capability. The goal is to create an initial IDE that can evolve as the LOGICS ISDT evolves.

Learning Objects are often criticized for focusing on technology and marketability rather than instructional design theory (Wiley, 2000b). This initial LOGICS project used two simple learning object techniques:

feedback and repetition. The goal is to determine if this approach is sufficient to achieve the learning objective.

Online Gaming combines interactivity and immersion with theatrical techniques into an intent altering persuasive context. Game artifacts that insert a human player into a PABMS environment provide a platform for participatory experimentation. The goal is to determine if this approach can be used to obtain a specific learning objective.

4.3 Meta-Requirements

The human computer interface (HCI) should create a dramatic experience that directs human action by stimulating the imagination and emotion through crafted uncertainty. The game GUI should use theatrical techniques to immerse a single player into a supply chain Retailer storefront context. The form and structure should always allow the player the option of using heuristics in managing the inventory. The game should implement instructional techniques to influence player actions through slight adjustments in the gaming experience. Dramatic instructional techniques in all designs should attempt to move the player to a new solution neighborhood.

4.4 Meta-Design

The product meta-design class of artifacts includes: the game human computer interface, the instructor's console and the cheat site.

The game human computer interface (HCI) creates a dramatic experience that directs human action by stimulating the imagination and emotion through crafted uncertainty. The experience provides the satisfaction of closure when a successful action has been constructed (Laurel, 1992, p. 67). The game is played from the perspective of the supply chain Retailer. The Retailer needs to receive orders from and ship products to a single customer; and orders and receives a single product from a single Wholesaler. Interactive manipulation uses physical actions or labeled buttons; instead of complex syntax sensitive typed commands. The player is presented with a continuous representation of the object of interest. The player is provided with timely, accurate and unambiguous game status information. The player is provided with timely and accurate advice on game goals, problem solving advice and optional actions (Schneiderman, 1987). The game provides a uniform perspective for every player.

The Instructor GUI uses theatrical techniques to immerse the instructor in a control room environment. The instructor is able to launch and monitor the game from a remote location not visible to the player. The instructor is able to monitor a player's actions and progress using graphs and dynamic displays. The instructor is able to send instructions to the player in real time.

The player cheat site and scoreboard GUI use theatrical techniques to immerse the player in a Supply Chain Campus. The players are able to easily locate a public scoreboard that allows comparing their score with the scores of previous players. The campus is populated with buildings that provide access to background information on supply chain dynamics and on the game-specific problem.

4.5 Meta-Design Product Run Time Client

A series of Photoshop background scenes were used to design and create a theatrical retail scene. The instructor launches a server hosted online game from a remote location. The player logs on using the client game console. The player receives runtime instructions from large posters displayed on the walls of the retail background set. The player interactively places an order using controls mounted on the wall of the retail scene. The player receives instructions and updates from the server that are displayed on monitors mounted on the walls of the retail scene.

Figure 9 shows the execution flow steps:

Step 0…..The instructor launches the online game from a remote location. The player logs on using the client game console. The first Photoshop theatrical storefront scene is sent to the player. The player receives the runtime instructions from a large poster displayed on the wall of the storefront.

Step1….. The player interactively places an order using controls superimposed over the storefront background scene.

Step2….. The server calculates the results.

Step3……The player receives instructions and updates from the server that are displayed on monitors in the client retail scene.

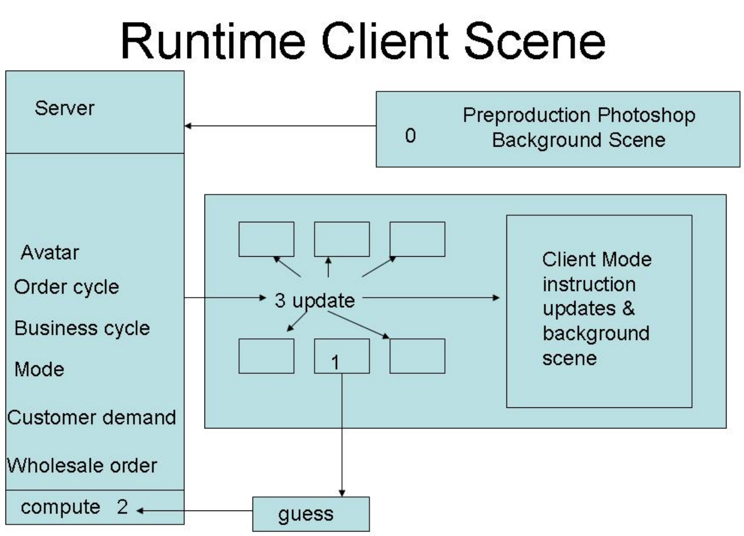

Figure 9. Functions and Interfaces

4.6 Design Method

The LOGICS ISDT uses design cycles through three complementary functional spaces to create a progressive series of game product prototypes. The first functional space is the Behavior Space Generator (BSG). This is an ABMS space used to evaluate the deterministic properties of an ABMS product artifact. The BSG was used to duplicate the input-output relationships described in the SBG publication (Sterman, 1989). This evaluation was performed on all designs.

The participatory ABMS (PABMS) functional space is used to introduce human agent variability (Berleant, 2003). This is the functional space where the game experiment is conducted. Human agents replace ABMS agents in order to introduce stochastic uncertainty into the gaming experience. Manual testing was conducted during the construction of all designs. Human agent manual input produced unpredictable irreducible uncertainty that was impossible to anticipate. Input and output gaming information was accurately captured in data files. This space has the capability to recreate a gaming experience for the purpose of player debriefings and animation creations.

The Analysis Space was used to statistically analyze the results of each product design. The space utilized the statistical capabilities of SPSS and Mathematica. This approach accommodates traditional and assumption-free statistical analysis. The full LOGICS design method is illustrated in Figure 10.

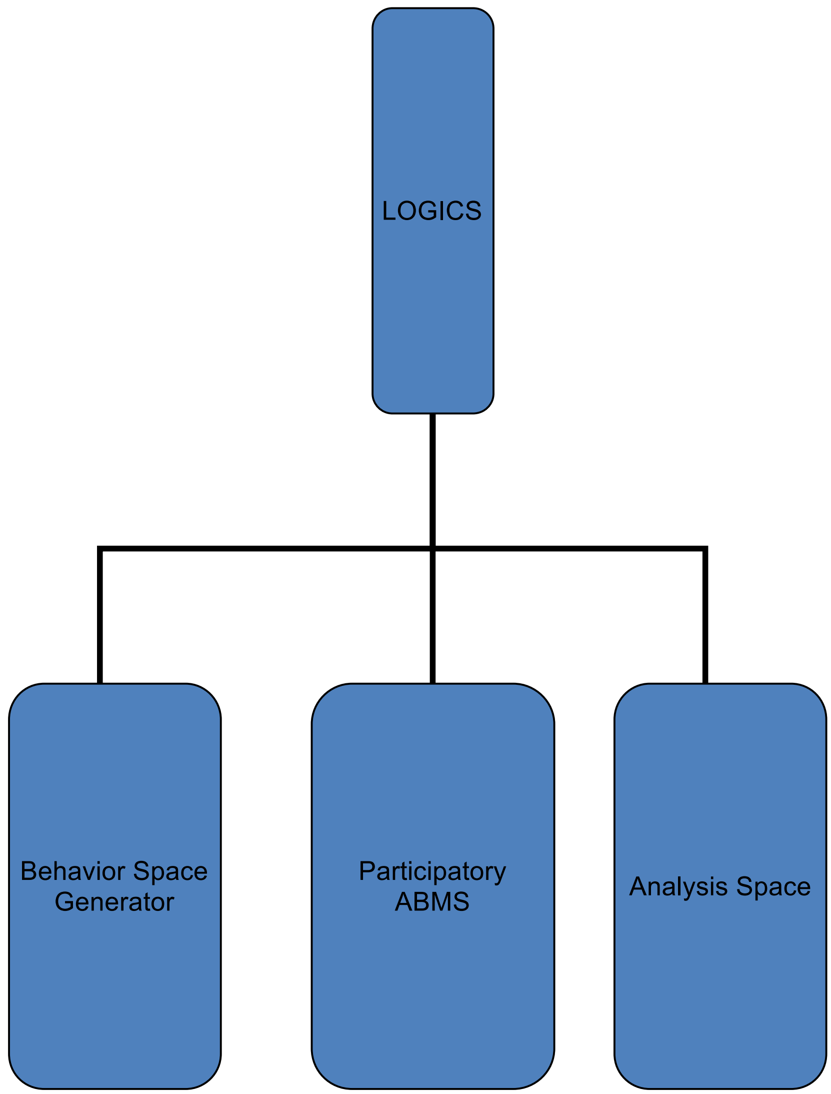

Figure 10. LOGICS Design Method

4.7 Hierarchy of Research Questions

A series of evolving LOGICS product and process artifacts need to be continually evaluated to ensure the designs remain consistent with the circumscriptive constraints. Several layers of research questions assisted in keeping the methodology consistent across numerous circumscribed design cycles.

4.7.1 General Research Question

The LOGICS general research question is:

"Can an online game player learn to abandon intuitive reactions to local events in favor of investing in system solutions provided by information technology?"

An affirmative answer is predicated on the ability of a LOGICS design to create a learning experience that results in a player obtaining the learning objective.

4.7.2 Kernel Theory Research Questions

A subset of five research questions was used to evaluate the expansion of kernel theories into areas that complement the evolution of the LOGICS approach. It was assumed that the initial LOGICS project may not obtain the learning objective. This information creates a baseline for improving future artifacts.

1. Cybernetics: Are the LOGICS artifacts capable of generating a purpose seeking system?
2. Complex business dynamics: Are the LOGICS artifacts capable of creating a dynamic version of the SBG?
3. Simulation: Is a PABMS capable of creating a learning object game?
4. Learning Objects: Can the learning object techniques of repetition and feedback be used to alter player behavior?
5. Online Gaming: Can the LOGICS artifacts lead a player to discover the value of IT investments in obtaining the optimal solution to the SBG?

4.7.3 Process Artifact Research Questions

A subset of five research questions listed in Section 4.1 (Table 1) was used to assist in evaluating the LOGICS ISDT design process:

1. Can a Behavior Space Generator (BSG) be used to evaluate the deterministic properties of an ABMS complex system model?
2. Can the PABMS functional space be used to introduce stochastic player behavior into the SBG?
3. Can an immersive PABMS be used to move the gaming environment to a stochastic parameter space?
4. Can a PABMS accurately capture all relevant data, use it to examine erratic game play and generate animations?
5. Can the analysis space accommodate assumption-free statistics?

4.7.4 Product Artifact Research Questions

A subset of six research questions listed in Section 4.1 (Table 1) was used to guide the LOGICS ISDT design method in the creation of product artifacts:

1. Can a PABMS use theatrical techniques to create a human computer interface?
2. Can a PABMS be used to accurately create and manipulate a dynamic version of the SBG?
3. Can a PABMS accommodate the use of heuristics?
4. Can PABMS be structured to alter player behavior?
5. Can a PABMS convince a player to abandon heuristics and invest in an IT enabled purpose seeking system?
6. Can a LOGICS product artifact quickly change behavior?

5. Research Method

The LOGICS ISDT research project was designed to expand the insight generated by a classic behavior economics board game experiment. A single player online game was constructed using a client-server LAN architecture. A single player interacted in real-time with a learning object ABMS game. The human player was the only agent capable of learning. All other agents were protoagents who were locked into traditional SBC behavior patterns. This assisted in isolating the player's influence on the game's traditional normal performance. Each game design was encapsulated. This allowed each player to be independent and generate an autonomous data set. The game generated and collected data in real-time in a server file. A modest sized sample allowed the exploration of five designs in a two year time frame. Contemporary psychological statistical techniques were used to examine the modest samples.

5.1 Software and Hardware Architecture

The Microsoft Client/Server architecture was used to create the online game runtime environment. This approach replaced a demonstration prototype consisting of two Wi-Fi portable laptops. The Wi-Fi approach proved to be highly unreliable and made it difficult to maintain player confidentiality.

The Microsoft server ran the MS Server 2003 operating system and was the host for the NetLogo 3.1.4 application. All runtime data folders were stored on the server in the Microsoft Excel file format. One hundred and four GUI theatrical set templates were stored on the server. One set template was transferred to the Client GUI every order cycle. Order cycle results were transferred to the client GUI in real-time. Runtime player data was sent to the Client GUI in real-time.

The player GUI runs on a Windows XP desktop PC. The GUI is launched from the NetLogo server and communicated with the server using the NetLogo “Hubnet” protocol.

The instructor console GUI was hosted on the server. Remote access allowed instructors to monitor game play from any Windows XP PC.

The cheat site resides on the Western Research Application Center (WESRAC) web server. WESRAC is an applied research center located at the University of California (USC) Viterbi School of Engineering (VSoE). A supply chain virtual campus consisting of various instructional buildings added theatrical elements to the auxiliary gaming space. A public scoreboard in the center of the games displayed a summary of player performance information. Buildings contained complementing Web content. The majority of the material consisted of royalty free Wikipedia sections. Wikipedia sections provided links to actual complementing research publications. The architecture diagram for the LOGICS platform is shown in Figure 11.

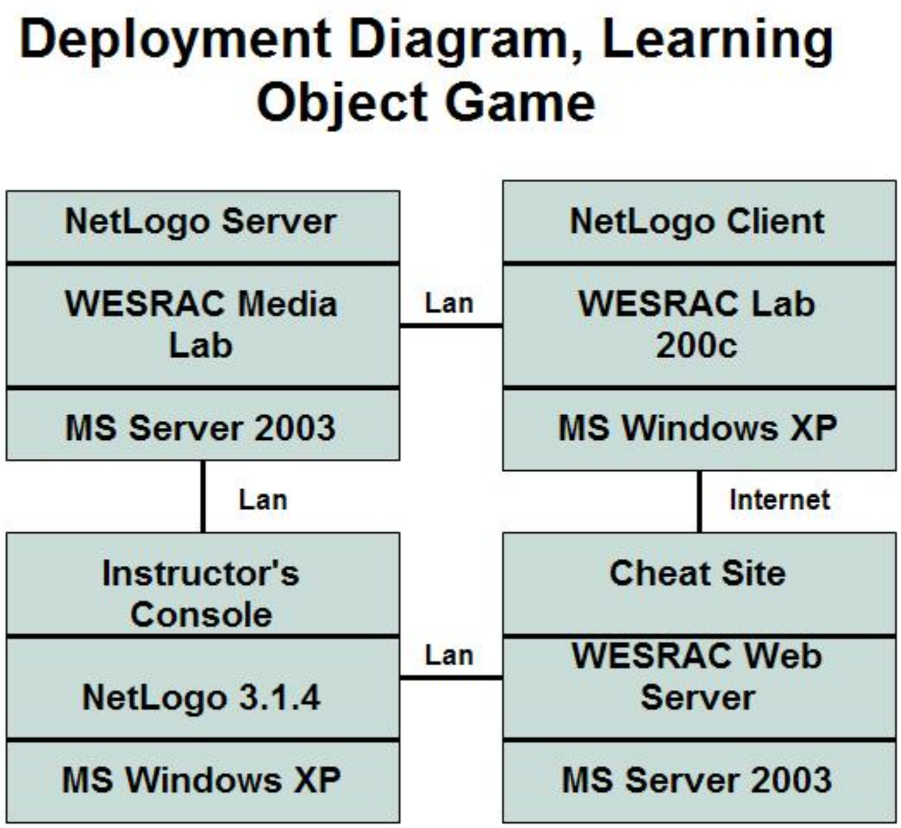

Figure 11. Architecture

5.2 The Product Artifact

A single player is immersed in a retail storefront that interactively provides a single product to a single customer. The player is presented with a series of storefront scenes that provide timely rule definitions and game hints. The scenes are designed to provide a simple unambiguous game interaction interface. The customer, Wholesaler (W), Distributor (D), and Factory (F) are invisible agents executing rules consistent with the SBG.

The instructor operates in a virtual control room environment in a location not observable by the player. The instructor is presented with graphs and dynamic displays that describe the players ordering techniques, display plots of local and total inventory costs, and a streaming display of key parameters in the simulation code.

5.3 Player Client GUI

Figure 12 is a screen capture of the actual player client GUI. The client-based player establishes an avatar name on login. The top row of monitors and buttons provide status information and control. The avatar name is displayed in the User monitor located in the upper left corner of the Retail storefront GUI scene. To its right, the ticks count monitor displays the customer order number. The goal of the game is to minimize the system TotalCost displayed on the monitor next to the right of ticks. The Instructor can provide guidance using the Instructor's monitor to the right of the TotalCost monitor. The top right Reset button is used to initiate a new game business cycle (trial).

Inventory flow and stock information is provided in the center of the storefront. The Product Delivered monitor shows the amount of product ready to be shipped to the customer. The Inventory monitor shows the amount of product stock on hand. The Product Received monitor shows the amount of product on the receiving dock that has just arrived from the Wholesaler. The large green wall mural explains the rules of the game and provides hints during the course of the game. The murals are updated using scripts that are indexed by the ticks counter. The Customer Order indicates customer demand for this tick count. In all designs, the No Added Cost method is visible and active. The player uses the Order Amount pull-down menu to select the amount to be ordered from the Wholesaler. Clicking on Manual Ordering sends an order to the Wholesaler. Designs 3, 4 and 5 provide a PC Automation ordering method. When the player clicks on this option an order is automatically calculated and sent to the Wholesaler. These three designs explain the cost and method for using either option in their instructional wall posters. Designs 4 and 5 provide an HPC Automation ordering method. When the player clicks this option an order is automatically calculated and sent for all four tiers of the supply chain. These two designs explain the cost method and cost of using either option in their instructional posters.

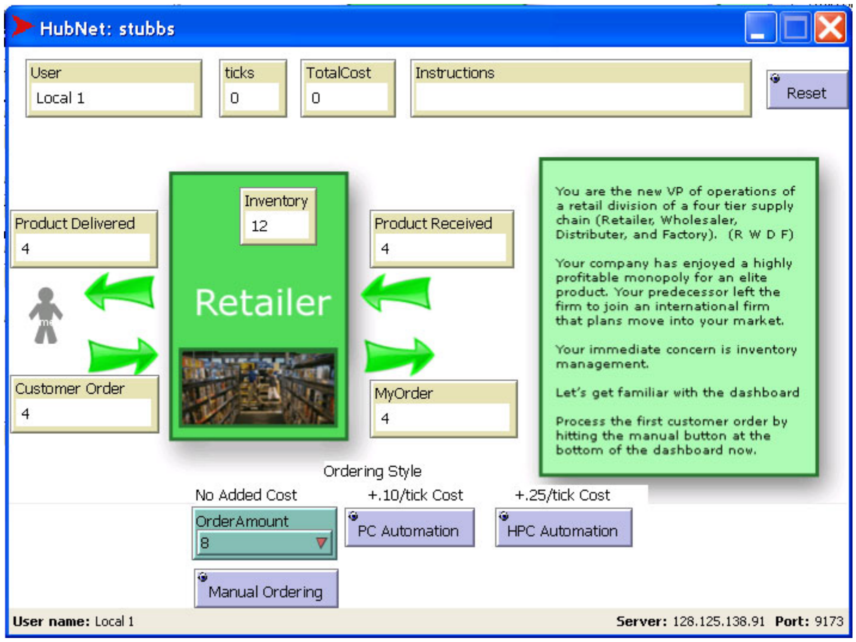

Figure 12. Player Client GUI

5.4 Instructor Remote Access GUI

Every player is monitored in real-time from an instructor console (see Figure 13). The monitoring assists in detecting unwanted player violations of game rules that might jeopardize data integrity. The instructor console is used to Setup the game simulation and Start Hubnet to instruct the player GUI to prompt the player to login in under an avatar name. The avatar name is displayed on the Team Name monitor. Progress through the game is synchronized to the ticks count and displayed on the instructors ticks monitor. The player ordering method is displayed in the Client Action monitor. The total system inventory cost is displayed on the Cost monitor. A mirror of the client GUI is displayed on the large monitor to allow the instructor to monitor the player's game experience. Two plots, one for Inventory levels and one for TotalCost, allow the monitoring of historical game performance. A code-monitoring window allows code execution to be monitored. The Instructor operates from a location that is outside the player's line of site. This prevents unwanted visual cues between the instructor and the player.

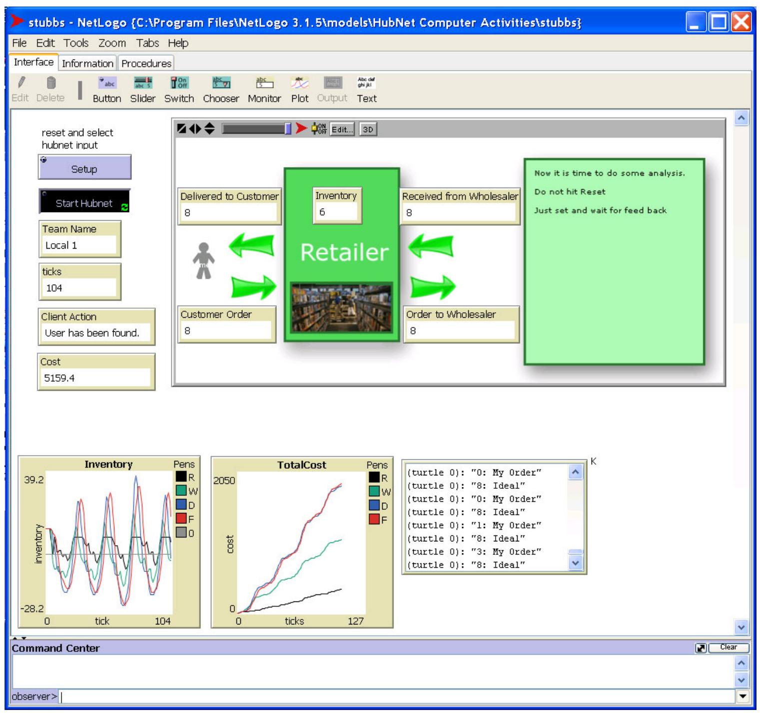

Figure 13. Instructor Console

5.5 Learning Object Techniques

This initial LOGICS project used two simple learning object techniques: feedback and repetition. The goal is to determine if this approach is sufficient to achieve the learning objective.

5.5.1 Use of Repetition

Design1 uses PABMS to allow three players five repetitions each of the Sterman Beer Game (SBG). Design1 is restricted to manual ordering. A pull-down menu is used to select the order amount and a manual ordering button sends the order. Figure 14 illustrates all five Designs and how the Designs use repetition.

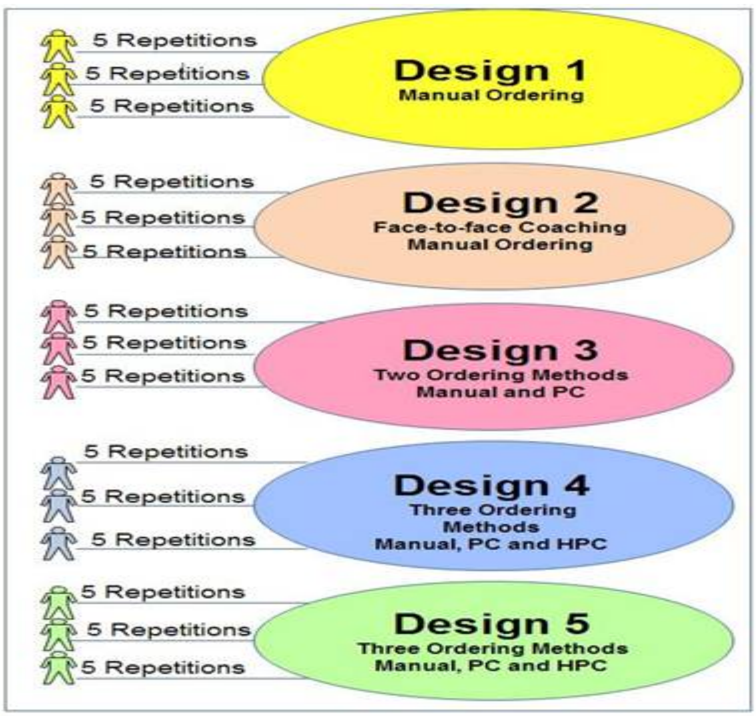

Figure 14. Use of Repetition

Design2 is identical to Design1. The player experience however, was altered. At the end of each trial, a coach conducts a face-to-face meeting with the player. The coach recites the contents of the wall murals and answers any questions on their content. This verbal reinforcement is restricted to game rules and published hints. This face-to-face is meant to minimize information confusion that may be generated by the distractions of a gaming experience. This design was motivated by related instructional design research findings that the online learning experience could be enhanced by a blended approach that utilized some face-to-face instruction (Means, Toyama, Murphy, Bakia, & Jones, 2009).

Design3 allows players to select between two ordering methods during their five trials. The first is the manual pull-down menu and order button method identical to the previous two designs. The second ordering method allows the player to pay for a PC to make the retail ordering decision. A minimal fee is added to the total system inventory cost each time this method is selected. This design is used to test for the presence of a technology bias. That is, to determine if a player would abandon their heuristics and defer to technology.

Design4 allows the player to choose from three ordering methods: manual ordering, PC ordering and high performance computer (HPC) ordering. The HPC assisted ordering is more expensive than the PC ordering method. The HPC ordering method activates an agent behavior modification rule that improves the performance of all production agents. An additional hint was added that any ordering method required four consecutive orders to be effective.

Design5 offers the player the same three ordering methods used in Design4. The feedback method was altered. Design5 provides the player with order-by-order ideal total system inventory cost information. This is meant to provide visible information the player can use to determine the discrepancy between actual and ideal economic performance. Design5 further increases the pressure on the player to consider technology assisted solutions.

5.5.2 Use of Feedback

All designs instructed players to access the online cheat site and web-based online scoreboard. All designs provided some form of feedback on total system inventory cost at the end of each trial. Design4 and Design5 had an additional poster hint to remind the player the product supply chain had four layers and several repetitions of any change in ordering method would take several ticks to impact product received. Design5 provided feedback on optimal system performance at the end of each order cycle. Figure 15 illustrates the feedback methods used in the five Designs.

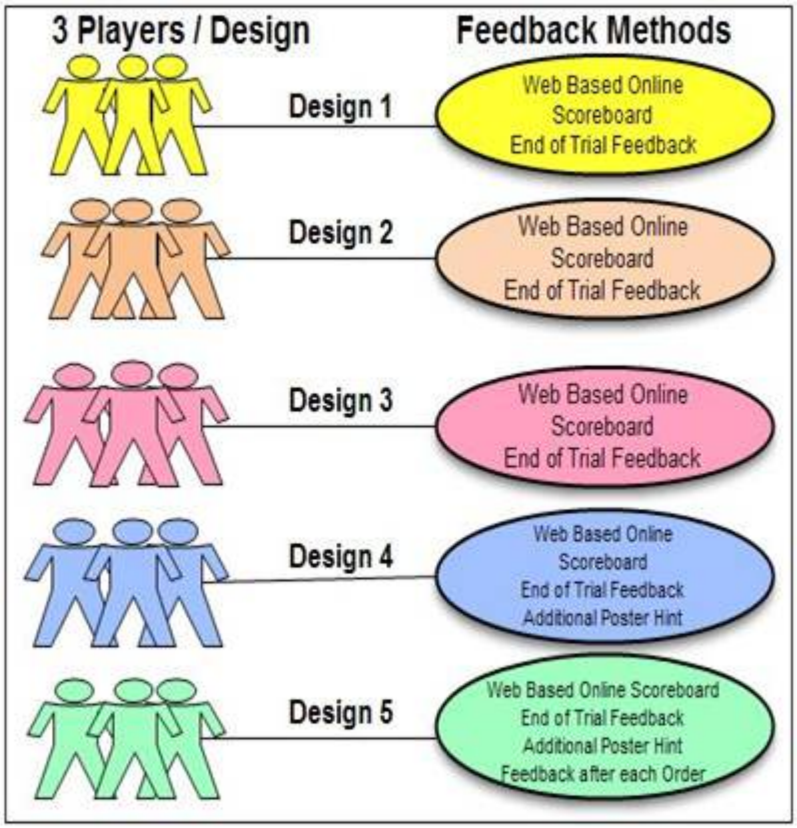

Figure 15. Use of Feedback

5.6 ABMS/PABMS game overview

A blended modeling and simulation approach was used in this research. North and Macal's (North & Macal, 2007) ABMS approach was blended with Smith's participatory economic experiment approach (Smith, 1989). Identifiable self-contained autonomous software agents are situated in a simulated environment that allows them to interact with a human agent. The software agents used embed behavioral rules, memory resources, and computational resources to respond to inputs and behavioral modification rules. This blended PABMS approach immersed the agent-modeling paradigm in an organizational theory context that was used to develop business insights, demonstrate concepts, and test ideas for further design development. Nobel Prize winner Vernon Smith pioneered the use of experimental economics to add a laboratory component to economic research. This research uses PABMS in a design research context to teach complex system concepts. An innovative NetLogo feature called "Hubnet" provided the PABMS capability necessary for constructing learning object online games.

The LOGICS design research experiment is immersed in the SBG problem. The SBG confirmed the presence of the addictive "anchor and adjust" heuristic mindset (Kahneman, Slovic, & Tversky, 1984). This mindset leads to bounded rationality (Simon, 1982), which causes underestimation of risk. This underestimation of risk leads to underinvestment in operation flexibility necessary to deal with actual business risks (Camerer, 1995).

The LOGICS simulation involves the real-time interaction of five autonomous agents: customer, Retailer, Wholesaler, Distributor, and Factory. The Retailer autonomous agent is an interactive human agent. The interaction of the human agent with the software autonomous agents transforms the system from deterministic to stochastic. The unpredictable behavior of an immersed player's reaction to a simple constant customer demand creates the potential to drive the chain reaction into nondeterministic parameter spaces (Mosekilde et al., 1991).

In this research, the customer, wholesale, Distributor and Factory agents are agents that do not learn. They must be modified by a behavior modification rule activated by the retail player. North and Macal (2007) describe this type of agent as a "protoagent." The use of protoagents restricts reactions to manipulations to the human retail agent.

Sterman used a deck of cards to generate a simple customer demand time series. The first four cards of his deck ordered four units of beer. This established an initial level of demand that allowed all four stages of the chain to settle to a stable state. The fifth (5) card introduced a system shock by changing the order level to 8 units of beer. Cards 6 through 104 generated a constant level time series of eight (8) units of beer. In simple terms the SBG supply chain was reacting to a single customer with a constant demand of eight (8). The SBG synchronized each customer order to a tick on a business cycle clock. Each session of his Beer Game consisted of a single business cycle or trial. LOGICS increments an integer counter to generate ticks. The tick count is passed to a function that generates the appropriate order amount. The first four ticks are a time series of value of 4 units to stabilize the chain at the initial SBG state. The fifth tick begins the generation of a constant 8 unit demand time series.

Many ABMS researchers use a variation on the well-known discrete SBG human behavior algorithm (Macal & North, 2005, p. 9). Orders are synchronized to the ticks of a system wide production clock. This generation of LOGICS ABMS designs uses a discrete supply chain with a human agent (player) interacting with a ABMS retail software agent. The human agent only makes the retail ordering decision. ABMS retail program processes any shipment received from the Wholesaler and adds it to inventory stock. The program then fills a customer order from existing stock. If there is a shortage, the program places the shortage on backorder and computes stock level. The program then processes the player's order and sends the order to the Wholesaler. This process continues up the chain to the Factory agent responsible for the production of goods and has access to unlimited raw materials. These agents only have access to local information; they do not have access to global information.

In summary, this LOGICS research resulted in a player-dominated retail agent that was capable of learning. All other agents were programmatically anchored to the published SBG average level of play (Sterman, 1989, p. 328).

The novelty is that LOGICS explores a range of information technology investment strategies. LOGICS designs were constructed to systematically explore the ability of different learning object techniques to move players from a heuristic neighborhood of solutions to a new rational neighborhood of solutions provided by information systems. Each design has a different ordering environment and one design features an agent behavior modification rule. Details are covered in the analysis of each design. Figure 16 shows the functional flow of the typical Sterman agent.

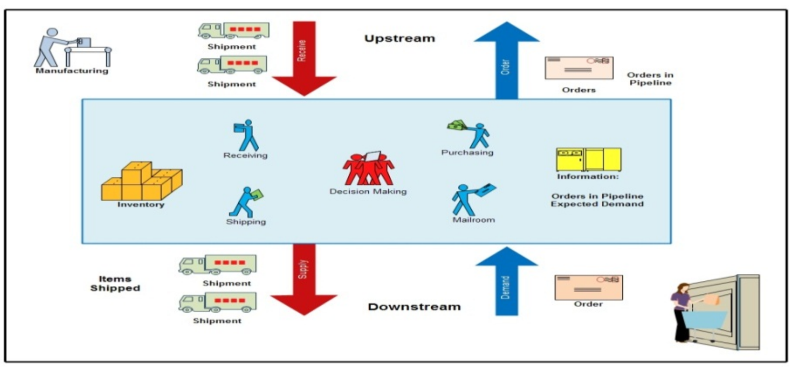

Figure 16. Sterman Agent (Macal & North, 2005)

5.7 Product Major Loops

The product consists of three ABMS loops and one PABMS loop. The setup loop is an ABMS major loop that is performed one time at the beginning of every game trial. The execution loop is an ABMS major loop that executes for a full business cycle. The setup loop sets all the environment variables to their default values; creates all the agents and sets local variables to their default values; creates or resets the data collection file; and resets the player and instructor GUI communication channels. The execution loop: manages the tick count; executes the customer function; executes the process player function; processes; updates the player and Instructor GUI, executes the plot functions; and updates the data collection files. Figure 17 shows the two major loops of the LOGICS game product artifact.

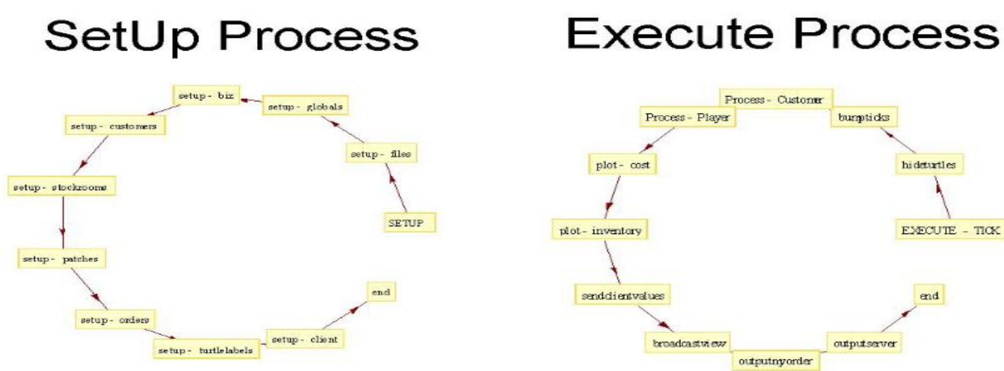

Figure 17. Product Major Loops

5.8 Product Minor Loop

The process customer loop generates the customer demand time series. The first four ticks are for four units. This allows the game to settle after being reset. The next one hundred orders are for eight units. This represents a constant customer demand. The process player loop is a PABMS minor loop that defines the agent ordering context; computes stock levels; places orders; and computes total cost. The retail agent order to the Wholesaler can be driven by the behavior space; a file or an actual player as required. The retail agent is capable of generating an agent behavior modification rule to supply chain agents. Figure 18 shows the product minor loops used to process the player's orders.

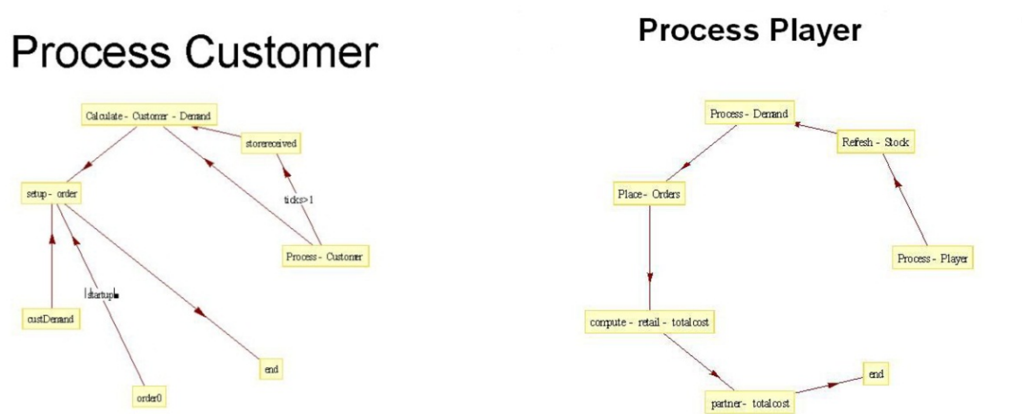

Figure 18. Product Minor Loops

5.9 Cheat Site

All players were provided with retail storefront wall poster instructions on how to access a Cheat Site. The wall posters also provided instructions on how to view game performance of other players on a Web scoreboard.

Players could view published articles on Sterman's Beer Game and Densmore's ABMS implementation of the Beer Game. Densmore's ABMS NetLogo applet allowed exploration of the Sterman behavior model. Players were allowed to request the removal of their game performance from the scoreboard during their exit interview.

5.10 Data Quality

Sterman's players kept manual data records. This resulted in accounting errors. Two-thirds of his data sets were rejected due to data collection errors (Sterman, 1989, p. 328) One of the advantages of ABMS is that all performance data is captured in a data file at runtime. Due to extensive use of simulation, the captured data can be processed in a manner that insures high data quality. Data quality has several dimensions: accuracy, precision, resolution, sampling rate, consistency and completeness. Accuracy deals with matches between actual and recorded data. LOGICS data is very accurate due to automatic collection at run time. Precision deals with the ability to maintain input and output accuracy over several repetitions. An ABMS problem model is capable of deterministically producing identical outputs for identical inputs. LOGICS behavior space allows confirmation of model precision before PABMS begins.

The PABMS experiment is stochastic because players react to inputs in a variety of ways. Unexpected results were examined for logical errors, “bugs” and nonconforming player behavior. Logical errors can be corrected easily. Player input data were extracted from the player data file. These extractions were then processed by the behavior space generator to generate a new output data set. Nonconforming player behavior was addressed in future designs by filtering out non-conforming commands. PABMS can be repeated using captured input data thus increasing the accuracy of the output data.

Ideally, the resolution of the input should equal the resolution of the output. LOGICS computational approach ensured resolution consistency. Sampling rate deals with the separation between adjacent samples. LOGICS SBG used Sterman’s discrete synchronized transaction approach this insured proper separation of adjacent samples. Consistency deals with the issue of different units of measure for different stages of the simulation. LOGICS SBG single product approach avoids the problem of consistent units. Completeness deals with the issue that all data that should be present is present. LOGICS SBG uses the same number of product orders for each trial. Model completeness deals with the issue of missing information for subsets of the model. LOGICS duplicates the entire SBG model, thus ensuring the complete data model is present.

5.11 Rapid Prototype Multi Design (RPMD) Sample Space

Deciding on the approach and dimensions for the sample space of a RPMD ABMS is challenging. The first decision was what approach to use for recruiting participants for the LOGICS design research experiment. It was assumed that generating a sequential set of designs would require an extended period of time. It was anticipated that analysis and design improvements between sequential designs could require an unpredictable amount of time. The evolutionary nature prevented randomly assigning people to one design in a design set. This added a quasi- experiment dimension to the research. This would make it hard to maintain a stable group of participants across multiple designs. It was decided that each experiment would be an encapsulated stand-alone experience. The total time involved from game login to completion of exit survey should require no more than two hours. It was decided to describe the experiment as a game during participant recruitment. All recruits were referred to as players and clinical terms such as subject or participant were avoided. This helped set a theatrical context for the experiment.

5.12 Sample Size and Recruitment

Three students played each LOGICS design. Players were restricted to the testing of one design. Each player was allowed to repeat a one hundred four (104) interaction business cycle five times. Each repetition is considered to be one trial. A trial is the unit of analysis. Related ABMS research found the SBG was highly resistant to reinforced learning techniques. Significant learning often required in excess of 100,000 interactions (Valluri et al., 2009). The goal was to design a LOGICS game where a player obtained the learning objective while being limited to only five hundred and twenty (520) interactions. Each LOGICS design data set consisted of fifteen (n=15) trials. A successful LOGICS design must produce at least one trial that has a total system inventory cost that was equal or less than the optimal value described by Sterman (Sterman, 1989, p. 329).

“Random sampling is virtually impossible” (Miles & Banyard, 2007). Many books have been written on the subject (Cochran, 1977; Kish, 1965). LOGICS designs were designed sequentially. LOGICS uses circumscribed design cycles where test data collected from a previous design is necessary to generate a new design. The time between designs was erratic and often lengthy. Some designs took several semesters to prepare for testing while others were ready for test immediately. A complete set of testable designs required by traditional randomization techniques just was not feasible. Time constraints dictated a modest number of designs and a modest sized sample.

A purposive sample of students was recruited from a steady stream of applicants for intern positions on an as needed basis. Intern applicants were from a wide variety of majors: engineering, computer science, business, policy/planning and liberal arts. Their academic levels varied from undergraduate to Ph.D. candidate. The applicants were given the option of including the game as part of their interviewing process and were allowed to examine a consent form. They were informed there would be an exit survey at the completion of the game. The exit survey would be conducted under their avatar name. The game score would not be a factor in their interview evaluation. They were also told they could request to have their avatar name removed from a public Web scoreboard at the completion of the game.

There was no direct recruiting for the research. While this approach has some randomization issues that may raise some sample of convenience concerns, it can be argued that the rigor of this method equals or exceeds the sample selection process used by Sterman (1989). Sterman restricted his players to a single trial. He used eleven (n=11) trials from a forty-four (n=44) trial data set in the analysis of his board game. Due to manual data collection problems Sterman found that trials with the largest total systems costs were most prone to manual data collection errors. The final sample of eleven is biased towards those who understood and performed best in the game (Sterman, 1989, p. 328).

5.13 Statistical Analysis (Approach)

Kristin Cobb, Clinical Assistant Professor with Health Research Policy at Stanford University says the first rule of statistics: "USE COMMON SENSE! 90% of the information is contained in the graph"(Cobb, 2011September 28, 2011 lecture, slide 13, Looking at Data). North and others warned about the difficulty of using traditional statistical techniques on ABMS time series data sets that often don't fit into known distributions. (North & Macal, 2007, p. 269).

North and Macal (2007) determined estimating the true mean from a time series generated by a stochastic model was not a simple task. The sample mean is an average of a limited number of values in a time series. Unlike the assumptions made in elementary statistics that all samples are independent and identically distributed, the results of time series models have a large degree of dependency and autocorrelation. Analysis for this type of data is very sophisticated and difficult. Most spreadsheets and simple statistical packages required expensive additions to do this kind of work. Non-parametric, sometimes called assumption-free, statistics can properly be applied in many situations where parametric assumptions are difficult to support. Unfortunately, ABMS researchers often use parametric statistics when their data does not belong to a particular distribution. This is inappropriate and can result in misplaced confidence in statistical results (North & Macal, 2007, p. 269).

The unit of analysis is a trial. Each LOGICS trial generates a time series of one hundred and four (104) values of total system inventory cost, one value for each interaction. The entire data set can be described as a two dimensional (75 x 104) array containing 7800 values. The first and last ten values for each trial were dropped to eliminate startup or closeout boundary effects. This reduced the data set for all designs to a two-dimensional (75 x 84) array containing 6300 values. Total system inventory cost is a single value computed by the sequential summing of the inventory cost for all trial interactions. This allows the last value of a trial to be used as a proxy for the trial. This reduced the sample data set to a (75 x 1) data array. That can be transformed into a two dimensional (5x15) array; one row for each of 5 designs with fifteen end-of-trail values per row. The reduced data set can also be transformed into a three dimensional array (5x3x5); One row for each of five designs, one column for each of three players, and one value for each of five trials per player. Box plots were used examine the (5x15) array for outliers. Outliers were eliminated in a manner that maintained equal sample size as recommended in Miles and Banyard (Miles & Banyard, 2007). The result was a (5x14) array for each design.

Two methods are traditionally used to determine if a distribution can be assumed to be normal; the Kolmogorov-Smirnov (K-S) and the Shapiro-Wilk (S-W) test. Sometimes these two tests return conflicting results. The K-S test works well for a variety of distributions. It is an exact test that can be used on small samples. Under certain conditions the test can be very conservative and may fail to detect deviations from the normal distribution. Lilliefors used a Monte Carlo Simulation to calculate an adjustment to make this approach more sensitive (Lilliefors, 1967). The Shapiro-Wilk (S-W) test was developed to specifically test for normality. This test is quite sensitive to a wide range of non-normalities and is especially sensitive to asymmetry, long-tailedness and to some degree of short-tailedness. In a case study of 500 samples, the S-W test demonstrated greater power than K-S at detecting deviations from normality (Field, 2009a; Shapiro & Wilk, 1965). In case of conflict this research deferred to the (S-W) test.

There are two different methods of organizing test groups: subject-subject (repeated measure design) and between-group (independent design). Each requires a different type of t-test. A repeated measure design would be difficult to sustain over the several semesters necessary for this research; it is also known to generate practice effects, sensitization effects and carry-over effects.

Independent design (between-group) eliminated the need to sustain a test group for an extended period of time. Each LOGICS game design was tested by an independent group of players. No player was allowed to play more than one game. Several repetitions of one design by the same player may tend to raise concerns about learning effects. This research project was designed to test the learning effects of five learning object techniques using a modest number of learning cycles. The counterintuitive nature of the SBG tends to resist learning effects. Numerous ABMS reinforced learning research publications discussed in Section 2.5.3 confirmed this specific SCM problem is extremely resistant to reinforced learning, often requiring over 100,000 learning cycles before significant improvement in performance was observed (Valluri et al., 2009). In this research, the sample data for each LOGICS design is considered to be independent.

6. Results

The LOGICS ISDT process artifact used circumscriptive design cycles to produce five PABMS online game instantiations. All PABMS game designs demonstrated strong internal validity. Each game demonstrated differing degrees of learning object effectiveness while accurately duplicating Sterman's SCM behavior model. All PABMS game designs were capable of producing trial-ability that can be duplicated and demonstrate observable economic results.

6.1 Analysis (Exploring the Data)

The proxy (5x15) array was explored for statistical properties. Box plots revealed some outlier issues. Design1, Design2 and Design5 were found to have outliers. Figure 19 is a box plot comparison of all five designs using fifteen data values.

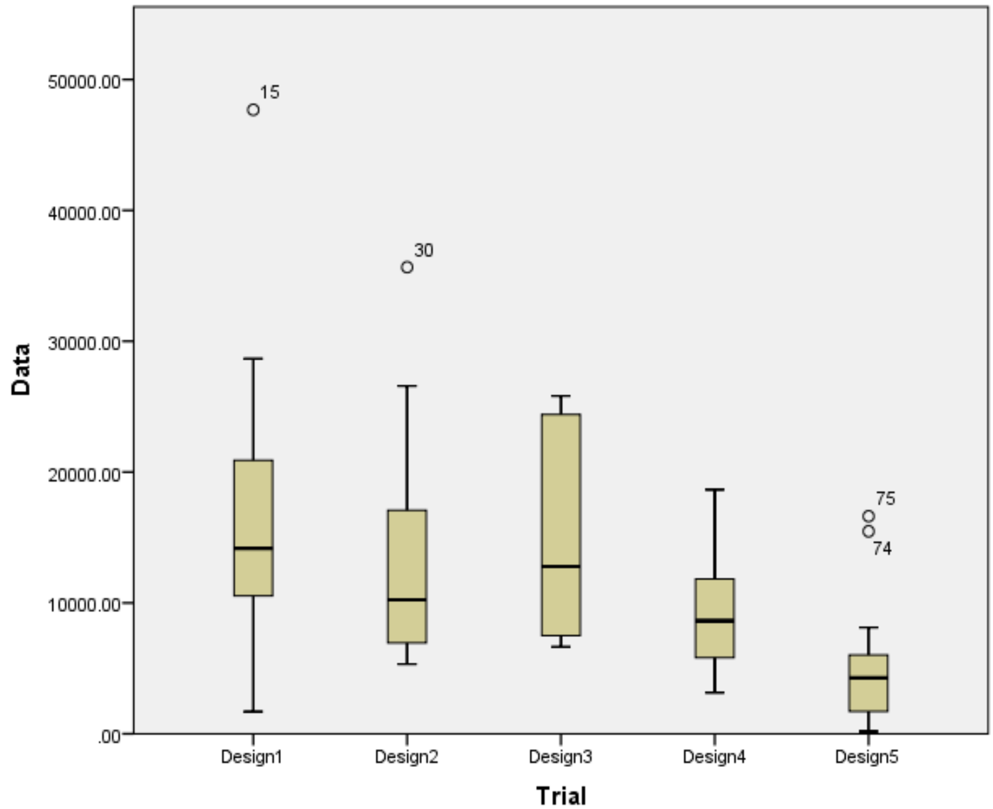

Figure 19. Box Plot of all Five Designs (15 Data Points)

One outlier was removed from each design, reducing the size of the data array to (5 x 14). Two outliers in Design5 were retained to keep sample sizes equal, thus mitigating possible homogeneity of variance issues (Miles & Banyard, 2007, p. 146). Figure 20 is a box plot comparison using fourteen data points.

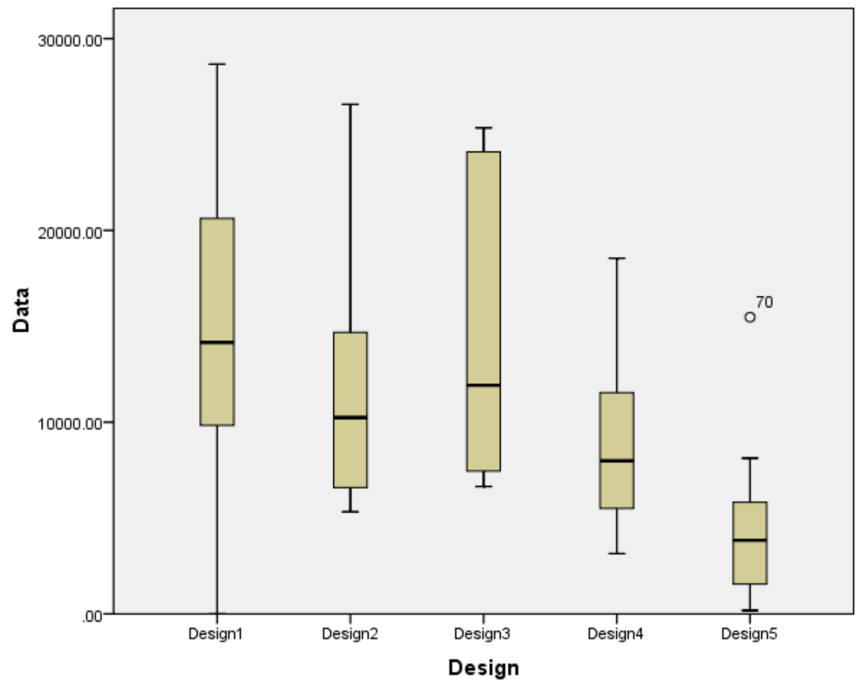

Figure 20. Box Plot of all Five Designs (14 Data Points)

The removal of one outlier reduced the range of the data analysis space by twenty thousand (20,000) units without disturbing the fundamental relationships between the various designs. Preliminary observations indicate that players of Design2 (repetition and coaching) performed better than players of Design1 (repetition only). Players of Design3 (PC ordering option added to Design1) appeared to have performed worse than players of Design1 and Design2. Players of Design4 (HPC ordering and hint added to Design3) appeared to perform better than players of the previous three designs. Players of Design5 (per order feedback information added to Design4) appeared to have outperformed players of all other designs.

The sample data appeared to be ready to accommodate statistical profiling.

6.2 Summary of Analysis

The analysis began with the assembly of a basic set of descriptive statistics for each design. The set consisted of: Sample Mean, Sample Median, Sample size, Std. Error of Mean, 95% Confidence Interval for Mean, Std. Deviation, Skewness, Kurtosis, Kolmogorov – Smirnov (K-S), and Shapiro-Wilk (S-W) normality test statistics. The assumption of normality did not hold for all designs. The LOGICS product instantiations produced a progression of positively skewed data samples. The degree of skewness of the data sets was examined to determine if parametric or non-parametric testing was appropriate.

Statistical exploration was performed on the data sample of each design. Design1, the SBG with repetition, was normally distributed. Design5, the best performing design, was highly skewed. Non-parametric testing was required to statistically compare the performance of the two designs. Non-parametric testing will be described in Section 6.5. Parametric t-testing was also performed and generated a set of results very similar to the findings of non-parametric testing. T-testing details are discussed in Appendix C.

Figure 21 is a summary of the statistical exploration for all five Designs. The histogram with a normality plot overlay gives insight into the skewness introduced by game manipulations. The frequencies of the histogram add up to the sample size of fourteen (14). The basic set of statistics is included in the figure; along with a summary of the t-testing results.

All LOGICS players were given the same objective of reducing total system inventory cost to a minimum. A positively skewed frequency distribution provided visual evidence that a system dynamic was at work, keeping the total system inventory cost below average performance levels. The Kolmogorov-Smirnov (K-S) and Shapiro-Wilk (S-W) normality tests were used. This research used modest sized samples in a rapid prototyping approach. The S-W test statistic yields exact significance values and was developed to specifically deal with the normal distribution of a small sample. It is quite sensitive to a wide range of non-normality (Field, 2009b, Chapter 5). In general the S-W is more accurate (Field, 2009a, p. 546). When the K-S and S-W test values do not agree, in this research, the S-W result was used.

Based on this data exploration, it was determined that the comparison of Design1 (Sterman with repetition only) to Design5 (the most successful design) was the critical comparison and needed to be conducted using non-parametric techniques. The results of the non-parametric testing are discussed in Section 6.5.

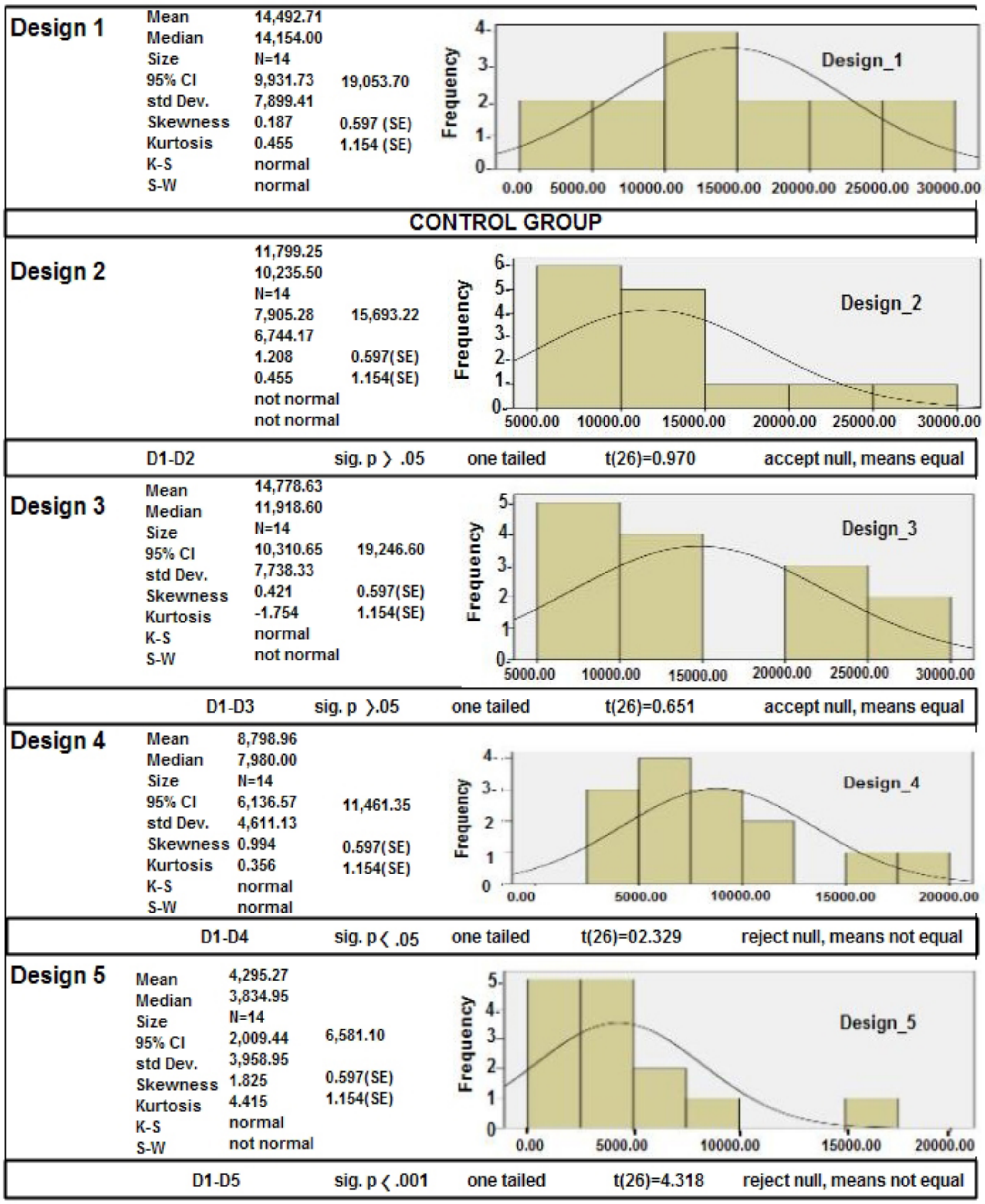

Figure 21. Summary of Statistical Analysis

6.2.1 Analysis of Design1

Sample Mean = 14493

Sample Median = 14154

Sample Size N = 14

95% Confidence Interval for Mean (9931, 19053)

Sample Std. Deviation = 7899

Sample Skewness = .187, (Std. Error of Skewness .597)

Sample Kurtosis = -.479, (std. Error of Kurtosis 1.154)

K-S test statistic, D (14) = .110, $p > .05$

S-W test statistic, W (14) = .976, $p > .05$

Both tests agree this sample distribution is normal.

The mean of Design1 was higher than expected, approximately seven times greater than the Sterman average performance level of 2028 (Sterman,1989, p. 329). Sterman admitted to having difficulty in data collection. Due to the highly accurate data collection capabilities of a LOGICS design, it was decided to use Design1 as the control group for this research rather than the Sterman average. The highly normal distribution of the Design1 data set supports the assumption that in the short run all trials can be considered independent.

6.2.2 Analysis of Design2

The game structure of Design2 added face-to-face coaching to Design1. At the end of each business cycle, an instructor conducted a coaching session. The coaching content was highly structured. A coach read from a script that was identical to the instructions that were displayed on wall murals of the retail GUI.

The same statistical analysis techniques were used to analyze Design2. A single outlier was removed reducing the data set to fourteen (n=14).

Sample Mean = 11799

Sample Median = 10236

Sample Size N = 14

95% Confidence Interval for Mean (7905, 15693)

Sample Std. Deviation = 6744

Sample Skewness = 1.208, (Std. Error of Skewness .597)

Sample Kurtosis = .455, (std. Error of Kurtosis 1.154)

K-S test statistic, D (14) = .266, $p < .05$

S-W test statistic, W (14) = .844, $p < .05$

Both tests agree this sample distribution is not normal.

6.2.3 Analysis of Design3

Design3 added a PC ordering option to Design1. A small fee is added to the total system inventory cost each time this method is selected.

The same statistical analysis techniques were used to analyze Design3.

Sample Mean = 14778

Sample Median = 11918

Sample Size N = 14

95% Confidence Interval for Mean (10310, 19246)

Sample Std. Deviation = 7738

Sample Skewness = .421, (Std. Error of Skewness .597)

Sample Kurtosis = -1.754, (std. Error of Kurtosis 1.154)

K-S test statistic, D (14) = .186, $p > .05$

S-W test statistic, W (14) = .817, $p < .05$

S-W test indicates the distribution is not normal.

6.2.4 Analysis of Design4

Design4 added an HPC ordering method to Design3. The player GUI was slightly altered to add a fee for using HPC. A hint was added to the wall poster to explain four repetitions of any technology choice was necessary before the effect could be evaluated. An Invisible change was made to the control logic. The first four orders were locked to 4 product units to insure compliance with the game initialization instructions. Players in Design3 did not properly follow reset instructions and reset the game at inappropriate times. The reset option was disabled until order 104 to ensure that games were played to completion. Design 4 invoked the game's only behavior modification rule when HPC was selected.

The same statistical analysis techniques were used to analyze Design4.

Sample Mean = 8799

Sample Median = 7980

Sample Size N = 14

95% Confidence Interval for Mean (6136, 11461)

Sample Std. Deviation = 4611

Sample Skewness = .994, (Std. Error of Skewness .597)

Sample Kurtosis = .356, (std. Error of Kurtosis 1.154)

K-S test statistic, $D(14) = .165$, $p > .05$

S-W test statistic, $W(14) = .910$, $p > .05$

Both tests agree this sample distribution is normal.

During a post-performance analysis, a bug was discovered in the HPC agent modification rule calculation. During game play, it was noticed that the HPC selection had less effect on the total score than was expected. A

BSG session and manual instructor testing was used to eliminate the bug. When the instructor selected the HPC option for every order, the resulting score was not the Sterman optimal score. Examination of the code revealed a logical error in selecting the HPC ordering method. The code was corrected. The instructor repeated the manual selection of HPC for every order cycle. The optimal score was generated. The data captured during the player session was resubmitted to the simulation. The results were more consistent. The corrected output file was used for all analyses.

6.2.5 Analysis of Design5 (Successful Design)

Design5 was the GUI from Design4. The difference was the use of feedback. Design5 provided the player with performance information from an optimal model on an order by order basis.

Sample Mean = 4295

Sample Median = 3833

Sample Size N = 14

95% Confidence Interval for Mean (2009, 6581)

Sample Std. Deviation = 3958

Sample Skewness = 1.825, (Std. Error of Skewness .597)

Sample Kurtosis = 4.415, (std. Error of Kurtosis 1.154)

K-S test statistic, D (14) = .208, $p > .05$

S-W test statistic, W (14) = .835, $p < .05$

S-W test statistic indicates the distribution is not normal.

Figure 22 shows the set of performance traces for the most successful of all fifteen players. The chronological order of a trace is identified by a trace number. Trace 1 represents the first game attempted by player 1. The end values of the traces are used for statistical purposes. The traces themselves provide a pattern of the method of play. The slope provides information on the ordering method being used in that section of the trial. Steep slopes occur when heuristics dominate. Moderate to flat slopes occur when investments dominate. Player 1 hops around aimlessly between all ordering methods for the first 20 orders of trace 1. The slope flattens out during heavy investing period between 20 and 30 orders and then takes off during a manual ordering block between 30 and 40 orders. A large block of pc investing between 40 and 60 orders begin to flatten the slope. HPC investing from 60 orders to 84 flatten the slope until it is almost horizontal; ending at a value slightly above 4000. This was the best trial one of all the players. This was the best performance of all the players. All five traces for this player fell below an ending value of 5000. Traces 4 and 5 visually overlapped and create two horizontally traces at 178; the learning objective. A summary of all traces for all three players of Design5 is in Section 6.6 Player Patterns.

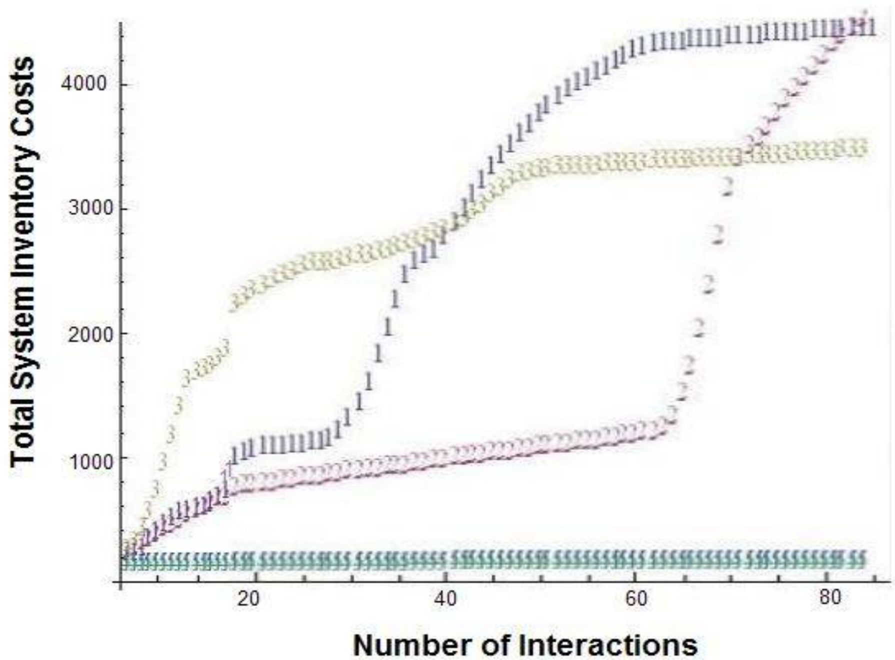

Figure 22. Traces for Player 1 Design5

The Figure 22 displays eighty four (84) interactions rather than the full one hundred and four (104) business cycle interactions. The first and last ten values were discarded from each business cycle trial to eliminate startup and completion boundary anomalies. Sterman used a Monte Carlo simulation to determine his optimal value for 104 interactions. This produced a total system inventory cost of $204. He determined the parameter values to produce this result. A LOGICS BSG deterministic simulation validated his parameters. The statistical analysis will discuss a value of 178. This is due to analysis truncation eliminating the last 10 values.

6.3 z-score

Field (2009a, p. 796) defines a z-score as the value of an observation expressed in standard deviation units. It is calculated by subtracting the observation from the mean of all observations, and dividing the result by the standard deviation of all observations. This converts the distribution of the observations into a new distribution that has a mean of 0 and a standard deviation of 1.

Certain z-scores are particularly important because they are used to calculate important regions of the distribution. Taken together, 95% of the z-scores lie between the cut-off values of plus and minus 1.96. Two other important regions are where: 99% of the z-scores lie between the cut-off values of plus and minus 2.58, and where 99.9% of the z-scores lie between plus and minus 3.29 (Field, 2009a, p. 26). These cut-off values are often used to examine distributions for the presence of outliers (Field, 2009a, p. 102). SPSS output for Mann-Whitney and Wilcoxon rank-sum non-parametric tests for two independent-conditions provide z-scores as part of their output test statistics.

6.4 Effect Size

Effect size is the name for a family of indices that measure the magnitude of a treatment effect The APA Publications Manual 6th Edition strongly encourages the use of effect sizes (Baggs & Froman, 2005). Effect sizes are important because they provide a standardized measure that can be compared across different studies that have measured different variables and used different scales of measurement (Field, 2009a, pp. 56-57). Many ways to calculate effect size have been proposed. Field prefers Pearson's correlation coefficient *r*; because it provides constrained values between 0 (no effect) and 1 (perfect effect). Effect sizes are useful because they provide an objective measure of the importance of the effect. The scale suggests: an r = .10 (small effect) represents 1% of the total variance, r = .30 (medium effect) represents 9% of the total variance, and r = .50 (large effect) represents 25% of the total variance. Field (2009a, p. 550) uses the method in Rosenthal (1991, p. 19) to compute r; he divides the z-score by the square root of the number of observations.

6.5 Non-Parametric Testing (Design1 - Design5)

Many of statistical tests make parametric assumptions about the normality of the sample data. ABMS time-series data is often unfriendly and does not always conform to any known set of distributions. Sometimes it is not possible to transform the sample data set to a known distribution.

Non-parametric testing is often referred to as assumption-free testing. Technically, that isn't true: they do make assumptions about the distribution being continuous (Field, 2009a, p. 540). Geyer (2003, pp. 5-6) goes even further, stating that Wilcoxon non-parametric testing may not require any particular shape for the distribution. But, the distributions are assumed to be independent, with no tied ranks (continuous) and identically symmetrical.

The two LOGICS observation sample distributions of interest are not identically symmetric. For reasons of consistency, this research will defer to Field (continuous). If there is a difference between two conditions and different participants have been used in each condition, the Mann-Whitney and the Wilcoxon rank-sum tests can be used. The Mann-Whitney test and the Wilcoxon rank-sum test are the non-paramedic equivalent of the independent t-test. Figure 23 demonstrates the ranking manipulations necessary for this type of the non-parametric testing.

Rank #	Group	Score	D1	D5
1	D5	178.3		1
2	D5	179.3		2
3	D5	1467.8		3
4	D5	1554		4
5	D1	1688.5	5	
6	D5	1857		6
7	D5	2863.8		7
8	D5	3393.3		8
9	D5	4276.6		9
10	D5	4355.6		10
11	D5	4362.4		11
12	D1	4425.5	12	
13	D1	5540	13	
14	D5	5821.8		14
15	D5	6224.6		15
16	D5	8118.3		16
17	D1	9838	17	
18	D1	11253.5	18	
19	D1	12275	19	
20	D1	14145	20	
21	D1	14163	21	
22	D5	15472		22
23	D1	16300	23	
24	D1	16583.5	24	
25	D1	20623	25	
26	D1	21166	26	
27	D1	16225.5	27	
28	D1	28672.5	28	
Sum			278	128

Figure 23. Parametric Data

The scores from the Design1 and Desing5 are merged and ranked. Each score is assigned a rank value as indicated in the Rank # column. The column begins with the value of 1 at the top of an ascending list. After the ranks are assigned, the rank scores are separated and listed in their appropriate column, either D1 or D5. The two columns are then summed. The smallest sum is used as the Wilcoxon test $W_{s.}$ A simple calculation can be used to convert the Wilcoxon W_s to the Mann- Whitney U test statistic.

Sample Size for Design1 and Design 5 = 14

Number of Observations = 28

Sum of the ranks for Design1 $\sum R_{\text{Design1}}$ = 278.00

Sum of the ranks for Design5 $\sum R_{Design5}$= 128.00

When the two data sets are of equal size the smallest sum is designated as the Wilcoxon test statistic (W_s) = 128 (Mean = 203, Standard Error = 21.76).

The Mann-Whitney U = 23.

z = -3.447, p < .000 (1-tailed)

r = - 0.65

Field (2009a, p. 544) recommends using a z-score to determine if the Ws test statistic is significant. Field's z-score calculation uses Ws, W_s mean and W_s standard error. This method produced a z-score = - 3.446, which agrees with the value generated by SPSS, -3.446, p < .000 (1-tailed). A z-score of -3.446 is clearly and outlier. The W_s is clearly significant.

The *z*-score produced by SPSS (-3.446) and the number of observations (28) can be used to compute the effect size r. This approach was recommended by Field and described in Section 6.3. The effect size was computed to be r = - 0.65. This result agrees with the result in the SPSS non-parametric test output.

The summary of results uses a format suggested by Field (Field, 2009a, p. 550). He suggests reporting the median for each condition rather than the mean for non-parametric tests.

The total system inventory costs for Design1 (Mdn = 14154) were significantly higher than total system inventory costs for Design5 (Mdn = 3834), $W_s = 128$, $z = -3.447$, $p < .000$, $r = -0.65$. Player performance for Design5 was significantly better than player performance for Design1.

6.6 Evaluation (Overview)

North and others warned about the difficulty of using traditional statistical techniques on ABMS time-series data sets that often don't fit into known distributions (North & Macal, 2007, p. 269). The evaluation of LOGICS ISDT process and product artifacts did not require the examination of mathematical formulas or logic-based arguments. Instead, it was evaluated on the results generated by five learning object game instantiations (Gregor & Jones, 2007). Five LOGICS designs were developed into five LOGICS PABMS rapid prototypes. These five prototypes generated data that was examined for evidence of an ability to quickly alter the behavior (actions) taken by players of the classic SBG. Effective learning objects generate highly skewed data. Traditional statistical exploration was able to determine that players of Design5 performed significantly better than players of Design1. The total system inventory costs for Design1 (Mdn = 14154) were significantly higher than total system inventory costs for Design5 (Mdn = 3834), W*s* = 128, z = -3.447, $p < .000$, r = - 0.65.

Three players of Design1 were allowed to repeat the SBG five times using only manual ordering techniques. Three players of Design5 were allowed to play the SBG using three ordering techniques: manual ordering, buying a local order from a PC, or buying a system-wide order from an HPC. For decades players of the SBG have focused on managing local issues and elevated the risk of the entire supply chain. The lack of systems thinking causes supply chains to perform at suboptimal levels. Unnecessary waste is incurred at all levels of the chain due to unwanted perturbations in product flows (Camerer, 1995, p. 594). This local overconfidence was the reason for the failure of many small firms. The players of Design 5 were given the technology and information necessary to eliminate these perturbations and operate rationally at optimal levels.

The pattern of play for all fifteen LOGICS players was to experiment for two or three trials and then commit to an approach on the last few trials. During their last two trials, all three players of Design5, invested in IT ordering 70% of the time. One of the players obtained the research learning objective of optimal performance on their fourth and fifth trial. This level of IT investment combined with the analysis results of Section 6.5 provides evidence that the answer to the general research and the learning objective questions are both "Yes."

6.7 Player Survey

The player post experience survey used a Likert scale from 1 (easy) to 10 (difficult) for a full list of questions (See Appendix A). There were six perceived ease of use (PEOU) questions and six perceived utility (PU) questions used in the survey. Four questions, two from each category, were omitted from the analysis due to missing data. Figure 24 contains a summary of the results of the Player Survey.

Topic	Mean	Group Mean	Group Std.
PEOU1	3.67	3.133	1.18
PEOU2	2.47	3.133	1.18
PEOU3	2.00	3.133	1.18
PEOU4	4.40	3.133	1.18
PU1	5.53	4.617	1.69
PU2	3.37	4.617	1.69
PU3	3.93	4.617	1.69
PU4	5.27	4.617	1.69

Figure 24. Player Survey Summary

PEOU has a mean $\bar{X}$ = 3.133 and PU has a mean $\bar{X}$ = 4.617. The lower score for PEOU indicates that players felt the game was easier to use than understand. This is not surprising since many of the players were not business or economics students.

Bivariate correlation analysis was used to determine the influence of PEOU and PU on each player's score. Perceived Ease of Use ($\bar{X}$ = 3.133, SE=.0303) accounted for 13% of the variability. Perceived Utility ($\bar{X}$ = 4.617, SE=0.4364) could account for only 0.6% of the variability.

7. Discussion

Simon (1969, pp. 17-22) believed that simulations could expand our knowledge of poorly understood systems by: teasing out the consequences of assumptions, extracting knowledge from individual inner system components, and demonstrating the behavior of their collective interaction.

This LOGICS ISDT process makes extensive use of simulation. A simulation in the form of a game appears to have the additional capability of moving players from one solution space to another. Sterman used a simple board game simulation to collect data that he used to develop an SCM behavior model. He was able to tease out a four-parameter description of the system dynamics and confirm the presence of "anchor and adjust" behavior predicted by behavioral scientists (Davis, et al., 1986).

LOGICS used its PABMS simulation capability to more accurately measure the dynamic range between average and optimal performance for players of the SBG. LOGICS used a theatrical GUI user interface and two traditional learning object techniques, to move players from a local "anchor and adjust” solution space to a system “see a rabbit and chase it” solution space. Immediate feedback amplified loss aversion concerns causing players to aggressively invest in technology and chase optimal system performance.

The primary research question was: “Can an online game player learn to abandon intuitive reactions to local events in favor of investing in system solutions provided by information systems?” A learning object lens was used to evaluate the LOGICS experiment. Design5 demonstrated improved levels of player performance

LOGICS designs will assist in bridging the gap between theory and application in many fields. The initial problem was a classic SCM problem. Sterman developed a behavior model that that explained how in a simple system heuristics, “anchor and adjust” human behavior and the bullwhip effect interact to generate complex dynamics. LOGICS produced an online game product that helps people to understand how information technology can be used to reduce supply chain waste. The LOGICS approach of using theatrical techniques to create new action altering interactive games can be expanded to address other behavioral economic dimensions of complexity in all fields of natural and social sciences.

7.1 Design Comparison

Five game designs were used to collect experimental data for different combinations of repetition and feedback. The power of these combinations was evaluated based on their ability to accomplish the learning objective. Design1 generated highly symmetrical data with minimal skewness and kurtosis. It was used as the control group. Design2 added face-to-face coaching to Design1 and generated a minor improvement in game performance. Design3 added a local PC ordering option to Design1. A small fee was added to total system inventory cost when this option was selected. Design4 added a High Performance Computer (HPC) ordering option to Design3. The fee charged for the HPC was 2.5 times larger than the fee charged for the local PC. Design5 was visually identical to Design4. The difference was in the feedback. Every order the minimal total system inventory cost was computed and displayed on the GUI Instructions monitor. This allowed the player to evaluate their total cost performance (TSC) on an order-by-order basis to the optimal TSC. This approach was suggested by Rittel and Webber (1973). Design5 was the best performing design. Players quickly abandoned manual ordering and invested aggressively in HPC.

7.1.1 Design1 (Control)

Sterman wanted to teach people that a simple system can generate complex dynamics. He wanted to confirm that people quickly anchor on local linear heuristics that generate system level perturbations in order and product flow. He wanted to confirm that customer demand distortions are amplified as they flow cyclically between Retailer and Factory. Design1 was simply a PABMS simulation of the SBG. A BSG deterministic ABMS confirmed Design1 duplicated the behavior of the board game.

When Design1 was tested in PABMS mode, the stochastic dimensions of the problem began to reveal themselves. The average performance level for Design1 was seven (7) times larger than the SBG published average performance level. Mosekilde and others had demonstrated that this type of behavior was possible. They discovered the SBG "parameter space to have an extremely complex structure having a fractal boundary between the stable and unstable solutions, and with fingers of periodic solutions penetrating deeply into regions representing quasiperiodic and chaotic solutions" (Mosekilde et al., 1991, p. 199). The distribution of the Design1 trial data was normal. The variance of the data was higher than typical Gaussian distributions. This may be demonstrating the near panic behavior described by Sterman (Sterman, 1989). A simple Mathematica model reproduced the LOGICS results (Chang, 2010). One possible reason for the wide fluctuations is the asymmetry of the stocking cost structure. The penalty for stock shortage is four times as large as the cost for storing stock. This may lead to an overreaction to potential stock shortages. Sterman based his behavioral model on Forrester's servo mechanical 23^{rd} order differential equation. Servo mechanical systems perform best when changes are smooth and laminar (Forrester, 1958). Abrupt reactions would deliver shock to the system and exaggerate unwanted perturbations and increase the variance.

Due to data set errors generated by manual data collection, Sterman restricted his sample data to players that understood and played it best. In the current study, Design1 was used as the benchmark for learning and control group for statistical testing. The Sterman optimal performance was retained as the learning objective.

7.1.2 Design2

Design2 added face-to-face coaching to the SBG. Game performance improved. One possible explanation is that the interaction had a calming effect on the player. More time between trials increased reflection on game rules and may have improved player understanding of the challenge. Design2 did establish the PABMS approach could be used constructively in traditional instructional environments

7.1.3 Design3

Design3 added a PC ordering option to the Design1 GUI. For a small fee, the PC option computes an optimal retail order for a specific order cycle. Players rarely exercised the PC option and player performance was surprisingly worse than player performance for Design1.

In a post-experiment exercise the researcher used Design3 in order to study the economic impact of various PC ordering patterns. The first study examined an ordering pattern that used PC ordering exclusively. Orders five (5) through one hundred and four (104) were purchased using the PC ordering method. Besides looking at total system inventory cost; the impact on each tier was examined. The Retailer benefited the most from this approach, absorbing only 10% of the total system inventory costs. The Factory absorbed the highest increase in costs. This is a powerful incentive for retailers to focus on local performance and ignore system performance. A second retail ordering pattern study compared a 50/50 mix of manual versus PC ordering. Total system inventory costs approached Sterman's average system performance level. Retail inventory costs were reduced compared to Retail costs in Sterman's average performance level. This raises an interesting question on the impact of highly rational Retailers (e.g.) Wal-Mart has on their suppliers.

There has been a significant amount of research published about the damage created by irrational SCM. Little has been published about the damage done by inter-chain rationality gaps. This raises some interesting questions on the ability of a Retailer to manipulate the margins of the entire chain.

LOGICS automatic real-time data collection technique captured an accurate record of these studies. The BSG imported the captured data and recreated the game allowing the creation of a digital video that could be displayed and analyzed off-line.

7.1.4 Design4

Design4 added a high performance computing (HPC) ordering option to Design3. High performance computing (HPC) generates system-wide rationality. An additional hint on the poster encouraged the players to place several sequential orders before evaluating the benefits of a technology investment. The HPC option activates the only agent behavior modification rule used in this research. All supply chain agents are set to values that make them perfectly rational for a single order. There is no exchange of information between supply chain tiers. There is no increased trust necessary between tiers. At the end of the order cycle, agents revert to their prior parameter values. Each tier computes the optimal value for that order cycle.

Preliminary analysis of the experimental data demonstrated behavior not predicted during deterministic testing. The PABMS code was examined and was found to have an error in the HPC calculation of total system cost. A correction was made and the full data set file was fed back through the simulation behavior space. A new output file captured the corrected scores.

It was determined that the data was skewed sufficiently to fail both tests for normality. This design was a candidate for nonparametric testing. This was not done due to the strong performance of Design5.

7.1.5 Design5 (Successful Design)

Design5 used the same player GUI as Design4. A different gaming experience was created by providing micro feedback at the end of each order cycle. The feedback consisted of supplying the player with the optimal total system cost at the end of every order cycle. This allowed the players to compare game performance to optimal performance (or a rational competitor) on an order-by-order basis. This type of feedback quickly changed player ordering actions. Dependence on manual ordering methods was reduced and investments in IT increased.

Visual inspection of the outcomes revealed the average performance level of the sample data set was much lower than the control group. The distribution of the data set was highly positively skewed towards lower costs. This high level of skewness affected assumptions of normality and influenced choice of statistical testing methods.

Non-parametric testing confirmed this form of manipulation has a strong effect on improved player performance. Visual inspection of the data sample revealed the performance of all three players improved by a factor of twenty (20). One player satisfied the learning objective requirement.

7.2 Answers to Research Questions

Several layers of research questions were used in the LOGICS project. The first layer is the broadest in scope and highest in importance. This layer consists of the general research question, the complementing hypothesis and ultimately an evaluation of the ability to obtain the learning objective. The second evaluation layer is less broad and uses a subset of research questions to assist in collecting and understanding the LOGICS project contributions to the ISDT research kernels. The third evaluation layer is narrow in scope and uses subsets of research questions to assist in constraining LOGICS instantiations to a set of meta-requirements. Figure 25 illustrates the three evaluation layers. Appendix B presents a summary chart of all three levels.

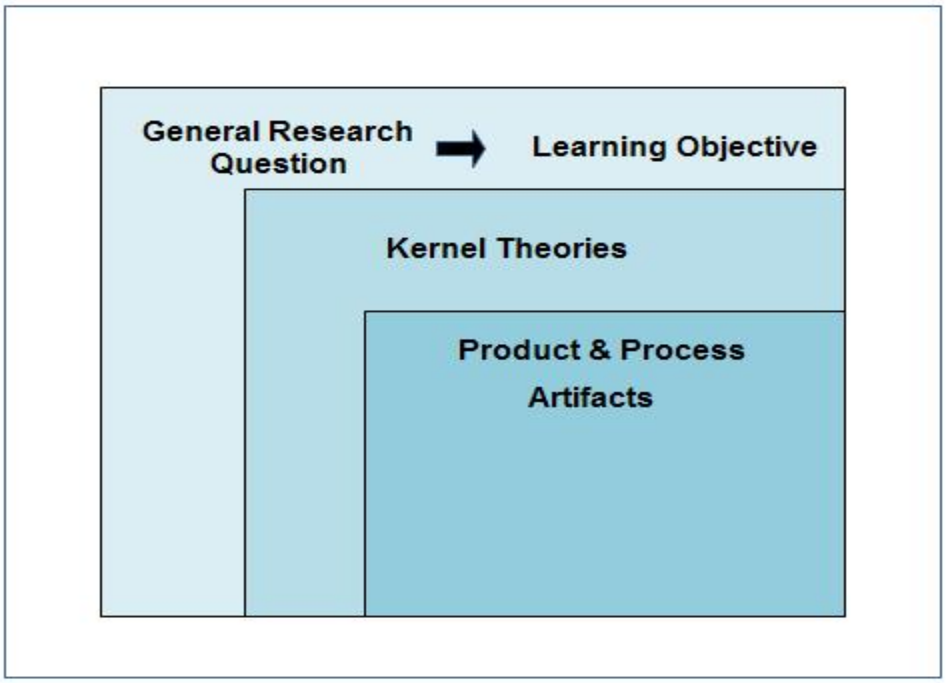

Figure 25. Evaluation Layers

7.2.1 General Research Question

Research Question: "Can an online game player learn to abandon intuitive reactions to local events in favor of investing in system solutions provided by information technology?"

The results in Section 6.5 describe how Design5 used a novel form of feedback to quickly change a player's ordering action. The major contribution to performance improvement was the feedback of information on an order-by-order basis that could be compared to a simulated optimal solution. All three players in Design5 invested in information technology and improved their performance over five trials by a factor of twenty-five (25). On trials 4 and 5, all three players invested in IT ordering 70% of the time. One player obtained the learning objective on their fourth trial and fifth trial. Design 5 provides evidence that the answer to the general research question is "Yes."

7.2.2 Kernel Theory Research Questions

A subset of five research questions was defined in Section 4.7.2 and was used to examine possible contributions to the kernel theories in the LOGICS project:

1. Cybernetics: Design5 confirmed that LOGICS artifacts are capable of generating a purpose seeking system.
2. Complex Business Dynamics: Design1 confirmed that LOGICS can create a dynamic version of the SBG.
3. Simulation: Design5 confirmed that a PABMS was capable of creating a learning object game.

4. Learning Objects: Design5 confirmed that the two learning object techniques of repetition and feedback could be used to alter player behavior.
5. Online Gaming: Design5 confirmed in that LOGICS artifacts could lead a player to discover the value of IT investments in obtaining the optimal solution to the SBG.

7.2.3 Process Artifact Research Questions

Section 4.1 and 4.7.3 presented a set of five ISDT process research questions to guide the development of process artifacts specific for the SBG problem environment.

1) Section 4.6 opened discussion on the use of the Behavior Space Generator (BSG) functional space to evaluate the deterministic properties of an ABMS SBG. The BSG was used to verify and validate the deterministic behavior of all five designs.

2) Section 4.6 opened the discussion on the use of the PABMS functional space to introduce a stochastic player element in the SBG. The PABMS functional space successfully introduced a stochastic retail human agent into all five designs.

3) Section 4.6 opened the discussion on the use of the PABMS functional space to move the gaming environment to an interactive stochastic parameter space. The parametric behavior of the five LOGICS designs generated a broad range of total inventory costs values. The difference between the medians of the best and worst design performance approached two orders of magnitude.

4) Section 4.6 opened the discussion on the ability of the PABMS functional space to accurately capture all relevant data. Captured PABMS data was used to analyze erratic game play, provide input for the statistical analysis and for animation generation.

The captured relevant data was later used to correct a software error (bug) in Design4. The first player of this layer generated unexpected results. Use of the HPC option did not generate the expected level of benefit. The NetLogo model was examined. An error was located in the calculation of total system cost. The error was fixed and the data set file was used to manipulate the BSG. Hand calculations confirmed the results. Data extracted from the data files of all five designs were loaded into the Analysis Space and traditional manual calculations were performed. Data from Design1, Design3, and Design5 were used to generate animations.

5) Section 4.6 began the discussion on the use of the analysis functional space. Extensive use of this functional space was discussed in section 6.0. In section 6.5, Design5 was compared to Design1 non-parametric testing.

7.2.4 Design Product Research Questions

Section 4.1 (Table 1) listed a subset of six research questions to guide the creation of a product artifact specific to the SBG problem.

1) It was confirmed that PABMS could use theatrical techniques to create a human computer interface (HCI). Laurel used design research to investigate how theatre, film and narrative can be profound and intimate sources of knowledge that generate actions with consequences. She argued that a dramatic approach was capable of supporting activities that create surprise and delight (Laurel, 1992).

2) All designs confirmed that the HCI was capable of accurately creating and manipulating a dynamic version of the SBG.

3) All designs confirmed that the HCI could accommodate the application of heuristics.

4) Design5 confirmed that the game could be structured to alter player behavior.

5) Design5 confirmed that the game was capable of convincing players to abdicate heuristics in favor of investing in rational decisions from information technology, thus creating a social purpose-seeking system.

6) Design5 confirmed that the game accelerated learning and adaptive action to complex system dynamics.

7.3 Limitations

The design and building of simulation instantiations was straight forward and provided a minimum of surprises. A methodology for understanding the effectiveness of the results is challenging.

The LOGICS ISDT was a quasi-experiment that lacked a key experimental ingredient, random assignment. The rapid prototyping approach uses small samples in order to cover the maximum number of designs in a minimum amount of time. There was often an extended period of time between designs. Simon (1969, pp. 18-20) felt that simulations are a source of new knowledge. Sometimes a simulation has a correct premise but it may be very difficult to discover what they imply. We must painstakingly and fallibly tease out consequences of our assumptions. This research project found that to be true.

One of the seminal papers that inspired the research suffered from high data collection errors. Traditional benchmarks had to be discarded and new ones had to be built. Successful LOGICS game instantiations produced highly skewed data sets required the use of non-parametric testing. These tests want data sets that are independent, and have identical symmetry. The LOGICS game instantiations produced highly skewed time-series data sets that are very difficult to analyze.

The traditional layering-up of challenges in response to improved performance was not used in this research. It was important to isolate the influence of the manipulations on a single isolated player.

There was extensive use of agents that do not learn (protoagents) in order to focus the study on the behavior of a single player.

A single agent behavior modification rule allows the Retail player to change the parametric configuration of the Wholesale (W), Distributor (D) and Factory (F) protoagents. Initially the W, D and F protoagents were set to Sterman's average play parameters. When a Retail player selects the HPC ordering option, the protoagents are set to the optimal performance parameters for one order cycle.

7.4 Future Research

Future research will explore the benefits of using traditional quasi-experimental analysis methodologies. Trial 1 will be treated as a pretest and trial 5 will be treated as a post test. This will allows multiple approaches will be evaluated to determine their abilities to assist in understanding the implications of the existing design set. Other topics to be explored are: Bayesian analysis, various forms of Meta-analysis and modified t-testing developed by psychologists to compare a patient's performance to a modest sample size (Crawford, Garthwaite, & Gray, 2004).

Future research will add more repetitions and players to Design1 and Design5. These data samples will be used to explore their impact on quasi-experimental and modified t-tests.

The exploration of a variety of gaming layering-up techniques, multi-player games and persistent duration of the game would assist in aligning the LOGICS approach with massive multiplayer online gaming. Future research will relax this constraint placed on the use of protoagents. Multiple human players will systematically replace the protoagents to increase the complexity of the LOGICS challenge.

The simple linear demand function can be replaced a sophisticated parameter space capable of using actual demand data generated by an enterprise of interest.

Newer releases of NetLogo will have semiotic interfaces that allow integration into sophisticated gaming spaces and sophisticated programming interfaces that use color to assist in the reduction of programming errors such as declaration of maverick variants on variable name declarations. A new Mathematica interface will be created to integrate simulation control and analysis.

8. Implications

The general research question asked: ***"Can an online game player learn to abandon intuitive reactions to local events in favor of investing in system solutions provided by information technology?"*** The question was synthesized from the content of several influential research publications. Csikszentmihalyi found games in general to be an engaging and enriching experience that requires full concentration. In addition, complex games require investing energy in obtaining goals that are challenging and new (Csikszentmihalyi, 1991). Camerer felt that firms constantly underestimate risk and failed to invest in the technology need to accommodate this risk (Camerer, 1995). Sterman determined supply chains were anchored to intuitive heuristics that limited their ability to adjust (Sterman, 1989). Camerer stated that firms were asymmetric in their risk assessment. Firms will not change unless they see an opportunity that is extremely better than the status quo (Camerer & Lowenstein, 2004). Rittel recommended providing timely information from simulations on optimal performance (Rittel & Webber, 1984).

LOGICS extended the dimensions of gaming by using learning objects as well as theatrical and optimal feedback techniques to address the need to quickly shift player focus and behavior. LOGICS demonstrated the ability to quickly teach players they needed to change their focus which has a broad range of implications for innovations in ISDT. These implications can enable advancements in SCM, behavioral economics and social sciences in general.

8.1 Implications for Innovation

LOGICS demonstrated the ability to quickly alter human behavior makes it a valuable tool for dealing with a variety of transitional contexts. People tend to substitute instinctive heuristics for calculated rationality. This substitution anchors them to old models and strategies. The need to assimilate advancements in cyber infrastructures and technology into private and public enterprises is accelerating.

John Seely Brown provided insight into how Xerox Palo Alto Research Center (PARC) built a rapid innovation model on four basic capabilities: learning, listening, learning, and leading (4L) (Brown, 1997). This innovation framework provides a convenient platform to evaluate the innovation implications of LOGICS ISDT. LOGICS can be used to link customers with complementing internal and external stakeholders; listen and capture communication traffic across linkages, analyze the communication for synergies and disconnects, and transform old management practices into new forms of leadership.

PARC's 4L approach required a collection of insights across multiple disciplines: economics, anthropology, psychology and sociology. ISDT in general and LOGICS specifically, create process and product artifacts deduced from kernel theories from a wide variety of research disciplines. The implementation of PARC's 4L approach requires disciplined leadership across the enterprise that is prepared to rationally determine, assemble and implement all the right elements for innovation.

LOGICS process artifacts were designed to produce product artifacts to assist in the determination of the appropriate organizational forms, alliances, competencies, resources, products, distribution channels and strategies. LOGICS artifacts are created to assist practitioners and academics in understanding and communicating the message that a disciplined IT enhanced technical approach is the best way to deal with the uncertainties and risks of innovating complex environments.

8.2. Implications for Practice

LOGICS evaluated the use of online games as a platform for ISDT. The specific goal was to create a learning object game that was capable of altering SCM behavior. LOGICS used learning objects and theatrical techniques to alter player behavior in the context of the SBG.

ISDT seeks new ways to create interventions that can improve alternative futures (Purao, 2002). The LOGICS product artifact can be easily scaled, expanded and enhanced. A broad range of single player, multi-player and massive multi-player games could be generated to assist practitioners and academics in gaining insight into important complex economic systems.

New attitudes bring new perspectives. New perspectives lead to new theories that generate innovative approaches to real world problems. Future LOGICS populations will consist of first class autonomous agent objects that share complex dynamic ecosystems with human agents. Both types of agents will interact and self-organize to generate novel solutions to highly complex dynamic problems. New theatrical methods will create interactive gaming experiences that stimulate rational technology investments on a global scale. Cloud-based autonomous agents will reside in future gaming spaces that communicate with and advise present gaming space agents on prescriptive actions to minimize the damage of existing approaches.

LOGICS used a LISP variant object-oriented language to create an ABMS modeling space and a PABMS experimental space. This extension of lambda calculus syntax is ideal for information rich semiotic applications. Semiotic languages are very robust compared to traditional programming languages. Binary numbers operating on binary numbers to generate binary numbers is replaced by symbols operating on symbols to produce symbols. Many of the logic-based theoretical foundations of computer science used the semiotic approach to explore "undecidable problems" (Hindley & Seldin, 2008) Traditional lockups and crashes of binary numerical systems are replaced by the robust exchange of informative messages on system state and logical obstructions.

Simon wanted to devise a new artificial way of remembering and learning. He knew it would require IS methods for storing massive amounts of information, massive amounts of computing and semantically rich domains (Simon, 1969, p. 103). IS has advanced sufficiently to meet all these requirements. A semantically rich environment uses natural language processing that is capable of interacting with the complexities of semantically rich domains and building their own understanding of this type of problem. Numerical IS struggles to mine prior knowledge for a problem domain. Semiotic IS learns by example and discovery and is capable of problem solving with or without goals. New solutions are discovered by locating invariants in bodies of numerical data. The recent demonstration of an IBM computer named "Watson" defeating human champions at a popular game called "Jeopardy" provided clear evidence that IS semiotics has arrived (Boles, 2011).

Practitioner-friendly semiotic environments utilize first-class agent objects that can be both executed and modified simultaneously. Simultaneous queries on state, structure and behavior create a robust and reflective architecture (Gjerlufsen, Ingstrup, & Olsen, 2009). A full semiotics approach would allow LOGICS to merge three encapsulated process capabilities into a real-time integrated development environment (IDE). This would allow LOGICS to accommodate development of an ISDT similar to those described in the PARC 4L discussion. This approach also allows LOGICS to support an holistic system level approach to complex systems. Software could be queried about its state, structure and behavior by its developers while being played by users. This would require various levels of abstraction. A LOGICS IDE needs to provide an environment that is capable of accommodating dynamic system relationships. Reflective simulations will be capable of being simultaneously executed and modified (Gjerlufsen et al., 2009). This semiotic approach allows interaction with intractable real world complex problems. New versions of NetLogo now support an interface that allows Mathematica to communicate with a PABMS during runtime. This capability makes it possible to create a reflective learning space where the designer, the instructor, the analyst and the player to interact concurrently. This type of reflective system makes it possible to create an artificial future gaming ecosystem. This approach can be accomplished in two ways, as Figure 26 shows.

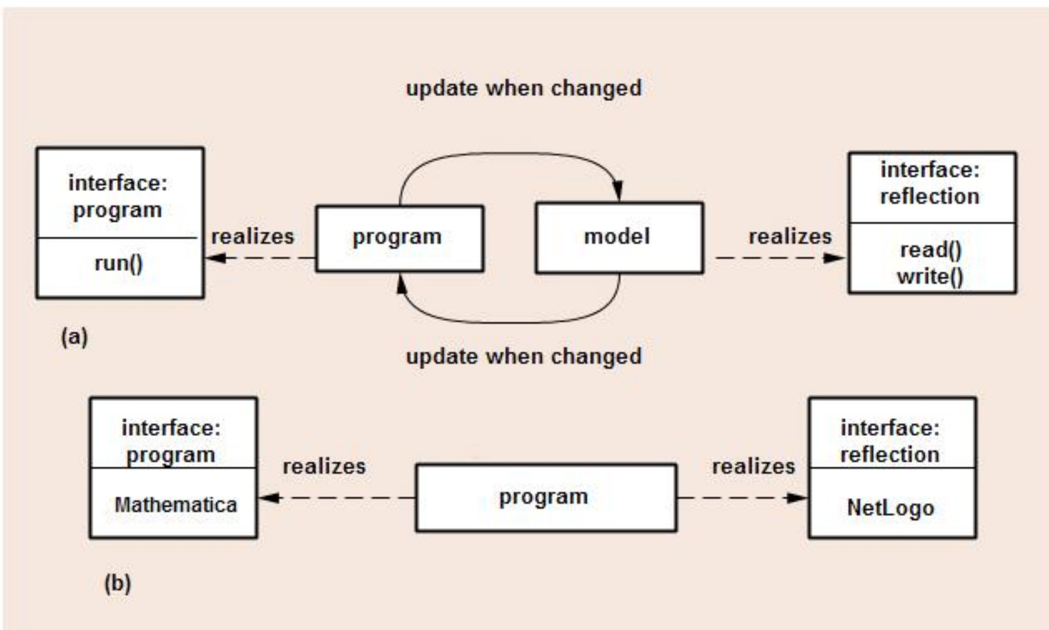

Figure 26. Self-reflective LOGICS Approach

Using the approach shown in Figure 26a, the developer builds a program that maintains a model of itself. The model realizes a reflective interface that interacts with the model a high level of abstraction and interacts with a program that may be running at another level of abstraction.

Figure 26b shows a second approach that requires only one representation that is both model and program. In this approach only one instantiation is required. This approach requires functional languages such as LISP and lambda calculus that use functions of first class objects capable of being executed and modified at the same time. The agent-based LOGICS approach is ideal for this second approach.

Practitioners invent artificial forms through the use of a particular paradigm of psychology called information processing (IP). IP is a symbol processing paradigm that forms the base of cognitive science (Dasgupta, 1996). Schön advocated an epistemology of practice based on the idea of reflection-in-action. Practitioners learn by mapping new situations onto known problems and techniques (Schön, 1983).

The next generation of LOGICS will be a semiotic program that is capable of concurrently realizing situations generated by Mathematica and NetLogo. Initial layers of the game will be designed to profile player knowledge and learning preferences. Reflective agents map this profile onto a gaming playing field, called a manifold. Gaps in functionality would be filled or modification by enhancements to existing functionality. Reflective semiotics allows the creation of a perpetual cycle of evolution, evaluation and learning. Mathematica can simultaneously feed environment altering information and receive and analyze reactions to these modifications. Reflective games evaluate learning capabilities during interactive competitive environments. A series of reflective object games would build trust and increase reliance on IS in artificial ecosystems. This approach can be used to improve management in both the public and private sector.

It is intended to expand LOGICS into new dynamic education workspaces. This allows the exploration of biotechnology and nanotechnology contexts that can only be supported by advanced IS such as cloud computing. Semiotics processes will run on clouds while local GPUs and CPUs are used to create augmented virtual realities. Specifically, LOGICS reflective games will expand in their ability to demonstrate how IS can usurp human micromanagement. New LOGICS designs will enable the practitioner to assume the proper role of setting goals and defining purpose. Sterman and others significantly underestimated the waste generated by complex business dynamics. Players need to experience how IS can be used to save time and money. Learning object platforms can be expanded to allow the exploration of socio-technology theory that uses statistical physics to describe advanced control mechanisms for complex systems.

In practice, LOGICS will be beneficial for any organization seeking to conduct interdisciplinary research in highly dynamic and complex environments. Online games and virtual worlds build new intuitions and synergies in what was once thought of as a purely entertaining exercise. Skills in using reflective ABMS, PABM and computational analysis form an integrated development environment for reflective research across systems in any natural or social science research discipline.

8.3. Implications for SCM ISDT

Technology is as much about the conceiving of artifacts as it is about making them (Dasgupta, 1996). Science and technology have flourished. As a consequence, a scientific worldview has emerged and gained dominance. Information system artifacts now dominate global public and private sector management systems.

A few decades ago, Herbert A. Simon saw this coming (Simon, 1969). He argued that we were entering an age dominated by technology and it might be time to revisit the value of design research. One of his initial areas of interest was in economic rationality. Resources are scarce and he felt the role of economics was to find a rational way to allocate them. Human behavior influences artificial components that operate at many levels simultaneously

(Simon, 1955). For example the specific SCM problem used in the LOGICS project focused on how the impulsive irrationality of a single actor can influence the economic performance of an entire supply chain. The amplification of irrational waste can manifest itself in entire economies. The variance of U.S. industrial production for raw materials is greater than the variance of intermediate goods; the variance of intermediate goods is greater that the variance of final products. This example of the *bullwhip effect* seems to have been resistant to SCM advances over a five decade period, as shown in Figure 27. The sixty point scale for final products is indicated on the top left vertical axis; a similar scale for intermediate goods is on the right vertical axis; a similar scale for raw materials is on the bottom left vertical axis. The source is the Federal Reserve Industrial Production Data, Series B51000 Consumer Goods, B54000 Intermediate Products, B53010 Materials each shown as the ratio to the best-fit exponential growth trend.

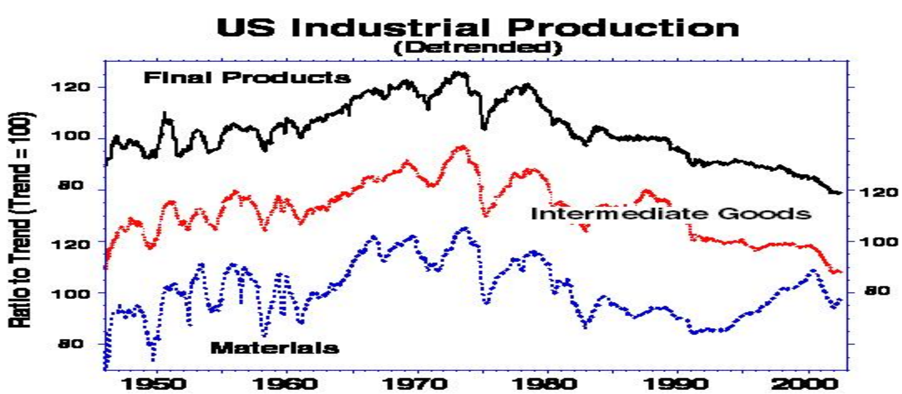

Figure 27. Amplification in the Macroeconomy (Crosen, Donohue, Katok, & Sterman, 2003)

LOGICS can be used to examine the benefits of supply clouds rather than supply chains. Companies are looking for ways to respond to rising volatility in customer demands and market conditions. Supply chains are increasingly powered by information technology IT. Cloud computing promises to enable new capabilities that will radically reshape how computing power is sourced, and managed, how information is controlled and the economics of supply chain information and technology (Schramm, Nogueira, & Jones, 2011). This emerging HPC architecture expands the dimension of SCM research.

8.4. Implications for ISDT Expansion

Simon argued that design should be opened up to all disciplines that seek to change existing situations into preferred ones. By seeking common properties among diverse complex systems, a point of view might be developed similar to cybernetics. This point of view could begin with the examination of the behavior of the ability of adaptive systems to select information in terms of feedback and homeostasis (Ashby, 1952; Weiner, 1961). He wanted to move away from the details of structure and instead deal with the complexity of systems in the abstract.

Ramage and Shipp grouped system thinking into seven types: early cybernetics, general systems theory, system dynamics, soft and critical systems, later cybernetics, complexity theory and learning systems (Ramage &

Shipp, 2009). LOGICS used kernels from cybernetics, system dynamics and learning systems. This kernel set could easily be expanded to include all seven groups of system thinking. A unique interdisciplinary approach would benefit from a common set of modeling and simulation techniques across all natural and behavioral science disciplines.

LOGICS product and process artifacts are a first step in using information technology in the form of an online game to increase understanding of the value of information technology investments. The capabilities of information technology are increasing exponentially. The complexity of information technology driven systems is increasing exponentially. The utilization of information technology to manage the exponential growth of this problem is not increasing exponentially. LOGICS presents a flexible and scalable ISDT that can be used to benefit those that are disciplined enough to apply it.

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Appendix A: IRB Information

The IRB Application for Review will contain the following information

Principle Investigator:
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Department: Information Science

Title of Research: Research to Design and Evaluate a Supply Chain Management Online Game Learning Object Artifact

Precis: This research is being done by a student for dissertation research and will evaluate the effectiveness of an online game learning object in communicating ability of information systems to mitigate the damage done by heuristics in the management of complex dynamic supply chains. Participation is voluntary.

Locations of Study: WESRAC office USC

Participants: Adults, over 18 years of age

Type of Data: Simulation performance and utility profiles

Nature of Information Obtained: The bulk of the data will be collected automatically during game participation. The data will be stored on the server disk using the online game team identity. The volunteers game performance parameters collected will be collected and factors such as final score, time of engagement, and risk profile will be analyzed.

Research Summary: The general hypothesis of this research is that an online game environment can be can be used as a learning object to meet a number of meta-requirements such as improved understanding of the value of information systems in dealing with the complexity of dynamic

systems. An online game will be constructed and hosted on a WESRAC server. Participants will use a client computer located in cubicles located in the WESRAC office at USC. The volunteer will create an online game identity. This prevents any linkage to an actual personal computer internet identity. The participant will conduct a series of exercises that requires judgment to be applied in making operational and financial decisions. Different feedback mechanisms will be used to inform the volunteer on game performance. Volunteer's scores will be increased or decreased based on their ability to tune their performance to match the ideal solution. The interaction can occur over multiple sessions. The volunteer may terminate the game at any time. They will be offered the option of posting their score on a public scoreboard using their online Avatar name.
The objective will be fully disclosed in the introduction section of the game. There will be no deception in the game. Participants create an online game confidential Avatar identity. There will be no limit on the number of visits allowed to the game.

Recruitment: The principle investigator will recruit volunteers from students in engineering and business classes.

Consent: Since participation is anonymous and they do not have to reveal any personal internet identity information in order to participate, there will be a simple online consent form that must be accepted before and online game team identity can be created. The online form will explain that the data is not linked to them and there is no deception or manipulate involved in the online game. Rule of ethical game conduct will also be explained. Participants will also be told that may voluntary participate in post experience interview. The consent form is included below.

Participants will use an online form to consent to the collection of this data. The online team name will identify the performance data. To protect confidentiality there will be no formal record that links the volunteer's actual personal or internet identity to the online game team identity.

Procedures and Methods: Participants will use WESRAC clients to access the login capability of the server. Hints will be placed in the various buildings of a virtual supply chain campus hosted on the WESRAC site. Volunteers may visit this site at any time search for information offline.

Confidentiality: There is no direct linkage between the online game identity and the personal or internet identity of the participants. This approach allows maximum confidential of personal information.

Benefits This information should be of real value to students involved in both engineering and business programs at USC. Volunteers can optionally choose to participate in a qualitative survey. There will be no release form for this survey. The survey will seek information on the value of their simulation learning object experience. Volunteers for the interviews may benefit from insight into qualifications for consideration for WESRAC work-study positions. If they agree to the qualitative interview they will be asked to sign a second consent form.

Consent form Text (adapted from University of North Texas Research Subjects Consent Form, http://insight.southcentralrtec.org/ilib/consent.html) the online consent form text is shown below. The online form is consent to create a team identity. The personal interview for will be signed by the volunteer as consent to the interview.

Title of Study: *The Challenges of Dealing with Supply Chain Complexity*

Principle Investigator: *Ken Dozier*

Faculty Advisor: *Dr. Thomas Horan (Tom.Horan@cgu.edu)*

Before agreeing to reveal your participation in this research study, it is important that you read and understand the following explanation of the purpose of the study. It describes the procedures, benefits risks, and discomforts of the study. It also describes your right to withdraw from the study at any time. Participation is voluntary. It is important for you to understand that no guarantees or assurances can be made as to the results of the study.

Purpose of the study and how long it will last:
The purpose of this study is to the test the ability of online gaming leaning objects to determine the need for technical assistance in dealing with complex dynamic business systems in general and supply chains specifically. The length of your experience was self-determined, but should take from one hour for the online game and an additional twenty minutes for the interview. You are allowed at your option to post your online team score on the master scoreboard. You may choose to be personally interviewed because you wish to participate in contributing information that would be beneficial for future learning object designs.

Description of the study including the procedures used:

You were asked to play and online simulation game that was intended to help you develop a sense of the issues involved in dealing with dynamic complex systems. Your score will be based on your ability to progress through the game. The game is intended to become increasingly difficult and you are allowed to use game score points to purchase technology to assist you in obtaining a higher game score. Your score, with your consent, can be posted on a universal score board. There is no intent to match your score to your identity until the personal interview. Upon the acceptance of this online consent form your data was collected and stored under online game team name. You used a WESRAC computer this eliminated the need for you to reveal any internet identity information. By volunteering to fill out an optional questionnaire following the game, you are allowing a better design of the next generation experiment. The questionnaire will be 12 questions covering the ease of use, clarity of instruction, participation, decisions making criteria and insight. The results of your performance and information from the interview will be used in a dissertation. Your true identity will be known only to the PI and no identity information will be published. You may use the results of the interview as a factor in consideration for work study or intern positions at WESRAC.

Description of procedures/elements that may result in discomfort, inconvenience, or foreseeable risks:

There are not foreseeable physical risks to you as you use the system. None of your information will be shared with others unless you decide to share it.

Confidentiality of research records:
The date, as well as answers to any surveys questions, will be kept in a secure file cabinet reserved for WESRAC personnel information at the University of Southern California. Only the PI has access to the data

There is a possibility that data from this survey will be used for further research, beyond the additional study. The Institution Review Board will examine any requests for future research and would require stringent control of confidentiality and security of the data.

Written and oral reports will never contain information about an individual person, nor will any person be identified in such reports.

Do you agree to participate?

Supply Chain Simulation Questionnaire

Avatar Name ______________________________________

Date ____

Please circle the number after each question that best describes your simulation experience.

1.) Were the directions easy to follow?

Easy---Difficult
[1] [2] [3] [4] [5] [6] [7] [8] [9] [10]

2.) Were the graphics easy to read?

Easy---Difficult
[1] [2] [3] [4] [5] [6] [7] [8] [9] [10]

3.) Was it easy to place your order?

Easy---Difficult
[1] [2] [3] [4] [5] [6] [7] [8] [9] [10]

4.) Was it easy to understand the management challenge?

Easy--Difficult
[1] [2] [3] [4] [5] [6] [7] [8] [9] [10]

5.) Was it easy to understand the benefits of technology?

Easy--Difficult
[1] [2] [3] [4] [5] [6] [7] [8] [9] [10]

6.) Was it easy to understand the benefits of collaboration?

Easy--Difficult
[1] [2] [3] [4] [5] [6] [7] [8] [9] [10]

7.) Was it easy to understand the difference between local performance and system performance?

Easy--Difficult
[1] [2] [3] [4] [5] [6] [7] [8] [9] [10]

8.) Was it easy to select the technology mix you wanted?

Easy--Difficult
[1] [2] [3] [4] [5] [6] [7] [8] [9] [10]

9.) Was it easy to find the WESRAC web page?

Easy--Difficult
[1] [2] [3] [4] [5] [6] [7] [8] [9] [10]

10.) Was it easy to locate the cheat information on the WESRAC Webpage?

Easy--Difficult
[1] [2] [3] [4] [5] [6] [7] [8] [9] [10]

11.) Was it easy to find cheat information on the Internet?

Easy--Difficult
[1] [2] [3] [4] [5] [6] [7] [8] [9] [10]

12.) Was it easy to understand the need for more simulations?

Easy--Difficult
[1] [2] [3] [4] [5] [6] [7] [8] [9] [10]

Appendix B: Research Questions

	Design1	Design2	Design3	Design4	Design5
General Research Question					
Can an online game player learn to abandon intuitive reactions to local events in favor of investing in system solutions provided by information technology (IT)?	NO	NO	NO	NO	YES
Kernel Thoery Research Questions					
Cybernetics					
Are the LOGICS artifacts capable of generating a purpose seeking system?	NO	NO	NO	NO	YES
Complex Business Dynamics					
Are the LOGICS artifacts capable of creating a dynamic version of the SBG?	YES	YES	YES	YES	YES
Simulation					
Is a PABMS capable of creating a learning object game?	YES	YES	YES	YES	YES
Learning Objects					
Can the learning object techniques of repetition and feedback be used to alter player behavior?	NO	NO	NO	NO	YES
Online Gaming					
Can the LOGICS artifacts lead a player to discover the value of IT investments in obtaining the optimal solution to the SBG?	NO	NO	NO	NO	YES
Process Artifact Research Questions					
Can a Behavior Space Generator (BSG) be used to evaluate the deterministic properties of an ABMS complex system model?	YES	YES	YES	YES	YES
Can the PABMS functional space be used to introduce stochastic player behavior into the SBG?	YES	YES	YES	YES	YES
Can an immersive PABMS be used to move the gaming environment to a stochastic parameter space?	YES	YES	YES	YES	YES
Can a PABMS accurately capture all relevant data, use it to examine erratic game play and generate animations?	YES	YES	YES	YES	YES
Can the analysis space accommodate assumption free statistics?	NO	NO	NO	NO	YES
Product Artifact Research Questions					
Can a PABMS use theatrical techniques to create a human computer interface?	YES	YES	YES	YES	YES
Can a PABMS be used to accurately create and manipulate a dynamic version of the SBG?	YES	YES	YES	YES	YES
Can a PABMS accommodate the use of heuristics?	YES	YES	YES	YES	YES
Can PABMS be structured to alter player behavior?	NO	NO	NO	NO	YES
Can a PABMS convince a player to abandon heuristics and invest in an IT enabled purpose seeking system?	NO	NO	NO	NO	YES
Can a LOGICS product artifact quickly change player behavior?	NO	NO	NO	NO	YES

Appendix C: Comparing Two Means (independent t-test)

Psychologists Miles and Banyard strongly support the use of t-test on modest sized samples, "It is a myth that sample size must be above some value, such as 6, for the t-test to be valid" (Miles & Banyard, 2007, p. 140). They also advocated for equal sample sizes to mitigate homogeneity of variance issues (Miles & Banyard, 2007, p. 146). North and Macal (2007, p. 269) stated that unfortunately ABMS researchers often use parametric statistics when their data does not belong to a particular distribution. This is inappropriate and can result in misplaced confidence in statistical results.

To understand the impact of this type of mistake, parametric independent t-tests were conducted for all designs. Sample data sets were of equal size and covered a large range of skewness. Independence between designs is valid since players were restricted to playing one design.

The independent t-test was used to compare the means of all designs. This layer of t-testing was conducted to better understand the problem of analyzing ABMS data using traditional parametric statistics cited in Section 6.0 (North & Macal, 2007).

Field (2009a, pp. 56-57) points out that just because a t-statistic is significant, this does not mean the effect it measures is meaningful or important. Effect size is usually a standardized measure of the magnitude of an observed effect. A standardized measure allows comparison across different studies that have different variables, or use different scales of measurement. Field also points out that the APA now recommends that all psychologists report the effect sizes in the results of any published work (Field, 2009a, pp. 56-57). Many measures of effect size have been proposed. Field prefers the correlation coefficient because it provides constrained values between 0 (no effect) and 1 (perfect effect). Effect sizes are useful because they provide an objective measure of the importance of the effect. Cohen(1988) suggests: an r = .10 (small effect) represents 1% of the total variance, r = .30 (medium effect) represents 9% of the total variance, and r = .50 (large effect) represents 25% of the total variance. Field suggests how to calculate the effect size for the independent t-test using the t –statistic and the degrees of freedom *df.* (Field, 2009a, p. 332)

The reporting formats were guided by recommendations made by Field (Field, 2009a, p. 333). He recommends first reporting the means and standard errors for each group in brackets. An italic t should be used to denote the fact that the t-statistic has been calculated, followed by the degrees of freedom in brackets. The probability can be reported in many ways. This report precedes the t-statistic information with the standard level of significance and follows it with an equal sign and the exact significance followed by the number of tails used in the calculation. Then a statement about the null hypothesis treatment is stated. This is followed by a statement on the relationship of the means. The effect size is reported last. Field fells strongly that there is no excuse for not reporting the effect.

Design1 versus Design2

On average, players incurred more total system inventory costs for Design1 (Mean = 14493, SE = 2111) than Design2 (Mean = 11799, SE = 1802). Since $p > .05$ for $t\ (26) = .970$ (one tailed), the null hypothesis can be accepted. The means of the two designs can be considered equal. The face-to-face coaching has a medium effect of r = 0.22.

Design1 versus Design3

On average, players incurred less total system inventory costs for Design1 (Mean = 14492, SE = 2111), than Design3 (Mean = 14778, SE = 2068). Since $p > .05$ for $t\ (26) = -.097$ (one tailed), the null hypothesis can be accepted. The means of the two designs can be considered equal. The PC option has a negligible effect of $r = 0.022$.

Design1 versus Design4

On average, players incurred more total system inventory costs for Design1 (Mean = 14492.82, SE = 2111.23), than Design4 (Mean = 8798.95, SE = 1232.37). Since $p < .05$ for t (26) = .014 (one tailed), the null hypothesis is rejected. The means of the two designs are not considered to be equal. The means the HPC ordering hint to use technology for several sequential orders ha a medium effect of r = 0.44.

Design1 versus Design5

On average, players incurred more total system inventory costs for Design1 (Mean = 14492.82, SE = 2111.23), than Design5 (Mean = 4295.27, SE = 1058.07). Since $p < .001$ for t (26) = .000 (one tailed). The null hypothesis is rejected. The means of the two designs are not considered to be equal. The use of per order feedback from an optimal model has a large effect of r = 0.68.