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STRUCTURAL INFLUENCES IN INFORMATION SYSTEMS PROJECTS: A VIRTUAL EXPERIMENT IN A MULTI-AGENT SYSTEM

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

In

Interdepartmental Program in Business Administration
(Information Systems and Decision Sciences)

by
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M.B.A., Palm Beach Atlantic University, 1997
August 2009

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Dedication

I dedicate this to all my family and friends as well as to all the idealists, romantics, iconoclasts and heretics from the past, present and future. Especially important in this work and my life has been my renaissance muse, Guinevere.

Acknowledgements

I thank my chairs and committee members (Suzanne Pawlowski, Edward Watson, Helmut Schneider, and Rudy Hirshheim) for their patience and confidence in my quest of my chosen topic. Special thanks are due Suzanne Pawlowski for her valuable feedback and editorial assistance with my writing, to Helmut Schneider for providing me with the opportunity to pursue this work at Louisiana State University, and Julliana Richard, who helped me navigate the administrative process.

Additional acknowledgement is due my grandmother, Frances Poh and my uncle Ronald Poh for their dinner table discussions of theology and philosophy when I was young; as well as instilling in me a love of discovery, creativity and knowledge. I am also indebted to the heated discussions comparing phenomenology and logical positivism over a pot of French coffee and a game of chess with Julie Tersigni at Café Espresso during my days in Gainesville. Thanks also to Jay Zeeman and the philosophy department at the University of Florida for laying the foundation that has finally come to some degree of fruition in this work.

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Abstract

A virtual experiment (in silico) of a complex social system is conducted in order to investigate the effects of social structure and organizational culture on an information system development project's outcome. This is performed within the context of user participation and project success. A 2x2 factorial design is employed with the social factor being measured as either low or high initial relationships between the customer and developer groups working on the project. The cultural factor is measured dichotomously with the two groups either having the same or different cultural beliefs. The project success outcome variable is measured as a percentage of the project that may be completed at a given time period. The simulation incorporates interactive, learning agents from two distinct groups within an information systems project; viz. the customers and the developers. A dynamic social system is first defined and then evolved which incorporates knowledge resources, tasks to be accomplished, and the agent communication social interactions in order to accomplish the given tasks.

In order to integrate the multi-theoretical concepts employed in the simulation, first a multi-dimensional philosophical foundation derived from Buddhist philosophy and psychology is described. Second, an Integrated Capital Ensemble model of social forces based on the works of Marvin Harris in cultural anthropology and Pierre Bourdieu in sociology is introduced. Third the operationalization of the conceptual model is described in terms of dynamic network analysis methods. Finally a discussion of the results of the experiment; the significant effect that the social and cultural factors have on project success are discussed.

Chapter 1 -- Introduction

"Begin at the beginning," the King said, very gravely, "and go on till you come to the end: then stop."
Lewis Carroll

The only thing that will redeem mankind is cooperation.
Bertrand Russell

The purpose of this study is to examine the structural social and cultural factors that may influence the outcome of an information systems development project. The philosophical motivation for this study was the desire to provide a systemic perspective of the social forces acting within the confines of an information systems development project. The practical motivation for this study began with my work as a software developer when my personal experience mirrored the observation of DeMarco and Lister (1987) that the “major problems of our work [information systems development] are not so much technological as sociological in nature." Earlier recognition that structure bore influence on the outcome of information systems development projects was made by Melvin Conway (1968) and has since been known as Conway’s Law: “Any organization which designs a system… will inevitably produce a design whose structure is a copy of the organization’s communication structure.”

The particular structural factors that will be examined in a virtual experiment are: (1) the social factor represented by the initial inter-group relationships between the customers and the developers involved in a virtual information systems development project, and (2) the cultural factor represented by the culturally held beliefs of each group as they relate to the other group. For this study the customers and developers will either hold the same (similar) beliefs in common or have antithetical (dissimilar) beliefs. The influence of these two factors on a project is measured in terms of the percentage of the project that is correctly completed at the end of time period (week) 100. Project completion is taken as a component of a successful information systems project. The remainder of this chapter introduces the study’s research questions, key concepts to aid in the topic discussion, an overview of the approach taken, the motivation for the research topic and the approach taken, the contributions of the study, a summary of the data source and methodology used and brief description of the contents of the remaining chapters.

RESEARCH QUESTIONS

The broad research questions of interest are:

(1) Do social relationships have an effect on the outcome of an information systems project?
(2) Do culturally held beliefs within different groups working together have an effect on the outcome of an information systems project?

The research questions of this study center on the structural forces at work within an information systems project. Therefore, it is important to address the concept of structure and some related vocabulary (e.g., agency) before beginning our discussion in earnest.

First, an actor may be defined as a human being, a group, or an organization. Thus actors may exist at various levels of units of analysis. Although there are different conceptions and degrees of agency, Dietz and Burns (1992) offered general criteria which include: (1) an actor have free choice, (2) an actor have some degree of power, (3) actions taken by an actor are intentional, and (4) actors have the ability to monitor and modify their actions in a reflexive manner. Structure is seen by some theorists as the dual to agency. Structure is most often viewed as social forces that act to constrain the actor, either making some actions necessary or other actions impossible (Ritzer and Goldman, 2004; Dietz and Burns, 1992). Anthony Giddens (1986) uses the term structure in a very different way from other social theorists in the discussion of his theory of structuration. In Giddens' own vocabulary a "system" (reproduced social practices) is roughly equivalent to what other researchers call structure. For Barry Wellman (1983:156) and other network analysts "The most direct way to study a social structure is to analyze the pattern of ties linking its members", and thus accounting for relationships among actors presents a measurable way of exploring the effects of structure in the social world. Perhaps as important as what structure is, is what it is not. Network analysts "dismiss as non-structural any explanations that treats social process as the sum of individual actors' personal attributes and internalized norms" (Wellman, 1983:162). However, it is also recognized that within the complex relationships that compose a social structure there are "values and norms [that] serve as mediating links for social transactions" (Blau, 1964). This study explores the effects of these social and cultural factors through a virtual experiment.

LITERATURE OVERVIEW

Approach

A social theoretical framework is examined at a conceptual level as reference for the systems perspective taken in the study and the multiple factors that may influence the outcome of a project. Four forms of capital are discussed and integrated into the model; viz., economic capital (Smith, 1776; Marx, 1849), social capital (e.g., Granovetter, 1985; Coleman, 1988; Burt, 2000; Lin, 2001; Bourdieu, 1983, 2005), cultural capital (Bourdieu, 1983), and human capital (Becker, 1964). Specific to the operationalization of the experiment, social network theory and practice (e.g., Blau, 1977; Feld, 1982; Wasserman and Faust, 1999; Carley and Hill, 2001) is relied upon for the evolution of the virtual project. Third, a review of the information systems literature and some of the predominant social oriented perspectives that have been taken in the past to address systems is discussed.

Limitations of the Social Perspective on IS Development

Although IS researchers have studied aspects of "the social" in information systems projects, the general perspective taken may best be described as that of social atomism; e.g., where individual actors' decisions, attributes, and attitudes are aggregated and presented as what is "the social". This ignores the importance of structural relationships among actors, and for network theorists such as Wellman (1983) it "is a job better left to psychologists." Support of this assertion is born out in Orlikowski and Iacono's (2001) categorization of research in their discussion of the IT artifact, where they reported that a structured view was used in 3.4% of articles reviewed over a ten year span of time, from the premier IS journal, *Information Systems Research*. Chen and Hirschheim's (2004) article that reviewed a wider number of journals and over the time period 1991 – 2001 found that 41% of the research conducted was survey research, which is suggestive

of an atomist and individual perspective. Chen and Hirschheim found a general lack of pluralism in IS research and this study proposes that opening the door to exploring the structural influences of social relationships can increase the diversity of perspectives and knowledge within the IS community.

The structural relationships under scrutiny in this study are those between customers and developers working on a virtual information systems development project. This is *user involvement* and it is measurable at the social structural level. The importance of user involvement in IS projects has long been discussed in the IS community. Early examples of academic research are Hirschheim (1983) and Ives and Olson (1984), where review and mixed results were reported. More recently Wagner and Newell (2007) explored user participation and information system success in the context of enterprise systems and Gallivan and Keil (2003) conducted a study focusing on the user-developer communication process and the key stages of communication that must occur for user participation to be effective. In spite of the contextual caveats, user involvement is considered critical to an information system project's success. It is promoted in industry practice; e.g., the Standish Group International, Inc. (2006) lists the top reason for project success as being user involvement, and it is part of the standard academic curriculum taught to our future professionals (e.g., Valacich et al., 2004; Dennis et al., 2004), where it is also stated to be a key ingredient for project success.

Project success in IS research has been discussed as a multi-dimensional construct, with the instrumental work on the matter generally being recognized as DeLone and McLean's (1992) review and model proposal for an information systems success outcome variable. Subsequent employment and refinement of this model has followed since its introduction e.g. (Petter, DeLone and McLean, 2008; Petter and McLean, 2009). This study views the DeLone and McLean model of success as the backend portion of project success with its focus on the product. The focus of project success in this study centers on the project management portion of success in line with (Baccarini, 1999; Shenhar et al., 2001; Markus and Mao, 2004). Further discussion and definition of project success is left to chapter four.

CONTRIBUTION

The general contribution of this study is to highlight the importance of structural social and cultural factors that can affect the outcome of an information systems project. Specific contributions resulting from the virtual experiment with implications for IS practice includes the following three findings. First, significant differences may arise in project success based on the initial levels of user involvement (which was measured objectively by the number of relationships specified among the customer and developer groups assigned to a project). Second, when customer and developer groups share the same cultural values the level of initial inter-group relationships is not significant; i.e., when people have the same view of the world increasing initial user involvement is inconsequential in terms of project success. Third, when groups have dissimilar cultural beliefs, project success is substantially enhanced by beginning the project with a higher level of user involvement with the developers.

Additional contributions to the information systems research discipline include: (1) introducing the use of multi-agent systems simulation methodology, (2) use of dynamic networks and related

methods of analysis, (3) suggesting an integrated model of capital that assists in explaining the interaction among different forces in the social world, and (4) providing an introduction to an ontology that is consistent with a pluralist world view and is compatible with the use of multiple methodological approaches.

DATA SOURCE AND METHOD

A virtual information systems project environment was developed using a network based multi-agent system simulation engine for the evolution of the projects in the experiment. Understanding what a *multi-agent system* is may best be explained by resorting to a simple analogy from popular culture and the movies. The movie "The Matrix" portrays unenlightened life as a computer generated world, where people (agents), live, work, learn and interact with other people. This is essentially the same environment that is created, on a more limited scale, in order to explore the effects of social structure and cultural values on information system project outcomes in this study. The initial agents, project task activities, and requisite knowledge facts were generated and presented to the simulation engine as input as a series of matrices. The virtual project evolved over the course of 100 time periods (weeks) and the task completion outcomes were tracked. A project completion percentage variable was computed based on the knowledge possessed by agents responsible for completing tasks and the required knowledge for those tasks.

The input matrices to the simulation engine were custom written. These included the customer and developer agents, the project activities, and the knowledge required to perform the project tasks as well as the initial knowledge possessed by the people (agents) involved in the projects and all of the resulting relationships. The project completion output measures algorithm, which is calculated from the evolutionary learning of the agents in the simulation was also custom written.

The design of the virtual experiment was a balanced 2 x 2 factorial design with fixed effects. Based on a significance level of .05 and a power level of .99 for the main effects and .95 for the interaction effect a total of forty simulation runs were made, with ten runs made for each interaction factor level. The categorical factor variables were the initial social and cultural variables. The outcome variable used was the project completion proportion at week 100 of the project.

CHAPTER SUMMARIES

A preview of the dissertation chapters follows:

Chapter 2 - Philosophical Foundation

This chapter establishes a philosophical foundation for the theoretical framework of the study. Although this study occurs "in silico", the symbolic and constructivist nature of aspects of the study have not gone unnoticed. In future empirical studies the ontology discussed can reconcile the dualism normally presented with a positivist versus interpretivist world view. This leads to an ontologically consistent foundation for a multi-leveled view of reality. The multi-realm nature of

reality presented is not pluralism as such, because the realms are not to be viewed as independent and mutually exclusive.

Chapter 3 - Social Theoretical Framework

Chapter three is presented in two parts. Part one presents an integrated approach to social forces based on Marvin Harris's work in cultural materialism in anthropology. The concepts of infrastructure, structure and superstructure are presented. A modified model of the interplay of these forces is presented, to adjust to shorter time frames and with the inclusion of the actor as an additional factor. Part two builds upon this model and introduces an integrated capital ensemble model of social forces, in terms of resource/economic capital, social capital, cultural capital and human capital. The interplay of these forces is discussed, along with examples of their transformational conversion and translational exchange.

Chapter 4 - Information Systems Literature

A review of the social perspective taken by previous information systems researchers is conducted. Additional discussion linking the independent variable of group interaction (user involvement) and the dependent variable (project success) to the literature is conducted.

Chapter 5 - Social Networks

Social networks concepts and definitions are introduced. The construction and operation of the multi-agent system simulation is based on networks and network dynamics.

Chapter 6 - Methodology

Simulation methodology is reviewed and the multi-agent system simulation is described in detail. An associated appendix is included for additional specifics and the program code that was used for construction, implementation runs, and output transformation and analysis which was performed prior to the statistical analysis.

Chapter 7 - Analysis and Results

Data analysis checking the validity of the experimental assumptions for analysis of variance is performed. The factorial ANOVA is performed on the 100th week of the project and the results are reported. Additional graphical data analysis is reported for the entire evolution of the project from week 1 to 100.

Chapter 8 - Implications, Limitations and Future Direction

Implications of the results of the virtual experiment are discussed, followed by a discussion of possible future research arising out of the current study.

The next chapter establishes a philosophical foundation for the theoretical framework of the study.

Chapter 2 -- Philosophical Foundation

Philosophy is the science which considers truth.
Aristotle

There is only one thing a philosopher can be relied upon to do, and that is to contradict other philosophers.
William James

INTRODUCTION

This chapter concerns itself with the general foundations upon which knowledge is seen to exist, how it may be obtained and the value placed on that knowledge. First a review and reflection of the discussion in the IS literature is presented. This is followed by the philosophical position taken for the current study.

The interest in the IS literature regarding an underlying philosophical foundation for IS research tends to supplement the discussion and categorization of research perspectives. Research perspectives, sometimes referred to as "paradigms[1]", are based on foundational considerations of ontology (what exists), epistemology (how we might come to know that which exists) and axiology (what we value).

The IS literature has discussed the categorization of *research perspectives* in a number of ways; e.g., categorization using: (a) a positivist/interpretivist/critical theory[2] views (Orlikowski and Baroudi, 1991), (b) a Burrell and Morgan (1979) based framework stipulating: functionalist/interpretivist/radical humanist/radical structuralist views (Hirschheim and Klein, 1989), and (c) those that derive from Burrell and Morgan's (1979) classification yet are framed in philosophical terms (Iivari et al., 1998; Iivari et al., 2001).

Perhaps as a result of this discussion it has led some researchers to call for restrictive, rather monist views of IS research (e.g., Benbasat and Zmud, 2003); as well as calls for more pluralist perspectives (e.g., Robey, 1996). Generally, references to pluralism have devolved quickly into a mutually exclusive dualist discussion of research perspectives along the lines of positivist versus interpretivist research (Orlikowski and Baroudi, 1991; Chen and Hirschheim, 2004; DeLucca et al., 2008). In order to accommodate this forced duality and place it into a mutually exclusive framework, a prescribed caricature of positivism is oftentimes provided that divorces it from any noticeable utility by its day to day adherents (Weber, 2004). Although it is beyond the scope of this chapter, it should also be noted that the discussion is somewhat muddled, as a result of an inconsistent use of philosophical terminology in the IS literature. For example, discussing "positivism" as being a research perspective in some cases and an epistemology in other cases (Orlikowski and Baroudi, 1991; DeLucca et al., 2008) or referring to epistemology and then

[1] The use of the word paradigm is avoided because of the word's overuse and misuse in both popular and academic press, wherein it has come to mean so many things, it has ceased to provide clarity.
[2] Critical theory is frequently mentioned in theory and subsequently rarely employed in practice.

subsequently discussing it in terms of those things that exist (i.e., ontology) (Weber, 2004) is cause for both misunderstanding and miscommunication.

The method of categorization chosen introduces a self imposed antimony for IS research perspectives. For example, DeLucca et al. (2008) recognize and call for a pluralist perspective and subsequently discount any perspective other than positivist or interpretivist. In addition, these perspectives are to be kept apart from one another during the course of a given study. Similarly imposing a dichotomy on IS research, Chen and Hirschheim (2004) define positivist and interpretivist perspectives in a mutually exclusive manner, viz. even if a study is labeled interpretivist, if it contains any element of their positivist definition it is discounted as being interpretivist in nature. This follows along the lines of incommensurability among perspectives advocated by Burrell and Morgan (1979) and discussed by Mingers (2001). Mingers (2001) advocates a middle ground based on critical realism, however he is not specific on the particulars of his renamed critical realism, which he calls critical pluralism. Weber (2004) on the other hand, is more radical in his approach and advocates eliminating labels of positivism and interpretivism for IS research perspectives and calls for the focus to be on good research, rather than focusing on the rhetoric of either of the two camps.

The following sections provide a research perspective based upon the philosophical foundational issues of ontology, epistemology and axiology. The multidimensional view described is one that is consistent with a holistic and inclusive concept of pluralism as opposed to a view of pluralism that is mutually exclusive. Every attempt has been made to leave the research perspective unlabeled and to rely on the foundational descriptors as a more accurate representation of what is constituted herein.

ONTOLOGY

... metaphysics, even bad metaphysics, really rests on observations, whether consciously or not; and the only reason that this is not universally recognized is that it rests upon kinds of phenomena with which every man's experience is so saturated that he pays no particular attention to them.

Charles Sanders Peirce

Orthodox Dichotomy

Virtually inherent in the Western academic mindset is the concept of duality when it comes to expressing our view of reality. This weltanschauung appears to be culturally inherited. One may point to the key philosophical milestone of Descartes' writings of *The Meditations and Discourses on Method* in the 15th century as to cause our wholehearted embrace of dualism. One may also reach further back in time to the third century and Manichee's influence on the early Christian church, which would eventually become the major theological influence in Western society. Earlier still is the debate between Plato's "ideal" Forms and Aristotle's focus on "real" empirical causes in his early version of scientific method. This cultural tradition, translated into an ontological dichotomy among academics of the past century, wherein realism with an objective reality is opposed by anti-realism in various forms (e.g., idealism, nominalism, relativism, constructivism) that supports a subjective and relativistic form of reality. In order to overcome this tradition of opposition, I present an alternative Eastern ontology that is integrative

rather than antagonistic in nature. This complementary ontological system derived from Buddhist philosophy and psychology is called the Trikaya. This system embraces a more complex and nuanced view of reality, and rather than moving from a dichotomous ontology to a compromised middle ground in a pastiche postmodern fashion it is formulated to be integrative from the start.

Relating to the previous discussion in the IS literature, the formulation addresses the incommensurability issue discussed by Mingers (2001) and provides a way to bridge the gap and reduce the rhetoric as discussed by Weber (2004). It does this in terms that are relevant to both sides of the debate and in a manner that provides for coexistence.

Table 2.1: Trikaya ontology and related epistemological concepts

Realm	Means of Knowing	Nature of Truth	Western Philosophy
Dharamkaya		parinishpanna; perfected nature, ultimate truth	
	↕ Direct Mind		Nous
Sambhogakaya		paratantra; dependent nature, non-conceptual pure relative truth	
	↕ Signs, symbols; consciousness		
Nirmanakaya		parikalpita; imaginary nature, conceptualized reality of relative truth	
	↔ Words and concepts; sensation		Dianoia Episteme Techne Doxa

Trikaya

The conception of the multiple realms of existence derives from Buddhist philosophy beginning with the Mahayana tradition as early as the 4th century. Additional interpretation has been added through the Vajrayana Buddhist tradition[3]. Within this highly categorized and symbolic framework there are three principal realms of existence, called the trikaya. The trikaya encompasses Nirmanakaya (physical form), Sambhogakaya (symbolic form), and the Dharmakaya (formlessness) (Fischer-Schreiber et al., 1991; Trunkpa, 2004; Ray, 2001). The Nirmanakaya represents the realm of physical existence in corporeal form. Its means of communication and knowing are through words, concepts, and sensation. The Sambhogakaya represents the realm of symbolic form. Transmission and understanding between the Nirmanakaya and the Sambhogakaya are through signs, symbols and consciousness. The third realm, that of the Dharmakaya, is formless and is representative of the non-dual nature of existence. Communication between the Sambhogakaya and the Dharmakaya realms is via direct mind transmission (Trunkpa, 2004; Ray, 2001). (Refer to Table 2.1 for a summary depiction of these multiple realms of existence.)

[3] The author acknowledges the indebtedness to the following Tibetan lamas for their talks on the Trikaya: Ven. Khenchen Palden Rinpoche, Ven. Khenpo Tsewang Dongyal Rinpoche, and Khentrul Lodrö Thayé Rinpoche

Dharmakaya is somewhat comparable to the highest level of truth in Aristotle's hierarchy of knowledge, which he referred to as nous. The union of the three kayas is called Svabhavikakaya, which is viewed as an experience of reality without an experiencer or subject (Ray, 2001). Part of the conception of Svabhavikakaya is the inseparability of the three kayas described earlier. This syncretic view of existence is in stark contrast to the Western orthodox view of mutual exclusion.

What is pertinent to this study is that the ontology of the Trikaya allows for the coexistence of what in Western terms are different forms of reality whether they are objective or subjective in nature. Acceptance of this view eliminates the necessary constraints of a sequential use, one size fits all view of reality.

The importance of the syncretic ontology presented here will become apparent in the next chapter within the discussion of the component forms of capital (social forces) that compose the integrated capital ensemble model.

EPISTEMOLOGY

A complementary epistemological position is found in the pragmatism originated by Charles Sanders Peirce (1878) and widely promoted by William James. Pragmatism is interested in both meaning and the method to achieve that meaning. For Peirce it "comes down to what is tangible and practical, as the root of every real distinction of thought" (1878). Yet "pragmatism... has no such materialistic bias as ordinary materialism labors under... no objection to realizing abstractions ... (it is) interested in no conclusions, but those which our minds and our experiences work out together" (James, 1904).

Continuity of Meaning

The pragmatism of Charles Sanders Peirce is employed as a means of acquiring knowledge. That which may be known and our actual knowledge of it may in fact be imperfect; however through an iterative process of inquiry what we know will converge toward the thing itself. Thus through Peirce's conception of refinement of thought and knowing via semiosis, which is inclusive of the iterative process of inquiry, yet more encompassing in its general view of the refinement of the understanding of a thing through that which signifies it. Although it is beyond the scope of this chapter to elaborate on Peirce's theory of signs (semiotics) it bears relevance to the current discussion because for Peirce semiotics governs how we come to know to a thing. Therefore, both concepts (rationalism) and observed manifestations (empiricism) are within the purview of pragmatism and may be apportioned in different proportions according to the form of inference (viz., abduction, induction, and deduction) being employed at a given time through the process of inquiry and in accordance with the scientific method. It is also worthy of note that Peirce stated that "the very origin of the conception of reality… involves the notion of a COMMUNITY" (Peirce, 1868), anticipating the social constructivism epistemology of the late 20th century. Although Peirce acknowledges the social conception of reality, he aims his sights towards a long run consensus to an objective truth; whereas constructivism is decidedly subjective in nature. This may be viewed as a less refined level of pragmatic understanding within the signification process.

Inquiry

William James (1904), in describing what pragmatism means, reveals the importance and interconnections of belief, doubt, thought, and action in Peirce's philosophy and in the process and impetus for inquiry:

> *Peirce, after pointing out that our beliefs are really rules for action, said that, to develop a thought's meaning, we need only determine what conduct it is fitted to produce: that conduct is for us its sole significance… To attain perfect clearness in our thoughts of an object, then, we need only consider what conceivable effects of a practical kind the object may involve – what sensations we are to expect from it, and what reactions we must prepare… This is the principle of Peirce, the principle of pragmatism.* (James, 1904)

For Peirce (1877) action begins the thought process by inducing within a person a sense of doubt. Thus thought arises as a result of doubt and ceases when a belief is attained. As a result of one's belief a rule of action in the world is obtained. This rule of action is what he calls habit. Essentially, an actor will function through habit until an external force generates doubt of a sufficient magnitude that a tipping point is reached so as to warrant conscious decision making on the part of the actor. Thus the degree to which a habit is instilled in an actor can play a significant role in their decision making processes and specifically in how they interact with other agents.

Thus belief is a driving force in inquiry and so is taken up in the following section's discussion of values.

AXIOLOGY

A great many people think they are thinking when they are merely rearranging their prejudices.
William James

A number of value judgments must be made in preparation for and over the course of a research project. Perhaps first among these is choosing what to study, as well as how to go about studying it (Peirce, 1878; Polanyi, 1958). Research is ideally conducted with equanimity; however, the socio-cultural beliefs that I have incorporated throughout my life via environmental conditions and that will arise through habit and produce their own aromatic effect on the work is inevitable. Those with similar backgrounds will inevitably not notice, while those with markedly different gestalts will find them glaring in the light of day. Thus I acknowledge a mixture of thoughtful conscious decision making along with the habitual and unconscious decisions that are made.

I make explicit a number of my personal values:

1. the importance of pursuing a systemic view of the problem
2. selecting a philosophical tradition that is intrinsically compatible with a multifaceted view of reality
3. the importance of obtaining an elegant solution (aesthetic)
4. the importance of a creative and personal solution (aesthetic and ethical)

5. the importance of obtaining a solution that has the potential to better the discipline and society (social and economic)

SUMMARY

This chapter is included to provide a clear indication of the system of beliefs that are employed in the undertaking of the ensuing research. It may at the same time frame any biases that may be present in the author's treatment of the study and thus act to forewarn the reader. It is hoped that an added benefit is that it acts as an introduction to an alternative philosophical landscape that is consistent with pluralistic methodologies that have not enjoyed a sufficient philosophical foundation within the typical orthodox dualistic discussion.

The application to the current research under investigation will become apparent over the course of the following chapter. The next chapter proposes an integrated model of capital for the social world which incorporates the real and the symbolic.

Chapter 3 -- Social Theoretical Framework

Dear friend all theory is gray, and green the golden tree of life.
Goethe

CULTURAL MATERIALISM AND AN INTEGRATED APPROACH TO SOCIAL SCIENCE

I contend that a systemic model will benefit research in information systems by providing the possibility for an integrative approach to the study of a topic that explicitly defines itself as a system. I acknowledge the inherent difficulties and complexities involved in the study of social systems, so a somewhat less ambitious use of an integrated social systems model may be for comparing alternative researcher approaches. Comparison of alternative studies to the model can provide insight into what questions are being asked as well as how they are being approached and answered.

As a first step in constructing an integrated model I begin by looking at cultural materialism as a basis of a systemic model for social-organizational contexts.

Marvin Harris, although not the originator of cultural materialism[4], put a name to it, wrote its definitive text, and was a strong advocate for its adoption as a scientific theory of culture (Johnson and Johnson, 2001). First stated in 1979, his strategy "to understand the causes of differences and similarities among societies and cultures … is based on the simple premise that human social life is a response to the practical problems of earthly existence" (Harris, 2001). In preface to describing the major principles of cultural materialism, Harris notes its origin and his debt to Marx with the following quote: "The mode of production in material life determines the general character of the social, political, and spiritual processes of life. It is not the consciousness of men that determines their existence, but on the contrary, their social existence determines their consciousness." (Marx, 1859/1971)

The theoretical principles of cultural materialism rest on the structural components of Harris's proposed research strategy and his concept of infrastructural materialism.

The basic concepts that constitute cultural materialism are infrastructure, structure and superstructure. Briefly, infrastructure is composed of features that link people to their physical environment; e.g., demographic, technological, ecological, and economic factors. Structure is composed of different forms of relations; e.g., family structures, political organizations, and economic relations. Superstructure refers to such things as values, beliefs, symbols, rituals, religions, philosophies, and science (Harris, 2001). Table 3.1.1 provides a more detailed categorization of the components of cultural materialism. Interrelated to these primary concepts are two pairs of distinction that further categorize the basic concepts. The first is between behavior and thought. This distinction is particularly important for Harris as he sets precedence of the material world over the mental world. The second distinction of importance is between emic and etic forms of study. Emic refers to the native informants being the ultimate judge of the

[4] Term provided by (Harris, 1968), in *The Rise of Anthropological Theory*.

researcher's descriptions and analyses. Etic refers to the researcher-observers as being the ultimate judge. The former provides knowledge and meaning in terms of the natives and their environment; the latter allows the observer to more freely categorize and document apart from what natives may find meaningful. Both are deemed necessary for a full explanation of socio-cultural thought and behavior; however precedence is given to etic over emic operations.

Table 3.1.1: Categories of Cultural Materialism, based on Harris (2001)

Structure	**Subcategory**	**Examples of Phenomena**
Infrastructure (Etic and behavioral)	Mode of Production	Technology of subsistence Techno-environmental Work patterns
	Mode of Reproduction	Demography Fertility, natality, mortality
Structure (Etic and behavioral)	Domestic Economy	Family structure Division of labor Socialization, enculturation, education
	Political Economy	Organizations, factions, clubs, associations, corporations Class, caste
Superstructure (Etic and behavioral)		Art, music, dance, literature, advertising Rituals Sports, games, hobbies
Superstructure (Emic and mental)		Subsistence lore Magic Religion Political ideology Symbols

The focus of Harris's strategy sets a priority for infrastructure over structure and structure over superstructure. Further priority is given to behavioral over mental identifications and of etic over emic operations. This layered prioritization is referred to as infrastructural determinism. Harris notes that the probabilistic determinations of the strategy does not preclude structural and superstructural components from having independence from infrastructure; however it is an option that is explored as a last resort in the hierarchy of discovery (Harris, 1979). Ferguson (1995) "sees the relationship between infrastructure, structure, and superstructure as a nested hierarchy of progressively more limiting constraints." Infrastructure provides the base characteristics and the subsequent factors append additional constraints to the system (Ferguson, 1995). Figure 3.1.1 provides a visual representation of the described model, with an additional sphere of influence that is attributed to the characteristics of specific actors. The characteristics of individual actors is not explicitly considered in Harris's Cultural Materialism, it is included here as a preview to the modification and adaptation of the model that is being proposed.

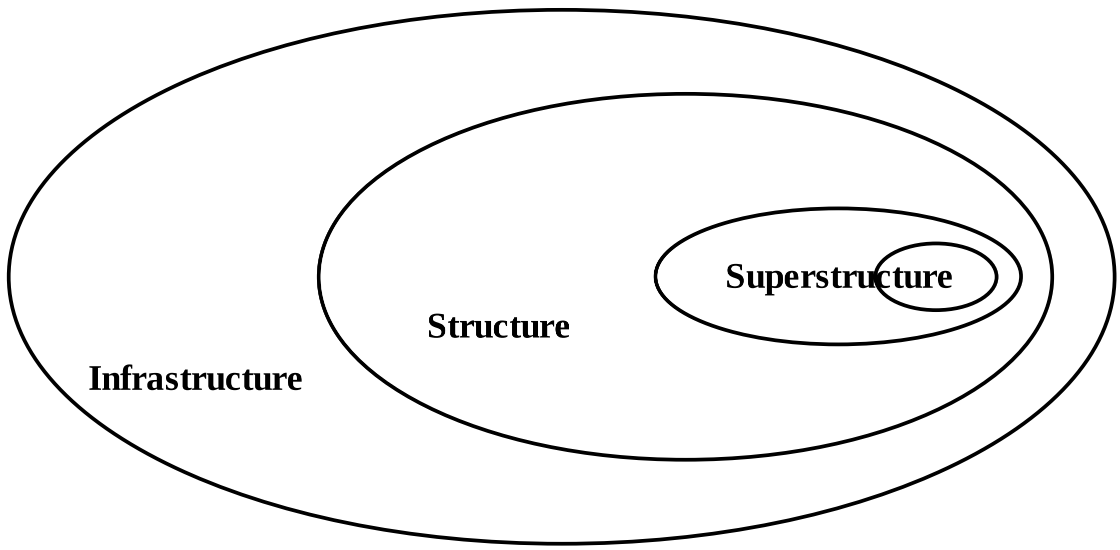

Figure 3.1.1: Model as a nested hierarchy based on Ferguson (1995)

Ferguson argues that the principle of infrastructural determinism may be interpreted in two forms. The first form of interpretation, or "*strict interpretation* holds that all sociocultural phenomena are to be explained with direct reference to the infrastructure; and the *broad interpretation* is that the infrastructure is the primary, general determinant of sociocultural form" (italics mine), but that other relationships exist to explain sociocultural phenomena (Ferguson, 1995). Furthermore, in following a broad interpretation other factors could be explored earlier in the research strategy and not merely as study of last resort.

Harris saw cultural materialism's principle of infrastructural determinism asserting itself most readily within evolutionary time frames (time as measured in centuries or more), with much less effect within historical time frames (measured in decades or less) (Ferguson, 1995; Harris, 1979; Harris and Ross, 1987). In fact, Harris and Ross (1987) note that "short time frames… leads to the impression that in certain historical moments and societies, structure and/or superstructure dominate infrastructure." This can lead to a reversal in the direction of causality or at the least a distinct level of feedback.

Combining Ferguson's notion of strict infrastructural determinism with Harris's predisposition toward long time frames suggests a model as described by Figure 3.1.2, where the asymmetric causal relationships are pronounced. Alternatively, Figure 3.1.3 is a model that is representative of a broad interpretation of infrastructural determinism along with allowances for short time frames.

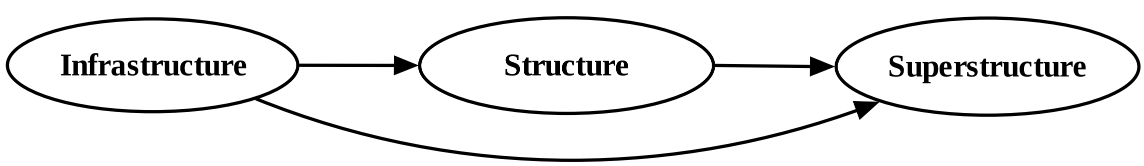

Figure 3.1.2: Strict interpretation

Murphy and Margolis's (1995) assertion that cultural materialism's three levels are in a "continuous dynamic state" in concert with predictable relationships is also in accord with the broad interpretation of infrastructural determinism.

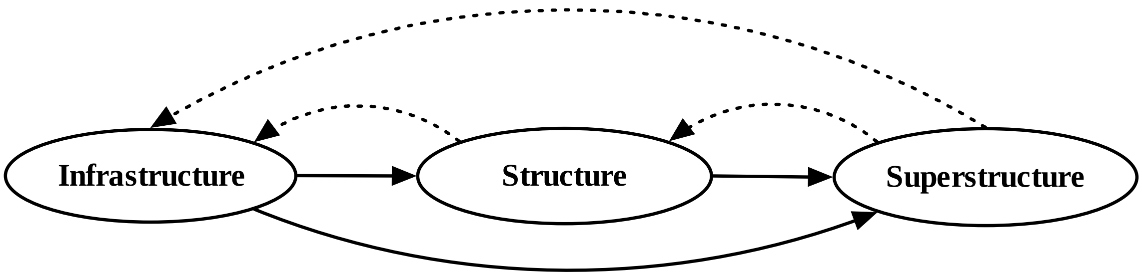

Figure 3.1.3: Broad interpretation

Taking the next step, the model depicted in Figure 3.1.4 has been modified to incorporate greater generality within the causal relationships, with the intention of providing a framework applicable to a larger range of research in the social sciences. First, a temporal assumption is made; viz. that the timeframe for the analysis is relatively short. I propose, based on prior discussion that with shorter time frames the likelihood of interaction among the model components is increased. Second, as a consequence of the prior proposition the interrelationships among the concepts are highlighted within the model; although the underlying proposition of probabilistic determinism is acknowledged by the inclusion of the causal arrows. Third, the perspective of the scale of analysis is altered to directly include the human actor in the model. Again, working in a shorter timeframe I assert that a greater influence from individual human actors will become significant.

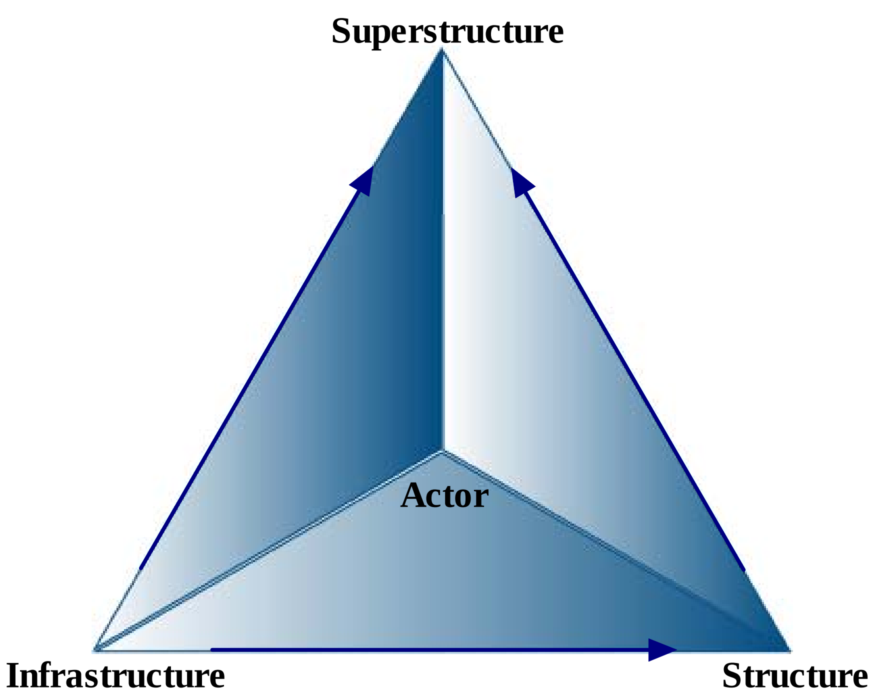

Figure 3.1.4: Modified model

The proposed modified model provides potential for a systemic view of social relations within current society and possibly within organizations; however, there are a number of features that are problematic. For example the underlying concepts may be too far removed from the terminology that organizations and businesses are familiar with. Another source of contention may be the timeframes under which the theory was originally conceived. Explanations of time lag in the explanation of probable causality may become muddled depending on one's interpretation of infrastructural determinism. Therefore, a corresponding model, formulated from the concept of capital is proposed in the following section that builds on the underlying framework presented here. It will provide a similar model with a terminology that is familiar to organizations and business. The model, while sensitive to historical antecedents within the system, is geared towards short time frames suitable for research within the commercial sector of society.

THE INTEGRATED CAPITAL ENSEMBLE MODEL

In theory there is no difference between theory and practice. In practice there is.
Yogi Berra

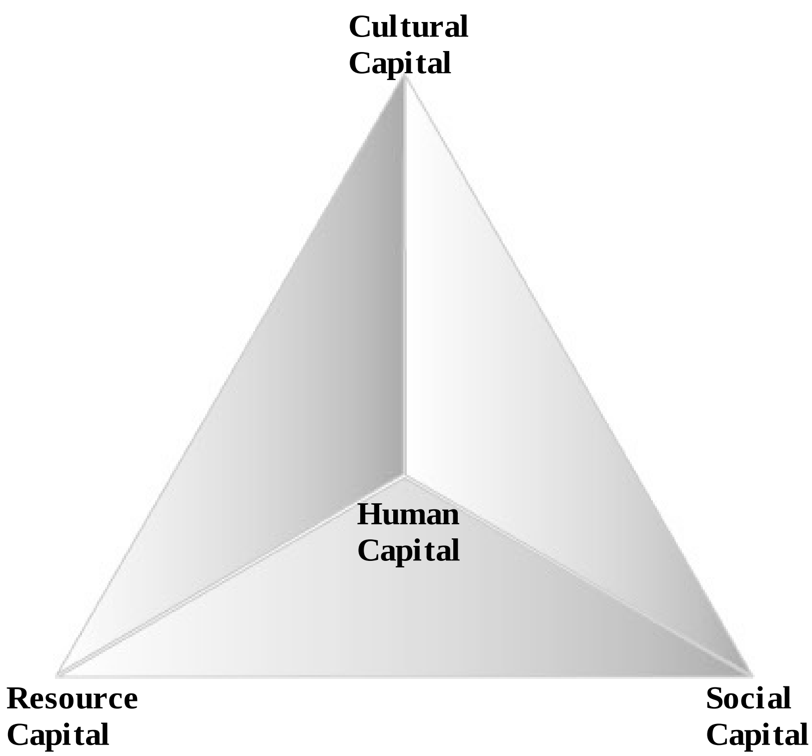

Figure 3.2.1: Integrated Capital Ensemble (ICE) Model

I first introduce the Integrated Capital Ensemble (ICE) Model (Figure 3.2.1) and point out the correspondence to the modified Model of Cultural Materialism in the previous section. Second, I

provide the framework from which ICE was developed by describing the theoretical concepts from which it arose. Third, a conception of conversion among the forms of capital is addressed. Fourth, the marked desire to span the chasm between the dichotomous frameworks of agency versus structure within intellectual inquiry by several of the contributing researchers to the model is noted. Fifth, an analogy is provided between the physical forces of nature and the social forces described within ICE.

The Conceptual Model

Whereas the Model of Cultural Materialism was developed to represent societies over large periods of time, the ICE model (Figure 3.2.1) is intended to represent social and organizational dynamics and interrelationships within shorter periods of time, e.g., during the course of a project.

Capital

What is capital and what forms of capital might there be? Many authors have addressed these questions with varied responses. For example, Lin (2001) provides a generic definition of capital "as *investment of resources with expected returns in the marketplace*." Pierre Bourdieu (1983) described capital as "vis insita[5] (innate force), a force inscribed in objective or subjective structures… it is also a lex insita[6] (innate law), the principle underlying the immanent irregularities of the social world." Bourdieu also sees "the structure of the distribution of the different types and subtypes of capital at a given moment in time represents the immanent structure of the social world" (Bourdieu, 1983).

Bourdieu outlines three fundamental forms of capital. They are "*economic capital*, which is immediately and directly convertible into money and may be institutionalized in the forms of property rights; as *cultural capital*, which is convertible, on certain conditions, into economic capital and may be institutionalized in the forms of educational qualifications; and as *social capital*, made up of social obligations ("connections"), which is convertible, in certain conditions, into economic capital and may be institutionalized in the forms of a title of nobility." (1983). Lin (2001) also examines different forms of capital prior to his extended examination of social capital. In turn, he reviews classical economic capital, human capital and cultural capital. I proceed with a similar format.

The four forms of capital that I will address are here termed resource capital, human capital, cultural capital, and social capital. A description and theoretical origin of each form of capital follows. The order of discussion roughly follows their historical emancipation and use.

Resource Capital

Adam Smith's *The Wealth of Nations* (1776) is generally taken as a definitive starting point in classical economics. For example, within Book II Smith discusses aspects of the accumulation of capital through labor. However, like Lin (2001), I will "call the notion of capital and its features

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[5] The use of this term calls to mind Newton's use in describing the force of inertia in his *Principia Mathematica* (1687).

[6] This is a reference to Bourdieu's concept of habitus or "immanent law, lex insita, inscribed in bodies by identical histories", (Bourdieu, 1990).

as described by Marx the classic theory of capital." Marx refines and clarifies aspects of capital beginning in 1849 with the publication of *Wage Labour and Capital* where he notes:

> "Capital consists of raw materials, instruments of labor, and means of subsistence of all kinds, which are employed in producing new raw materials, new instruments, and new means of subsistence. All these components of capital are created by labor, products of labor, accumulated labor. Accumulated labor that serves as a means to new production is capital."

This new capital that occurs through the process of production and exchange is what Marx called surplus value (Marx, 1867). It is necessary in Marx's formulation that money be exchanged for a commodity before again being exchanged for money for it to be considered capital. With this, two propositions are arrived at: "Capital is money; Capital is commodities" (Marx, 1867), both of which Marx credits to Macleod (1855) and James Mill (1821).

Taken collectively, I refer to the component pieces of the classical economic view of capital as *Resource/Economic Capital*. The term therefore encapsulates the general factors for production discussed in the classical economics of Smith and Marx and is consistent with the working concepts of Lin (2001) and Bourdieu (1983). The term therefore includes money, real and natural resources, as well as labor. Figure 3.2.2 highlights Marx's discussion of capital with an emphasis on resource capital. It is the change of perspective from labor to human capital that I will now address.

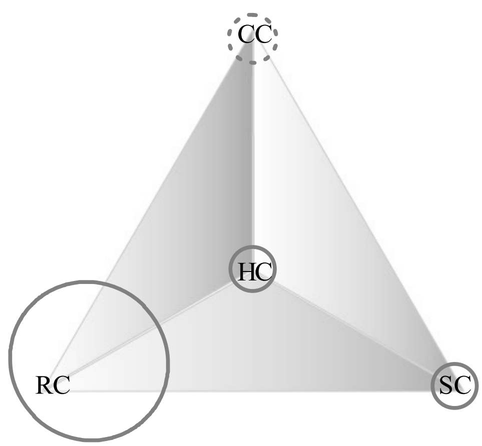

Figure 3.2.2: Resource Capital and Marx (1849, 1867) in ICE

Human Capital

In the classical economic view, labor is included as part of (resource) capital as it constitutes an input for the means of production. Just over one hundred years later labor became identified as a different form of capital, i.e., human capital.

Three researchers of the Chicago school of economics addressed the concept of human capital in the beginning of the 1960's; two of whom would go on to become Nobel laureates in economics, Schultz in 1979 and Becker, primarily for his work on human capital in 1992. It was, however, Johnson (1960) who first made the case in print for economists to stop viewing "labour as a unique original factor of production" and instead embraces "a more useful approach … to lump all factors together as items of capital equipment." He notes that in an advancing industrial society the laborer brings to his task knowledge and skills that are required to accomplish their task, and further that the knowledge and skill is a product of a capital investment in their education (Johnson, 1960).

In this same article that Johnson initiates the concept of human capital he also mentions the idea of generally accepted standards which can be learned for distinguishing better or worse taste in terms of commercial products, education, cultural and artistic activities (Johnson, 1960). This is a feature of socio-economic life that Bourdieu goes on to address in terms of his concept of cultural capital that shares some of the characteristics of human capital described by the Chicago school.

Schultz provides comment and preliminary analysis on investments in human capital. In so doing he points out that what has hitherto been viewed simply as consumption is in fact types of human capital investment. He expands upon the notion touched upon by Johnson in regards to knowledge and skills investment by categorizing forms of human capital investment into five areas; viz., health related, on-the-job training, formal education, extended adult study programs, and migration adjustments (Schultz, 1961). Gary Becker was also working in this area from at least 1960, and published the definitive text on human capital in 1964, providing both theoretical and empirical analysis of human capital in relation to many aspects of economic life (Becker, 1993). Figure 3.2.3 highlights Becker's discussion of capital with an emphasis on human capital and economics.

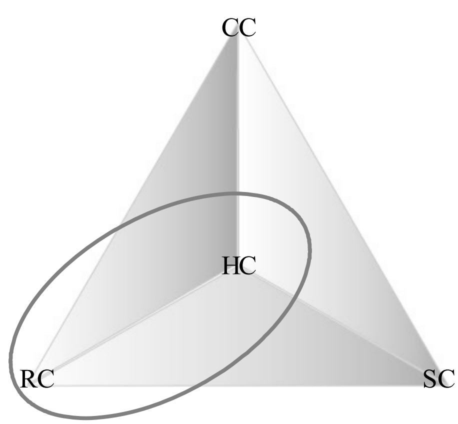

Figure 3.2.3: Human Capital and Becker (1993) in ICE

The following section will now address cultural capital. As a precursor, I note here that just as there exists an overlap between resource capital and human capital, so too there is an overlap

between human capital and cultural capital. In particular, we will see that Bourdieu's definition of embodied cultural capital is essentially Becker's concept of human capital.

Cultural Capital

Bourdieu's concepts of capital are strongly influenced by Marx, with an important aspect being the interaction between the dominant and the dominated classes. This is particularly prominent in his discussion of cultural capital.

Bourdieu, the originator of the term and concept of cultural capital, subdivides his view of cultural capital into three forms. The first of these is the *embodied* state, which is the form inherent in the individual and is part and parcel of one's mind and body. The second is the *objectified* state, which is instantiated as cultural goods (e.g., artwork, books, machinery). The third is the *institutionalized* state, which finds its manifestation objectified by way of conferred qualifications and certifications (e.g., university degrees) (Bourdieu, 1983).

Although Swarzt (1997) indicates that Bourdieu contends he has little in common with human capital theorists, beyond some shared vocabulary (Bourdieu and Wacquant, 1992), Bourdieu's *embodied* state of cultural capital is essentially what Becker (1964) described as human capital (Portes, 1998). However, there are three important distinctions to be made. First, rational choice action is the primary explanatory force in human capital theory; whereas cultural capital theory emphasizes class structure in society and its effects on individual actions (Lin, 2001). <In terms of the Integrated Capital Ensemble (ICE) Model, both individual actor (choice) and structural influences are important.> Second, as a consequence of the perspective differences in regards to rational choice, human capital theory views self-improvement and the acquisition of skills and knowledge as a deliberate activity; whereas from a cultural capital perspective self-improvement may be a deliberate action, but it can be and often is a result of unconscious actions (Bourdieu, 1983). The actions of the individual and the acquisition of cultural capital are inherently tied to Bourdieu's notion of habitus: "habitus, a mental structure which, having been inculcated into all minds socialized in a particular way, is both individual and collective." (Bourdieu, 1998). Third, Bourdieu sees human capital theorists as focusing on the material/monetary relationship with human capital. Cultural capital identifies both material and symbolic profits. Therefore, the monetary conversion of cultural capital is identified as in human capital, but the symbolic profit in terms of production and reproduction of social and cultural structures, in particular class structure, is also addressed (Bourdieu, 1983; Swarzt, 1997).

The *objectified* state of cultural capital (e.g., artwork) has both a material component (the painting for example) and an inherent relationship to the agent based *embodied* form of cultural capital. The reason for this is that possession alone of the material object does not necessarily imbue the "owner" with the rights and abilities to "consume" the cultural object (Bourdieu, 1983). Economic capital allows material possession, human capital/embodied cultural capital appropriate use.

The *institutionalized* state of conferred recognition of cultural qualifications recognized by (high) society enhances the ability to convert between cultural and economic capital (Bourdieu, 1983). So again, Bourdieu ties cultural capital to the production and reproduction of class structure and

thus an influence on social structure as a whole. Figure 3.2.4 highlights Bourdieu's discussion of capital with an emphasis on cultural capital in relation to economics.

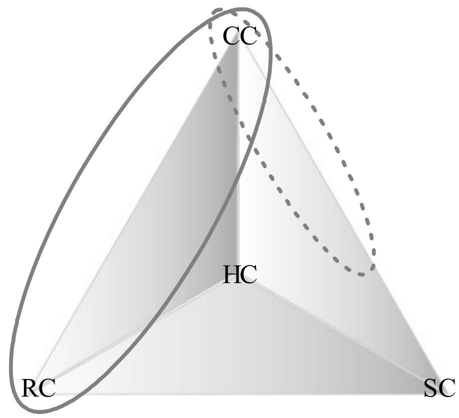

Figure 3.2.4: Cultural Capital and Bourdieu (1983) in ICE

Social Capital

In his review of social capital in 1998, Portes points out that "despite its current popularity, the term does not embody any idea really new to sociologists… the term social capital simply recaptures an insight present since the very beginning of the discipline." However, at the same time, because of its popularity outside of sociology and many new-found applications in new contexts there is a danger that it will lose any distinct meaning (Portes, 1998). Burt (2000) notes that there is general agreement about the social capital metaphor, of people doing better because they are better connected. However, "disagreements begin when the social capital metaphor is made concrete in terms of network mechanisms that define what it means to be 'better connected'."

In order to introduce the primary concepts of social capital, both concepts held in common and those where disagreement arise, I will first provide a brief review of key points and perspectives in the modern discussion of social capital. A summary of the key points will then be provided.

The term first arose in the work of Pierre Bourdieu in 1980. In 1983, he discussed it in conjunction with his conception of other forms of capital; viz., economic and cultural capital. He defined it as "the aggregate of the actual or potential resources which are linked to possession of a durable network of more or less institutionalized relationships of mutual acquaintance and recognition – or in other words, to membership in a group" (Bourdieu, 1983). The relationships exist in order to enact a series of material and/or symbolic exchanges, the exchanges providing some measure of profit to the members either in the short or long term. Bourdieu acknowledges a "collectively-owned capital" and also discusses "social capital possessed by a given agent" (Bourdieu, 1983). Overall, Bourdieu is interested in the interaction of the different forms of capital including their exchange values, but especially their effects on the production and reproduction of class structure and social and cultural structures in general, as noted in the previous section.

The introduction and concepts of social capital that are better known to an American audience are from the researchers James Coleman and Ronald Burt. Another researcher not directly tied to the term social capital but instrumental nonetheless is Mark Granovetter. Granovetter's network concepts and mechanisms of structural embeddedness (1985) and the strength of weak ties (1973) underlie the arguments of social capital for Coleman and Burt respectively. Granovetter's argument for embeddedness lays out the role of personal relations within a network of relations and its importance in generating trust (Granovetter, 1985). This we will soon see is key point of Coleman's social capital.

Coleman's explicitly stated interest in introducing the concept of social capital was to bridge the divide between the economists and the sociologists and to incorporate their respective world views together, i.e., that of the independent rational actor and the socialized actor governed by a social context (Coleman, 1988). Coleman retains the rational actor of economics in his concept of social capital while acknowledging the influence of the social world upon his actor.

For Coleman (1988), "Social capital is defined by its function. It is not a single entity but a variety of entities, with two elements in common: they all consist of some aspect of social structures, and they facilitate certain actions of actors…social capital inheres in the structure of relations between actors and among actors. It is not lodged either in the actors themselves or in physical implements of production." As such, he recognizes that social capital in combination with other resources can influence outcomes for individual actors as well as for the system as a whole.

Coleman (1988) specifically identifies three forms of social capital. The first form is composed of *obligations and expectations*, where trust is an important issue within exchange relations among actors. The second form, *information channels*, exists in order for actors to transfer information. The particular tie between actors may or may not exist for this particular purpose; i.e., it may exist as a formal channel of information exchange or it may exist for some other primary purpose but include information transfers as another benefit of the actors' relations. The third form of social capital identified is *social norms*. It is this form that encroaches into the realm of cultural capital, as it is clearly founded in terms of a network of actors' shared values and beliefs. Coleman underscores the importance of the network mechanism called closure (a high degree of interconnection among the actors within a group), which he sees as "a necessary, but not a sufficient condition for the emergence of effective norms". Closure is also an important precursor for the trust shared in the obligations and expectations of the exchange relations in his first form of social capital. In terms of information channels it can be envisioned that closure is obtained as a result of the overlap of multiple forms of ties among the actors (termed a multiplex network; Gluckman, 1967). This structural precondition in order to facilitate, but not dictate, a cultural outcome is coincident to the (Harris inspired) model of cultural materialism, (causal) effect of structure on superstructure.

"Where closure creates advantage by lowering the risk of cooperation… brokerage, creates advantage by increasing the value of cooperation" (Burt, 2000/02). Where Coleman focused his argument of social capital on the former, Burt concentrates his efforts on the latter in the form of what he calls structural holes. The structural holes create a competitive advantage for an

individual whose network spans the holes (Burt, 1992). The people who bridge the holes between groups are in a position to see new ideas before others and be able to broker projects to implement these ideas. As a result these people can reap greater profits (Burt, 2000/02).

Burt actually sees a "general agreement about social capital as a metaphor", for people who are better connected do better. The difficulty and "disagreements begin when the social-capital metaphor is made concrete in terms of network mechanisms that define what it means to be 'better connected'" (Burt, 2000/02).

Lin (2001) supplies a definition to encapsulate the prior discussion: "The theory of social capital focuses on the resources embedded in one's social network and how access to and use of such resources benefit the individual's actions." Figure 3.2.5 highlights the discussion of capital with an emphasis on social capital in relation to economics.

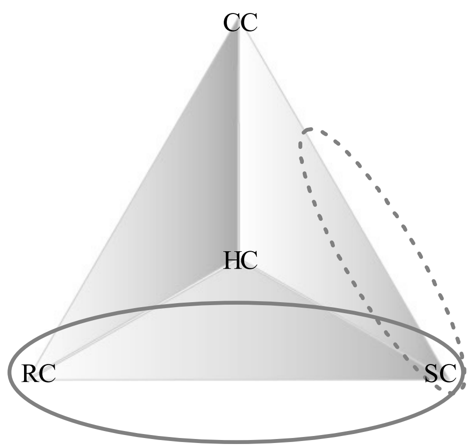

Figure 3.2.5: Social Capital & Burt (1992), Coleman (1988), & Lin (2001) in ICE

An Example of Capital Exchange and Conversion

The discussion of capital conversion is most often focused on the exchange of one form of capital into money. Classical examples of this would be the conversion of natural capital (land, trees, etc.) into money. Likewise, the idea of accumulating knowledge and education in terms of human capital is for the purpose of making a profit and exchanging knowledge for money. The same can be said for both cultural capital and social capital, however with greater difficulties in being able to determine rates of exchange value. Within Bourdieu's theory of capital he posits the concept of exchange occurring not only in a material manner, i.e., money, but also within symbolic terms. This symbolic exchange occurs via what he calls symbolic capital (Bourdieu, 1983), thereby providing a term for the non-material exchange. An example that incorporates both forms of exchange can easily be envisioned in the case of the conferral of an educational degree. For Becker and his theory of human capital, the skills that are part and parcel of the agent's education are transferable into economic capital, i.e., money. Bourdieu would agree, but would term this form of capital as an embodied state of cultural capital. However, Bourdieu would go further by stating that in addition to this material exchange a symbolic exchange also

occurs by way of the educational elites conferring a degree upon the recipient, so that this is an instance of both objectified and institutionalized cultural capital. The objectified cultural capital is represented in a material form in terms of the physical diploma. The institutionalized cultural capital is the conferred recognition by society that the person who has been granted the degree now has something they previously did not have. The individual now having received recognition essentially obtains a particular rank in the social structure. The rank and role within the social structure can have an immense impact on the contacts one is able to make in society. This shows the cultural capital being transformed through 'symbolic capital' into social capital. And as previously discussed this social capital may then be transformed into economic capital.

Briefly, it should be noted that capital may in fact be viewed as a latent form of power, i.e., (potential energy); therefore, the conversion from one form of capital to another acts as a conduit to translate different forms of power. It is beyond the scope of the current study to discuss this transactional/translational exchange of power, but it may be worth the reader's time to imagine.

Agency vs. Structure

Two different perspectives by which different researchers frame their weltanschauung were mentioned numerous times in the preceding discussion. The two perspectives are often discussed within the context of an agency versus structure argument. A number of the researchers above explicitly stated their wish to bring together the disparate extremes of the atomized rational agent and the socially constrained agent, into a model of the world that includes both. They include: Granovetter, with his conception of embeddedness, Bourdieu with his forms of capital (economic, cultural, and social), and Coleman with his concept of social capital in order to complement financial and human capital.

Other social scientists have attempted to integrate the intellectual cliques of agency and structure as well. These include Anthony Giddens and his Theory of Structuration and Ann Archer's work with its influence from systems theory (Ritzer and Goodman, 2004).

The Integrated Capital Ensemble model builds upon this work and presents itself as first, a conceptual means of viewing the social world; and second as a way in which to view social science research. For the first case a computational experiment using a multiagent simulation based on social network theory will operationalize and test the model. Examples of the second case have been included within the review of the literature that composes the model. Additional examples will be included within the review of the Information Systems literature in the following chapter.

Analogy of Social and Physical Forces

Previous remarks have been made in regard to capital as it relates to social forces and physics. For example, Swartz (1997) notes that Bourdieu (1990) referred to capital as "a kind of "energy of social physics" that can exist in a variety of forms and under certain conditions and exchange rates can interconvert from one into another." Here I provide a more complete analogy between the fundamental forces of nature and those of society.

Physical reality is envisioned as being composed of four fundamental forces; viz., gravity, electro-magnetism, the weak nuclear force and the strong nuclear force. Here social forces

described in terms of four forms of capital are posited in relation to the physical forces for the benefit of a very rough comparison. I do not mean to imply a direct one to one correspondence between the physical and social forces of nature; rather the discussion is included (at a superficial level) to provide additional insight into the essential nature of the interactions of the forces; as well as the primacy of one force over another depending upon the circumstances at play. Table 3.2.1 provides a list of the physical and social forces under discussion.

Gravity is the physical force that is most readily apparent in our everyday life, although in relation to the other fundamental forces it is actually the weakest. I submit that Resource/Economic capital may be viewed in a similar manner. It is the social force/form of capital that is most apparent in our everyday lives and its effects are readily understood and intuitive in a causal manner. Like gravity, despite its relative weakness in magnitude to the other forces, it often takes a primary position in everyday activities. This coincides with Harris's concept of infrastructural determinism.

The electromagnetic and weak nuclear force can be described as two different manifestations of the same force, the different manifestations being dependent on the energy conditions under which they are observed. The concepts of human and cultural capital lend themselves to similar inspection depending upon environmental conditions and the perspective of the researcher. These relationships are depicted in Table 3.2.1 by the bracketing of the Electromagnetic and Weak Nuclear forces and Human and Cultural capital.

Within the standard model of particle physics the three fundamental forces are able to be modeled in order to make valid predictions about the world. Gravity is found to be somehow different from these other three forces. Again, the same may said in the case of the four forms of capital. Resource capital is substantially different from the other three forms of capital. This is true in both a literal and figurative sense. Resource capital presents itself in a material form and therefore is usually immediately apparent; whereas to varying degrees the other forms of capital are in a sense invisible to the eye, yet their effects in society and on the individual are measurable in both a qualitative and quantitative manner. These relationships are depicted in Table 3.2.1 by the bracketing of the Electromagnetic, Weak and Strong Nuclear forces and Human, Cultural and Social capital.

Table 3.2.1: Fundamental Forces

Fundamental Forces	
Physical	**Social**
Gravity	Resource
Electromagnetic	Human
Weak Nuclear	Cultural
Strong Nuclear	Social

SUMMARY

This chapter has presented an integrated model of four forms of capital. The conceptual origin of this integrated capital ensemble model (ICE) has been presented, beginning with Marvin Harris's

model of cultural materialism through a modification to capture and explain the world in a shortened time frame by focusing on what is deemed four primary forms of capital (resource, social, cultural, and human). Key aspects and history of each of these forms of capital have been included in the discussion and explanation of the model. The transformative nature of capital was discussed with brief mention of the transactional power that is inherent within all of the forms of capital. The importance of the interaction of agents and structure in the model was highlighted. Finally, an analogy was presented between the fundamental physical forces in nature and the social forces represented in the ICE model to further elucidate the interplay of the different forms of capital in the social world and how contextual events may determine which form of capital will have a predominant effect on the unfolding actions of life.

The virtual world of an information systems development project that is created in chapter six includes the interplay of these social forces throughout the evolution of the IS project. Chapter seven will then analyze and present the result of these forces on the outcome of the project. The following chapter reviews the IS literature in relation to the variables of interest within the virtual experiment.

Chapter 4 -- Information Systems Literature

If we knew what it was we were doing, it would not be called research, would it?
Albert Einstein

INTRODUCTION

As previously stated, the purpose of this study is to examine the structural social and cultural factors that may influence the outcome of an information systems development project. Previous IS literature has been interested in the related concepts of user involvement and its influence on information systems (project) success since the early days of the discipline. For the purposes of the current study Baccarini's (1999) categorization of project success is employed, which differentiates between the success of the project deliverables and the success of the product (information system). The preponderance of IS research on the topic has centered on the psychological perspective of the customers (users) in the organization and therefore it has rarely addressed a social perspective in any meaningful way. Attitudes, beliefs and perceptions of the actors, in regards to their involvement and likes or dislikes of the information system constructed are frequently collected either via psychometric surveys or interviews in the context of case study based research. This study's focus on the exploration of social structure and its influence on project outcome success provides a different perspective than what has been explored previously. First, the social relations of the actors are seen as a direct translation to user involvement. Second, the cultural values held by the actors provide an important influence on the likelihood of agent interaction which is readily translated into user involvement. The measures of interaction and shared beliefs are seen to focus on the social aspects of information systems development rather than the attitudes of users.

User Involvement

This study does not make a distinction between user involvement and user participation, as any possible nuances that may or may not exist between these two concepts do not exist in the virtual environment. What is important to this study is the interaction between the users (customers) and the developers. Therefore, user involvement (participation) occurs when actor interaction and transfer of knowledge in relation to the project takes place. Social behavior is what is measured, rather than people's attitudes. Within the virtual environment, interactions may take place without a transfer of knowledge, just as in the physical world. However, the virtual environment does not account for a transfer of knowledge without some form of interaction taking place, which may also be argued to be aligned with the physical world. Also, in keeping with the physical world lack of knowledge does not preclude agents from guessing about how to do something.

Social

A link is drawn between the current study and previous research in information systems development that has included some element of an approach to the social. Specific interest is drawn to the ISD approaches of Socio-Technical Design (STD) (Mumford, 1983, 1995) and Soft Systems Methodology (SSM) (Checkland, 1984) along with research involving structuration

theory (Jones and Karsten, 2008; DeSanctis and Poole, 1994; Orlikowski and Robey, 1991) and social networks (Yang and Tang, 2004; Aydin and Rice, 1991).

This chapter begins with a discussion of user involvement in information systems development and its link to IS project success. This is followed by an understanding of the information systems literature discussion on information systems success and project success in terms of project management. This provides a bridge to the metrics used within this study and the previous discussion within the information systems literature. Third, different approaches to incorporate *the social* in information systems are highlighted and critiqued.

USER INVOLVEMENT AND PROJECT SUCCESS

Most people are more comfortable with old problems than with new solutions.
Charles Brower

For the purposes of this study user involvement and user participation are taken as being equivalent concepts, as this study defines user involvement (participation) as being users (customers) interacting with developers. It is through the interaction between customers and developers that knowledge (requirements) is transferred from the customers and learned by the developers, so that the developers are able to construct a quality information system. This process is described in more detail in subsequent chapters.

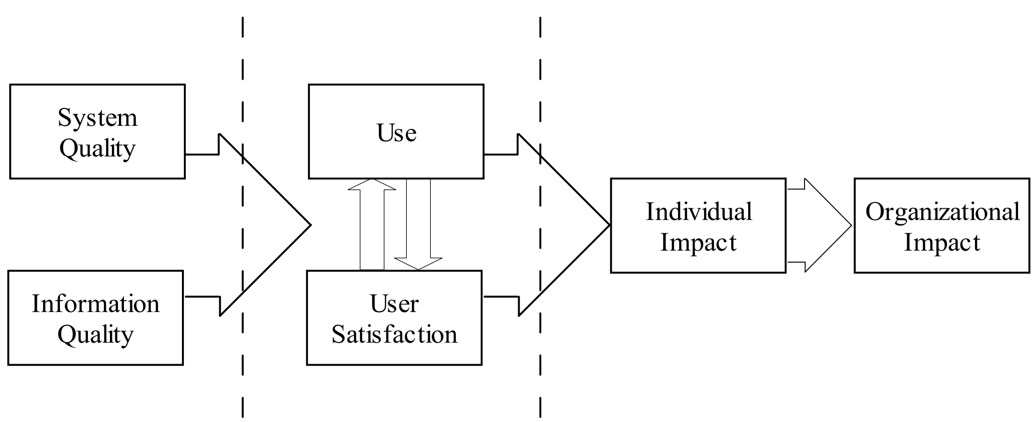

Figure 4.1: IS Success Model (DeLone and McLean, 1992)

User involvement and systems development success has been a topic of consideration for IS academics since the 1960s (Swanson, 1974; Markus and Mao, 2004). In general, "user involvement (is) considered paramount to the success of a systems development" (Hirschheim and Klein, 1984). It is acknowledged that the user involvement success factor finds itself implemented in vastly different ways. However, what is of interest to this study is not individual peculiarities of user participation, but the relational interactions of users with developers in a way that identifies a social structural component.

Early assessment and review of user involvement was performed by Hirschheim (1983) and Ives and Olson (1984). The Ives and Olson review presented a descriptive model of user involvement in relation to outcome success components such as system quality and system acceptance. Recently Wagner and Newell (2007) explored user participation and enterprise systems success while a study by Gallivan and Keil (2003) centered on the user-developer communication process and its necessary components for user participation to be effective. DeLone and McLean (1992), while allowing for user involvement as a contributing factor to IS success, focused their review and model proposal on an information systems success outcome variable (Figure 4.1). DeLone and McLean's success model focuses on the product portion of project success as opposed to the project success of the development process of the information system.

The multi-dimensional model that DeLone and McLean present includes six generic constructs based on their categorization of the measures found in the literature. However, it is noted that any specific construct is identified with a wide range of possible measures; e.g., system quality may be measured by 'ease of use', 'data accuracy', or 'realization of user requirements'.

DeLone and McLean (2003) updated their original model based on subsequent empirical research. The updated model is pictured in Figure 4.2. The authors view the updated model as "largely changes in degree, not in kind", with the addition of a service quality construct and combining individual impacts and organizational impacts into the single construct net benefits (DeLone and McLean, 2003).

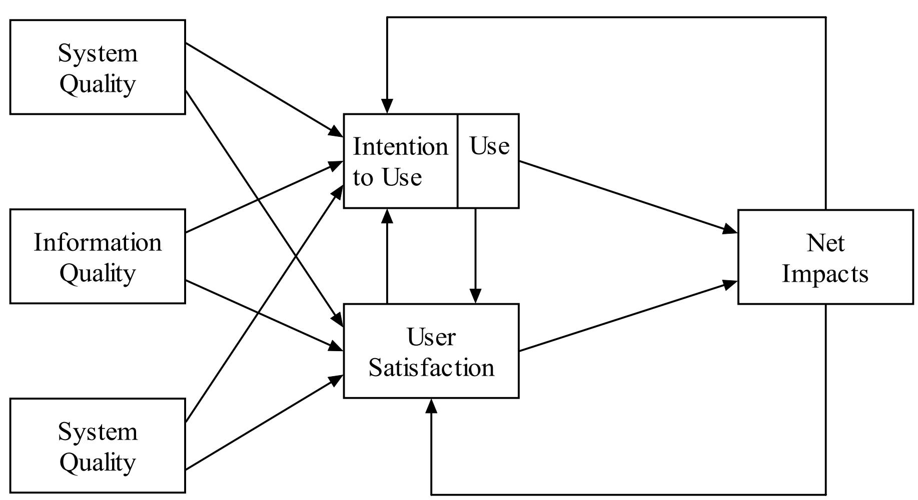

Figure 4.2: Updated IS Success Model (DeLone and McLean, 2003)

Recently Markus and Mao (2004) undertook a critique of what they term "traditional IS participation theory" and its relation to IS success. Markus and Mao describe new categorizations for: (1) explaining "how and why participation leads to system success" (viz., buy-in, system quality, and emergent interactions) and (2) partitioning the system success concept into system development success and system implementation success. Through their categorization and discussion, Markus and Mao (2004) propose an explanation of some of the

inconsistencies described previously about user involvement (e.g., Hirschheim, 1983) and highlight the contextual nature of the value of user involvement and system success. What is of particular interest to this study is that Markus and Mao (2004) recognize the importance of the interaction between the users and developers in an information systems development project.

Components of Project Success

Where DeLone and McLean (2003) compress the impact outcome variable from individual and organizational impact into the more generic net benefits, Shenhar et al. (2001) present a multi-dimensional model of project success that identifies different forms of impact a project can have along with the timeframes within which these impacts may be recognized. This is represented in Figure 4.3. The four dimensions identified are: (1) project efficiency, (2) impact on the customer, (3) impact on business success, and (4) preparing for the future. This approach expands Shenhar et al.'s (2000) distinction between operational projects and strategic projects. The first dimension is concerned with the immediate goals of the project; viz., meeting time, budget and requirements goals. The second dimension, benefit to the customer is contingent on the level of technology being addressed in the project. However, it can be related to a number of measures and constructs in the DeLone and McLean (1992) model; e.g., 'meeting user requirements' and 'ease of use' as measures of *system quality* or varying elements of *user satisfaction*. The third dimension, benefit to the organization, is coincident with DeLone and McLean's original organizational impact construct concerning itself with "profits, market share, and other business related results." The forth dimension is concerned with long term strategic benefits that may be realized "long after the project has been completed and often indirectly." This dimension is meant to address the question: "How does the current project help prepare the organization for future challenges?" (Shenhar et al., 2001).

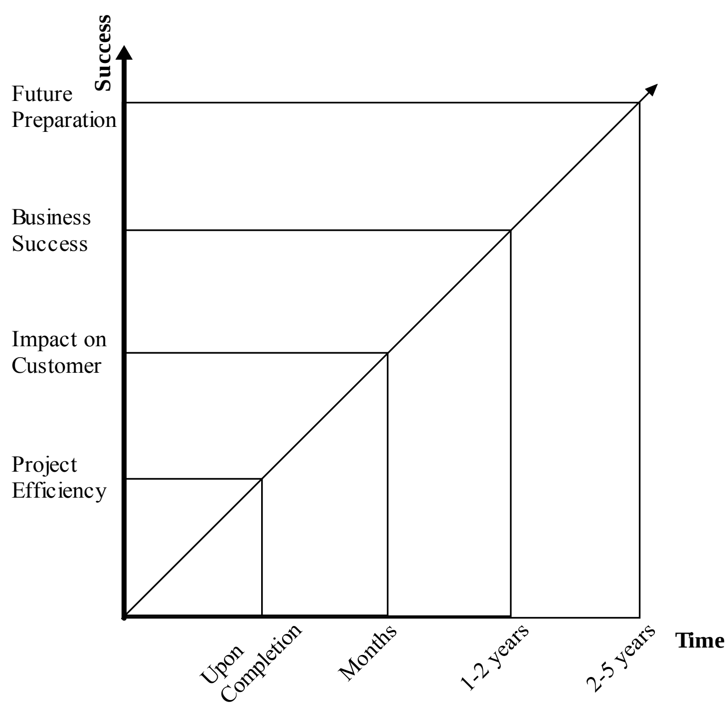

Figure 4.3: Time Frame of Success Dimensions; based on Shenhar et al. (2001)

Baccarini's (1999) classification of project success anticipated Markus and Mao (2004) by viewing project success as including: (1) project management success and (2) product success. This appears analogous to what Markus and Mao propose, referring instead to *system development success* and *system implementation success*. Baccarini, like Shenhar et al. (2001), views different dimensions of success at different timeframes, ranging from the immediate to long-term. Table 4.1 provides a summary of Baccarini's framework for project success. The highlighted portion represents the portion of project success that is the focus of the current study.

Table 4.1: Categories of Project Success; based on Baccarini (1999)

Project Success					
Project Management Success • Outputs: deliverables of the project • Inputs: resources & activities required and defining how the project will be accomplished; e.g., the WBS, responsibility chart, schedule, & budget			**Product Success**		
Time, Cost, Quality (Effective)	Quality of PM Process (Efficient)	Satisfaction (client and PM team)	Goal (Long-term objective)	Purpose (Short-term objective)	Satisfaction (Goal & Purpose)

This framework is useful in describing the current study's project success outcome variable that is used in the virtual experiment. The outcome variable used in the experiment to measure project success is the proportion of the project that is complete, at a given time, based on the knowledge available to the developers at that time. Inherent in the algorithm is a determination of matching knowledge possessed by the developers and an objective predefined knowledge requirement to perform given tasks in the project. Therefore, the single outcome variable 'percentage project complete' determines project success at the level of project management success for both effectiveness (time and quality task objectives) and efficiency (coordination of stakeholders). Considering the cost element of effectiveness and measuring attitudes and stakeholder satisfaction, though important, are beyond the scope of the current study.

CULTURE

David Swartz (1997:1) begins his book on culture and power by stating that "Culture provides the very grounds for human communication and interaction… (it) mediates practices by connecting individuals and groups to institutional hierarchies". This underscores the fundamental nature of culture and cultural capital in terms of the social physics described in the preceding chapter. It further provides the rationale for including this factor in the model.

The American Heritage Dictionary (2009) defines culture as "The totality of socially transmitted behavior patterns, arts, beliefs, institutions, and all other products of human work and thought." Iivari and Huisman (2007) in describing organizational culture note that it "covers almost

everything in an organization." The notion of culture is very wide and incorporates both physical and symbolic aspects of a social group. For the purposes of this study cultural values may be equated with the beliefs held by actors within the organizational social framework. These beliefs may be held either consciously or unconsciously by the social actors. Culture implies something held in common with other actors in the social framework; however this does not imply universally held beliefs by all members. Therefore, sub-cultures or groups may exist within the larger social framework whose actors hold the same values and beliefs apart from other groups. These concepts are addressed in more detail momentarily.

Recent treatment in the IS literature includes a review by Leidner and Kayworth (2006) where they categorized the treatment of culture in IS into six groups, one of which was culture and information systems development. More recently Kappos and Rivard (2008) conducted a more focused review of the IS literature concentrating their efforts on articles concerned with culture and information systems development and use. They adopted a three-perspective model of culture following Martin (1992) as a way of categorizing the IS literature. The three perspectives employed are integration (collective-wide shared beliefs, values and interpretations), differentiation (not shared collective-wide, but within subgroups), and fragmentation (ambiguous beliefs and interpretations exist) (Kappos and Rivard, 2008).

Alternatively, Iivari and Huisman (2007) conducted an exploratory study on the relationship between organizational culture and the deployment of systems development methodologies. Iivari and Huisman used a competing values framework for organizational culture in the course of their study.

The conceptualization of organizational culture employed by this study focuses on the values and beliefs of the project participants within the organization. Although a specific empirical manifestation is not immediately necessary for the virtual experiment, an organizational cultural assessment instrument, based on the competing values framework described by (Cameron and Quinn, 2006), is embraced. Before describing the model, a number of reasons are suggested for its selection. First, it presents a direct link to conducting an empirical study in the future. Second, the model allows for a proportional representation of organizational culture and thus provides for a more nuanced measurement of the concept. Third, it has been employed and tested in over a thousand organizations (Cameron and Quinn, 2006). Forth, as Iivari and Huisman (2007) note, there are not many alternative measurement instruments.

The competing values framework is built on indicators of organizational effectiveness and is presented in two dimensions and four quadrants (Quinn and Rohrbaugh, 1983; Cameron and Quinn, 2006). The relationship of the dimensions and quadrants is depicted in Figure 4.4. The first dimension, represented by the vertical axis in the diagram, portrays a spectrum of change/stasis, where the extremes are high flexibility at the top and stability and predictability at the bottom. Examples of flexible oriented organizations are Nike and Microsoft. Examples of more stable organizations are universities and government agencies (Cameron and Quinn, 2006). The second dimension, represented by the horizontal axis, describes a spectrum with extremes of internal orientation on the left and an external orientation on the right. An example of an organization with an internal focus is HP and their HP-way. An example of an organization with an external focus is Toyota (Cameron and Quinn, 2006). An extended discussion of the

framework and its components is not warranted for this study, as the virtual experiment explores a simple dichotomous situation; i.e., the two subgroups either share the same cultural values and beliefs or the two groups have disparate cultural values and beliefs. Thus this study tests two of the perspectives within the three perspective model of culture described by Martin (1992) above.

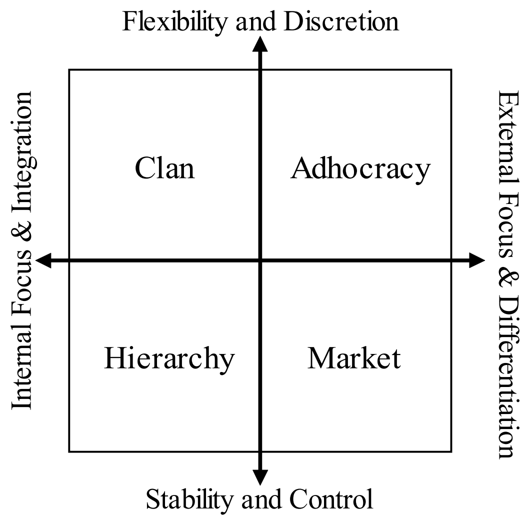

Figure 4.4: Competing Values Framework (Cameron and Quinn, 2006)

APPROACHES TO THE SOCIAL IN INFORMATION SYSTEMS

You think that because you understand ONE you understand TWO, because one and one makes two. But you must understand AND.
Sufi proverb

The classification schema of information systems development proposed by Iivari et al. (2001) identifies eleven different approaches. Interestingly, the approach that identifies an information system as being a social object is an approach that is merely a place holder, because it "has not been elaborated into a concrete methodology for ISD" (Ivari et al., 2001). Two approaches that most clearly identify with social aspects of information systems development are the Socio-Technical and Soft Systems Methodology approaches and are discussed in the following sections. Also discussed will be Structuration theory and Social Networks in the IS literature.

Socio-Technical Design

Although Socio-Technical Design includes the root of the word social as part of its name and is interested in the shared values of people in the workplace, the social view of STD is that of social atomism with a focus on the individual rather than interactions among individuals.

The socio-technical design methodology was developed by the London Tavistok Institute, which was founded in 1946. Its roots are intertwined with that of action research and humanist philosophical principles. Foundationally, socio-technical design intends to balance the

importance of human and technical factors in the workplace. These two factors are viewed systemically. The systems perspective adopted by Socio-Technical Design stems from the work on general systems by Bertalanffy (1950). In order to provide even footing for the human social system, the two most important goals are to: (1) “humanize work through the redesign of jobs” and (2) provide a democratization of the work (Mumford, 2006).

Socio-technical designs focus on eliminating job dissatisfaction and alienation through job redesign and providing personal control to the individual. In terms of structural relationships, Mumford (2006) notes that socio-technical design “required the identification of shared values”, “but not a great deal of attention was paid to interpersonal relationships”.

Conceptual / Theoretical Discussion
Bostrom and Heinen (1977) provides a visualization of the inter-relationships of the different components of the socio-technical work system that are affected by the development and implementation of a new information system (Figure 4.4). Here again, although structure is identified as being an important aspect of the socio-technical system little has been done in terms of research.

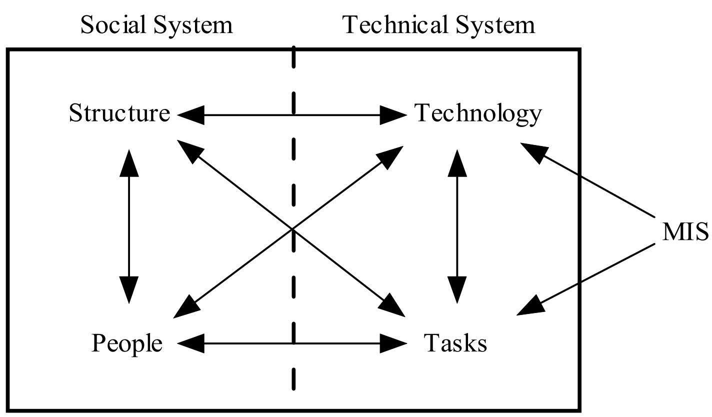

Figure 4.5: STS Interacting Variable Classes (Bostrom and Heinen, 1977)

Prescriptive / Practice Oriented
In application to computer (information) systems development the importance of user participation is considered essential. Enid Mumford (1983, 1995) describes a development methodology based on the principles of socio-technical design in an Effective Technical and Human Implementation of Computer-Based Systems, ETHICS.

The heyday of socio-technical design was in the 1960’s and 1970’s, when organizations were vying for scarce human resources. Since the 1980’s cost cutting, downsizing, and organizational focus on shareholder value all have helped drive the humanist oriented design methodology out of favor (Mumford, 2006).

Soft Systems Methodology

Like Socio-technical systems methodology, Soft Systems Methodology was researched and developed hand-in-hand with action research. Also like STD, SSM has seen limited interest by researchers in the information systems community. A further connection of note is that Checkland (1984) suggests as one possible course of model building in step 4 of his guidelines (Figure 4.5) is to frame the system in terms of a socio-technical system based on the work of the Tavistock group. However, whereas STD began as a means of organizational development and design and was later introduced to information systems as a means for system development, SSM began as a method for information systems development and recently has been used as an impetus for organizational design by Oura and Kijima (2002). Although the originator, Peter Checkland, views SSM as being rooted in human systems and sociology, little if any attention is paid to the structure of the social relationships in the guidelines of the method.

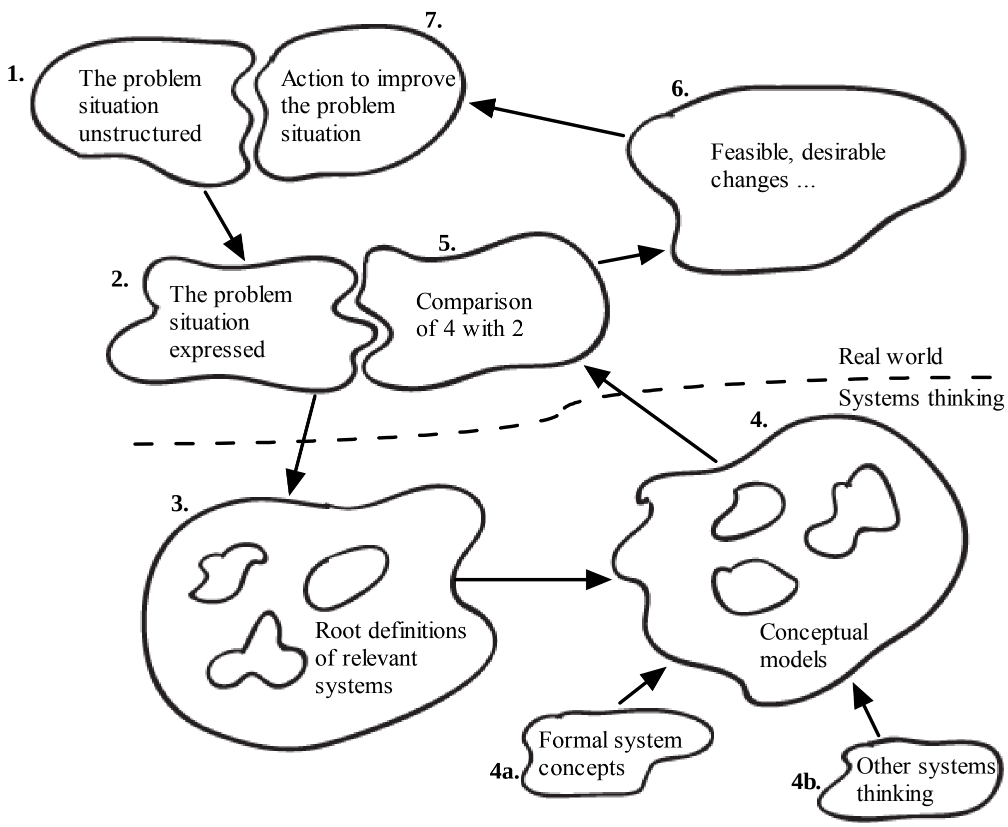

Figure 4.6: Summary of SSM Steps; (Checkland 1984)

Peter Checkland began his work on what would become SSM in 1969. The original intention was to use systems ideas to tackle ill-defined problems in the social sciences, including management problems. Thus SSM is another methodology that arose from an extension of general systems theory. Checkland took as his starting point the systems methods developed in

engineering related disciplines and the systems analysis methods of RAND Corporation. These methods were identified as successful for tackling goal-directed problems, in so-called hard systems. Social science problems have less clearly defined problems and goals, so a degree of modification to the existing hard systems methodology was undertaken. The outcome of Checkland's research program was a set of principles for a Soft Systems Methodology, which would enable a means of "structuring a debate" about "human activity systems", where the "goals are often obscure" (Checkland, 1984).

The complexity of human activity systems is viewed as being in the realm of sociology which Checkland discusses in relation to a scientific hierarchy he attributes to Comte and a real-world hierarchy to Boulding. Owing to the complexity and uniqueness of each human activity system it is important for Checkland that the general methodology he lays out not be taken as rules or a recipe to be followed, but rather as a set of principles that may be applied in whole or in part, depending upon the circumstances of the situation. Checkland's original guidelines are summarized in Figure 4.5.

Through various iterations SSM "moved from being concerned with facilitating change in the real world to a focus on learning in the real world" (Houghton and Ledington, 2002).

Soft Systems Methodology's overall focus is on learning, understanding and thus a transfer of 'what the customer knows' to the developers so that they can create an information system that meets the needs of the organization and their customers. The current study incorporates this transfer of knowledge within the evolution of the IS development project; however, this study has a more fundamental concern with the actual customer – developer interactions as a prerequisite and necessary condition to this knowledge transfer. In the idealized simulation, the learning process is able to proceed without obstruction or subterfuge; i.e., a free flow of information is possible once a relationship is made. Some degree of antagonism is accounted for in propensity to interact based on shared values of the actors.

Structuration Theory

Structuration theory is at its root concerned with the social aspects of systems. However, where STS and SSM were originally developed in order to solve real world problems in combination with action research, complete with procedural methods, structuration theory does not include any part of a methodology for problem solving. It provides no method or research strategy. It "is more a guiding philosophy of social scientific inquiry than a theory" and is "sometimes referred to as a 'meta-theory'" (Poole and DeSanctis, 2002). In fact, this methodological open-endedness may explain its appeal to some researchers.

General Description

Anthony Giddens developed structuration theory in order to move past the traditional dichotomy of atomized individualism and social structuralism. Giddens (1984) discounts previous uses of the term 'structure' and defines his notion of structure as "rules and resources, recursively implicated in the reproduction of social systems." Giddens (1984) defines system explicitly as "the patterning of social relations across time-space, understood as reproduced practices." Giddens' use of the term 'social system' is on par with this study's (and the predominant use of the term in sociology) discussion of network social structure. Patterns of relations are discussed

nominally as part of a narrative or linguistic exercise versus measures of empirical social relations between actors.

Principles of structuration theory that are frequently discussed in IS research are duality of structure and the knowledgeability of agents. A key component of structuration theory is the concept of 'duality of structure', which is meant to acknowledge the importance of both agency and structure, though the emphasis of the theory is clearly geared towards agency. This is expressed through the importance of the 'knowledgeability of agents' in the theory, and where "Structure only exists in so far as people do things knowledgeably and do them in certain contexts that have particular consequences", and "is primarily expressed in the things that people do in a regularized and institutionalized way. Much of what we do in everyday life is governed by what I call practical consciousness – 'going on' with the rules and conventions of life"[7] (Giddens, 1984). In addition to the habits that people follow and the conscious intentions of actors, structuration acknowledges "the unintended consequences of what they do" as affecting structure too.

IS Literature and Structuration Theory

Interestingly Giddens gives no special consideration to technology in structuration theory. For Giddens (1984) "Technology does nothing except as implicated in the actions of human beings." The fact that Giddens does not address technology uniquely makes it all the more interesting that IS researchers have embraced it so thoroughly. IS researchers have had much more occasion to use structuration theory and several structuration theory variants in greater numbers than STS and SSM in the last two decades. The relative popularity is evidenced by both the number of uses of the theory in IS research studies as well as the number of self-reflective reviews of structuration theory use in IS research that have been generated. Poole and DeSanctis (2002/2004) in their review of structuration theory in information systems research, cite an unpublished review (Pozzebon and Pinsonneault, 2002/2005) as having discovered 116 articles published between 1985 and 2000. Jones and Karsten's (2008) more recent review identified 331 IS research articles that used structuration theory between 1983 and 2004.

Within this volume of work a number of researchers have sought to explore information systems development under the auspices of structuration theory; e.g., Boland and Greenberg (1992). Other examples include Nandhakumar and Jones (1997), where the User–Developer relationship is discussed in relation to structuration theory. In 2001, Nandhakumar and Jones explored "the temporal and spatial organization of information systems development work practices" (Jones and Karsten, 2008). Researchers have approached their use of structuration theory with varying degrees of emphasis ranging from a general context to an isolated portion of the theory (Jones and Karsten, 2008; Pozzebon and Pinsonneault, 2005).

Difficulties and Limitations

Pozzebon and Pinsonneault (2005) point out that "Despite the fact that ST is an important research perspective that has been used for a number of years, our knowledge on the topic and on how best to apply it remains limited." In fact, IS-centric implementations of structuration theory may in fact be at odds with Gidden's theory; e.g., Adaptive Structuration Theory from DeSanctis

[7] This is essentially what Peirce (1878) describes as habit, which is formed via a fixation of belief.

and Poole (1994) and Orlikowski and Robey (1991) where special consideration is afforded technology.

Again it is suggested that structuration theory's disconnect from empirical research may in fact be its appeal to IS researchers, as its high level of abstraction provides a highly malleable medium with which to work. This affords ample opportunity for innovation as well as misinterpretation. Information System specific structuration modifications accounted for more than 34% of the papers reviewed by Jones and Karsten (2008). This is contrasted to 46% of the papers that applied Giddens' concepts of structuration theory.

Some of the limitations of structuration theory as implemented in the IS literature are also discussed by Jones and Karsten (2008), where they note that "IS work has adopted a rather narrow interpretation of Giddens' work, both in terms of the aspects they make use of and the way in which they employ it…needs to be on the basis of a rich understanding of both the substantive content of the theory and its substructure. Such an understanding would seem to require a careful reading of original writings and critical commentaries rather than solely relying on secondary sources within the IS field."

Social Networks

Where STS, SSM, and Structuration all acknowledge the potential and actual variable effects regarding structural relationships, none of these take a specific interest in the relationships in and of themselves. Social network method and theory has as its focus the structural relationships among actors. Social networks take a view of social structure that is based on a realist ontology, wherein, structure is described by relationships between actors in a system. Actors may be described as individuals, groups, organizations or nations. Examples of relationships are friendship, advice, communication, and trading partner. It is important to emphasize the distinction between structure in social networks and structure as it is uniquely defined by Giddens. In social networks structure refers to the (enduring) relational ties among actors as opposed to Gidden's use of the word whereby structure is defined by Giddens (1984) as "rules and resources, recursively implicated in the reproduction of social systems."

<u>IS Literature and Social Networks</u>

Early recognition of the importance of social structure and its effect on information systems development was described by Melvin Conway in 1968, where he notes the difficulties that are encountered in design efforts that encompass large numbers of people due to the sizable non-linear increase in the number of possible communication pathways. Conway states that "organizations which design systems are constrained to produce designs which are copies of the communication structures of these organizations." Conway is able to succinctly tie communication patterns to design alternatives and thus the final product of development.

Yang and Tang (2004) noted that although "social network analysis is regarded as a powerful tool for diagnosis, analysis and study of group dynamics in many fields, it has not received much attention in the IS domain." In general, the IS discipline has ignored the benefits of social networks in studying information systems. Other early works with scarce recognition, without actual use are found in Zmud (1983) and Kwon and Zmud (1987).

However, Aydin and Rice (1991) employ network methods in order to identify and understand interactions among different groups within a health care organization and to supplement their regression based models for predicting attitudes towards the implementation of a medical information system.

More Recent IS Research and Networking

Recently more articles have begun to appear espousing aspects of social network concepts. However, this may be regarded with some degree of skepticism. Frequently network analytic words, phrases and concepts have been used in IS papers, without actually following through with the data collection and analysis that is bound up as part of the theory and method of networks and its structural social perspective. Thus social network work in IS shares some of the troubles of structuration theory as previously discussed. For example, Wasko and Faraj (2005) in a study of knowledge contribution within a legal professional association via an online message board, discuss what they call social/structural capital and relational capital. The authors tangentially employ an elementary measure of centrality as a variable within their soft structural model for their social/structural capital. And rather than using measures of actual relationships for reciprocity, the authors instead measure attitudes and beliefs regarding helping others. Thus a concept that is social structural in nature is transformed into a psychological construct. Another example of social structural concepts transformed into attitudinal surveys occurs in Shin et al. (2007), in a study about information sharing where the relational tie of sharing information is not measured and is instead captured via psychometric questions regarding the subjects' attitudes towards sharing.

There are, fortunately, examples that both discuss social network concepts and also collect and analyze the relational data; for example, Wakefield's (2005) study on knowledge sharing and coordination in a pharmaceutical research and development process. The author measures knowledge transfer events and subsequently reports how much sharing occurs, who does the sharing and, employing network analysis methods, is able to determine the level of influence of individuals as well as subgroups have on the R&D process. Another example is Yang and Tang (2004) where they study team structure and team performance in IS development projects. Some of their preliminary findings were that centrality of domain knowledge and cohesion of the team advice network were both found to be good predictors of the final performance of the IS development project.

It is hoped that with the passage of time social network theory and methods may come to be accepted and incorporated more strongly into the IS academic discipline.

Comparison of Social Perspectives

Table 4.2 provides a summary of the previously discussed subset of social perspectives available in the IS literature. It is presented for general discussion and is not meant to be definitive. All of the perspectives provide, in varying degrees, a systemic, dynamic, social view of an information systems development project. Of the four perspectives, social networks is the only one to focus on structural relationships among the agents in a system. All recognize user participation as being fundamental to the overall process. STD and SSM were born out of practice, ST from theory, and social networks is seen as an entanglement of theory and method.

SUMMARY

The importance and tradition of user involvement and information systems success was highlighted from the IS literature. Two multi-dimensional frameworks of project success from project management literature were incorporated and the outcome variable used in the virtual experiment, 'percentage project complete' was described in light of this. An overview of the treatment of 'the social' in the IS literature was provided to contrast with the structural view of 'the social' that is used in the current study. The following chapter will discuss key aspects of social networks for additional understanding of the social structural perspective and to prepare the reader for the expanded discussion of simulations and meta-networks in the subsequent chapter.

Table 4.2: Comparison of Social Perspectives

	Socio-Technical Design	**Soft Systems Methodology**	**Structuration Theory**	**Social Networks**
Social view	X	X	X	X
Systems view	X	X	X	X
Dynamic	X	X	X	X
Agent / Structure	A	A	A*	S
User participation	X	X	X	X
Theory / Method	M	M & T	Meta-Theory	T & M
Designed:	(1) Org Dev (2) IS Dev	(1) IS Dev (2) Human-based systems	Explain social systems	Explain and model social systems

Chapter 5 -- Social Networks

[People] are the primary units of the actual community, and the community is composed of the units. But each unit has in its nature a reference to every other member of the community.
Alfred North Whitehead

INTRODUCTION

This chapter provides a brief introduction to social networks and network analysis. Networks are used as the operationalizing bridge between the concepts within the Integrated Capital Ensemble model and the components of an IS development project in the "real world", where people are assigned tasks to be performed in order to develop an information system. Developers and customers must have the requisite knowledge in order to carry out their assigned tasks. If they do not have that knowledge at the outset of a project they must **learn** it in order to complete the project successfully. As discussed in the previous chapter an assumption is made that the customers possess knowledge about 'how the information system should work' when it is complete. This knowledge must be transferred to the developers working on the project and this is achieved through a learning process based on the social interactions between the developers and the customers.

The remainder of this chapter first provides some historical background of social networks and a definition of social networks and what social is considered to be. Second, some fundamental concepts of social networks are presented. Third, the operationalization in network terms of the physical world and the abstract world is presented.

Social Networks

Social networking has been used and influenced by a diverse range of disciplines, such as, sociologists, psychologists, anthropologists, business management, mathematicians, all manner of structuralists and most recently by physicists. Freeman (2004) observed that the basic concepts of social networking or viewing "society in terms of the interconnections of social actors" are found in the writings of Auguste Comte, with the first truly structural view of sociology coming from Simmel (1908). Network diagrams and relational studies were part of the famous Hawthorne Experiments begun in cooperation with Western Electric and MIT and subsequently taken over by researchers from the Graduate Business School at Harvard during the 1920's – 30's. Earlier diagramming methods (sociometry) can be traced to the psychiatrist/psycho-sociologist Jacob Moreno in the early 1930's (Blau, 1977; Freeman, 2004).

More recently, within the past two decades, social networking has become rather fashionable in both popular culture and in the academic community. For example, there are a host of Internet social networking web sites. Facebook alone currently has 70 million active users and approximately 115 million different members (*Time Magazine*, 2008). In academia, "Over the past decade, there has been an explosion of interest in network research across the physical and social sciences. For social scientists, the theory of networks has been a gold mine, yielding explanations for social phenomena in a wide variety of disciplines from psychology to economics" (Borgatti et al., 2009). Regrettably the networking perspective has not been

embraced by the leading information systems journals. Questions and quibbles regarding the reasons for this are beyond the scope of the current study.

What, then, is a social network? A social network is a set of actors that have a set of ties among them. This generic definition allows for a plethora of possibilities, which include the ability to analyze structural components at multiple levels. For example, an actor may be an individual, an organization, a computer or a country. A tie is some form of dyadic relation between actors within the network. Examples of ties are friendship, business acquaintance, trading partner, diplomatic communication and exchange. The basic network includes one type of actor and one type of tie. Figure 5.1 provides an example of an informal information exchange network among executives in the exploration and production division of a large petroleum company (Cross and Parker, 2004).

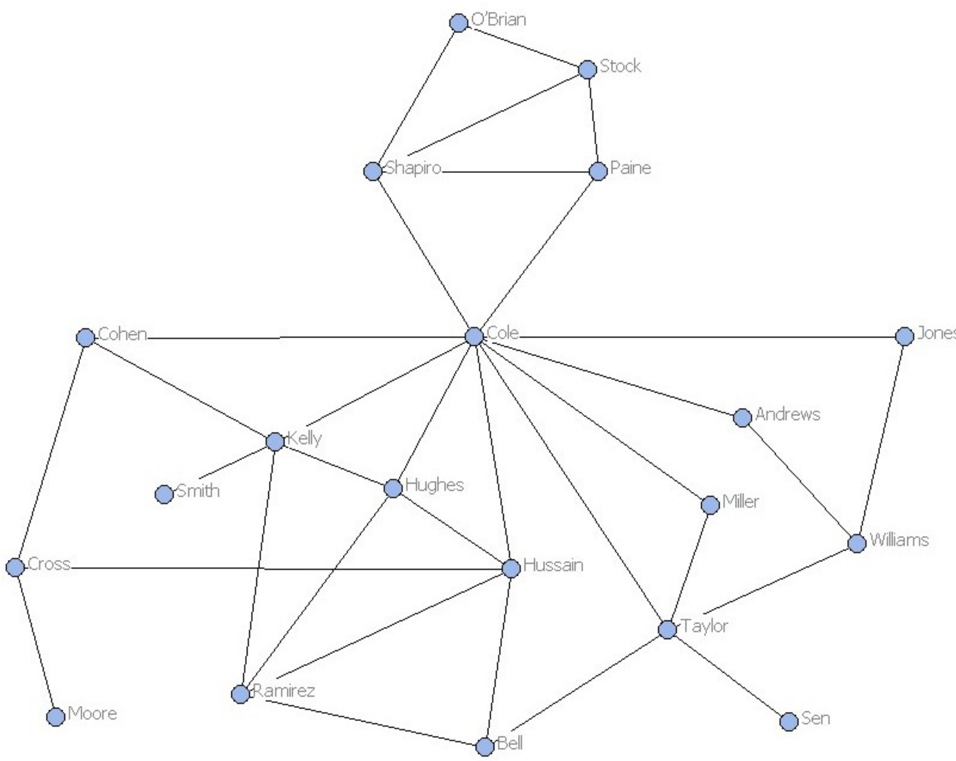

Figure 5.1: Informal Information Exchange Network (Cross, 2001)

In this example, actors are executives in the exploration and production division of the petroleum company. The relationship ties are frequent information exchange between the executives. The diagramming of this information provides an important view of the social structure and flow of information within this business. It is particularly instructive to compare the working information network described in Figure 5.1 with the formal organizational chart in Figure 5.2. Even on an intuitive level it is easy to see that the executive Cole has a much greater role in the company in terms of information and communication than anyone would suspect by looking at the firm's

organizational chart. In addition to inspection, further analysis on the structure of the network is available and is discussed briefly in the next section.

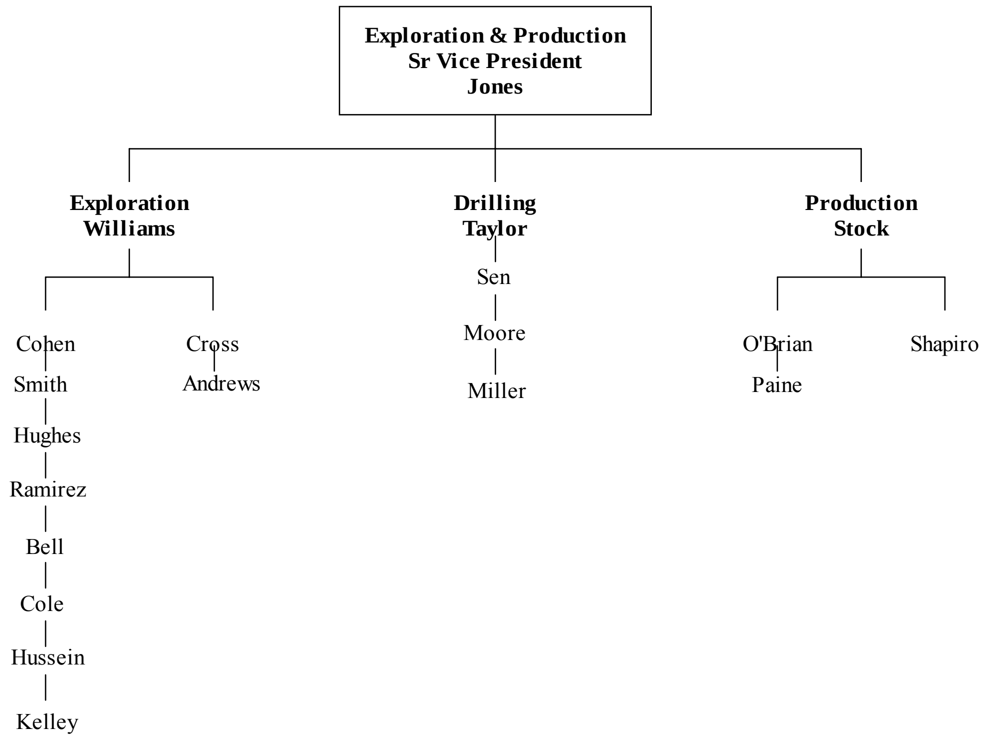

Figure 5.2: Formal Organizational Chart (Cross, 2001)

The network perspective begins with the view that "the primary business of sociologists is to study social structure" (Wellman, 1983). Wasserman and Faust (1999) present their position regarding social network analysis as being "a distinct research perspective within the social and behavioral sciences; distinct because social network analysis is based on an assumption of the importance of relationships among interacting units." For them, "The social network perspective encompasses theories, models, and applications that are expressed in terms of relational concepts or processes. That is, relations defined by linkages among units are a fundamental component of network theories." For some researchers network concepts represent a way, perhaps the only way, to construct a theory of social structure (White et al., 1976). At the very least, network concepts provide researchers with a means of measuring social relations with the possibility of discovering trends, tendencies, and probabilistic causalities in quantitative terms. Also, because of its focus on relations, it embodies a systemic view of social reality.

FUNDAMENTAL CONCEPTS

"When I use a word," Humpty Dumpty said in rather a scornful tone,
"it means just what I choose it to mean - neither more nor less."
Lewis Carroll

The networking perspective requires familiarity with some fundamental terms and concepts. To begin, let us review some terms that are used interchangeably for the basic ideas of network, actor, and tie. Because of definitional and theoretical grounding in mathematics, networks may be discussed in terms graph theory and matrix algebra. Therefore, a network is also called a graph, digraph (directed graph) or matrix. An actor may be called a node or vertex; and a tie as a relation or edge.

Table 5.1 is an example of an alternative way of presenting network data in a matrix, called a socio-matrix. This socio-matrix represents Cole and the production department executives, the group at the top of the social network diagram that is described in Figure 5.1. Ones represent a tie between two actors and zeros indicate that no tie exists.

Table 5.1: Socio-matrix of Cole and the Production Dept. Executives

	Cole	O'Brian	Paine	Shapiro	Stock
Cole	0	0	1	1	0
O'Brian	0	0	0	1	1
Paine	1	0	0	1	1
Shapiro	1	1	1	0	1
Stock	0	1	1	1	0

Data

Fundamental to the network perspective is the primary data type that is analyzed. The data type is relational data, which are the ties and connections that relate one actor to another and are unable to be reduced to a characteristic of an individual actor (Scott, 2000). This is in stark contrast to the attribute data and ideational data that has historically been the data types collected and analyzed. Attribute data constitutes data that are attributable to individual agent's characteristics, e.g., attitudes, qualities, and behaviors. Ideational data are data that describe meanings and motives (Scott, 2000). In both cases data are essentially attributed to an individual agent and at some point aggregated through the process of analysis and interpretation. Where attribute data normally assumes or strives for independence between atomized autonomous actors, the relational data perspective sees actors as being interdependent. Therefore, the most basic datum requires two actors (dyad) to be in some form of relationship. In the information network in Figure 5.1, the lines represent an exchange of information between two executives. Visually, we see that executive Cole exchanges information with ten other executives on a frequent basis; where as the Senior Vice President Jones exchanges information on a frequent basis with only two executives, with Cole being one of them.

Network Measures

Network measures exist on multiple levels. These measures form the basis of some of the theoretical concepts within social networking. Table 5.2 identifies a number of network related measures which highlights the multiple levels of analysis that exist within social networks. Elaboration of the individual measures is beyond the scope of the current study, rather the

information is provided in order to present the complex nature of network analysis to the reader. The reader will notice that measures exist at the individual level, the network level, and a sub-network level. Particular attention is drawn to the fact that some measures have very different meanings depending upon the unit level of analysis that is being measured and discussed (e.g., social capital).

Table 5.2: Network Categories and Concepts; based on Borgatti et al. (2002)

	Level of Analysis		
	Network Level	**Network Subset**	**Individual**
Connection	**Cohesion**	**Groups**	**Centrality**
	Density	Cliques	Degree
	Avg. Distance	n-clique	Closeness
	Centralization	k-plex	Betweenness
	Components	Factions	Structural Holes
Similarity		**Classes:**	**Role:**
		Structural Equivalence	Identical ties
		Regular Equivalence	Analogous ties
Social Capital	**Cohesion**		**Centrality**

Guiding Principles for Relations

Homophily

Homophily is defined in a number of related ways, e.g.,

> "Homophily is the principle that a contact between similar people occurs at a higher rate than among dissimilar people…" (McPherson et al., 2001)
>
> Homophily is the "tendency for people to associate with others who are similar to themselves" (Feld, 1982)
>
> or using the term quoted by Lazarsfeld and Merton (1954), "birds of a feather flock together".

The pervasiveness and robust nature of the principle of homophily is thus a "basic organizing principle" (McPherson et al., 2001).

Forms of Homophily

The principle of homophily guides the structure of network relations in many forms, detailed in a review of the literature by McPherson et al. (2001). Homophily has been found to be active across a spectrum of attributes, actions, and behavior patterns. These include readily identifiable agent attributes like sex, age, and ethnicity to level of education, varying forms of status, and religious affiliation.

Results of Homophily

Within a network of relations, Friedkin (1993) has verified that homophily occurs for people that are structurally similar to one another. With added communication comes added influence with one another (McPherson et al., 2001).

Feld (1981, 1982) provides one explanation for a cause for the principle of homophily. It arises as a consequence of many relationships being formed as a result of "focused choice" due to organized foci of activities. This is in line with a baseline pattern of homophily, whereby a given network restricts the opportunity for contacts. However, there is also a pattern of inbreeding homophily, whereby even given limited opportunity of other contacts, individuals will still associate with others that are similar to themselves.

Knowledge Seeking

Alternatively, there may arise the need for actors to specifically seek out "others" that are dissimilar to themselves in particular ways. An example of this occurs when an actor is in need of "new" facts (knowledge) in order to be able to make an informed decision or to carry out a particular activity successfully. Hirshman et al. (2007a) call this impetus *knowledge seeking* and it may be viewed as part of the process of intentional learning.

OPERATIONALIZNG THE FOUR FORMS OF CAPITAL

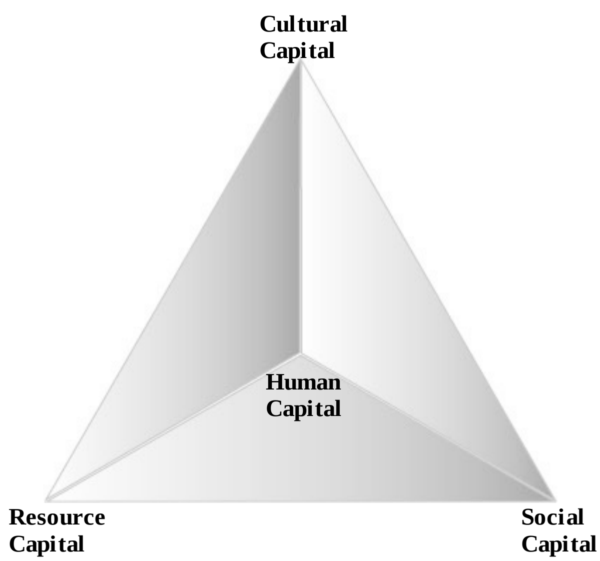

Figure 5.3: Integrated Capital Ensemble (ICE) Model

Extending Beyond the Basic Network

The basic network (Figure 5.1) as described previously is a single set of actors that have a single set of ties among them. To be more precise, the network can be described as being a one mode (one type of actor), simplex (one type of relation) network. By extension, if we construct a network that includes two types of actors, e.g., researchers and the educational institutions with which they are affiliated, we have a two mode network. We may follow this pattern of

nomenclature as presented by Wasserman and Faust (1999) for additional types of actors or instead settle upon the use of the term multi-modal for networks having multiple types of actors. Similarly, we can observe networks of actors that have more than one form of relation. For example, a set of actors, as in Figure 5.1, may be tied together by exchanging information, friendship, and community service. Multiple forms of relations among the same agents is called a multiplex network after Gluckman (1967). Alternative terminology does exist; e.g., Wasserman and Faust (1999) provide the term super-sociomatrix and Wellman (1983) discussed multistranded ties. MetaNetwork and metamatrix are the terms used to describe a network of networks, which combines multiple types of actors with multiple types of ties. It is a term used by Krackhardt and Carley (1998) and the researchers at the Center for Computational Analysis of Social and Organizational Systems (CASOS).

It is via a metamatrix that we operationalize the information systems development project components in terms of the concepts described by the Integrated Capital Ensemble model (Figure 5.3).

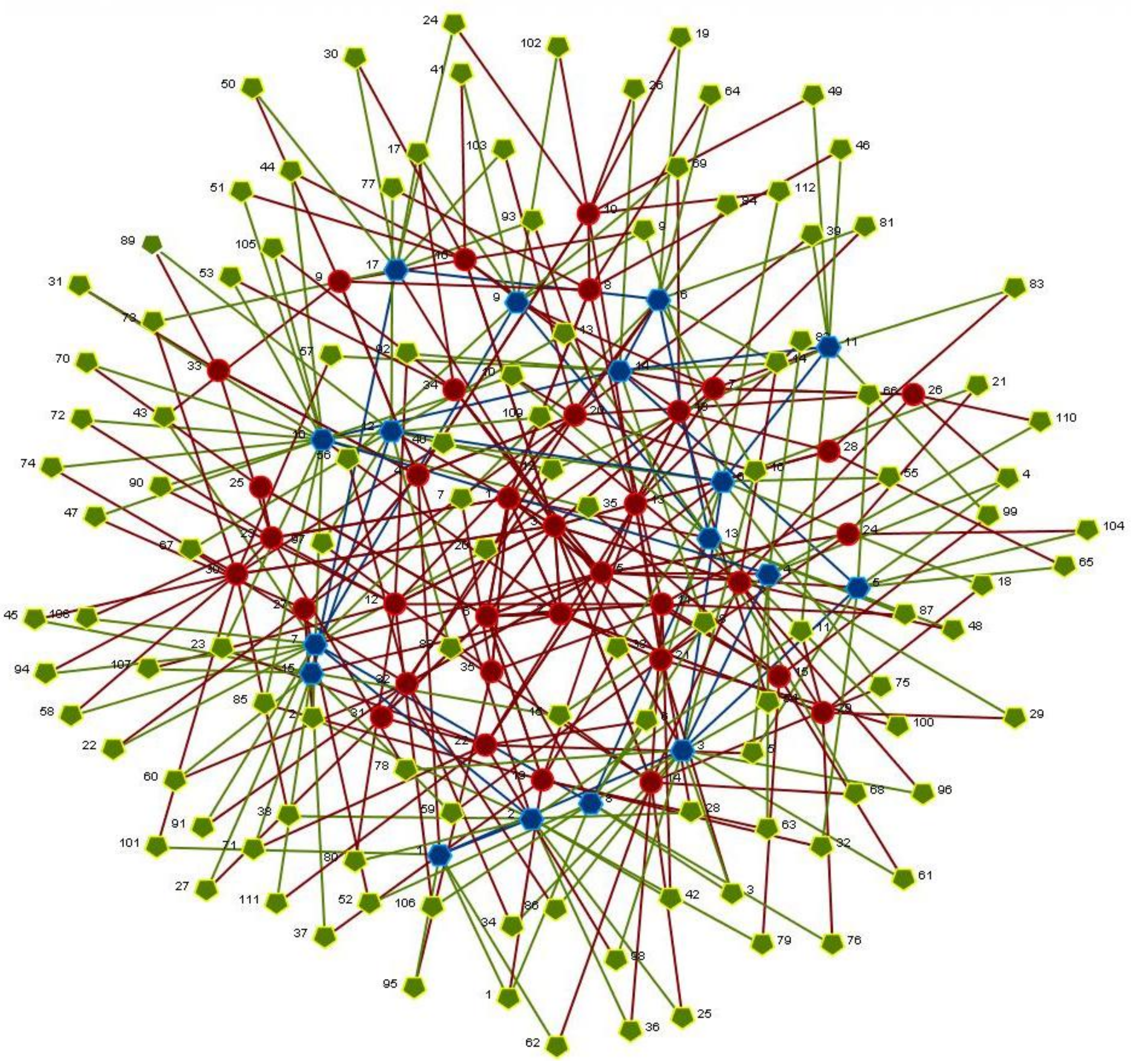

Figure 5.4: MetaNetwork (metamatrix)

Recall the project components of interest: two distinct groups of people associated with the project, i.e., the customers and the developers of the information system; the project tasks to be performed; the knowledge elements required to successfully complete the tasks in the project; the communication and learning available via the social relationships among the actors within the project network and the shared values of the project participants viewed in terms of organizational culture. Figure 5.4 depicts a metanetwork that includes all of these components in addition to the extended networks that are discussed below and in the forthcoming chapter.

Table 5.3 provides a summary of the correspondence among the real world components of a project, the concepts of the Integrated Capital Ensemble model, and the network operationalization of both the concrete and the abstract. People are operationalized as agents and appear as nodes within the network. Tasks and knowledge resources are also operationalized as nodes. Social relations in the form of communication ties are represented as the links between two agents. This is known as a social network. Other individual networks employed within the meta-network are: the knowledge network, the nodes of which are agents and knowledge facts, the assignment network, the nodes of which are agents and tasks, the needs network, the nodes of which are tasks and knowledge facts, and a precedence network which identifies the directed ties between task nodes. For the purposes of this study, shared cultural values and beliefs are operationalized as agent attributes.

Table 5.3: Correspondence among three levels of abstraction

Project Component (Physical World)	**Network Element (Virtual World)**	**Form of Capital (Conceptual World)**
People	Nodes	Human
Tasks	Nodes	*[8]
Knowledge	Nodes	Resource
Communication	Relational Tie	Social
Shared Values	Actor Attributes	Cultural

The processes and interactions of the nodes within these interrelated networks are addressed in detail in the following chapter on simulation methods.

SUMMARY

This chapter provided a basic introduction to social networks and analysis in order to form the basis of the muli-level operationalization that is the symbolic bridge between the conceptual world and the physical world of the IS development project. The following chapter discusses the simulation methodology used for the virtual world of the study's experiment and also provides additional detail of the multi-level operationalization.

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[8] * Tasks are activities and like time are not explicitly depicted within the ICE model.

Chapter 6 -- Methodology

For every complex problem, there is a solution that is simple, neat, and wrong.
H. L. Mencken

INTRODUCTION

What this study does is describe a social system within which an information system project is to be developed. A multi-agent system simulation is employed in order to study the effects of structural forces, in terms of initial social structure and organizational cultural beliefs between two groups identified as being customers and developers, on the task performance in the course of the ISD project. This multi-agent system is representational and not isomorphic to any one specific ISD project. Although a simulation may be undertaken to map an actual development process in order to fine tune the simulation parameters and enhance its veracity, such an empirical test is beyond the scope of the current study.

The purpose of this chapter on methodology is to make clear the representational nature of multi-agent simulations, their veracity, the goals of this particular multi-agent simulation, and also provide some level of detail to the components within the system simulation and its initial construction. First a brief discussion of general computational analysis and simulations in social scientific research and simulations involving multi-agent systems in particular is undertaken. This is followed by a discussion and a recent example in the literature, provided as evidence in order to champion the use of multi-agent simulations and their viability to provide insight into the complex social systems within which information systems reside. Issues of justification concerning veracity and verifiability are discussed. Third, a model for the virtual experiment is presented with accompanying propositions to be measured for the inquiry into the effects of social and cultural forces on ISD project task performance outcomes. Fourth, a review of the primary model components of the multi-agent system within Construct, the system used for the virtual experiment, is provided. Fifth, a description of the system construction and simulation is provided including the data generation process used to populate the primary input networks for simulation.

SIMULATIONS AND MULTI-AGENT SYSTEMS

The method of research employed for this study is a multi-agent simulation. Agent based and in this case multi-agent based simulation is a form of computational analysis (Gilbert, 2008). Simulations are a method to model real world processes via computer (Davis et al., 2007). Carley (2001) refers to simulations as virtual experiments.

Utility

There are a number of reasons to choose computational analysis as a research methodology. First, it allows the researcher to improve upon the descriptive realism of their models (Taber and Timpone, 1996). Simulation provides the researcher with a method to represent complex social systems and processes that otherwise may be oversimplified in more traditional quantitative methods or in the case of qualitative methods presented as a subjective narrative, which while

richer in detail, is problematic in terms of generalizability and predictive utility. Second, agent-based models are particularly well suited to understanding processes and their consequences (Gilbert, 2008). Third, simulation techniques can be especially useful when the target of interest involves multiple, interactive processes, longitudinal situations and/or other non-linear effects (Davis et al., 2007). Fourth, Taber and Timpone (1996) also view computational models as a way "to combine the rich detail of qualitative research with the rigor of quantitative" research. Simulation does this by affording the researcher the ability to incorporate richer detail into a model, something that tends to be appropriated by qualitative researchers. However, simulation also provides the researcher with the ability to experiment and replicate studies in the quest for greater understanding, generalizability and predictive ability, which tends to be the domain of orthodox quantitative research methods. Fifth is the benefit that a simulation approach may also be employed in theory development (Davis et al., 2007; Carley, 1999). To this end Davis et al. (2007) argue that simulation is the "sweet spot" between theory-creating research (e.g., inductive multiple case studies and formal modeling) and theory-testing research (multivariate statistical analysis). The preceding benefits represent the rationale for employing simulation methods for this study, as it allows the opportunity to model a complex social system in a way that is not currently available with conventional quantitative and qualitative methods alone.

Overview of Computational Models and Simulation

Examples of Simulation

Early examples of simulations are found in Schelling's (1978) seminal work that studied the interactions of agents within the confines of a neighborhood, and which found that even with agents tolerant towards integration, given social constraints, over time neighborhoods would become segregated. Axelrod's (1984, 1997) work on cooperative action and game theory provided understanding into paired relationships and cooperation. More recent examples involving multi-agent system scenarios include Schreiber and Carley's (2003) simulation studying the impact of databases on knowledge transfer within organizations, and the study by Ren et al. (2006) that provides an example of the use of a multi-agent simulation using ORGMEM to model and study the contingent effects of transactive memory in dynamic task environments involving groups of agents.

Table 6.1: Characteristics that a simulation may encompass

1. Algorithms use
2. Agent based: Agents vs. Social Agents
3. Smaller scale Intellective models vs. Larger Emulative models
4. Clarity vs. Verisimilitude; i.e., simplicity vs. greater complexity
5. Spatial vs. non-spatial environment; along with mobile vs. non-mobile agents

Different Methods of Simulation

There are in fact many different forms of simulation available to researchers. Table 6.1 provides a rudimentary typology list of possible simulation characteristics.

Davis et al. (2007) provide a comparison of a number of types of simulation approaches, based primarily on the form of computational algorithm(s) to be used in the simulation. These include: (a) system dynamics, (b) NK fitness landscapes, (c) genetic algorithms, (d) cellular automata, and (e) stochastic processes. Each form is well suited to a family of experiments that are commonly associated with them, in addition to theoretical logic and a particular research focus. Davis et al. (2007) are interested in general guidelines for experiments involving simulations and thus do not discuss multi-agent systems simulation directly. However, both genetic algorithmic and cellular automata approaches involve the use of agents involved in evolutionary processes and behavioral rules respectively. The list that Davis and colleagues provide is by no means comprehensive (other examples of interest: simulated annealing, neural networks and social networks), however it provides a good indication of the many possibilities that are available to researchers when choosing an underlying algorithmic method.

Another important characteristic of the simulation is whether the simulation is agent based or not, and if it is, are the agents social (i.e., do they interact with one another). For example, a systems dynamics based simulation is interested in a temporal cause and effect relationship between variables and does not specifically represent individual agents (Gilbert, 2008). Construct is an example of a social networking based multi-agent system that does specify individual agents and includes behavioral rules by which the agents interact.

Table 6.2: Fractionation Matrix (Carley and Newell, 1994)

Type of Agent ↓ / Type of Situation →	Non-Social Task	Multiple Agents	Real Interaction	Social Structural	Social Goals	Cultural Historical
Omnipotent Agent	Goal directed models of self; Produces goods; Uses tools; Uses language	Models of others; Turn taking	Face-to-Face; Timing constraints	Socially situated; Class differences	Multiple competing goals; Social goals; Organizational goals	Historical &/or Cultural motivation
Rational Agent	Reasons; Acquires all information	Learns from others education	Scheduling	Social ranking; Social mobility; Competition	Dissallusionment	Social inheritance; Social cognition
Boundedly Rational Agent	Satisfices; Task planning; Adaptation	Group Making	Social planning; Coercion; Priority disputes; Mis-communication	Restraints on mobility; Uses networks for information; Corporate intelligence	Party line voting; delays gratification; Moral obligation, Cooperation; Altruism	Gate keeping; Diffusion; Etiquette; Deviance, Roles, Sanctions
Cognitive Agent	Compulsiveness; Lack of awareness; Interuptability; Automatic action	Group Think	Crisis Response	Automatic response to status cues	Class wars; Power struggles	Develop language, Role development; Institutions
Emotional Cognitve Agent	Intesity of response; Habituation; Variable performance	Protesting; Courting	Mob Action; Play; Rapid Emotional Response	Campai(g)ning?; Conformity	Nationalism; Patriotism	Norm maintenance; Ritual maintenance; Advertising

Early work on the concept of social agents was conducted by Carley and Newell (1994), where they presented what they termed a Fractionation Matrix, in order to summarize levels of social situation interaction and individual agent complexity. A review of the Fractionation Matrix in Table 6.2 reveals that the level of modeled reality increases as one reads from left to right and from the top down. Table 6.3 provides a summary comparison of different social methodologies and theories in light of the Fractionation Matrix. For the purposes of this study it is sufficient to note that a multi-agent simulation provides a more realistic model of the world than what may be seen as the general orthodox rational choice approach. The multi-agent system seeks to incorporate and account for more of the social aspects of human situations. In this study, we seek to measure the effects of different initial levels of social interaction between customers and developers within an ISD project as well as take into account shared and disparate beliefs about the organization; i.e., organizational cultural beliefs.

Table 6.3: Comparative view in light of the Fractionation Matrix (Carley and Newell, 1994)

Type of Agent \ Type of Situation	Non-Social Task	Multiple Agents	Real Interaction	Social Structural	Social Goals	Cultural Historical
Omnipotent Agent		Classic Game Theory		Structuralism	Functionalism	
Rational Agent						Symbolic Anthropology
Boundedly Rational Agent	Behavioral Decision Theory	Rational Choice Theory	Ethno-methodology			
Cognitive Agent		Cognitive Dissonance Balance Theory		**Multi-agent Simulation**		
Emotional Cognitve Agent						Model Social Agent

The third and fourth characteristics in Table 6.1 both involve the degree of realism to be encompassed by the model. Point three concerns the scale of the model and point four the degree of complexity that will be encompassed. Both of these points are important considerations in identifying the level of realism and the approach taken to verify and validate the model. The following subsection will elaborate these considerations.

The fifth characteristic in Table 6.1 specifies whether the simulation is or is not spatially oriented. Some agent simulations are laid out on a grid (and at times more complex mathematical surfaces) allowing agents to interact with their environment in prescribed ways. Construct is not a grid based system, although agents can be provided attributes that define their geo-spatial coordinates in relation to other agents.

Different Levels of Models

Different levels of model building are identified based upon researcher intention, simulation characteristics and degree of maturity for the model. The researcher's intentions are manifest in the choices made for the simulation's characteristics. For example, is the simulation grid based in order to enable interaction with the environment in a particular way, is it multi-agent based in order for agent interactions to be taken into account. Other choices involve the degree of realism to be simulated, e.g., will the simulation emulate a particular real-world phenomenon or will it be more general.

In their roadmap for using simulation models to develop theory Davis et al. (2007) suggest two levels of model building, i.e., computational representation for the simulation. They are an initial model representation and an experimentation representation. The first is an initial and more basic representation geared to verification of the accuracy of the computational representation of the simulation. "The simulation results should replicate the simple theory, bolster internal validity, and thereby increase confidence in the results of the simulation." The second level of representation, experimentation, is "at the heart of the value of simulation methods for developing theory". In order to expand the reach of the simulation and give greater weight to the results, additional value levels will be added to the existing "constructs" and additional complexity will be introduced by way of varying the values of constructs previously held constant (Davis et al., 2007).

Gilbert (2008) categorizes models into three levels as: (1) abstract models, (2) middle range models, and (3) facsimile models. Each model has a designed purpose and each model has a particular level of validation that is attainable.

> "The aim of abstract models is to demonstrate some basic social process that may lie behind many areas of social life. … With these models, there is no intention to model any particular empirical case, and for some models, it may be difficult to find any close connection with observable data at all."
>
> The aim of middle range models is "to describe the characteristics of a particular social phenomenon, but in a sufficiently general way that their conclusions can be applied widely. … The generic nature of such models means that it is not usually possible to compare their behavior exactly with any particular observable instance. Instead, one expects to be satisfied with qualitative resemblances. This means that the dynamics of the model should be similar to the observed dynamics and that the results of the simulation should reveal the same or similar 'statistical signatures' as observed in the real world."
>
> "Facsimile models are intended to provide a reproduction of some specific target phenomenon as exactly as possible, often with the intentions of using it to make a

prediction of the target’s future state. …If such exact matches can be obtained, they would be very useful, not only as a powerful confirmation of the theory on which the model is based, but also for making plausible predictions.”

Gilbert (2008) also points out that the ability to generate facsimile models that exactly match the real-world is a very rare event.

The intention of this study is to provide a middle range model that assists in understanding the processes and agent interactions that contribute to the outcome of an ISD project.

Table 6.4: Representative guidelines for simulation-based research

Taber and Timpone (1996)	**Sallach and Macal (2001)**	**Davis et al. (2007)**
1. Pose the question	1. Define hypothesis and/or theory	1. Begin with a research question
2. Period of study	2. Represent (define) and implement the theoretical constructs in the context of the simulation	2. Identify simple theory
3. Create a process model	3. Set up an agent simulation model environment	3. Choose a simulation approach
4. Create a Computational Representation	4. Set up global (system) measures for comparison of simulation results	4. Create a computational representation
5. Evaluate the Computational Model	5. Interpret simulation results by mapping them back into the theory space	5. Verify computational representation
6. Explore the model’s behavior		6. Experiment to build novel theory
7. Experiment with the model		7. Validate with empirical data
8. Modify theory about the real world		

General Frameworks/Guidelines for Building, Using and Testing Simulations

Table 6.4 provides a comparison of guidelines for building, using and testing computational models. Summarizing by way of Taber and Timpone (1996), the various steps roughly fall into four phases; viz., Theory Development, Model Development, Model Evaluation, and Refinement. It is understood that the steps are iterative and not simply linear. The degree of model maturity should be correlated with the level of subsequent experimentation following the original model development. Sensitivity analysis is a process that may be undertaken to systematically explore the model’s parameterization and breaking points. The more the model is explored, the greater the understanding and with it an enhanced sense of validity should follow. The steps advocated by Davis et al. (2007) are part of their roadmap for developing theory with simulation methods. This is their second level form of simulation research, and in the final step

they specify validating the model with empirical data. Also advocating this position, when simulation is being used to generate hypotheses or test theory are Ren et al. (2006) and Carley and Svoboda (1996).

Judging the Veracity of Simulations

As a precursor to a justification of multi-agent systems simulations in the context of social scientific research, I note the words of Jean Baudrillard (1981) in his discussion of the breakdown between the real and the simulation of the real in postmodern existence.

> *The models no longer constitute either transcendence or projection, they no longer constitute the imaginary in relation to the real, they are themselves an anticipation of the real…the real cannot surpass the model – it is nothing but its alibi.*

As was noted previously the level of validation is contingent on the type and level of simulation being tested. Gilbert (2008) provides a breakdown for judging the veracity of agent-based models based on verification and validation of the model. Verification is the process of checking that a model is a good representation of what it is specified to be and that it does not include errors. As Davis et al. (2007) point out the "key point of verification is to ensure that the computational representation accurately represents the underlying theoretical logic." Validation involves checking that a model is a good representation of the social phenomenon that is represented by a model. For validation this should be examined in two ways. First the fit between a theory and the model of the theory should be validated. The second form of validation should be the fit between the model and the real world phenomena that are being modeled.

Verification and Validation for the Current Study

In this study, verification has been conducted by contacting programmers of the simulation software to review the simulation code in order to eliminate programming errors in the simulation. Validation of the fit between theory and the model has been conducted numerous times in the past for Construct, the simulation software. The validations have been conducted in conjunction with empirical data (Carley, 1990; Carley and Krackhardt, 1996; Carley and Hill, 2001; Schreiber and Carley, 2003). The validation of the fit between the model and the real-world that it is simulating can be assessed following the guidelines suggested by Gilbert (2008) for a middle range model simulation; whereby validation may be "satisfied with qualitative resemblances" to the real-world phenomenon that is being modeled, quantitative matches are not expected. The verification process may be framed in terms of different forms of validity and reliability and is addressed as part of the following section.

Evaluation Alternatives and Validity

For the sake of completeness, additional discussion is required in regards to evaluating simulation models. For example, Taber and Timpone (1996) suggest a number of ways to assess the accuracy of a model. One method may be to compare the simulation results with that of chance performance. A second method is to compare the performance of the model with the expectations of experts in the field under consideration. Third, the simulation model can be compared to existing competing models of the phenomenon. It should be noted that while making comparisons, outcome results alone should not be the sole criteria for evaluation. For example, a regression model might provide a better predictive outcome, but provide little insight

into the actual social processes that contribute to the outcome. An example may be drawn from astronomy where Kepler's elliptical orbits of the planets did not predict their path any better than that of the Copernican system of epicycles, yet provided a clearer understanding of the workings of nature.

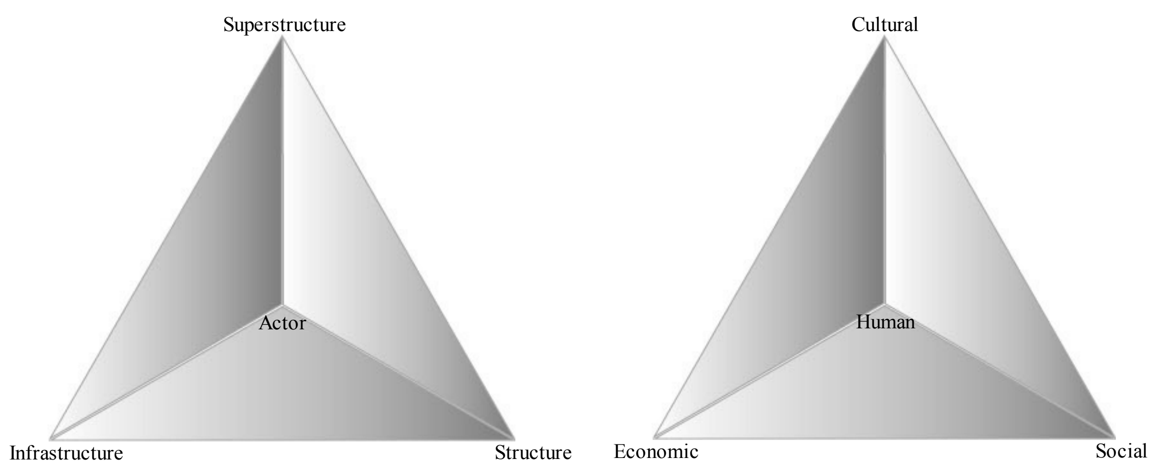
Table 6.5: Validation measures for computational models (Taber and Timpone, 1996)

Validity	**Meaning**	**Assessment**
Outcome	The degree of correspondence between a model's predictions and real-world data; contrast with process validity.	1. Face validity 2. Direct comparison to empirical data
Process	The degree of correspondence between a model's mechanisms and real-world processes; contrast with outcome validity.	1. Face validity 2. Multi-level testing of processes and sub-processes 3. Direct testing with sensitivity analysis
Internal	The degree of correspondence between a model and the theory it represents; see face validity.	1. Face validity 2. Reliability 3. Sensitivity analysis
Face validity	The subjective assessment of a model's validity, based on general knowledge of the research domain.	1. Reasonable to experts 2. Extended Turing test 3. Sensitivity analysis
Reliability	The level of robustness of stochastic models, i.e., consistency of measurement outcomes over repeated tests. (Precision)	Multiple runs of the simulation performed
Turing test	If a model's output and/or processes are indistinguishable from the real system's output and/or processes, it is valid.	The original version only concerned output comparisons, though the idea has been extended to include process validation; from Turing (1950)
Sensitivity analysis	A set of procedures to illuminate the inner workings of a complex model and to discover which parts of a model are responsible for a particular output.	Model parameters are varied individually and in combination over value ranges in order to explore and assess the model's validity and reliability

This discussion draws a distinction between predictive or outcome validity and that of process validity. Other forms of validity that have been identified and discussed are internal validity, face validity, and reliability by Taber and Timpone (1996). Table 6.5 provides a summary of forms of validity, their meaning and means of assessment. Davis et al. (2007) also point out the strengths of simulation in regards to the statistically familiar forms of validity; viz., construct validity

(Cook and Campbell, 1979), convergent and discriminant validity (Campbell and Fiske, 1959). Because of the specification accuracy in computational analysis construct measurements, construct validity should not be an issue. Likewise, the measurement errors associated with empirical data are non-existent and therefore convergent and discriminant validity are not relevant (Davis et al., 2007).

Outcome validity addresses the reasonableness of the model's predictions as compared to the real-world. Process validity addresses the processes within the simulation as compared to processes in the real-world. Internal validity is an assessment of the internal logic of the model. Associated with internal validity is the reliability of the model which addresses the consistency of the output of the model. Even as it is noted as not being a requirement for a simulation to be considered valid, comparison of simulation results with empirical data may be thought of as something of a gold standard for validating a computational model. Davis et al. (2007) provide two alternative ways to validate a model empirically. The first is based on statistical results of large-scale data and the second involves comparison with case study data. They do note that there is a debate over the value of validation. Davis et al. (2007) take the stance that if the theory is empirically based "validation is less important"; whereas, if the theory is not empirically based then "validation is more important".



(a)

(b)

Figure 6.1: Conceptual Integrated Models; adapted from (Harris, 1979) and ICE

Sensitivity analysis is a systematic analysis of the simulation's outcomes as the model parameters are changed (Gilbert, 2008). Sensitivity analysis is used to refine the model, determine how the outcomes are dependent on particular parameter values, explore its strengths and weaknesses, and discover its breaking points; as well as to assess the model's consistency and accuracy. Sensitivity analysis is an important part in refining the model and part of the iterative process of model adjustment.

This study focuses its attention on a middle range model in order to provide a sufficiently general scenario to be of use to a variety of IS researchers. It employs an underlying theoretical model that has been tested repeatedly in the past and thus does not propose new social theory per se. It does however employ this theoretical model in a new way which specifically seeks to identify processes behind the social phenomena that occur during the course of an ISD project and thus provide additional understanding and explanation of the subsequent results of a project.
The following section presents the research questions under investigation in this study.

VIRTUAL EXPERIMENT

The ICE model (Figure 6.1) introduced in chapter three is a meta-theoretical framework presented at a conceptual level and based on substantive previous social theory. Chapter five provided a discussion of the general operationalization of these concepts in network theoretic and methodological terms. This section specifies the specific virtual experiment being investigated in this study. The subsequent sections of this chapter and material provided in the appendix provide a detailed description of the specifications and coding performed in order to carry out the virtual experiment.

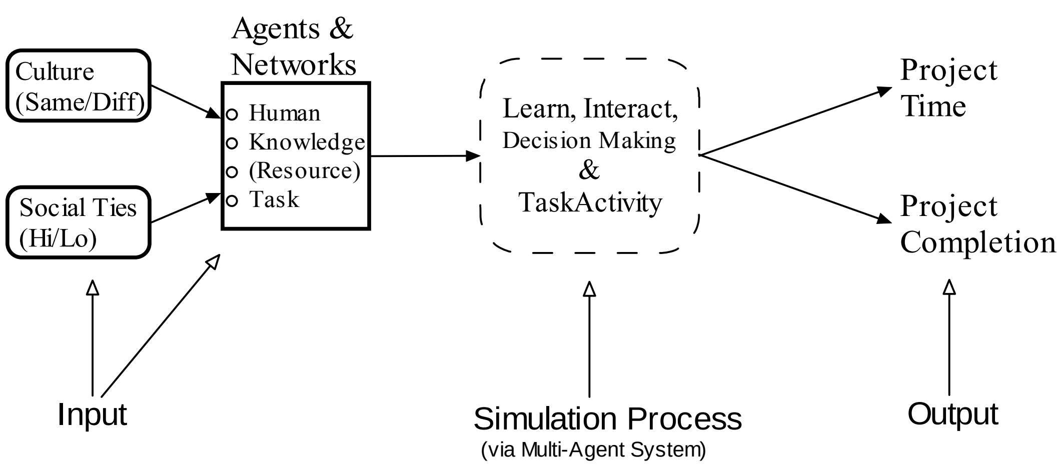


Figure 6.2: Virtual Experiment - Linear Process View

Experiment Description

This experiment aspires to provide: (a) greater understanding of the underlying processes involved in the outcomes of ISD projects, and (b) some degree of predictive ability concerning those outcomes. Specifically, this experiment is concerned with how the initial level of customer-developer interaction may affect knowledge transfer from customers to developers in terms of the results on project task performance. The experiment also explores the possible effects that customer-developer shared and/or divergent organizational cultural beliefs may have on task performance, as well. The experiment is visualized in terms of a linear process view in Figure 6.2. Inputs are agents representing customers and developers, tasks to be performed, and

knowledge facts known by customer agents that are required to perform tasks that must be accomplished by developers as part of the ISD project. In addition to the individual components the networks of relationships of all of these components are part of the input specifications to the simulation. The simulation process is coded in Construct (Carley, 2008), a network based multi-agent simulation system. Discussion of the parameterization of the simulation is found in the following section and in the appendix. Output from the simulation is analyzed with network analysis tools and finally analyzed using a 2 x 2 factorial design for an analysis of variance.

Research Questions and Hypotheses

The research questions of interest are:

(1) Do social relationships have an effect on the outcome of an information systems project? For the purposes of the present investigation the initial level of interrelationship between the customer and developer groups is examined in terms of the relative number of ties between the two groups. This is done dichotomously in terms of starting with a low or high number of interrelationships between the groups.

(2) Do culturally held beliefs within different groups working together have an effect on the outcome of an information systems project? For the purpose of the present investigation agents possess two attributes which are representative of two culturally held beliefs about the organization. These attributes are tested dichotomously between the customer and developer groups.

Within the context of this discussion *social factor* refers to the initial ties between the customer and developer groups. The *cultural factor* refers to the belief attributes possessed by agents within the project. Under the experiment any member of a given group will hold the same beliefs in common with all other members of their group. The experiment explores the possible of effects of the cultural factor by varying the values between the two groups as either being shared or disparate. The response variable used as representative of the *project outcome* is the proportion of the project that may be completed based on the number of tasks within the project. The algorithm and specifics are provided in the system construction section of this chapter. The C++ programming code appears in Appendix F.

Hypotheses

H1: Social Main Effect

- H_0: There is no social factor effect on project outcome; i.e., both levels of the social factor will have the same mean
- H_1: There is a social factor effect on project outcome; i.e., the two levels of the social factor will have different means

H2: Cultural Main Effect

- H_0: There is no cultural factor effect on project outcome; i.e., both levels of the cultural factor will have the same mean
- H_1: There is a cultural factor effect on project outcome; i.e., the two levels of the cultural factor will have different means

H3: Social*Cultural Interaction Effect

- H_0: There is no interaction between the social and cultural factors

H$_1$: There is an interaction between the social and cultural factors

Graphical Representation

Figure 6.3 provides a graphical representation of the (2 x 2) factorial design of the experiment. The three spheres within the figure represent the customer network in green, the developer network in blue and cultural values in red. The lines between the spheres represent relationship attachments. The relationships between customers and developers are represented using a light line to indicate relative low group interrelationships and a thick line to indicate a high group interrelationship. The lines from either agent network to specific cultural values provides a visual key indicating that the two groups either hold disparate or shared values.

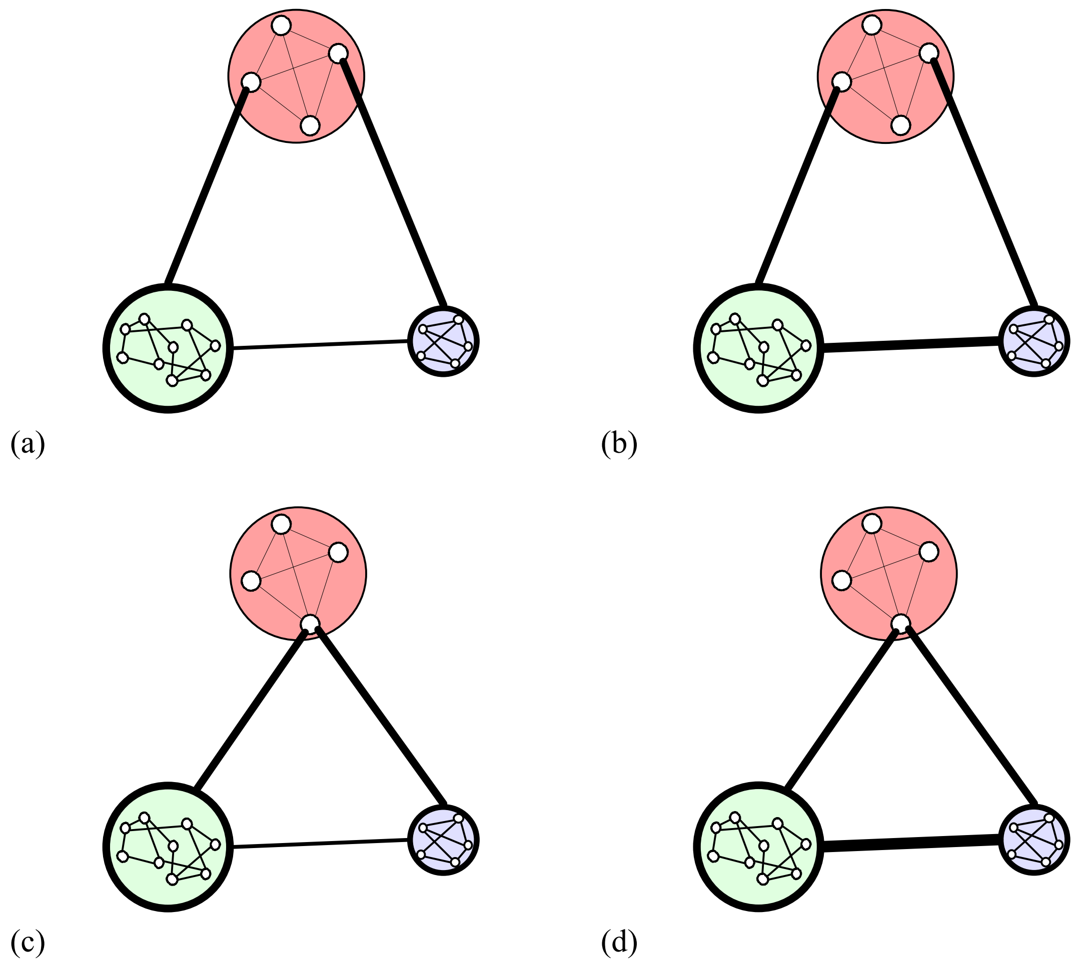


Figure 6.3: Network representation of Experimental Factorial Design (2 x 2)

Having presented the questions of interest the following section will provide additional detail and insight into the virtual experiment's specifications and parameterizations.

MODEL COMPONENTS OF A MULTI-AGENT SYSTEM IN CONSTRUCT

Construct is a multi-agent simulation tool that is commonly used to investigate dynamic behavior in complex socio-cultural systems. It can be used to run a series of virtual experiments using similar agents in order to examine how a diverse group of agents would behave in a slightly modified situation (Hirshman et al., 2007). This section will describe components of the simulation in three steps; i.e., primary input to the simulation, the simulation process, and the resulting output. This section will provide a general overview of the simulation and the following section, in conjunction with the accompanying appendix, will provide further detail specific to the current research investigation.

Input Elements

Agents and Nodes

A number of types of nodes may exist in a multi-agent system, the most recognizable being a human agent. As with traditional variable allocation, agents can possess attributes. Examples of agent attributes include the usual demographic data like gender, education, and salary. In addition, agents may also be members of a group. Groups may be an affiliation with a functional department, a team, or a given organization. Agents can be affiliated with multiple groups.

In Construct, there are seven important parameter categories which govern an agent's behavior during a simulation. Modifying an agent's parameters can change how an agent interacts, what an agent does, and with whom an agent chooses to interact within the course of a simulation. The seven parameter categories are an agent's: (1) knowledge and beliefs, (2) its internal characteristics, (3) its task and performance characteristics, (4) its message content parameters, (5) its interaction characteristics, (6) its interaction patterns, and (7) its statistical parameters (Hirshman et al., 2007a). Although there are many possible parameters to manipulate, even for a complex model it is prudent to limit the number of variables that are included within the course of a given study.

Examples of other nodes besides human agents that exist within Construct represent entities such as resources, knowledge facts, tasks, locations, and organizations (Carley, 2001).

Network Types

The dynamic nature of the complex system is based on the inter-relationships among the constituent nodes. The network that we are familiar with from the previous discussion is the Social Network, a network of ties among human actors, indicating who knows who. It is often convenient to abbreviate such a network as (A x A), referring to the matrix notation of a list of actors row by column. Due to the existence of other types of nodes, e.g., knowledge and tasks, other types of networks can be created. A number of examples will prove useful. The actor by knowledge network, (A x K), is referred to as the Knowledge Network, indicating who knows what. The actor by task network, (A x T), referred to as the Assignment Network, indicates who does what. The Needs Network, (K x T) indicates what knowledge is needed to carry out a task (Carley, 2001; Krackhardt and Carley, 1998). Envisioning these multiple networks can be challenging. Figure 6.4(a) depicts an actor who has been assigned a task. In addition the task has specific knowledge that is needed for the task to be carried out successfully. Through the course of the simulation the actor will come to learn the requisite knowledge as depicted in Figure

6.4(b), or the actor may guess in attempting to complete the task; alternatively the actor may not be able to complete the task successfully (Hirshman et al., 2007b).

(a) (b)

Figure 6.4: Relationship among human agents, knowledge, and tasks

Besides the networks that are visually and more immediately apparent, in the course of a project, there are a number of internal networks that may be important to the outcome of the simulation. For example inherent to the process of an agent performing a binary task is ascertaining the veracity of the knowledge known (or guessed at) by the agent, which is required to perform a particular task. So in addition to the task assignment network, (A x T), the knowledge network (A x K) and the requirements network (K x T), there exists a 'truth value' network (K x K^*) that is specified usually in order to provide a degree of randomness and chance to the performance of tasks. This provides another element of realism to the simulation. It is beyond the scope of this study to provide a comprehensive list of all of the possible elements available within the simulation program. Having reviewed the primary components for input into the simulation we now turn to a discussion of the internal mechanics of the model.

Simulation Process

Construct is a multi-agent network model designed to capture dynamic behaviors of group interactions within a complex system. The model is non-linear and provides for complex behaviors as the agents interact over time (Schreiber et al., 2004). Schreiber et al. (2004) define Construct as being "grounded in structuration theory (Giddens, 1984), social information processing theory (Salancik and Pfeffer, 1978) and symbolic interactionism (Manis and Meltzer, 1978)."

The dynamic process of choosing an interaction partner, communicating, learning, making task related decisions, altering beliefs and realigning within the social network is fully iterative throughout the course of the simulation, thus enabling evolutionary change to occur within the system. The interaction model within Construct is based on constructuralism (Carley, 1986a; Carley, 1986b; Carley, 1990; Carley, 1991; Carley, 1995; Schreiber et al., 2004). Constructuralism is a cycle of action, adaptation, and motivation (Carley, 1986a) and acknowledging Giddens' duality of structure; Kaufer and Carley (1993) provide a finer grained analysis of action and structure especially in regards to the communication transaction process (Schauder et al., 2005). The dynamic nature of constructuralism "states that the socio-cultural

environment is continually being constructed and reconstructed through individual cycles of action, adaptation and motivation" (Schreiber et al., 2004).

Schreiber et al. (2004) indicate that Construct's "basic interaction mechanism embodies three empirical generalizations: (1) knowledge acquisition occurs through interaction (Festinger, 1950; Granovetter, 1974), (2) homophily (Lazarsfeld and Merton, 1954; McPherson and Smith-Lovin, 1987) and (3) social relativity (Merton, 1968; Festinger, 1954)." These core principles are the initial driving force of the agents' cycle of existence within the simulation.

Every simulation run has a prescribed time period under which it is run. At the completion of the run a number of data outputs may be obtained.

Output

The primary concern of this study is obtaining data relevant to the overall performance of the agents in terms of task accomplishment. A meta-network, in the form of multiple matrices, is output for each time period over the course of the project, which includes information relevant to the evolution of the multiple networks. The matrix data is subsequently used to compute the final outcome variable for project completion. The outcome variable for project completion is based on agent knowledge and task requirements. The data is then analyzed in standard statistical software packages in order to determine differences among outcomes using ANOVA. Additional longitudinal data analysis comparisons are also provided. Future work will incorporate more detailed analysis of the social relationships and individual social capital over time.

SYSTEM CONSTRUCTION AND SIMULATION

To conceive an idea is noble. To execute the work is servile.
Leonardo Da Vinci

If people knew how hard I had to work to gain my mastery, it wouldn't seem wonderful at all.
Michelangelo di Lodovico Buonarroti Simoni

This section along with the referenced appendix provides a more detailed description of the specifics of the simulation specifications and parameters used in the current experiment. First, input networks are described with a detailed example for generating the social networks. The reader is referred to the appendix and the programming code for further description of the networks generated for input for the simulation. Following the description of the network generating process are a series of network diagrams intended to assist the reader in their visualization and understanding of the complex system that is developed as a starting point for the virtual experiment. Second, a brief description of the basic parameterization and coding is provided, again with a reference to the appendix to view the simulation code in its entirety. Third, reference is made to the final meta-network as part of the output from the simulation.

Input Nodes and Networks

The primary nodes and networks that are most identifiable in the real-world are all generated by the researcher. The nodes represent actors (both customers and developers), tasks to be

performed, and knowledge required to perform the tasks. The accompanying networks are the social networks (among the customer, among the developers, between the customers and the developers), the knowledge network (who knows what), the task precedence network (what task is performed when), and the requirements network (what knowledge is required to perform what task). Some of the initial specifications were explicitly chosen by the researcher at the outset. These were the number of customers, the number of developers, the number of tasks to be performed, and the number of knowledge facts. Also determined by the researcher at the outset was the task precedence network, as this network is initially designed to be held constant throughout the course of the experiment. The developer networks have been generated through UCINET's random network generator function. All other networks have been generated through a random process using prescribed boundary conditions by coding the network generation procedures into C++ by the researcher. The programming code is found in the accompanying appendix. The following section provides an explanation of the social networks generation procedure. This is provided as an example of the coding procedure used throughout the code, and any additional interest in the code is left to the reader and their knowledge of C++ in order to conserve space.

Customer and Developer Actor Networks and Their Interaction

Random networks were generated for the two groups of interest, the customer network and the developer network. The customer group is envisioned as being a rather traditional functional hierarchy. The customer network was generated with a program written specifically for the experiment. The program code appears in the appendix. The network was generated as a hierarchical network with the following boundary parameters. First, the customer networks generated were specified as having twenty-eight members with an equal number of relations. Second, each network includes five levels in its hierarchy, with a single actor at Level 1. The number of nodes for network levels 2 through 5 is randomized according to the following boundaries; Level 2 to have 2 to 4 nodes, Level 3 to have 3 to 8 nodes, Level 4 to have 6 to 12 nodes, and Level 5 to include the remaining nodes of the network for a total of 28 nodes. The relational connections are then randomly assigned between the adjacent levels of the network.

The developer group is viewed as having a high degree of communication and interconnectivity. The developer networks were randomly generated using the UCINET 6.17 software as a fully connected Erdos-Renyi network with a node size of seven and a density of .50. A summary of the networks is found in Table 6.6. An Erdos-Renyi graph represents a uniform random probability of selecting a network from the population of all of the possible graphs that meet the specified conditions.

Table 6.6: Agent network description

Network Name	**Size**	**Density**	**Network Type**
Customer	28	0.07	Hierarchical
Developer	7	0.5	Erdos-Renyi

Two interdependence networks for the customer and developer networks are specified. The program code is found in the appendix. The first is defined as low interdependence with a total of

11 links between the networks. A link is defined between the top managers of each network. Five links are defined from each of two members of the developer group to members of the customer network. Each of the 10 links is randomly assigned. The two members of the developers group represent what would be considered system analysts, with the corresponding links representing communication within the requirements gathering process of a systems development project. The second level interdependence network is defined as high. The high level interaction network has a total of 28 links, assuring every member in the customer group has a contact in the developers group. Again, a link is established between the top managers of the two groups. The remaining links are then randomly assigned with links being established from the customer member to a randomly chosen developer.

Example Networks

Agent Social Networks

Figures 6.5 and 6.6 provide examples of the individual customer and developer agent networks. Figures 6.7 and 6.8 provide examples of the inter-connected agent networks; Figure 6.7 represents a low level of initial interconnectivity between the two groups and Figure 6.8 represents a high level of initial group interconnectivity between the two groups in the overall agent social network.

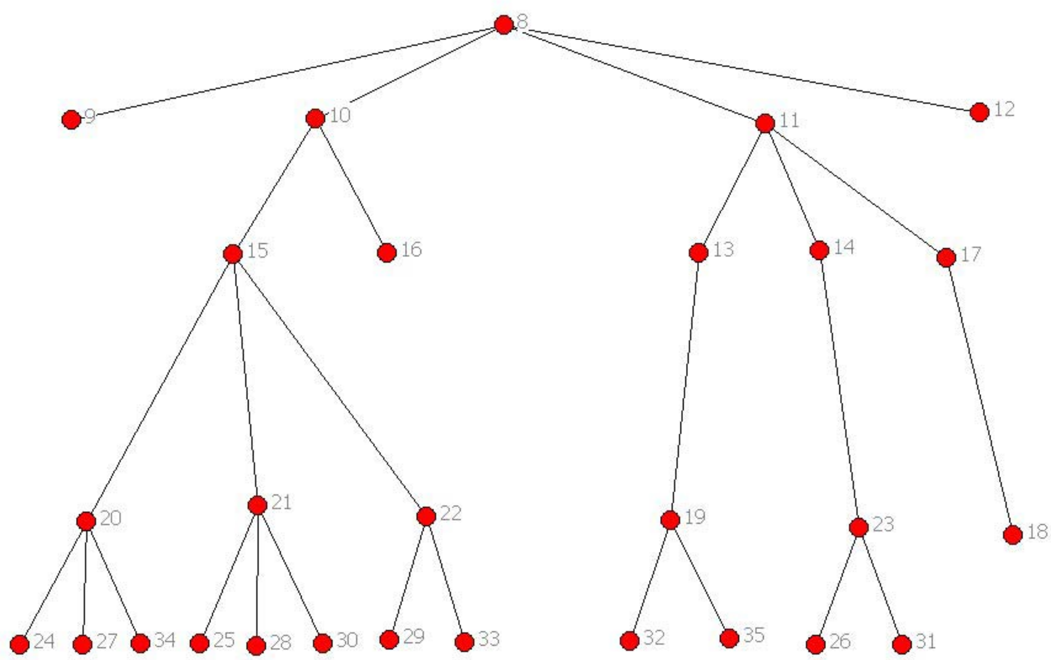


Figure 6.5: Customer Network

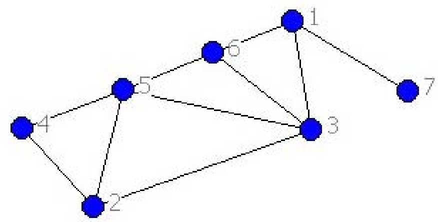


Figure 6.6: Developer Network

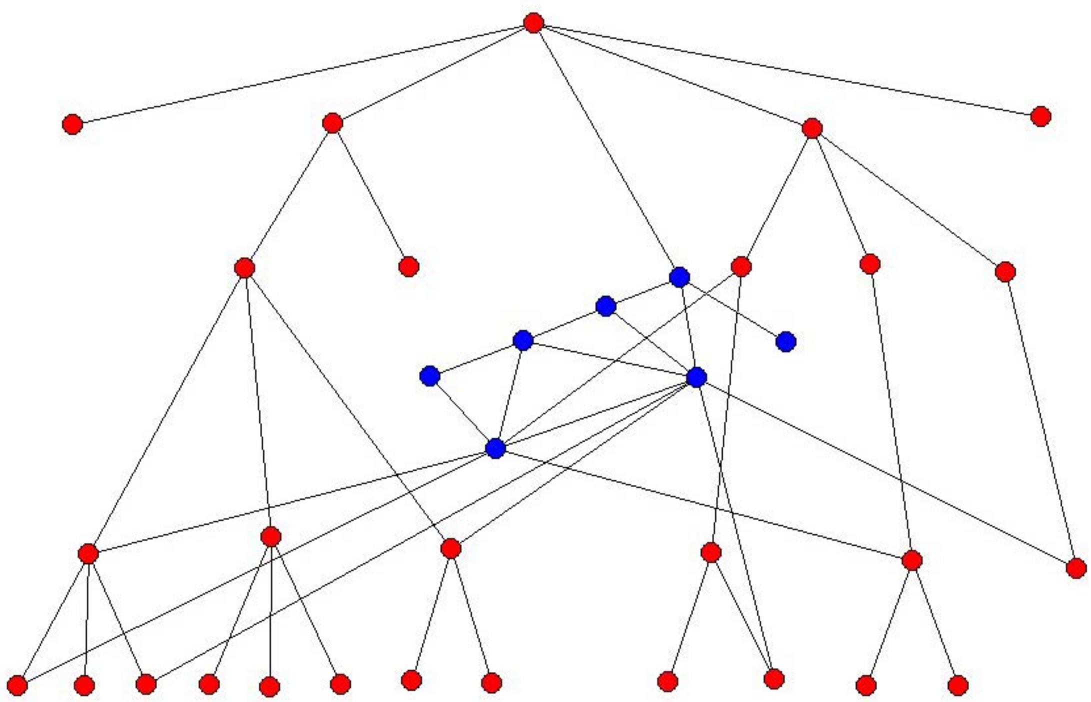


Figure 6.7: Low-level Interaction between Customers and Developers

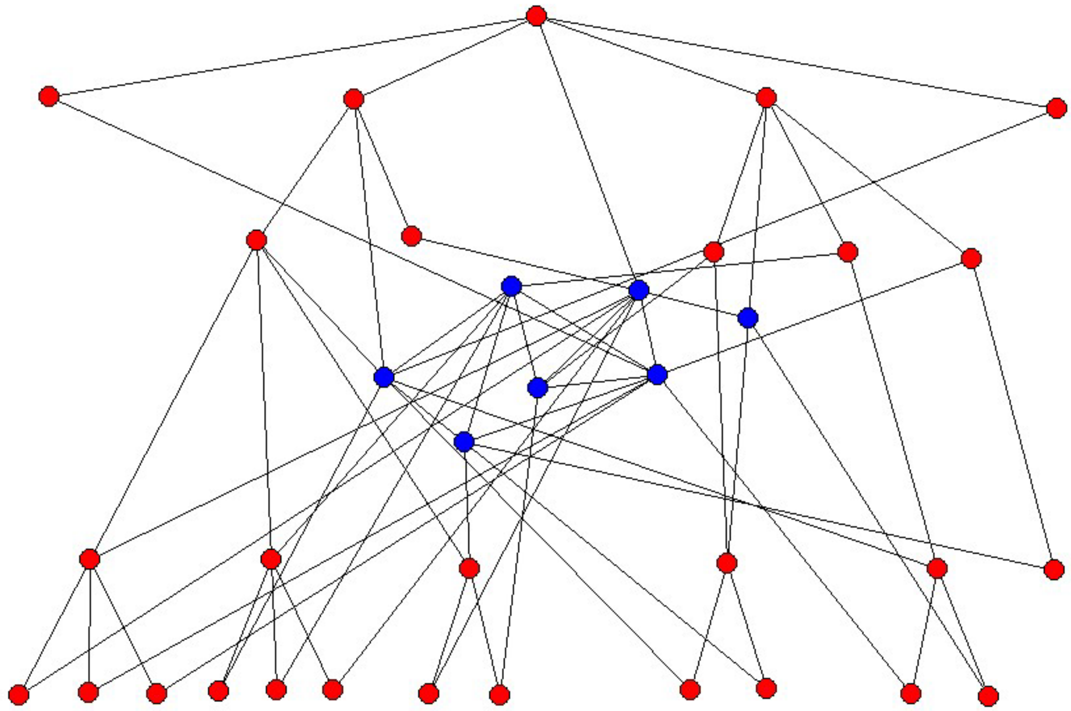


Figure 6.8: High-level Interaction between Customers and Developers

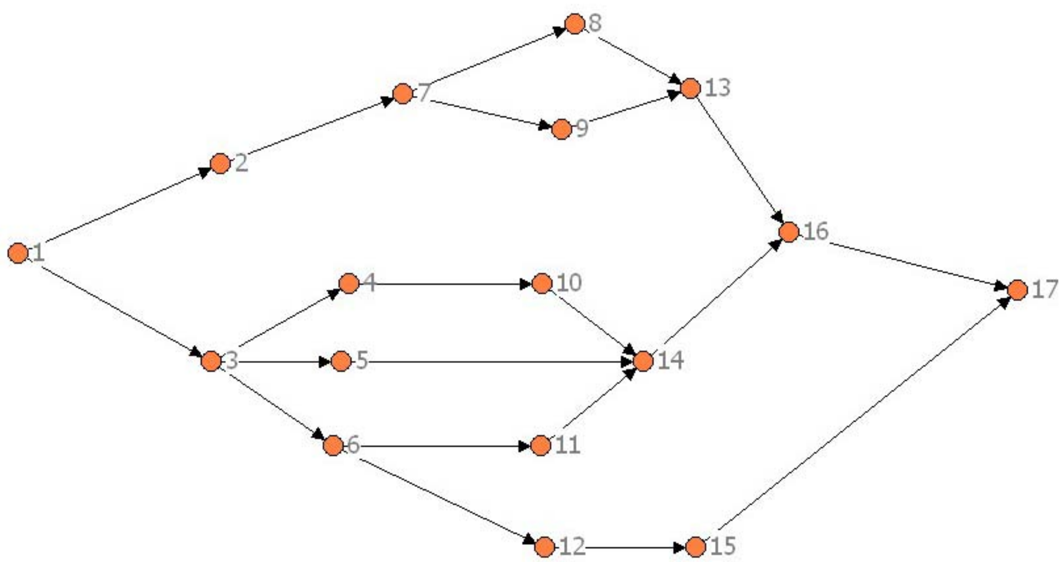


Figure 6.9: Task Network as a directed graph

Task Project Network

Figure 6.9 provides an example of a project task network in the form of a directed graph that will be familiar to readers involved in project management and popular software programs that

generate project tasks in the form of a network graph. Table 6.7 provides an example of the same network but depicted as a task x task matrix.

Table 6.7: Task Network represented as a matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
3	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
6	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
7	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Actor x Task Network

Figure 6.10 is an example of an assignment network. In the example, agents in the developer group have been assigned tasks that must be completed as part of the IS development project.

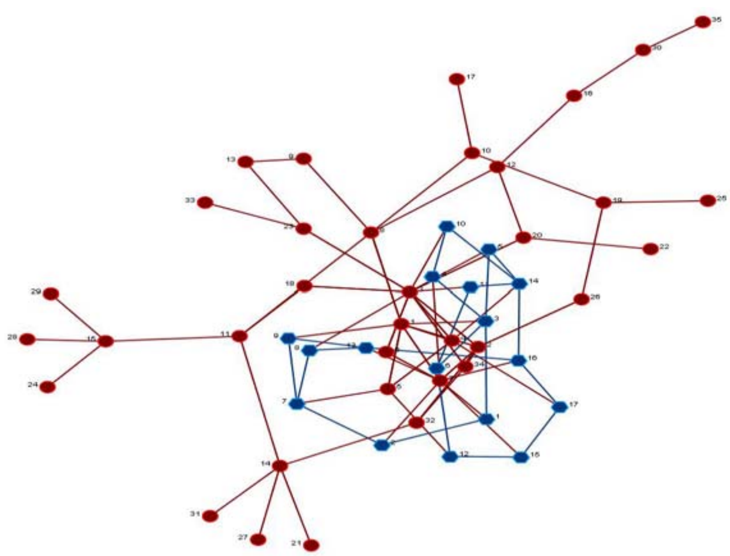


Figure 6.10: Actor x Task Network; actors in red; tasks in blue

Actor x Knowledge Network

Figure 6.11 is an example of a knowledge network. In the example, agents in the customer group possess knowledge that is required in order to complete specific tasks in the project, which must be completed as part of the IS development project.

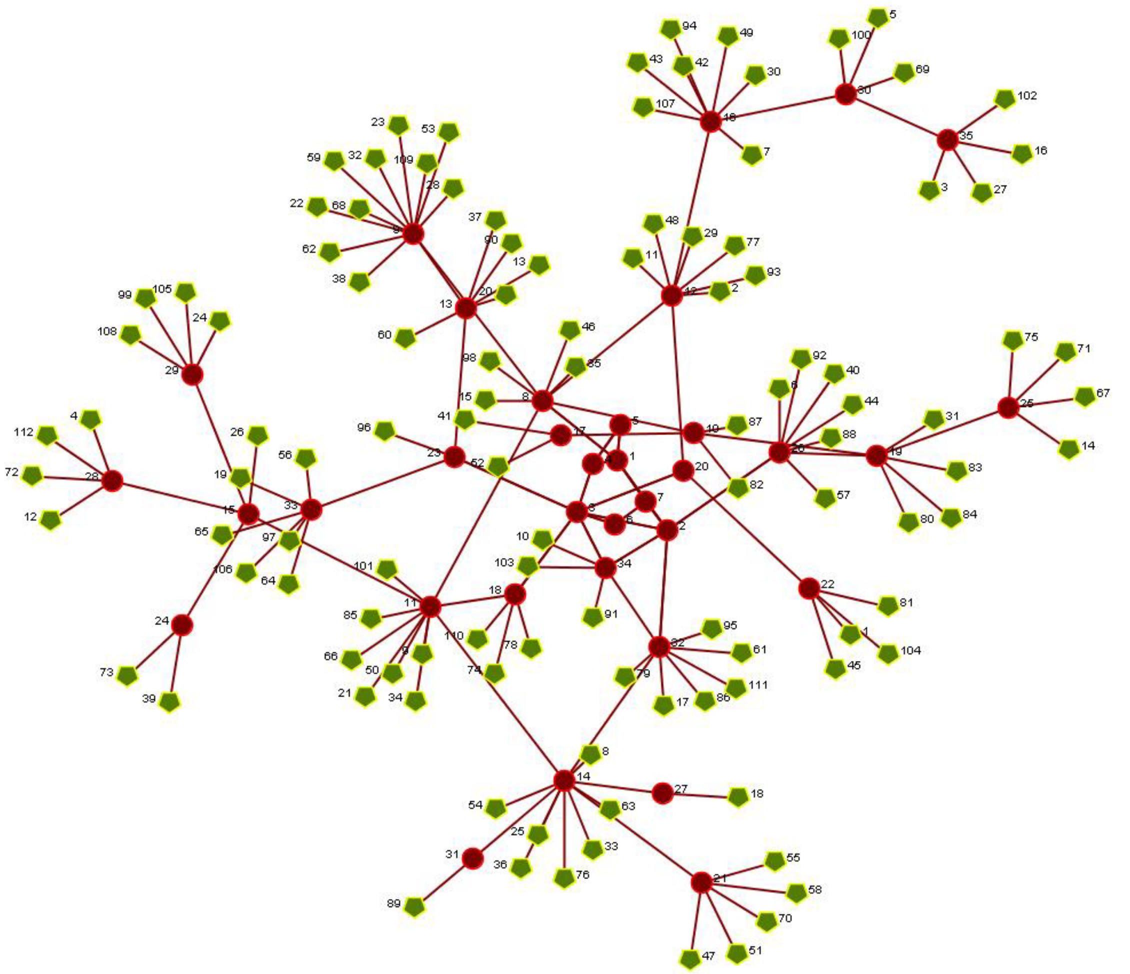


Figure 6.11: Customer Knowledge Network; actors in red, knowledge in green

Meta-network

Figure 6.12 is an example of a meta-network that represents the start of an IS development project. It includes the following networks: social network (A x A), knowledge network (A x K), task assignment network (A x T), task precedence network (T x T), knowledge requirements network (T x K). The collection of nodes and relationships constitute the meta-matrix that is the IS development project. This “matrix” evolves throughout the term of the project.

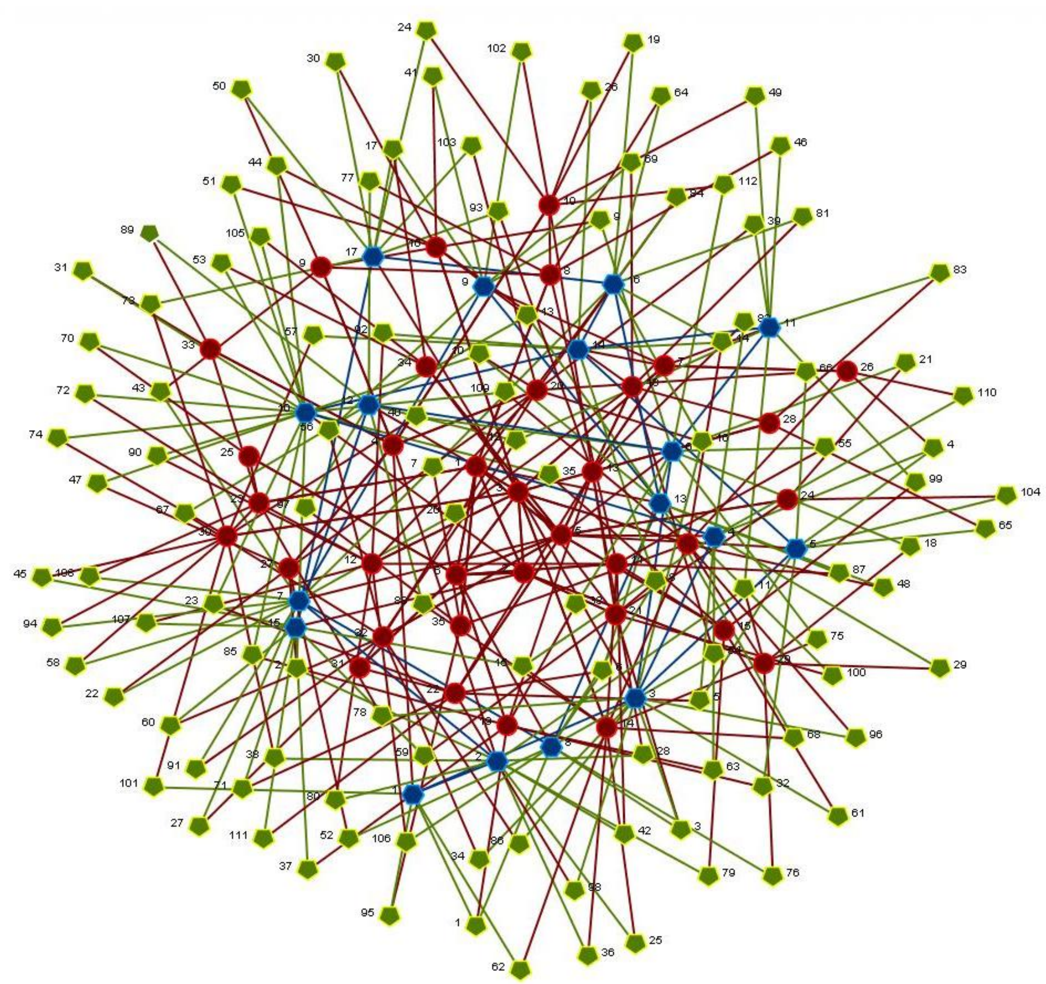


Figure 6.12: Meta-network used as input for the simulation

Simulation Coding and Evolution

Additional detail of the simulation is included in the appendix. General information regarding the parameters available in the simulation engine Construct is found in the sections for:

- Agent Style Sheet
- Agent Specification
- Network Specifications and Behavioral Rules

The specific software code is included in the Construct Code Simulation section of the appendix.

Output

The simulation engine provides output of the project's meta-matrix at the end of every time period (week). The networks contained within the meta-matrix are used as input to a custom C++ software program, written by the author, which calculates the proportion of the project that has been completed to date (outcome variable) for every time period over the course of 100 weeks. The outcome variable for proportion of project completed is calculated as an aggregate average of the percentage of individual task completion. (Each task has equal weight in terms of project

completion.) The calculated percentage of task completion is based on the knowledge possessed by the agents assigned to a task as a proportion of the knowledge that is required to complete the task. The following equation provides a summary of the last stage of the algorithm.

$$P_c = \frac{\sum \left(K_p \big/ K_r \right)}{n}$$, where

P_c: proportion of the project that is complete
K_r: knowledge that is required for a given task; derived from the knowledge requirement network (K x T)
K_p: knowledge possessed by an agent(s) assigned to perform a given task; derived from the task assignment network (A x T) and the knowledge network (A x K)
n: number of tasks within the project

The complete C++ code is included within the appendix.

SUMMARY

This chapter has provided an introduction to multi-agent simulations methodology. A case has been made for the use of simulations to study complex social systems, which in this instance is an ISD project. Further detail on the constituent components and the construction of the meta-networks necessary for input to the simulation and the parameterization of the simulation itself has been provided. The resulting output following the simulation runs is analyzed and discussed in the following chapter.

Chapter 7 -- Analysis and Results

There are two possible outcomes: If the result confirms the hypothesis, then you've made a measurement. If the result is contrary to the hypothesis, then you've made a discovery.
Enrico Fermi

INTRODUCTION

The following statistical analysis uses the data derived from the preceding simulation. The chapter proceeds first with an overview of the analysis with some summary results. Second, a detailed discussion of the experimental design is presented. Third, a more detailed analysis and results section is provided for the ANOVA, as well as data analysis of the evolution of the simulation runs.

A balanced 2 x 2 factorial ANOVA with fixed effects experimental design is employed (in silico) to discover the effects of social and cultural factors on the outcome of virtual IT projects. The social factor is defined as the initial social inter-group connectivity (high or low) between two groups, the customers and the developers of the virtual information system. The cultural factor is defined as the cultural beliefs (shared/identical or disparate) between the customer and developer groups. These beliefs are held by the individuals within each of the groups. The response variable for project outcome is calculated as a proportion of the project having been completed at the end of 100 time periods. Standard assumptions for ANOVA were evaluated and found to be satisfactory.

A significance level of α=.05 was employed for all the tests. Significant differences were found between the two levels of the cultural main effect, $F_{1,36}$=120.77, p-value<.001, MSE=.228. The relative importance of the effect is highlighted by the effect size measure of η^2=.50, thus accounting for 50% of the total variance in the project completion outcome.

A significant difference was also found between the two levels of the social main effect, $F_{1,36}$=52.51, p-value<.001, MSE=.099. The effect size measure of η^2=.22, accounting for 22% of the total variance in the project completion outcome is of interest also.

The interaction effect between the social and cultural factors was also found to be significant, $F_{1,36}$=31.98, p-value<.001, MSE=.060. The effect size measure of η^2=.13, or 13% of the variance explained in the project outcome variance. Thus the main effects are influenced by the interaction of the two factors. This is readily seen in Figure 7.2 accompanying the more detailed description of the analysis results below. Additional review of the confidence intervals for the estimated marginal means of the interaction effect indicate an interval overlap for the pair high social interconnectivity-similar cultural beliefs and low social connectivity-similar cultural beliefs. The confidence interval pair of high social interconnectivity-dissimilar cultural beliefs and low social connectivity-similar cultural beliefs is also found to overlap, although the degree of overlap is such that it may be inconsequential from a practical standpoint. This is also underscored by further statistical analysis whereby different methods provide different outcomes for its significance.

The findings suggest that shared cultural beliefs have the most influential bearing on the outcome of a project. Also, although the mean project completion is greatest for groups that began with high social interconnectivity and similar cultural beliefs the overlap of the 95% confidence interval with that of the groups that began with low social connectivity and similar cultural beliefs is statistically not significant.

EXPERIMENTAL DESIGN

Method of Analysis

A balanced 2 x 2 factorial ANOVA with fixed effects is employed to discover the effects of initial social inter-group connectivity (high or low) and cultural beliefs (shared or disparate) on project task completion. It is hypothesized that the social and cultural factors influence two different groups involved in a virtual information systems project. The two groups of interest are the customers, who collectively are interested in acquiring an information system and the developers, who are the individuals responsible for building the information system. The three hypothesis tests are tested at a significance level of $\alpha=.05$ and appear below.

Hypothesis Tests

H1: Social Main Effect

- H_0: There is no social factor effect on project outcome; i.e., both levels of the social factor will have the same mean
- H_1: There is a social factor effect on project outcome; i.e., the two levels of the social factor will have different means

H2: Cultural Main Effect

- H_0: There is no cultural factor effect on project outcome; i.e., both levels of the cultural factor will have the same mean
- H_1: There is a cultural factor effect on project outcome; i.e., the two levels of the cultural factor will have different means

H3: Social*Cultural Interaction Effect

- H_0: There is no interaction between the social and cultural factors
- H_1: There is an interaction between the social and cultural factors

Design Considerations and Assumptions

The variable values of interest for this experiment are limited to dichotomous pairs; as such a fixed effects model is appropriate.

The general assumptions for analysis of variance experiments should hold; e.g., the response variable data should be normally distributed, homogeneity of variance and random and independent data samples with independence of errors. These assumptions are tested and confirmed in the following section.

Data Collection

The data were collected by means of the simulation runs described in the preceding chapter. As such, the data has been well controlled and there is no evidence of dependence between measures or missing data.

Power

This study marks an initial foray into a method of research and so there are no known guideposts to follow in terms of what effects may be observed in the outcome of the experiment. Because of this, a number of design components have been put in place in order to enhance the power of the experiment. The first is the simulation method itself, which allows for rather stringent experimental control and thereby reduces the influence of extraneous noise variance. The second design component to influence power is the choice of dichotomous factor levels, which influence the outcome by way of producing stronger treatment effects and thereby reducing the probability of overlap (Tabachnick and Fidell, 2001). Finally, a sample size was selected to provide a sizeable probability for rejecting the null hypothesis appropriately when the alternative hypothesis is in fact true. First, as a guide, Cohen's (1988) standardized method for effect size was taken into account with the aim of including a sample size large enough to have the opportunity to find a large effect. Second, Lenth's (2006) power and sample size application was run to obtain more accurate measurements of power for each of the factors. A sample size n=10 for each of the four factor levels provides a total sample size of N=40. The sample size combined with a significance level of α=.05 provides for power=.8680 for the interaction effect between the social and cultural factors and power=.9916 for both of the main effects in the model. This is summarized in Table 7.1.

Table 7.1: Power and Sample size

Design	2 x 2 Factorial with Fixed Effects	
		Power
Main Effects	Social	0.9916
	Cultural	0.9916
Interaction	Social x Cultural	0.8610
Factor level sample size (n)	10	
Total sample size (N)	40	
Significance Level	0.05	

RESULTS

Assumption Evaluation

<u>Normality</u>

First, descriptive statistics were computed for every treatment level of the experiment. Skewness and kurtosis statistics were reviewed and found to be well within the generally accepted tolerance of plus or minus three. This provides an indication that general shape and symmetry of the treatment level distributions are in accordance with a normal distribution.

Second, a Q-Q Plot Matrix was constructed for all of the treatment levels of the experiment. The plots represent the actual observed values in the dataset on the x-axis and the computed expected normal value on the y-axis. Strict adherence to the normal distribution is found when the plot of the coordinate pairs are on the y=x diagonal line. A review of Figure 7.1, reveals that the two treatment levels with low initial social inter-group connectivity are in excellent agreement with a normal distribution. The two treatments with high initial social inter-group connectivity are less exact in their conformance with a strict normal distribution. However, ANOVA is robust with departures from this assumption, so there is no sense of a violation of the normality assumption.

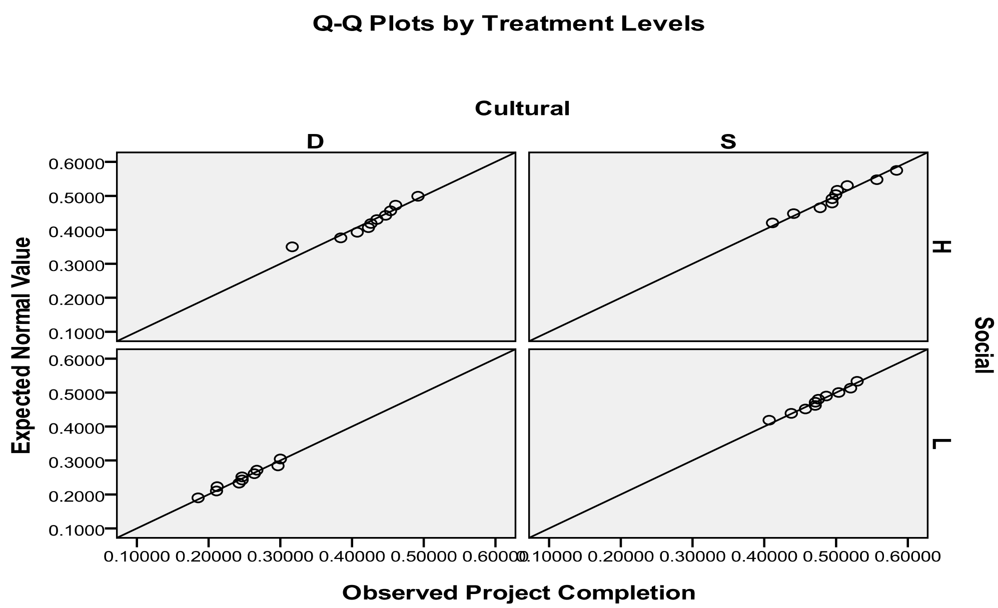


Figure 7.1: Q-Q Plot Normality Test

Absence of Outliers

Inspection of the standardized scores for the response variable for Project Completion indicates that no outliers exist within the dataset.

Homogeneity of Variance

To check the assumption of equal variances Levene's test to disprove the homogeneity of variance is computed at a significance of α=.05, (Table 7.2). The results of Levine's test statistic provide an $F_{3,36}$=0.150 and a p-value = 0.929. The results fail to reject the hypothesis that the variances are equal and we proceed accordingly.

Independence of Errors

The design of the experiment provides for random and independent assignment of both categorical factor variables. The dataset is built through random construction of the social inter-relationships of the groups, paired dichotomous beliefs, and shared random seed variables used in the initialization and evolution of the simulation. Per Tabachnick and Fidell (2001a) the

assumption of independence of errors is “not violated if all cases from all levels are tested together, because cases tested together are subject to the same nuisance variables.”

Table 7.2: Levene’s Test of Equal Variance

Levene's Test of Equality of Error Variances

F	df1	df2	Sig.
.150	3	36	.929

Hypothesis Tests

The 2 x 2 factorial ANOVA with fixed effects was run using SPSS version 17. Each of the three hypotheses were rejected at a significance level of α=.05. Table 7.3 provides the detail of the results of the analysis.

Table 7.3: ANOVA 2 x 2 Factorial Design

Source	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.387	3	.129	68.424	< .001
Intercept	6.768	1	6.768	3586.524	< .001
Social	.099	1	.099	52.514	< .001
Cultural	.228	1	.228	120.770	< .001
Social * Cultural	.060	1	.060	31.987	< .001
Error	.068	36	.002		
Total	7.223	40			
Corrected Total	.455	39			

R^2 = .851 (Adjusted R^2 = .838)

First, there is evidence for the social main effect indicating a statistically significant difference in project outcomes for the two levels of initial social connectivity between customers and developers. Higher initial connectivity provides considerably better project outcome, and using estimated marginal means, produces a mean project completion proportion of .461, with $CI_{95\%}$=(.441,.481). On the other hand low initial connectivity produces a mean project completion proportion of .362, with $CI_{95\%}$=(.342,.381).

Second, there is evidence for the cultural main effect, where each of the two groups of agents (customers and developers) either share cultural beliefs or have dissimilar beliefs with the other group. Shared inter-group beliefs produces the greatest project outcome of the main effects with an estimated marginal mean of .487, with $CI_{95\%}$=(.467,.507). Disparate beliefs between the

customer and developer groups fairs the worst for project outcome with an estimated mean of .336, with $CI_{95\%}$=(.316,.356).

Third, there is also statistically significant evidence for the interaction between the social and cultural factors on project outcome. This can be seen readily in Figure 7.2, where the y-axis represents the proportion of the project completed, the x-axis represents the two levels of the cultural factor, (D: Dissimilar beliefs and S: Similar beliefs), and the two lines represent the two levels of the social factor, (H: High initial inter-connectivity and L: Low initial inter-connectivity).

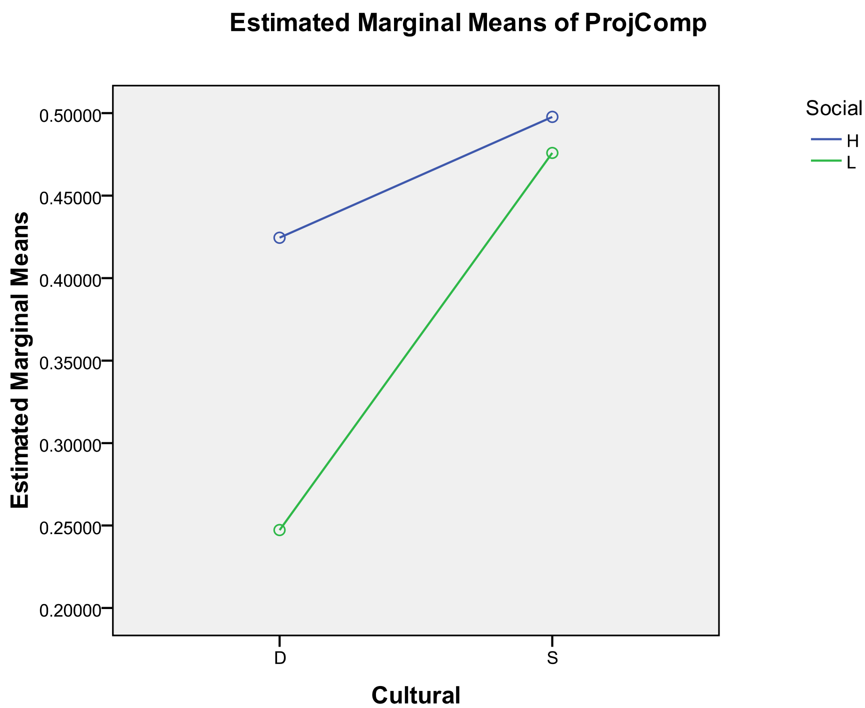


Figure 7.2: Estimated Marginal Means for Interaction Effects

The interaction effect measured with the greatest positive influence on project outcome is the combination of (H) high initial social inter-connectivity coupled with (S) similar inter-group beliefs. The estimated marginal mean for project completion for the High-Similar interaction is .498 with $CI_{95\%}$=(.470,.526). Although this is the best mean outcome for project completion, a review of the other estimated marginal means for the interaction effect in Table 7.4 shows that the confidence intervals for HS and LS overlap, indicating there is no statistically significant difference between the two means. A post hoc analysis of the pair confirms this giving a p-value=.667 for significance with α=.05, using Tukey's algorithm for comparisons.

Also of note is the overlap between LS and HD. The magnitude of the overlap in this case is 0.004 and it is suggested that in practical terms the two means are in fact different. Further support for this position is that inconsistent results may be had in terms of testing for a statistical

significant difference. It should be noted that a p-value=.056 is obtained when using Tukey's method for comparisons. Below, Figure 7.9 – Mean Factor Comparisons of the Evolution of a Project provides additional visual support for the suggestion of treating the two means as significantly different.

Table 7.4: Estimated Marginal Means for the Interaction Effect

				95% Confidence Interval	
Social	Cultural	Mean	Std. Error	Lower Bound	Upper Bound
H	D	0.424	0.014	0.397	0.452
	S	0.498	0.014	0.470	0.526
L	D	0.247	0.014	0.219	0.275
	S	0.476	0.014	0.448	0.504

Effect Size

Effect measures are calculated, in order to assess any possible degree of importance that may be attached to having found significant differences in the treatment levels. Three measures of effect are reported; two effect measures (eta-squared and partial eta-squared) are calculated for the sample and a third measure (omega-squared) is calculated as representative of the population of interest. The formula for each measure is provided below. All three measures can be interpreted as the proportion of variance explained by the independent variables of the total variance in the response variable. Table 7.5 provides a summary of the calculated effect sizes for each of the treatment level effects. Focus is placed on the sample measure eta-squared, as it is representative of the dataset and it is an additive model, which allows us to compare the factor level effects in relation to one another and in relation to random error. This can be seen in Figure 7.3. Eta-square also will be the most recognizable of the measures as it is comparable to R-square in regression.

Table 7.5: Comparison of Effect Measures

Effect	η_p^2	η^2	ω^2
Social	0.593	0.218	0.212
Cultural	0.770	0.501	0.495
Social * Cultural	0.469	0.132	0.127

The greatest proportion of the variance is accounted for by the cultural treatment effect and amounts to 50% of the total variance in project completion. The social treatment effect accounts for nearly 22% of the total variance in project completion. The interaction between the social and cultural effects accounts for about 13% of the total variance in project completion. Finally,

because this is an additive model we are able to attribute the remaining 15% of variance to random error.

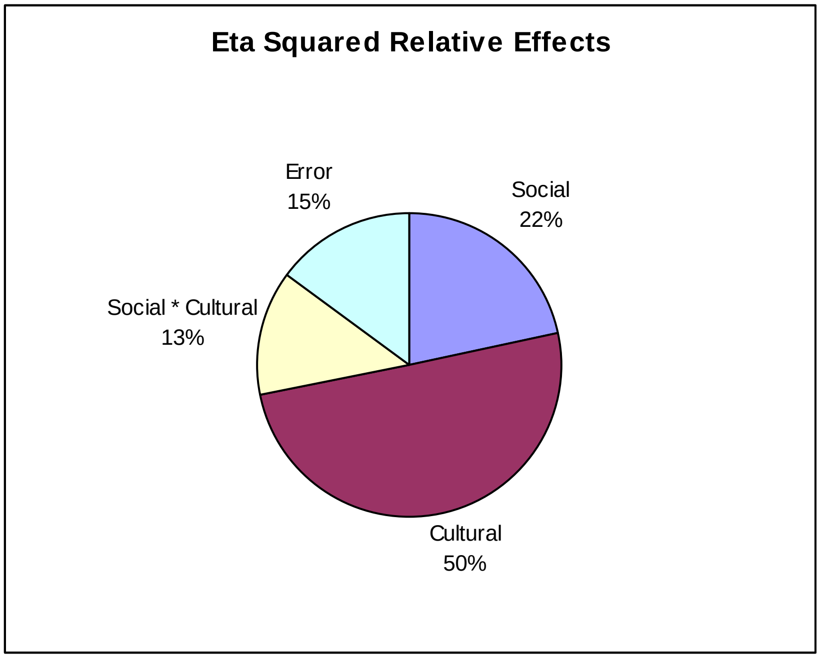


Figure 7.3: Comparison of Effects using η^2

It is suggested that the cultural effect proportion may be more pronounced due to the less nuanced features of the simulation description; e.g., the dichotomous nature of the beliefs held by the two groups; i.e., the customers and developers either hold identical beliefs or they have completely different beliefs. In general belief recognition and propagation are rudimentary in this model and may have a higher utility factor than is appropriate.

Formulae for measures that describe the amount of variance accounted for in the sample:

$$\eta^2 = SS_{effect} / SS_{total}$$

$$\eta_p^2 = SS_{error} / (SS_{effect} + SS_{error})$$

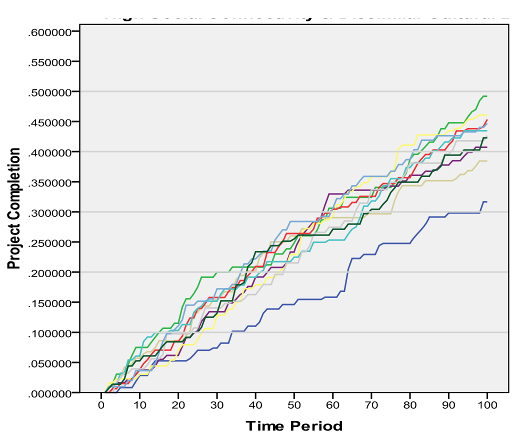
Formula for the measure that describes the amount of variance accounted for in the population:

$$\omega^2 = (SS_{effect} - (df_{effect})(MS_{error})) / (MS_{error} + SS_{total})$$

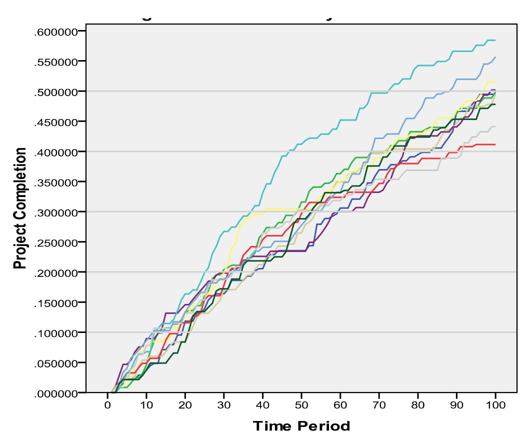
Data Analysis of Simulation Runs

The ANOVA discussed above is based on the value of the response variable for the proportion of the project that was completed at the end of 100 time periods for a total of 40 simulation runs. The following graphical analysis provides a visual indication of the evolutionary paths taken from the project start to the time period measured for use in the analysis of variance experiment.

Figures 7.4a-d provide a summary matrix that represents each of the four factor levels and include the running project completion measure throughout the entire timeframe of project tracking; i.e., time period 1 to 100. Figures 7.5-7.8 provide the individual graphs from the matrix in a larger format for easier assessment.



(a)



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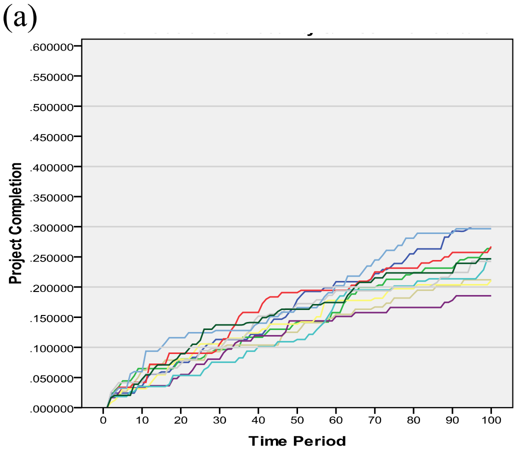
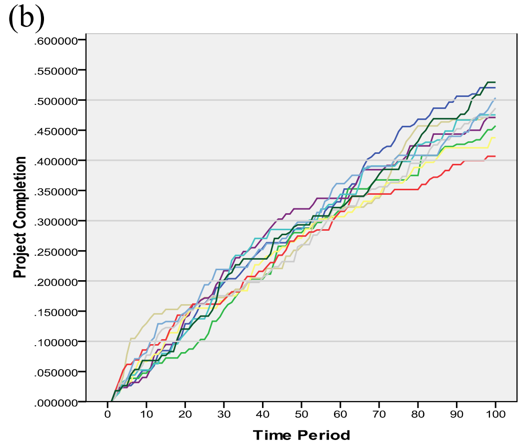


(c)



(d)

Figure 7.4: Comparison of 2x2 factorial design

A number of observations of interest are noted. First, it is clear that a project that begins with low inter-group connectivity and dissimilar inter-group beliefs should be avoided if the project is to hope to maximize project completion within the given timeframe. By week 20 both high and low initial connectivity with similar inter-group beliefs outpace the low-dissimilar interaction projects and by week 30 the high initial interconnectivity with dissimilar inter-group beliefs projects also outpace this poor performing combination.

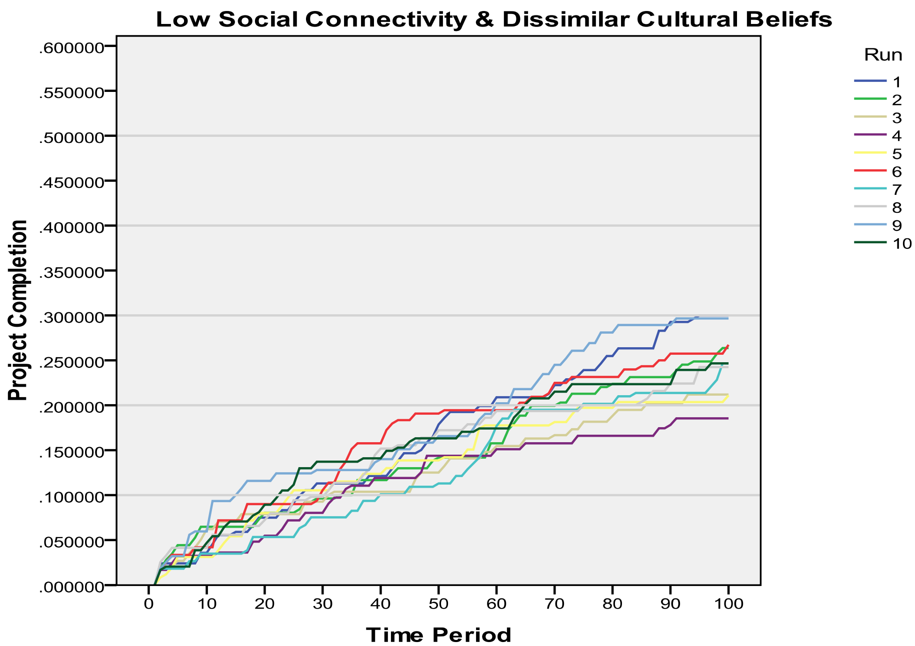


Figure 7.5: Low Social Connectivity – Dissimilar Cultural Beliefs

Second, the high interconnectivity with similar beliefs (Figure 7.6) projects suggests this combination has the potential to outpace all of the other effects combinations. This is seen clearly in one of the projects from this factor level, whereby it begins to outpace all other projects by week 30 and continues to do so dramatically until the end of the tracking period at week 100. A second, though less dramatic instance of this kind of "break out" in project performance also is identifiable and begins in week 60 and again continues to the end of the tracking period. Although this combination of high connectivity and similar beliefs is not statistically different from the low connectivity and similar beliefs combination (Figure 7.7) it would appear that in practice this would be the combination of choice.

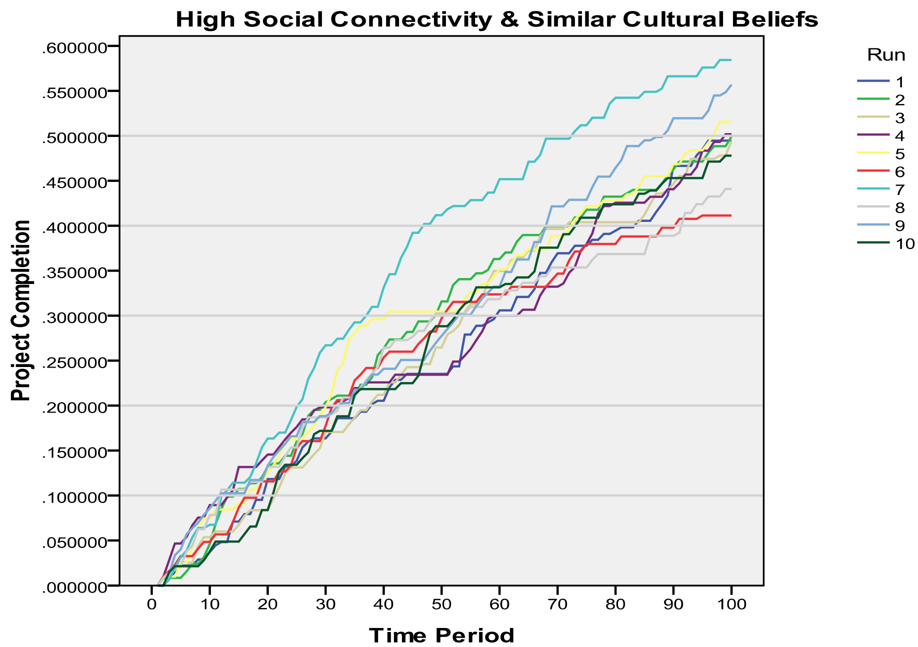


Figure 7.6: High Social Connectivity – Similar Cultural Beliefs

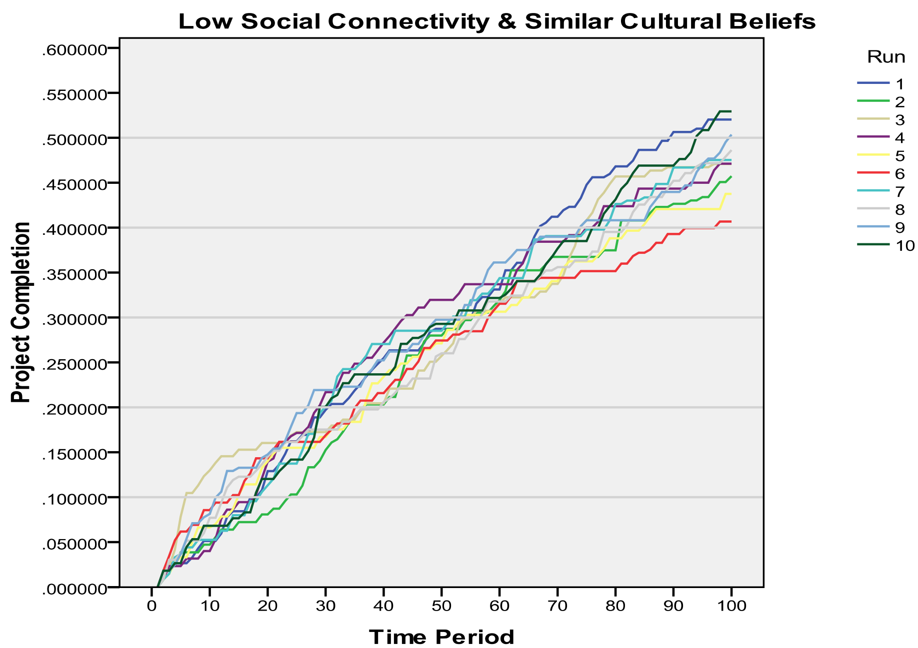


Figure 7.7: Low Social Connectivity – Similar Cultural Beliefs

Third, the interaction effect combination of high connectivity with dissimilar beliefs, (Figure 7.8) suggests that an increase in social relationships between two groups can counteract the negative consequences of the groups not having similar cultural beliefs.

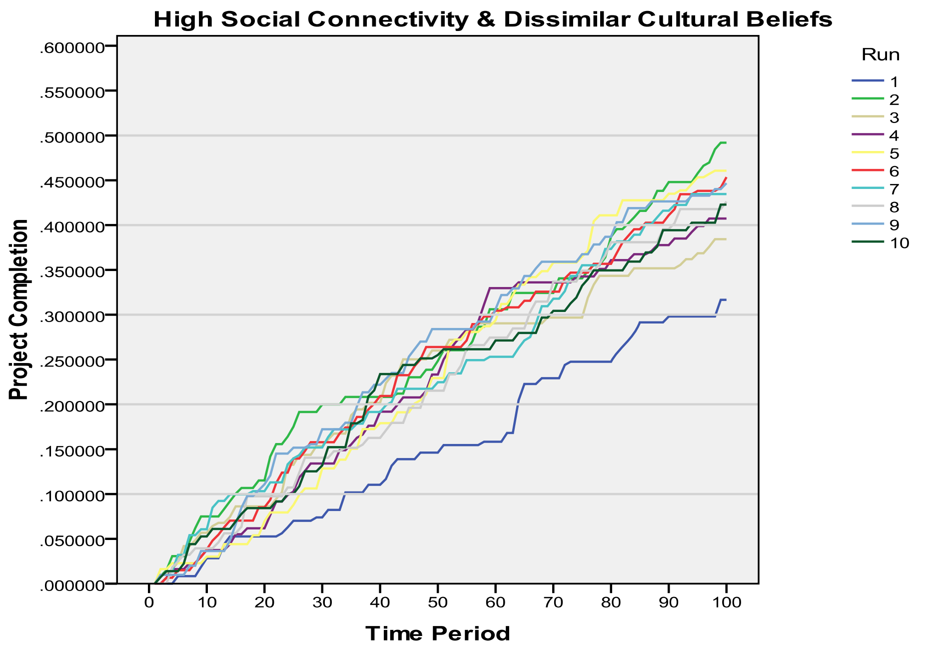


Figure 7.8: High Social Connectivity – Dissimilar Cultural Beliefs

Figure 7.9 represents the average project completion for the four factor levels at each time period throughout the time frame of project tracking.

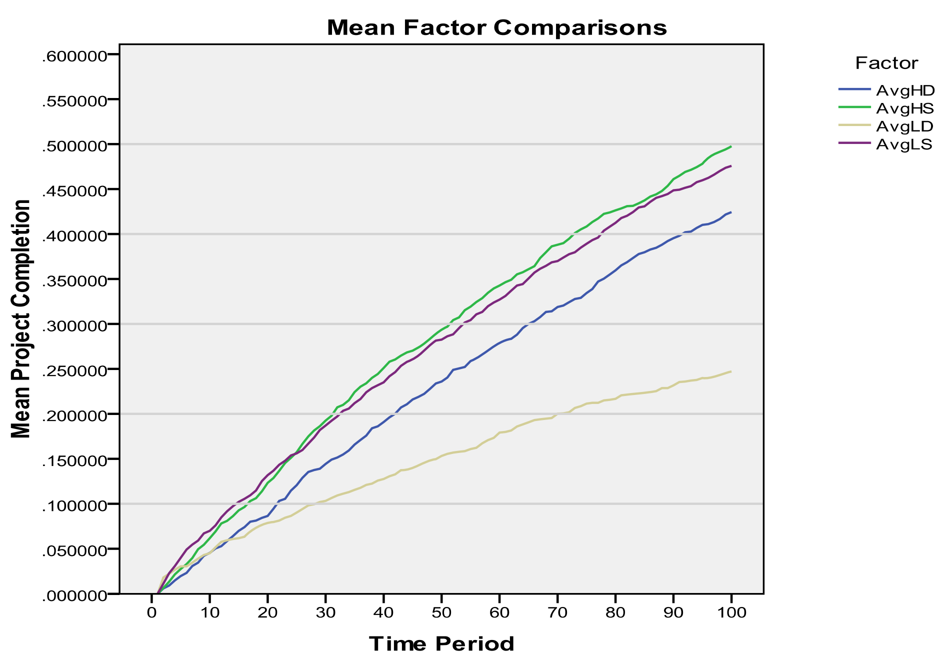


Figure 7.9: Mean Factor Comparisons over 100 Week Time Period

The mean factor comparisons graph reinforces the previous discussion concerning the significance of the mean differences among the four interaction factor levels. Where the previous analysis was limited to project outcome at time period 100 (week 100), this figure represents the

evolution of the projects over the entire period of project tracking. It is interesting to note that the outcomes measured in week 100 appear to have been in place as early as week 30.

Figure 7.10 includes the evolutionary track of all four factor levels for a single simulation run combination. Although this graph is not representative in terms of the calculated mean differences among the factor levels, it provides a clearer view of the evolutionary progress of the projects. Worthy of note is the fairly common stair step pattern of project progress. This indicates a period of time during which agent interactions and transfer of knowledge (learning) occurs, but the knowledge known by the agents is insufficient to complete the project tasks at hand. Over a period of time knowledge is acquired to the point that a breakthrough is made and project tasks can once again be completed, thus advancing the overall project. This cognitive-social build-up of knowledge followed by its use (release) to perform a project task and advance the project bears resemblance to the pattern of build-up and release of energy levels within an atom; which was first modeled accurately by Heisenberg's matrix model of the atom. The significance of this stepped phenomenon in the physical world lends additional credence to the analogy and conceptual model of social forces presented earlier in chapter three.

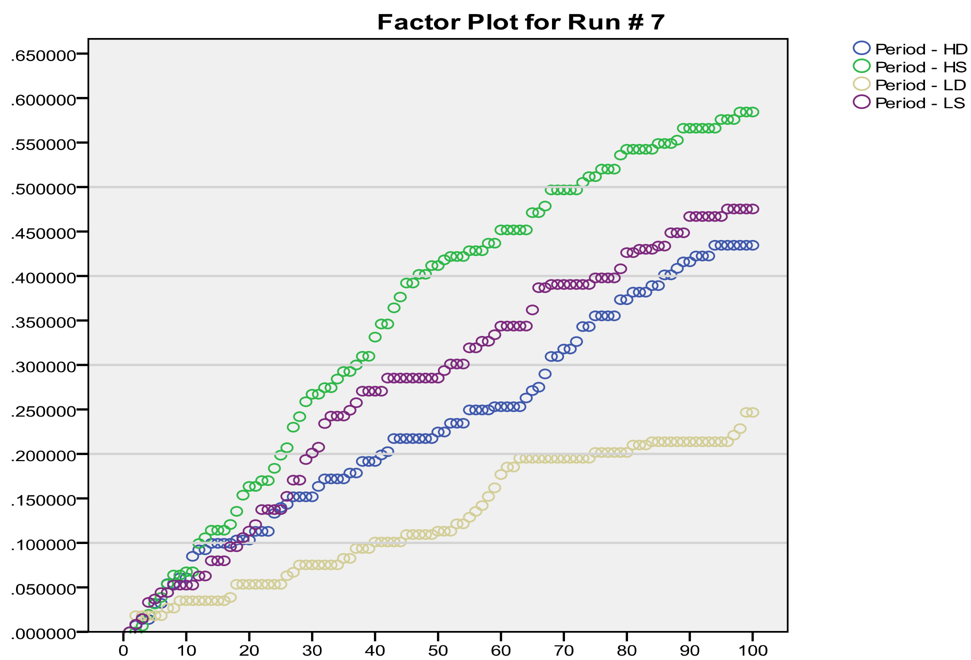


Figure 7.10: Evolution of Project Outcome over 100 Week Time Period

SUMMARY

This chapter has provided the analysis and results of a virtual experiment conducted using a multi-agent systems simulation. The experimental design used was a 2 x 2 factorial analysis of variance with fixed effects. The main factors of interest included a social component and a cultural belief component and how they might affect the outcome of an IS project as measured by the proportion of the project completed at the end of week 100 of the project. The social component included two factor levels, high and low, which represent the degree of initial social

inter-group connectivity between the customers of the information system and the developers of the information system. The cultural component included two factor levels (similar; i.e., identical and dissimilar) which specify the initial inter-group cultural beliefs between the customers and developers. Sample size and power were calculated. General model assumptions were analyzed and found satisfactory. The results of the ANOVA found that both main effects for the social and cultural factors were significant. The main effects respectively accounted for 22% and 50% of the project outcome variance as measured by eta-square. The interaction effect was also found to be significant and was found to account for 13% of the project outcome variance. A comparison of estimated means, confidence intervals for the interaction effects along with a review of the evolution of progress for the virtual projects provided a good indication for wanting to avoid beginning projects with low interconnectivity and dissimilar beliefs between the customers and developers involved in a project. Statistically either social factor coupled with similar cultural beliefs held in common between the customers and developers was found to be equivalently good in relation to the other factor combinations. However inspection of the evolutionary project graphs indicates there is a greater potential for breakout project performance when similar beliefs are combined with a high initial inter-group connectivity. Although beyond the scope of the current study, it is suggested that in practice, it may be easier to affect the social component more than the cultural belief component. This together with the vagueness in empirical terms of individually held beliefs and their accurate assessment points to the benefits to be had in enabling higher contact between customers and developers when it is believed that the customers actually possess knowledge that are instrumental in building a success information system.

A strict statistical generalization for this study is impossible given the non-corporeal nature of the agents (customers and developers) that participated in the virtual experiment. However, a logical generalization to an empirical population of customers and developers working together on a project in order to build an information system is feasible given some degree of latitude in regards to the conditions described for the virtual experiment described here.

Chapter 8 -- Implications, Limitations and Future Direction

Let the mind be enlarged... to the grandeur of the mysteries, and not the mysteries contracted to the narrowness of the mind.
Francis Bacon

The preceding chapters described a Weltanschauung applicable to the study at hand as well as to other social systems. This world view provides a philosophical foundation which makes commensurate what is traditionally held as opposing perspectives in the IS field. It provides a conceptual explanatory model of social systems, leading to an operational and applicable model that was then tested by means of a virtual experiment.

The experiment of this study sought to identify the possible effects that structural influences of social structure and organizational culture could have on the outcome of an information systems project. The direct findings were reported in the preceding chapter and will be highlighted along with the implications they have for information systems academics and practitioners. Given the complexity of the system there are a number of assumptions that were made which thus result in caveats for the results reported and their interpretation. Some of these limitations are made explicit below. Following the description of limitations, I end with an optimistic look at some of the future work that may follow from this research.

CONTRIBUTION

The general contribution of this study is to highlight the importance of structural social and cultural factors that can affect the outcome of an information systems project. Specific contributions resulting from the virtual experiment with implications for IS practice include the following three findings. First, significant differences may arise in project success based on the initial levels of user involvement (which was measured objectively by the number of relationships specified among the customer and developer groups assigned to a project). Second, when customer and developer groups share the same cultural values the level of initial inter-group relationships is not significant; i.e., when people have the same view of the world increasing initial user involvement is inconsequential in terms of project success. Third, when groups have dissimilar cultural beliefs, project success is substantially enhanced by beginning the project with a higher level of user involvement with the developers.

Beyond the stated goal of the virtual experiment a number of contributions have been made throughout the course of the study.

1. In an effort to provide an integrated foundation for the complex social system that was modeled for the experiment a philosophical foundation rooted in Buddhist philosophy and psychology was introduced which recognizes existence as being inherently multidimensional. Thus the ontology presented is consistent with both objective physical manifestations as well as relative symbolic manifestations in the world. The philosophical perspective represents an alternative to simply pasting what are frequently termed as opposing perspectives together as a pastiche without a solid base of reason.

2. A conceptual social theoretical model integrating four forms of capital (viz. resource/economic capital, social capital, cultural capital, and human capital) was introduced as an extension of Marvin Harris's work in cultural anthropology and Pierre Bourdieu's work in sociology. The Integrated Capital Ensemble model (ICE) was presented as the fundamental social forces that affect the outcome of general social systems. Agency and structure are integrated within the context of the ICE model, thus capturing both self determination and characteristics under the domain of the individual along with the opportunities and constraints that are imposed by the general social structure. ICE was not presented as a deterministic model, but as a model adaptive to the nuances of the particular social circumstances.
3. Based on a review of the IS literature there appears to be a gap in regards to social structural aspects of information systems. This study is meant to begin to fill this gap.
4. A multi-dimensional model of project success was introduced from the project management literature to supplement the existing IS perspective on success.
5. In the course of describing the simulation method employed in the current study, an overview of some alternative computational methods was discussed, which may be of benefit to the discipline.
6. An introductory discussion of networks and social networks was provided prior to introducing the underlying mechanism of the multi-agent simulation system. The drivers of the multi-agent simulation system are a complex of networks and thus concepts of meta-networks and dynamic network analysis were introduced.
7. The use of a multi-agent system methodology itself is to my knowledge also a new introduction to the IS literature.
    a. During the course of designing the components of the multi-agent system it was necessary to create algorithms to generate specific types of network scenarios for input to the system.
    b. Also, an algorithm calculating the percentage of project completion based on agent task assignments, task knowledge requirements and current agent knowledge was designed and written.

IMPLICATIONS

All things are subject to interpretation whichever interpretation prevails at a given time is a function of power and not truth.
Friedrich Nietzsche

The results of the virtual experiment found that:

1. Greater initial connectivity of customers with developers enabled the project to be completed faster than projects that began with lower initial contact between the customers and developers
2. Shared cultural beliefs between the customer and developer groups facilitated faster project completion than projects that had groups with divergent cultural beliefs
3. Among the four factor combinations high social connectivity combined with shared beliefs had on average the greatest amount of the project completed compared to the other combinations; although multiple comparisons tests found that it was not

significantly different from low social connectivity combined with shared beliefs between the two groups. The next best combination was found to be projects that began with high social connectivity combined with divergent beliefs. The worst case scenario is projects that begin with low social connectivity combined with divergent cultural beliefs between the customer and developer groups.

Given that the culturally held beliefs between the two groups were idealized dichotomous conditions of the cultural beliefs either being fully shared or completely different, this is problematic in a real world scenario where a spectrum of beliefs among people is likely to be encountered. As such, the high level of influence of shared belief should be adjusted accordingly.

Based on the results of this study a number of possibilities present themselves to IS practitioners.

1. Take the organizational culture temperature of the employees and their work groups prior to beginning a ISD project. This may be done with Cameron and Quinn's (2006) instrument. The results may help determine the amount of contact time to plan for between your customers and your developers
    a. This may be particularly useful if outsourced consultants will be the developers and are essentially unknown to your staff.
2. In preparation for upcoming ISD projects, it may be beneficial to arrange for IS staff members to relocate for a portion of their in-house schedule to the department/work group that they will be working with on the upcoming project.
    a. This preliminary initial contact suggests better and faster project success directly from the study.
    b. Even without scheduled contact, simple proximity provides for an increase in social contact and in fact can be a key element in determining whether two people will interact.

For the practitioner that would like to benefit from the results of this study, it is suggested that it is almost certainly easier to initiate and verify relationship introductions (observable) between users and developers than it is to change the beliefs of individuals of either group.

Academics may benefit from the results of this study by recognizing the effects of structural influences on information systems projects and the opportunity of exploring and uncovering new possibilities; as well as explaining old questions through the use social network analysis, dynamic network analysis or multi-agent simulation methods. Also, some or all of the secondary contributions discussed above may benefit IS and possibly other social scientists and researchers.

LIMITATIONS

It is a fool's prerogative to utter truths that no one else will speak.
William Shakespeare

Assumptions

The first assumption that is made is that people know something and have the ability to contribute to the project irrespective of their position within the organization, ostensibly a

humanist perspective held by both Social Technical Design and Soft Systems Methodology as well. Part of this assumption is that the knowledge possessed is unique (not readily known by others, especially the developers) and that it is pertinent to the project at hand. The remaining assumptions and resulting limitations essentially follow from the fact that the simulation provided is a model of the social world and not the world itself, and thus simplifications are used within the context of a complex system. The second assumption is that of an idealized dichotomous condition for the cultural beliefs between the two groups. As discussed above, this is not likely to occur in the world within which we live and thus the resulting effects should be viewed more moderately. Third, a specific proportion governing agents' intent to interact with one another was specified based on a balance of knowledge seeking behavior, which propels agents to connect with other agents that are different from themselves, versus homophily, which is the tendency of agents connecting with other agents that are similar to themselves. Different proportions for these interaction rules will undoubtedly produce different results, something which is intended for future research. Fourth, cultural beliefs held by the agents were identified as agent attributes rather than other potential modeling methods, e.g., beliefs may be identified as nodes within a signed valued graph, which would allow greater flexibility for agent beliefs.

Other inherent limitations result from the different initial conditions and specifications of the social world described by the simulation of the information systems development project, e.g., the number of customers and developers involved in the project, the number of tasks involved, the facts required to complete tasks, etc.

FUTURE DIRECTION

Prediction is very difficult, especially about the future.
Niels Bohr

"It's a poor sort of memory that only works backwards," the Queen remarked.
Lewis Carroll

One of the effects found was that by increasing the initial social ties between customers and developers the project was more successful. A follow-up to this would be to explore the relationships developed over the course of the project and compare this to the alternative scenarios in terms of the amount of social capital (cohesion) engendered over the course of the project for the organization. A corollary to be tested that may be of interest is a comparison of the organizational learning and cohesion (shared understanding and experience) lost or under-realized if outside developers are used for the project and at the end of the project the relationships essentially walk out the front door and disappear.

Taking a more general view, the model should be refined through iterative testing and sensitivity analysis, to adjust the input parameters to the simulation in order to better understand the intricacies of the model and their relative effects on the outcome variables. Additional refinement would also: (a) incorporate a more flexible model of belief, (b) incorporate demographic

attributes for agents, and (c) incorporate additional resources available for use by the agents in the model.

In addition to refining and enhancing the model components, the model can be fitted to the data collected from an empirical study in the physical world. This can be done at different levels of analysis; e.g., an empirical study at the level of an information systems development project, or in a study at the level of inter-organizational policy making. Empirical measurements for cultural beliefs could be made using: (a) a modification of Cameron and Quinn's (1999) instrument for measuring organizational culture, based on the competing values framework, or (b) aggregated measurements incorporating relatively accessible demographic information; e.g., education, race, population proportions, geographic origin, etc. Social ties could be measured via: (a) electronic trails, e.g., e-mail, phone calls, IM, and texting, and (b) face to face interaction may be captured via sociometric survey instruments, personal schedules, or even RFID badges. Data indicating the geo-spatial proximity of agents is also an important indicator for tendency to interact and should also be collected.

Apart from refining the model and comparing simulation results to a physical organization, there is more to be explored in the context of the current simulation by collecting additional data from the simulation and analyzing specific network measures of interest. For example, identifying and tracking key players throughout the course of a project may provide valuable insights for how information flows through a project as well as a means of risk abatement, as the loss of a key player during the course of a project can be disastrous. Another example is determining instances of agent work overload relative to the benefits gained by increases in knowledge sharing across the project landscape.

Simulation of a complex system can be seen as a methodology that is positioned between an interpretive narrative research agenda and research focused on the data analysis of observational measurements found in the physical world. It relies to varying degrees on the validation and practices used by both perspectives and as such may be attacked on both fronts; i.e., for some parties there are too many qualitative assumptions made and for others the quantitative and algorithmic formulations are too rigid. Alternatively, simulation of complex social systems can be viewed as a middle ground that can incorporate the best of both worlds and thus act as a bridge for greater understanding of information systems and the social environment within which it is embedded.

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Appendix A -- Human Agent Specifications

Table A.1: Human Agent Specification Style Sheet, based on (Hirshman, Carley & Kowalchuck, 2007a)

Knowledge & Beliefs		**Message Content**	
Has fact knowledge	Yes	Can send facts	Yes
Has initial knowledge	Yes	Can receive	Yes
Has beliefs	Yes	Can send beliefs	Yes
Has initial beliefs	Yes	Can receive	Yes
Has who-knows-who TM	No	Transmits who-knows-who TM	No
Has who-knows-what TM	Yes	Transmits who-knows-what TM	Yes
Has who-is doing-what TM	No	Transmits who-is doing-what TM	No
Has beliefs TM	Yes	Transmits beliefs TM	Yes
Has initial values	No	Sends and receives	Yes
Follows referral suggestions	Yes	Can send referral	Yes
Has initial values	No	Can receive	Yes
Internal Characteristics		**Interaction Characteristics**	
Minimum influentialness rate	0.0	Minimum interaction / period	++
Maximum rate	1.0	Maximum	++
Minimum influenceability rate	0.0	Minimum initiations / period	1
Maximum rate	1.0	Maximum	1
		Minimum reception / period	1
Minimum attention rate	0.0	Maximum	1
Maximum rate	1.0		
Minimum forgetting rate	0.0	Minimum unique / period	1
Maximum rate	1.0	Maximum	++
Minimum risk aversion rate	0.0	Minimum length of message	1
Maximum rate	1.0	Maximum	1
Has social demographics	Yes	Minimum distinct messages sent	1
Has initial values	Yes	Maximum	1
Task & Performance		**Interaction Patterns**	
Minimum number of tasks	0	Minimum	0.0
Maximum simultaneously	++	Maximum	1.0
Maximum in total	++		
		Randomly generated sphere	Yes
Performs binary tasks	Yes	S-D similarity matching	Yes
Performs energy tasks	Yes	2-away network generator	No

Table A.1 continued

Can be pre-assigned to tasks	Yes	Sphere size changes over time	No
Tasks change over time	Yes	Membership changes over time	No
Can choose task assignments	Yes		
		Agent can be isolated	Yes
Minimum task learning rate	0.0	Isolation is cyclical	No
Maximum	1.0	Isolation occurs randomly	No
Different rate across tasks	No		
Different rate across time	No	% interactions using homophily	100
		% interactions deliberate search	0
Has communication network	Yes	% interactions with co-workers	0
Has command network	No	Fraction changes over time	No

Appendix B -- Networks Based on Node Combinations

Table B.1: Multiple Networks, based on (Hirschman, Carley & Kowalchuck, 2007)

	People	**Knowledge**	**Tasks**
People	Social Network Who knows who	Knowledge Network Who knows what	Assignment Network Who does what
Knowledge		Information Network What informs what	Needs Network What knowledge is needed to do the task
Tasks			Precedence Network Which task must be done before which

Appendix C -- Lab Notes: Outline of Simulation Steps

Phase I – Generate the Key Input Graphs (primary node sets and networks are created external to construct) – Genesis/inception

1. TxT fixed digraph; create in Excel, save as cvs, translate to dl with ORA, visualize with Netwdraw, save as vna and jpg
2. AxA graphs for developer, customer and combined group inter-relationships
    a. Random graph for 10 Developer groups in UCINET
    b. Create AxA_hi and AxA_lo networks; randomized in C++
3. Randomly created graphs (custom C++ code) *
    a. AxT
    b. AxK
    c. KxT

    Steps for Network build

    1- UCINET used to generate Developer networks; Excel used to separate the networks
    2- TxT.csv and Dev.csv co-located in folder
    3- Run NetworkBuilder.exe, select options as needed
        a. 'a' – Build AxA_hi and AxA_lo agent networks
        b. 't' – Build AxT
        c. 'u' – Build AxK
        d. 'v' – Build KxT

4. Integrate and translate individual graphs
    a. into metamatrix using ORA and
    b. save as dynetml files, (isd_H.xml and isd_L.xml)

    Steps in ORA (1.9.xxx, July 2008)

    1- Create base network including TxT, AxT, AxK, and KxT
        a. Import into ORA
        b. Save as baseNetwork.xml
    2- Generate paired meta-networks (for each dataset group; initial trials n=10 groups)
        a. Import AxA_hi with baseNetwork; save as isd_H.xml
        b. Import AxA_lo with baseNetwork; save as isd_L.xml

5. Insert *shared cultural values* as sociodemographic agent attributes using xml editor
    a. Naming convention - save dynetml files as:
    isd_HD.xml, isd_HS.xml, isd_LD.xml, and isd_LS.xml

Phase II – Running the Simulation with Construct – production/process Evolution & progression/growth

1. Specify the construct code
2. Load and Run Construct *
    a. Load primary nodesets and networks

   b. Specify construct parameters for construct
   c. Generate other internal networks via construct; random networks can be duplicated across runs using "-seed=99" parameter for Experimental Design purposes

   Command line syntax (see separate doc for more info):
   construct –seed=108 construct_XX.xml > isd_XX/log_XX.txt
3. Key output: evolution of the AxK network

Phase III – Analysis of the Outcome from Construct – Conclusion/fruition

1. Calculate (Potential) Project Completion for each simulation run (custom C++ code) *
   a. End of run calculation, Run Series-1, single value per run (AxK_last.csv)
   b. End of period calculations, Run Series-2, 100 values per run (AxK_all.csv)

   Run:

   ProjectMetrics-2.exe – calculates the proportion of the project completed based upon current available actor knowledge; project completion is defined to be the potential portion of the project completed based on actor knowledge possessed and the knowledge required to complete the project tasks; a proportion is calculated for each task and an average is calculated for the project level metric

   Input:

   original KxT, AxT
   evolved AxK

   Output:

   ProjCompKnow_Last.csv
   ProjCompKnow_All.csv

2. Statistical Analysis and Graphs with SPSS and/or SAS
3. Network Analysis (future):
   a. ORA
   b. UCINET
   c. Netdraw, Keyplayer and other tools

Appendix D -- Phase I Code and Examples

C++ CODE USED TO CREATE RANDOM GRAPHS (NETWORKBUILD_MAIN.CPP)

```
/***************************************************************/
/***************************************************************/
/* Pierce Hopkins                              v1  JAN 2008  */
/*   Customer Network Build                                  */
/*   Project Network Build                                   */
/*  Additional Network Builds                       FEB 2008  */
/*   A x T - Developer - Task network build                  */
/*   K x T - Knowledge - Task network build         APR 2008  */
/*   A x K - Customer - Knowledge network build              */
/*   A x A - MakeAxA function to build AxA_hi       JUN 2008  */
/*           and AxA_lo                                      */
/***************************************************************/
/***************************************************************/
#include <cstdlib>
#include <iostream>
#include <fstream>
#include <ctime>

#include "randomc.h"
#include "mersenne.cpp"
// Random Number Generator Author: by Agner Fog
// based on Mersenne Twister algorithm -
// M. Matsumoto & T. Nishimura: "Mersenne Twister:
// A 623-Dimensionally Equidistributed Uniform Pseudo-Random Number
Generator".
// ACM Transactions on Modeling and Computer Simulation,
// vol. 8, no. 1, 1998, pp. 3-30.

using namespace std;

const int CustSize=28;     // 28 Customer agents
const int DevSize=7;       //  7 Developer agents
const int ProjSize = 35;   // 35 = CustSize+DevSize;
const int TaskSize = 17;
const int KnowSize = 112;
const int Lev=5;              // number of levels in hierarchy

#include "Developer.h"


// Customer class used for building hierarchical customer network
class CCustomer
{
   private:
      ;
   public:
      CCustomer(char cArray[CustSize][CustSize]);
      void initArray(char cArray[CustSize][CustSize]);
      void scrnArray(char cArray[CustSize][CustSize]);
      void ifileArray(char cArray[CustSize][CustSize]);
      void ofileArray(char cArray[CustSize][CustSize]);
      void symArray(char cArray[CustSize][CustSize]);
```

```
      void BuildHierarchy(char cArray[CustSize][CustSize]);
      void BHnodes(char customer[CustSize][CustSize],int lmin[Lev],int
lmax[Lev]);
      void BHedges(char customer[CustSize][CustSize],int lmin[Lev],int
lmax[Lev]);
};
// Constructor
CCustomer::CCustomer(char cArray[CustSize][CustSize])
{
   // initialize the array
   initArray(cArray);  // diags = 0's; otherwise 0's
} // end constructor

/***************************************************************/
/*  Initialize an Array */
/***************************************************************/
void CCustomer::initArray(char cArray[CustSize][CustSize])
{
   int row=0; int col=0;         // loop counters
   // initialize the array
   for(row=0; row<CustSize; ++row){
      for(col=0; col<CustSize; ++col){
         if(row==col){
            *(*(cArray+row)+col) = '0'; // load diagonals to 0's
         }else{
            *(*(cArray+row)+col) = '0'; // other edges to 0's
         }
      }//end for
   }//end for
} // end initArray()

/***************************************************************/
/*  Input an Array from a file  */
/***************************************************************/
void CCustomer::ifileArray(char cArray[CustSize][CustSize])
{
   //  parameters:
   //    cArray   - the Array to input
   //    InFile   - input file name
   ifstream InFile("Cust.csv", ios::in); // input from file
   int row=0, col =0;         // counters

   if(InFile.fail())
   {
      cout << "Error opening output file." << endl << endl;
      exit(2);
   }

   for(row=0; row<CustSize; ++row){
      for(col=0; col<CustSize; ++col){
         InFile >> *(*(cArray+row)+col);
         InFile.ignore(1);
      }//end for
   }//end for

   InFile.close();
} // end ifileArray()
```

```
/***************************************************************/
/*  Output an Array to the screen  */
/***************************************************************/
void CCustomer::scrnArray(char cArray[CustSize][CustSize])
{
   //  parameters:
   //    cArray   - the Array to output to screen
   int row=0; int col=0;

   for(row=0; row<CustSize; ++row){
      for(col=0; col<CustSize; ++col){
         cout << cArray[row][col];
         if(col<CustSize-1)
            cout  << ',';     // Add comma between numbers
      }//end for
      cout << endl;           // Add New Line after last col in row
   }//end for
   cout << endl << "End of Screen Display." << endl;
} // end scrnArray() output array to screen

/***************************************************************/
/*  Output an Array to an output file */
/***************************************************************/
void CCustomer::ofileArray(char cArray[CustSize][CustSize])
{
   //  parameters:
   //    cArray   - the Array to output the file
   //    OutFile  - output file name
   ofstream OutFile("Cust.csv", ios::out);
   int row=0; int col=0;      // counters for loops

   if(OutFile.fail())
   {
      cout << "Error opening output file." << endl << endl;
      exit(2);
   }

   for(row=0; row<CustSize; ++row){
      for(col=0; col<CustSize; ++col){
         OutFile << cArray[row][col];
         if(col<CustSize-1)
            OutFile  << ',';  // Add comma between numbers
      }//end for
      OutFile << endl;              // Add New Line after last col in row
   }//end for
   // cout << endl; // extra newline between network arrays
   OutFile.close();
} // end ofileArray() output array to file

/***************************************************************/
/*  Symmetrize the Network  */
/***************************************************************/
/*                       <double check algorithm>  */
void CCustomer::symArray(char cArray[CustSize][CustSize])
{
   int row=0; int col=0;      // counters for loops
```

```
   char c = ' ';

   for( row=0; row<CustSize; ++row){
      for( col=0; col<CustSize; ++col ){
         if(cArray[row][col] == '1')
            cArray[col][row] = '1';
      } // end for
   } // end for
} // end symArray()

/***************************************************************/
/***********    Generate Hierarchical Network       ***********/
/***************************************************************/
/*                                                             */
/***************************************************************/
/*  Define and Initialize  */
/***************************************************************/
void CCustomer::BuildHierarchy(char customer[CustSize][CustSize])
{
   // Parameter passed -
   // char customer[CustSize][CustSize];  /* customer network */
   int lmin[Lev];    /* node number start for level */
   int lmax[Lev];    /* node number end for level */
   int row=0;          // loop counter

   // initialize the arrays to all zeroes (0's)
   for(row=0; row<Lev; ++row){
         *(lmin+row) = 0; // min node to 0's
         *(lmax+row) = 0; // max node to 0's
   }//end for

   BHnodes(customer, lmin, lmax);
   BHedges(customer, lmin, lmax);

} // end BuildHierarchy()

void CCustomer::BHnodes(char customer[CustSize][CustSize],int lmin[Lev],int
lmax[Lev])
{
   int32 seed = (int32)time(0);  // create seed variable for RNG
   CRandomMersenne rn(seed);     // seed the random number generator

   int i = 0;                 /* counter */
   int TotalN = 0;         /* count of Total # of nodes used */

   int nnMin[Lev];         /* minimum # nodes possible for a level */
   int nnMax[Lev];         /* maximum # nodes possible for a level */
   int nn[Lev];         /* number of nodes for each level */

   /***************************************************************/
   /*  Array - specifies the possible number of nodes */
   /*  per hierarchy level.    */
   /*  Min - Max provide boundary constraints for the hierarchy levels  */
   /***************************************************************/
   // These are the initial boundary constraints
   nnMin[0]=1; nnMax[0]=1;     // Level 1 has only 1 node
   nnMin[1]=2; nnMax[1]=4;     // Levels 2-4 have initial boundary
```

```
   nnMin[2]=3; nnMax[2]=8;     // constraints.
   nnMin[3]=6; nnMax[3]=12;
   // nnMin[4]=; nnMax[4]=;    // Level 5 is based on previous levels

   /*************************************************************/
   /*  Randomize # of nodes per level with boundary constraints  */
   /*************************************************************/
   // number of nodes for level 1 is fixed to 1
   nn[0]=1;
   TotalN += nn[0];       // add first level node to the total
   // determine the number of nodes for levels 2-4
   for( i = 1; i<Lev-1; ++i){
      // random number generator function should be updated
      // for truer/better randomization
      nn[i] = rn.IRandom(nnMin[i],nnMax[i]);  // randomize between boundaries
      TotalN += nn[i];
   }
   // calculate the number of nodes at level 5
   nn[4] = CustSize - TotalN;
/*  // for testing
cout << endl;
for(i=0;i<Lev; ++i){
   cout << "nn[" << i << "]= " << nn[i] << endl;
}
*/
   /*************************************************************/
   /*  Load node #'s for each level 1 through 5  */
   /*************************************************************/
   // node for level 1 is fixed to 1
   lmin[0]=1; lmax[0]=1;

   // calculate the node numbers for levels 2-5
   // based on how many nodes for each level
   for( i=1; i<Lev; ++i){
      lmin[i] = lmax[i-1]+1;
      lmax[i] = (lmin[i] + nn[i] - 1);
   }
/*  // for testing
cout << endl;
for(i=0;i<Lev; ++i){
   cout << "lMin[" << i << "]= " << lmin[i] << "     ";
   cout << "lMax[" << i << "]= " << lmax[i] << endl;
}
system("PAUSE");
*/
} // end BHnodes()

void CCustomer::BHedges(char customer[CustSize][CustSize],int lmin[Lev],int
lmax[Lev])
{
   int32 seed = (int32)time(0)+3;  // create seed variable for RNG
   CRandomMersenne rn(seed);       // seed the random number generator

   int i=0; int k=0;  // counters
   int col=0;         // stores node to link to on level above

   /*************************************************************/
```

```
   /*  Load Edges for Level 1 - 2          */
   /***********************************************************/
   for( i=(lmin[1]-1);i<=(lmax[1]-1); ++i){
      customer[i][0] = '1';
   }

   /***********************************************************/
   /*  Randomize and Load Edges for Level 2 through 5  */
   /***********************************************************/
   for( k =(Lev-1);k>=2; --k){  // start with level 5
      for( i=lmin[k]-1; i<=lmax[k]-1;++i){
         // randomize who reports to whom from lower level to higher level
         // determine the node to connect with in the level above: col
         // k-1 to adjust for the level above
         // lmin[]-1 and lmax[]-1 to adjust for C++ array syntax
         col = rn.IRandom((lmin[k-1]-1),(lmax[k-1]-1));
         // define the edge/link between the two nodes
         customer[i][col] = '1';
      }
   }
} // end BHedges()
/***********************************************************/
/***********  end Generate Hierarchical Network     ***********/
/***********************************************************/


/***********************************************************/
/***********           Developer Network           ***********/
/***********************************************************/
// Constructor
CDeveloper::CDeveloper(char dArray[DevSize][DevSize])
{
   InDeveloper(dArray);  // loads array from file

} // end constructor CDeveloper()

// Input developer matrix from file
void CDeveloper::InDeveloper(char dArray[DevSize][DevSize])
{
   //  parameters:
   //    dArray   - the Array to input
   //    InFile   - input file name
   ifstream InFile("Dev.csv", ios::in);
   int row=0, col =0;         // counters

   if(InFile.fail())
   {
      cout << "Error opening output file." << endl << endl;
      exit(2);
   }

   for(row=0; row<DevSize; ++row){
      for(col=0; col<DevSize; ++col){
         InFile >> *(*(dArray+row)+col);
         InFile.ignore(1);
      }//end for
   }//end for
```

```
   InFile.close();
} // end InDeveloper()

void CDeveloper::scrnArray(char dArray[DevSize][DevSize])
{
   //  parameters:
   //    dArray   - the Array to output to screen
   int row=0; int col=0;   // counters

   for(row=0; row<DevSize; ++row){
      for(col=0; col<DevSize; ++col){
         cout << dArray[row][col];
         if(col<DevSize-1)
            cout  << ',';     // Add comma between numbers
      }//end for
      cout << endl;           // Add New Line after last col in row
   }//end for
   cout << endl << "End of Screen Display." << endl;
} // end scrnArray()

/****************************************************************/
/***************************  main  ***************************/
/****************************************************************/
void viewCust(void);
void viewDev(void);
void viewProj(void);
void makeAxA(void);
void makeAxT(void);
void makeAxK(void);
void makeKxT(void);
/****************************************************************/
int main(int argc, char *argv[])
{
   char ch_select=' ';

do{
   cout << "Make network options are... a: AxA, t:AxT, u:AxK, v:KxT" << endl;
   cout << "Make selection: ";
   cin >> ch_select;

   switch (ch_select)
   {
      case '1':
        viewCust();
        break;
      case '2':
        viewDev();
        break;
      case '3':
        viewProj();
        break;
      case 'a':
        makeAxA();
        break;
      case 't':
        makeAxT();
```

```
        break;
      case 'u':
        makeAxK();
        break;
      case 'v':
        makeKxT();
        break;
      default:
        cout << "Have a nice day. " << endl;
   }
}while(ch_select!='x');
   system("PAUSE");
   return EXIT_SUCCESS;
}
/**************************************************************/
/**************************************************************/

/**************************************************************/
/***************         Build Project         ****************/
/***********       Actor Interaction Network        ***********/
/**************************************************************/
/**************************************************************/

class CBuildProject
{
     public:
        CBuildProject(char cArray[CustSize][CustSize],
                      char dArray[DevSize][DevSize],
                      char pArray[2][ProjSize][ProjSize]);
        void Build(char pArray[2][ProjSize][ProjSize]);
        //void initArray(char pArray);
        void scrnArray(char pArray[2][ProjSize][ProjSize]);
        void ofileArray(char pArray[2][ProjSize][ProjSize]);
        void ifileArray(char pArray[2][ProjSize][ProjSize]);
}; // end class CBuildProject


// CBuildProject constructor
/**************************************************************/
/*  Combine Developer & Customer groups into a single network */
/**************************************************************/
CBuildProject::CBuildProject(char cArray[CustSize][CustSize],
                             char dArray[DevSize][DevSize],
                             char pArray[2][ProjSize][ProjSize])
{
   int row=0; int col=0; int i=0;  // counters

   // initialize the project array
   for(row=0; row<ProjSize; ++row){
      for(col=0; col<ProjSize; ++col){
         if(row==col){
            pArray[i+1][row][col]=
            pArray[i][row][col]= '1'; // load diagonals to 1's
         }else{
            pArray[i+1][row][col]=
            pArray[i][row][col]=  '0'; // other edges to 0's
         }
```

```
      }//end for
   }//end for

//  scrnArray(pArray);
//  system("PAUSE");

   // Developer group inserted into Project network
   i=0;
   for(row = 0; row<DevSize; ++row){
      for(col=0; col<DevSize; ++col){
         pArray[i+1][row][col]=
         pArray[i][row][col]= dArray[row][col];
      }//end for
   }//end for

   // Customer group inserted into Project network
   i=0;
   for(row = 0; row<CustSize; ++row){
      for(col=0; col<CustSize; ++col){
         pArray[i+1][row+DevSize][col+DevSize]=
         pArray[i][row+DevSize][col+DevSize]= cArray[row][col];
      }//end for
   }//end for
} // CBuildProject constructor


/**************************************************************/
/*********     Generate Interaction Actor Network     *********/
/******   Build Low & High Interaction Project Networks   *****/
/**************************************************************/
void CBuildProject::Build(char pArray[2][ProjSize][ProjSize])
{
   int i=0; int j=0; int k=0; int m=0;  // counters
   char dev=' ';
   int tmp[4];
   int32 seed = (int32)time(0);  // create seed variable for RNG
   CRandomMersenne  rnLo(seed), rnHi(seed+42);     // seed the random number
generator
   /***********************************************************/
   /*  Low Interaction  */
   /***********************************************************/
   // Link the two managers - 0: developer mgr, 7: customer mgr
   pArray[0][7][0]=pArray[0][0][7]='1';   // Link the two managers

   for(m=1;m<=2; ++m){        // Create links to Sys Analysts; nodes 2 and 3
      i=0;
      while(i<4){ // i: count # of nodes in customer group for linking
         tmp[i] = rnLo.IRandom(8,34);
         if(i>1){    // skip if this is the first pass
            k=i;     // otherwise, check for a duplicate link
            while(k>1){  // compare current value with all previous values
               if(tmp[i]==tmp[i-1]){  // check for duplicate link
                  --i;                // reset counter in order to select
               } // end if            // another random number for the link
               --k;
            } // end while
         } // end if
```

```
         ++i;
      } // end while

      // load the links between the randomly selected customers
      // and the two 'systems analysts'
      for(j=0; j<4; ++j){           /* Link other group members */
         dev=tmp[j];
         pArray[0][m][dev] = pArray[0][dev][m] = '1'; // create link &
symmetrize
      } // end for
   } // end for
   // end Low interaction network

   /*************************************************************/
   /*  High Interaction  */
   /*************************************************************/
   // Link the two managers - 0: developer mgr, 7: customer mgr
   pArray[1][7][0]=pArray[1][0][7]='1';

   // every customer is randomly linked to a developer
   for(i=DevSize+1;i<ProjSize; ++i){      // i: customer nodes
      dev = rnHi.IRandom(0,DevSize-1); // dev: dev node randomly selected
      pArray[1][i][dev] = pArray[1][dev][i] = '1';
   } // end for
   // end High interaction network

} // end Build()


/****************************************************************/
/*  Output Project Actor Network  */
/****************************************************************/
// Display to Screen
void CBuildProject::scrnArray(char pArray[2][ProjSize][ProjSize])
{
   //  parameters:
   //    pArray   - the Array to output to screen
   int i=0; int row=0; int col=0;   // counters

   for(i=0; i<2; ++i){
      for(row=0; row<ProjSize; ++row){
         for(col=0; col<ProjSize; ++col){
            cout << pArray[i][row][col];
            if(col<ProjSize-1)
               cout  << ',';  // Add comma between numbers
         } //end for
         cout << endl;              // Add New Line after last col in row
      } //end for - rows
      if (i==0){
         cout << endl << "End of Low interaction project network." << endl;
         system("PAUSE");
      }
   } //end for - Low & High interaction
   cout << endl << "End of High interaction project network." << endl;
} // end scrnArray()
```

```
// Output to Files ...
/***************************************************************/
/*  Output the Project Arrays to files */
/***************************************************************/
void CBuildProject::ofileArray(char pArray[2][ProjSize][ProjSize])
{
   //  parameters:
   //    pArray   - the Array to output the file
   //    OutFile  - output file name
   ofstream OutFileLo("AxA_lo.csv", ios::out);
   ofstream OutFileHi("AxA_hi.csv", ios::out);

   int row=0; int col=0;      // counters for loops

   if(OutFileLo.fail()|| OutFileHi.fail())
   {
      cout << "Error opening output file for Project Networks." << endl <<
endl;
      exit(2);
   }

   for(row=0; row<ProjSize; ++row){
      for(col=0; col<ProjSize; ++col){
         OutFileLo << pArray[0][row][col];
         OutFileHi << pArray[1][row][col];
         if(col<ProjSize-1){
            OutFileLo  << ',';      // Add comma between numbers
            OutFileHi  << ',';
         }
      }//end for
      OutFileLo << endl;            // Add New Line after last col in row
      OutFileHi << endl;
   }//end for
   // cout << endl; // extra newline between network arrays
   OutFileLo.close();
   OutFileHi.close();
} // end ofileArray() output array to file

/***************************************************************/
/*  Input a Project Array from two files  */
/***************************************************************/
void CBuildProject::ifileArray(char pArray[2][ProjSize][ProjSize])
{
   //  parameters:
   //    pArray   - the Array to input
   //    InFile   - input file names
   ifstream InFileLo("AxA_lo.csv", ios::in); //
   ifstream InFileHi("AxA_hi.csv", ios::in);

   int row=0, col =0;         // counters

   if(InFileLo.fail() || InFileHi.fail())
   {
      cout << "Error opening input files for Project Networks." << endl <<
endl;
      exit(2);
   }
```

```
   for(row=0; row<ProjSize; ++row){
      for(col=0; col<ProjSize; ++col){
         InFileLo >> *(*(*(pArray+0)+row)+col);
         InFileLo.ignore(1);
         InFileHi >> *(*(*(pArray+1)+row)+col);
         InFileHi.ignore(1);
      }//end for
   }//end for

   InFileLo.close();
   InFileHi.close();
} // end ifileArray()
/**************************************************************/
/**************************************************************/

/**************************************************************/
/***********   (A x T)  Developer - Task Network    ***********/
/**************************************************************/
class CAxT
{
   private:
      ;
   public:
      CAxT(char AxT[ProjSize][TaskSize]);
      void Build(char AxT[ProjSize][TaskSize]);
      void ofileArray(char AxT[ProjSize][TaskSize]);
};

CAxT::CAxT(char AxT[ProjSize][TaskSize])
{
   Build(AxT); // initialize and build AxT network
} // end CAxT constructor

void CAxT::Build(char AxT[ProjSize][TaskSize])
{
   /***********************************************************/
   /*  Initialize Developer - Task (A x T) Array  */
   /*             ProjSize x TaskSize             */
   /***********************************************************/
   int row=0; int col=0;   // counters
   // initialize the AxT array to all 0's
   for(row=0; row<ProjSize; ++row){
      for(col=0; col<TaskSize; ++col){
         AxT[row][col]=  '0';
      }//end for
   }//end for

   /***********************************************************/
   /*  Build Developer - Task (A x T) network  */
   /*        Tasks are only assigned to Developers here  */
   /***********************************************************/
   int i=0;                            // loop counter
   int dev=0;                          // row position for Developer actor
   int32 seed = (int32)time(0);        // create seed variable for RNG
   CRandomMersenne  rnDev(seed+108);   // seed the random number generator
```

```
   // every task is randomly linked to a developer
   for(i=0;i<TaskSize; ++i){  // i: task nodes
      dev = rnDev.IRandom(0,DevSize-1); // dev: dev node randomly selected
      AxT[dev][i] = '1';
   } // end for
} // end build AxT Developer-Task network

/**************************************************************/
/*  Output AxT Array to an output file */
/**************************************************************/
void CAxT::ofileArray(char AxT[ProjSize][TaskSize])
{
   //  parameters:
   //    AxT      - the Array to output the file
   //    OutFile  - output file name
   ofstream OutFile("AxT.csv", ios::out);
   int row=0; int col=0;      // counters for loops

   if(OutFile.fail())
   {
      cout << "Error opening output file." << endl << endl;
      exit(2);
   }

   for(row=0; row<ProjSize; ++row){
      for(col=0; col<TaskSize; ++col){
         OutFile << AxT[row][col];
         if(col<TaskSize-1)
            OutFile  << ',';  // Add comma between numbers
      }//end for
      OutFile << endl;              // Add New Line after last col in row
   }//end for
   // cout << endl; // extra newline between network arrays
   OutFile.close();
} // end ofileArray() output array to file
/**************************************************************/
/**************************************************************/


/**************************************************************/
/*********   (A x K)  Customer - Knowledge Network    *********/
/**************************************************************/
class CAxK
{
   private:
      ;
   public:
      CAxK(char AxK[ProjSize][KnowSize]);
      void Build(char AxK[ProjSize][KnowSize]);
      void ofileArray(char AxK[ProjSize][KnowSize]);
};

CAxK::CAxK(char AxK[ProjSize][KnowSize])
{
   Build(AxK); // initialize and build AxK network
} // end CAxK constructor
```

```
void CAxK::Build(char AxK[ProjSize][KnowSize])
{
   /*********************************************************/
   /*  Initialize Customer - Knowledge (A x K) Array  */
   /*            ProjSize x KnowSize             */
   /*********************************************************/
   int row=0; int col=0;   // counters
   // initialize the AxK array to all 0's
   for(row=0; row<ProjSize; ++row){
      for(col=0; col<KnowSize; ++col){
         AxK[row][col]=  '0';
      }//end for
   }//end for

   /*********************************************************/
   /*  Build Customer - Knowledge (A x K) network  */
   /*       Knowledge Facts are only assigned to Customers here  */
   /*********************************************************/
   int i=0;                            // loop counter
   int cust=0;                          // row position for Developer actor
   int32 seed = (int32)time(0);        // create seed variable for RNG
   CRandomMersenne  rnCust(seed+48);   // seed the random number generator

   // every knowledge fact is randomly linked to a customer
   for(i=0;i<KnowSize; ++i){  // i: task nodes
      cust = rnCust.IRandom(DevSize, ProjSize-1); // cust: cust node randomly
selected
      AxK[cust][i] = '1';
   } // end for
} // end build AxK Customer-Knowledge Fact network

/*************************************************************/
/*  Output AxK Array to an output file */
/*************************************************************/
void CAxK::ofileArray(char AxK[ProjSize][KnowSize])
{
   //  parameters:
   //    AxK      - the Array to output the file
   //    OutFile  - output file name
   ofstream OutFile("AxK.csv", ios::out);
   int row=0; int col=0;      // counters for loops

   if(OutFile.fail())
   {
      cout << "Error opening output file." << endl << endl;
      exit(2);
   }

   for(row=0; row<ProjSize; ++row){
      for(col=0; col<KnowSize; ++col){
         OutFile << AxK[row][col];
         if(col<KnowSize-1)
            OutFile  << ',';  // Add comma between numbers
      }//end for
      OutFile << endl;              // Add New Line after last col in row
   }//end for
   // cout << endl; // extra newline between network arrays
```

```
   OutFile.close();
} // end ofileArray() output array to file
/***************************************************************/
/***************************************************************/



/***************************************************************/
/*********   (K x T)  Knowledge - Task Network    *********/
/***************************************************************/
class CKxT
{
   private:
      ;
   public:
      CKxT(char KxT[KnowSize][TaskSize]);
      void Build(char KxT[KnowSize][TaskSize]);
      void ofileArray(char KxT[KnowSize][TaskSize]);
};

CKxT::CKxT(char KxT[KnowSize][TaskSize])
{
   Build(KxT); // initialize and build KxT network
} // end CKxT constructor

void CKxT::Build(char KxT[KnowSize][TaskSize])
{
   /************************************************************/
   /*  Initialize Knowledge - Task (K x T) Array  */
   /*            KnowSize x TaskSize            */
   /************************************************************/
   int row=0; int col=0;   // counters
   // initialize the KxT array to all 0's
   for(row=0; row<KnowSize; ++row){
      for(col=0; col<TaskSize; ++col){
         KxT[row][col]=  '0';
      }//end for
   }//end for

   /************************************************************/
   /*  Build Knowledge - Task (K x T) network  */
   /*  Knowledge Facts are assigned to Tasks   */
   /*  Every Task requires at least one Knowledge Fact  */
   /************************************************************/
   int i=0;                              // loop counter
   int task=0;                            // row position for Developer actor
   int32 seed = (int32)time(0);         // create seed variable for RNG
   CRandomMersenne  rnTask(seed+24);    // seed the random number generator

   // every task is assigned a single knowledge fact
   for(i=0;i<TaskSize;++i){           // in test 0 to 16 = 1 - 17
      KxT[i][i] = '1';
   }

   // knowledge facts are then randomly linked to the tasks
   for(i=0;i<KnowSize; ++i){  // i: task nodes; 17 to 33 = 18 - 34
```

```
      task = rnTask.IRandom(0, TaskSize-1); // task: task node randomly
selected
      KxT[i][task] = '1';
   } // end for
} // end build KxT Knowledge Fact - Task network

/**************************************************************/
/*  Output KxT Array to an output file */
/**************************************************************/
void CKxT::ofileArray(char KxT[KnowSize][TaskSize])
{
   //  parameters:
   //    KxT      - the Array to output the file
   //    OutFile  - output file name
   ofstream OutFile("KxT.csv", ios::out);
   int row=0; int col=0;      // counters for loops

   if(OutFile.fail())
   {
      cout << "Error opening output file." << endl << endl;
      exit(2);
   }

   for(row=0; row<KnowSize; ++row){
      for(col=0; col<TaskSize; ++col){
         OutFile << KxT[row][col];
         if(col<TaskSize-1)
            OutFile  << ',';  // Add comma between numbers
      }//end for
      OutFile << endl;              // Add New Line after last col in row
   }//end for
   // cout << endl; // extra newline between network arrays
   OutFile.close();
} // end ofileArray() output array to file
/**************************************************************/
/**************************************************************/






/**************************************************************/
/*  Test functions called by main()                           */
/**************************************************************/
void viewCust(void)
{
   char customer[CustSize][CustSize];
   CCustomer aCust(customer);    // initializes new network
   aCust.ifileArray(customer);  // reads customer network from file
   aCust.scrnArray(customer);    // display to screen
   cout << endl;
   return;
}
void viewDev(void)
```

```
{
   char developer[DevSize][DevSize];
   CDeveloper aDev(developer);  // reads network from file
   aDev.scrnArray(developer);   // display to screen
   cout << endl;
   return;
}

void viewProj(void)
{
   char project[2][ProjSize][ProjSize];

   char developer[DevSize][DevSize];
   CDeveloper aDev(developer);  // reads developer network from file
   char customer[CustSize][CustSize];
   CCustomer aCust(customer);   // creates new network
   aCust.ifileArray(customer);  // reads customer network from file

   // create project object
   CBuildProject aProject(customer, developer, project); // combine networks
   aProject.Build(project);          // build project inter-network links
   aProject.scrnArray(project);      // display to screen
   aProject.ofileArray(project);     // output Hi & Lo interaction networks

   cout << endl;
   return;
}

void makeAxT(void)
{
   char AxT[ProjSize][TaskSize];   // define array to store A x T network
   CAxT tmpAxT(AxT);               // initialize and build
   tmpAxT.ofileArray(AxT);         // output A x T network
   cout << "A x T network generated and output to AxT.cvs" << endl;
   return;
}

void makeAxK(void)
{
   char AxK[ProjSize][KnowSize];   // define array to store A x K network
   CAxK tmpAxK(AxK);               // initialize and build
   tmpAxK.ofileArray(AxK);         // output A x K network
   cout << "A x K network generated and output to AxK.cvs" << endl;
   return;
}

void makeKxT(void)
{
   char KxT[KnowSize][TaskSize];   // define array to store K x T network
   CKxT tmpKxT(KxT);               // initialize and build
   tmpKxT.ofileArray(KxT);         // output K x T network
   cout << "K x T network generated and output to KxT.cvs" << endl;
   return;
}

// Make the AxA_hi and AxA_lo agent networks
void makeAxA(void)
```

```
{
   char project[2][ProjSize][ProjSize];       // initialize project array
space

   char developer[DevSize][DevSize];          // initialize developer array
space
   CDeveloper aDev(developer);                // reads developer network from
file

   char customer[CustSize][CustSize];         // initialize customer array
space
   CCustomer aCust(customer);                 // initialize customer array to
0's
   aCust.BuildHierarchy(customer);            // build customer hierarchy
network
   aCust.ofileArray(customer);                // output customer network to
file

   // create project object
   // combine developer and customer networks into a single project network
   CBuildProject aProject(customer, developer, project);
   aProject.Build(project);          // build the project inter-network links
   aProject.scrnArray(project);      // display to screen
   aProject.ofileArray(project);     // output Hi & Lo interaction networks

   cout << endl;
   return;
} // end MakeAxA()
```

SAMPLE CODE OF COMBINED META-NETWORK IN DYNETML FORMAT (ISD_H.XML)


```
<?xml version="1.0" standalone="yes"?>

<DynamicNetwork>
  <MetaNetwork id="Meta Network">
    <documents></documents>
    <nodes>
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        <node id="3"></node>
        <node id="4"></node>
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        <node id="8"></node>
        <node id="9"></node>
        <node id="10"></node>
        <node id="11"></node>
        <node id="12"></node>
```

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</nodeclass>

```
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        <node id="9"></node>
        <node id="10"></node>
        <node id="11"></node>
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        <node id="17"></node>
      </nodeclass>
    </nodes>
    <networks>
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x task">
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        <link source="15" target="17" type="double" value="1.0"></link>
        <link source="16" target="17" type="double" value="1.0"></link>
      </network>
```

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SAMPLE CODE OF META-NETWORK WITH CULTURAL VALUES INCLUDED (ISD_HS.XML)


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</network>
</networks>
</MetaNetwork>
</DynamicNetwork>

Appendix E -- Phase II Code, Notes and Examples

CONSTRUCT CODE USED TO RUN SIMULATION (CONSTRUCT_HS.XML)

```
<?xml version="1.0" encoding="UTF-8"?>
<construct>
<!--  ********************  CONSTRUCT VARS  ********************  -->
	<construct_vars>
		<var name="time_count" value="100"/>	<!--  base on approx time to
complete for (Low x Diff)? -->
		<var name="run_count" value="1"/> <!--  TBD -  power of experiment?  -->
		<var name="agent_count" value="35"/>	<!--   Developers = 7; Customers =
28 -->
		<var name="fact_count" value="112"/>	<!--  General facts known by
Customers -->
		<var name="factgroup_count" value="1"/>
		<var name="agentgroup_count" value="2"/>  <!--  group 1: Developers, group 2:
Customers  -->
		<var name="task_count" value="17"/>
		<var name="energy_task_count" value="0"/>
	</construct_vars>

<!--  ********************  SIMULATION PARAMETERS  ********************  -->
	<simulation_parameters>
		<parameters>
			<param name="dynamic_environment" value="false"/>	<!--    -->
			<param name="default_agent_type" value="human"/>
			<param name="forgetting" value="false" />		<!--  -->


			<param name="use_mail" value="false" />		<!--  -->
			<param name="thread_count" value="1" />		<!--  -->
			<param name="belief_model" value="disable" />		<!--  -->
		</parameters>
	</simulation_parameters>

<!--  ********************  AGENT TYPES  ********************  -->
	<agent_types>
		<agent_type name="human">
			<parameters>
				<param name="canSendCommunication" value="true"/>
				<param name="canReceiveCommunication" value="true"/>
				<param name="canSendKnowledge" value="true"/>
				<param name="canReceiveKnowledge" value="true"/>
				<param name="canSendBeliefs" value="true"/>
				<param name="canReceiveBeliefs" value="true"/>
				<param name="canSendBeliefsTM" value="true"/>
```

```
                    <param name="canReceiveBeliefsTM" value="true"/>
                    <param name="canSendKnowledgeTM" value="true"/>
                    <param name="canReceiveKnowledgeTM" value="true"/>
                    <param name="canSendReferral" value="true"/>
                    <param name="canReceiveReferral" value="true"/>
                </parameters>
            </agent_type>
        </agent_types>

<!-- ******************************************************************  -->
<!-- *******************  SIMULATION SECTION  *******************  -->
            <!-- What weighting default values are generally used for these parameters?  -->
            <!-- Weights will remain the same for all runs; therefore no foreseeable effect  --
>
            <!-- *** PROXIMITY TYPES  ***  -->
            <!-- CV1 and CV2 included as sociodemographic info  -->
        <simulation
            runs="run_count"
            time="time_count"
            terminate="time"
            forgetting="false"
            transactiveMemory="true"

            sharedWork="0.0"
            physical="0.20"
            social="0.50"
            sociodemographic="0.30"

            communicationWeightForBelief="0.2"
            communicationWeightForBeliefTM="0.1"
            communicationWeightForFact="0.5"
            communicationWeightForKnowledgeTM="0.2">
<!-- test effect of social="0.2" and sociodemographic="0.8" -->


<!-- *******************  AGENTS  *****************  -->
<!-- *******************  FACTS  *******************  -->
<!-- *******************  TASKS  *******************  -->
      <energytasks count=" energy_task_count " />
      <binarytasks count="task_count" />

<!-- *******************  Load 'nodes' from DYNETML file  *******************  -->
<!-- *******************  Agents, Facts, & Tasks  *******************  -->

        <agents dynetml_type="_auto_build_network_" src="isd_HS.xml" type="dynetml"/>
        <facts dynetml_type="_auto_build_network_" src="isd_HS.xml" type="dynetml"/>
```

```
          <binarytasks dynetml_type="_auto_build_network_" src="isd_HS.xml"
type="dynetml"/>


<!--  ********************  AGENT GROUPS  ********************  -->
      <agentGroups count="agentgroup_count">
            <group id="0" name="Developers" />
            <group id="1" name="Customers" />
      </agentGroups>


<!--  ********************  FACT GROUPS  ********************  -->
<!-- May use later for alternative method of representation  -->
     <!-- General Facts known by Customers -->
     <!-- Shared Cultural Values -->

<!--  ********************  BELIEFS  ********************  -->
 <!--Not used in this simulation. Current design views Belief in terms of 'shared values'
      and relies on homophily of sociodemographic attribute that is a proxy for the 'shared values'
-->

<!--  ********************  INTERACTIONS  ********************  -->
      <!--  Interaction strategy for the simulation. Syntax? Needed and/or operating in this
version?  -->
      <!--  % breakdown for (1) homophily=0.65, (2) deliberate search=0.35, (3) co-worker
preference=0.0  -->
      <!--  Total of three should be 100%  -->
      <interactions />

<!--  ********************  ISOLATIONS  ********************  -->
      <isolations />


<!--  ****************************************************************  -->
<!--  ********************  NETWORKS  ********************  -->
<!--  ****************************************************************  -->
<networks>
             <!--  "influencialness" and "beInfluenced" randomized  -->
             <!--  <influence> … </influence>  -->
          <influence>
                  <beInfluenced type="randomuniform" min="0" max="1"/>
                  <influencialness type="randomuniform" min="0" max="1"/>
          </influence>


            <!--  ************************************************  -->
```

```
<!--  ******************  AGENT only  ****************  -->
 <!--  Complete learning = 1  -->
 <agent_learning_rate type="randomuniform" min="1.0" max="1.0"/>

 <!--  No forgetting = 0  -->
 <agent_forgetting_rate type="randomuniform" min="0.0" max="0.0"/>

 <!--  No learning by doing = 0  -->
 <agent_learning_by_doing_rate type="randomuniform" min="0.0" max="0.0"/>

 <!--  Misrepresentation rate; used to simulate agents lying; No misrepresentation = 0  -
->

 <agent_misrepresentation_probability type="constant" value="0"/>

 <!--  Agents consider all possible knowledge = 1; i.e., set to one when not using it  -->
 <!-- selective_attention_effect rows are agents and column is always 0 -->
 <selective_attention_effect type="constant" value="1"/>


<!--  ***********************************************  -->
<!--  ***************  AGENT interaction  ***************  -->

  <!--  Interaction sphere to be based on sociodemographic values.   -->
  <!--  In this simulation the values represent "shared values"  -->
  <!--  What is the simplest and best way to do this?  -->
  <!--  Will auto_build automatically use sociodemographic agent attributes for   -->
  <!--   the interaction sphere? -->
                    <!--   -->
  <proximity>

        <physical name="agent x agent" src="isd_HS.xml" type="dynetml"/>

        <sociodemographic type="scale" min="0.1" max="1.0">
           <network type="relativesimilarity" inputtype="integer">
           <network type="agentattributes" pattern="*" />
           </network>
        </sociodemographic>

        <social name="agent x agent" src="isd_HS.xml" type="dynetml"/>

  </proximity>

  <!--  potential interaction partners are defined by interaction_sphere; hard limit  -->
  <interaction_sphere type="constant" value="1.0"/>
```

```
<!-- ************************************************* -->
<!-- ******************** FACTS ******************** -->
<!-- *************** more KNOWLEDGE ************** -->
<!-- Initial knowledge known by agents -->
<knowledge name="agent x knowledge" src="isd_HS.xml" type="dynetml"/>

<!-- knowledge priority; different weights may be given to facts for different agents -->
<!-- Not used in this simulation -->
<knowledge_priority type="constant" value="1.0"/>

<!-- knowledge interaction weight; weight an agent places on a fact -->
<!-- in choosing an interaction partner using similarity and expertise -->
<!-- Not used in this simulation -->
<interaction_knowledge_weight type="constant" value="1.0"/>

<!-- knowledge transmission weight; not used in this simulation -->
<transmission_knowledge_weight type="constant" value="1.0"/>

<!-- learnable knowledge by agents; may be used to limit the amount of knowledge; not
used in this simulation -->
<learnable_knowledge type="constant" value="1"/>



<!-- TM -->
<transactivememory type="randombinary" mean="1.0" />


<!-- ************************************************* -->
<!-- ******************** TASKS ******************** -->
<!-- network_name instead of name -->
<binarytask>
<!-- pt 1: K x T -->
<!-- specifies the knowledge Fact(s) required to accomplish a given Task -->
<requirement name="knowledge x task" src="isd_HS.xml" type="dynetml"/>

<!-- pt 2: K x K' -->
<!-- Truth value of the knowledge Fact that is required for a given Task -->
<truth type="randombinary" mean="0.5" />

<!-- pt 3: A x T -->
<!-- specifies which Agents are assigned which Tasks -->
<!-- Want to load A x T from file, but constuct bombs with the following -->
<!-- < assignment name="_auto_build_network_" src="isd.xml"
type="dynetml"/> -->
<assignment name="agent x task" src="isd_HS.xml" type="dynetml"/>
```

```
            </binarytask>


            <!--  ***********************************************  -->
            <!--  *****************  BELIEF related  ****************  -->
        <!--  ************  Beliefs x Facts matrix definition and weightings  **************  --
>
        <!--  Beliefs x Facts matrix is not used in this simulation  -->


            <!--  ***********************************************  -->
            <!--  *****************  TIME Dependent  ***************  -->
                  <!--  not used for current simulation  -->

            <!--  Sets the the time periods that agents are active  -->
            <!--  In this ex. it is activity is randomly assigned; mean=1 always active  -->
            <!--  Test what happens with mean = .90 later.  -->
            <!--  if 1 agent is active, if 0 the agent is inactive  -->
            <agent_active_timeperiods mean="1.0" type="randombinary"/>

            <!--  No turnover = 0; i.e. set this to zero when not using it  -->
<!--
            <turnover type="constant" value="0"/>
 -->
            <!--  *****  Proximity weights for physical, social, and sociodemo.   ***** -->
            <!-- agent x timperiod --> <!-- set this to zero when not using it -->
            <physical_proximity_weight type="constant" value="0.2"/>

            <!-- agent x timperiod -->  <!-- set this to zero when not using it -->
            <social_proximity_weight type="constant" value="0.5"/>

            <!-- agent x timperiod -->  <!-- set this to zero when not using it -->
            <sociodemographic_proximity_weight type="constant" value="0.3"/>


            <!--  Knowledge similarity  -->
            <!-- agent x timeperiod matrix that sets the relative similarity weight for an agent at a
timeperiod -->
                  <knowledge_relative_similarity_weight type="constant" value=".65"/>

            <!--  Knowledge expertise  -->
            <!-- agent x timeperiod matrix that sets the relative expertise weight for an agent at a
timeperiod -->
                  <knowledge_relative_expertise_weight type="constant" value=".35"/>

   <!--  *******************  MEMBERSHIP  *******************  -->
```

```
<membership>
    <!--  *******************  Agents in Agent_Groups  *******************  -->
      <!--  Initially not used in this simulation; however it is available for future use  -->
      <!-- x==agent count y==agentGroup count -->
      <agent type="data" x="agent_count" y="agentgroup_count">
          <!-- x==agent index y==agent group index -->
        <!-- Developers -->
          <data x="0" y="0" value="true" />
          <data x="1" y="0" value="true" />
          <data x="2" y="0" value="true" />
          <data x="3" y="0" value="true" />
          <data x="4" y="0" value="true" />
          <data x="5" y="0" value="true" />
          <data x="6" y="0" value="true" />
        <!-- Customers -->
          <data x="7" y="1" value="true" />
          <data x="8" y="1" value="true" />
          <data x="9" y="1" value="true" />
          <data x="10" y="1" value="true" />
          <data x="11" y="1" value="true" />
          <data x="12" y="1" value="true" />
          <data x="13" y="1" value="true" />
          <data x="14" y="1" value="true" />
          <data x="15" y="1" value="true" />
          <data x="16" y="1" value="true" />
          <data x="17" y="1" value="true" />
          <data x="18" y="1" value="true" />
          <data x="19" y="1" value="true" />
          <data x="20" y="1" value="true" />
          <data x="21" y="1" value="true" />
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          <data x="23" y="1" value="true" />
          <data x="24" y="1" value="true" />
          <data x="25" y="1" value="true" />
          <data x="26" y="1" value="true" />
          <data x="27" y="1" value="true" />
          <data x="28" y="1" value="true" />
          <data x="29" y="1" value="true" />
          <data x="30" y="1" value="true" />
          <data x="31" y="1" value="true" />
          <data x="32" y="1" value="true" />
          <data x="33" y="1" value="true" />
          <data x="34" y="1" value="true" />
      </agent>

      <!--  *******************  Facts in Fact_Groups  *******************  -->
```

```
            <!-- x == fact count y == fact group count-->
             <!-- List members of different fact groups here -->
            <!--  Not used in this simulation  -->
        </membership>

    <binarytask_dependency type="constant" value="0"/>

      </networks>
    </simulation>

<!--  ****************************************************************  -->
<!--  *******************  OUTPUT  *******************  -->
<!--  ****************************************************************  -->
    <operations>
        <!-- include all Performance based measures for output  -->

        <!--  A x K  -- knowledge matrix  ALL  -->
        <operation name="ReadKnowledgeMatrix">
           <parameters>
                <param name="output_filename" value="isd_HS/AxK_All.csv"/>
                <param name="output_format" value="csv"/>
                <param name="run" value="all"/>
                <param name="time" value="all"/>
           </parameters>
        </operation>

        <!--  A x K  -- knowledge matrix  LAST  -->
        <operation name="ReadKnowledgeMatrix">
           <parameters>
                <param name="output_filename" value="isd_HS/AxK_Last.csv"/>
                <param name="output_format" value="csv"/>
                <param name="run" value="all"/>
                <param name="time" value="last"/>
           </parameters>
        </operation>

        <!--  T x K -- task requirement matrix  LAST  -->
        <operation name="ReadTaskRequirementMatrix">
           <parameters>
                <param name="output_filename" value="isd_HS/TxK_Last.csv"/>
                <param name="output_format" value="csv"/>
                <param name="run" value="all"/>
                <param name="time" value="last"/>
           </parameters>
        </operation>
```

```
<!--  A x T -- assignment matrix   LAST  -->
<operation name="ReadTaskAssignmentMatrix">
   <parameters>
         <param name="output_filename" value="isd_HS/AxT_Last.csv"/>
         <param name="output_format" value="csv"/>
         <param name="run" value="all"/>
         <param name="time" value="last"/>
   </parameters>
</operation>

<!--  TaskCompletionSpeed  LAST  -->
<operation name="TaskCompletionSpeed">
   <parameters>
         <param name="output_filename" value="isd_HS/TaskCompSpdend.csv"/>
         <param name="output_format" value="csv"/>
         <param name="run" value="all"/>
         <param name="time" value="last"/>
   </parameters>
</operation>

<!-- Task Completion  LAST  -->
<operation name="ReadTaskCompletion">
   <parameters>
         <param name="output_filename" value="isd_HS/TaskCompletion.csv"/>
         <param name="output_format" value="csv"/>
         <param name="run" value="all"/>
         <param name="time" value="last"/>
   </parameters>
</operation>

<!--  Task Accuracy Matrix   ALL  -->
<operation name="ReadBinaryTaskAccuracy">
   <parameters>
         <param name="output_filename" value="isd_HS/TaskAccuracy.csv"/>
         <param name="output_format" value="csv"/>
         <param name="no_empty_lines" value="true"/>
         <param name="run" value="all"/>
         <param name="time" value="all"/>
   </parameters>
</operation>

<!-- InteractionMatrix - shows who talked to who  ALL  -->
<operation name="ReadInteractionMatrix">
   <parameters>
         <param name="output_filename" value="isd_HS/InteractionMatrix.csv"/>
         <param name="output_format" value="csv"/>
```

```
                <param name="run" value="all"/>
                <param name="time" value="all"/>
            </parameters>
        </operation>

        <!-- InteractionMatrix - shows who talked to who  ALL  -->
        <operation name="ReadProbInteractionMatrix">
            <parameters>
                <param name="output_filename" value="isd_HS/Prob_InteractionMatrix.csv"/>
                <param name="output_format" value="csv"/>
                <param name="run" value="all"/>
                <param name="time" value="all"/>
            </parameters>
        </operation>

    </operations>
</construct>
```

CONSTRUCT COMMAND LINE SYNTAX & MS-DOS BATCH FILES

It is often the case that a researcher would like **to use the same set of random numbers within a simulation across several replications while modifying the input**. This is possible by specifying the random seed at the beginning of the simulation. Here is how:

```
Construct.exe -seed=10 input_file.xml
```

Run xA – seed number constant for all 40 runs
Run xB – seed number constant for dataset groups of 4, changing for each dataset

jmpRun.bat (move to the Simulation Run directory)

```
D:
cd My Documents\Simulation-2\Experimental Runs\Run-1
```

cpSet.bat (copy the runSet.bat file to the dataXX directories)

rmSet.bat (delete the runSet.bat files from the dataXX directories)

runSet.bat (run a 2x2 dataset)

```
construct -seed=108 construct_HD.xml > isd_HD\log_HD.txt
construct -seed=108 construct_HS.xml > isd_HS\log_HS.txt
construct -seed=108 construct_LD.xml > isd_LD\log_LD.txt
construct -seed=108 construct_LS.xml > isd_LS\log_LS.txt
```

runSet10.bat (run all 10 2x2 datasets)

```
cd data01
```

```
  call runSet.bat
  cd ..
etc.
```

Appendix F -- Phase III Code and Algorithm

PROJECT METRICS: PERCENT COMPLETE CODE (PERCENTCOMPLETE.CPP)

```
/**************************************************************/
/**************************************************************/
/* Pierce Hopkins                              v1  MAR 2009  */
/*                                                           */
/* PercentComplete.cpp                                       */
/* Calculate 'current direct completion potential percentage  */
/* for the project based on based on the average of the task  */
/* percentage where: PercentTaskComplete =                   */
/*          = (knowledge possessed / total knowledge needed) */
/*                                                           */
/*  Update: option to process AxK networks         APR 2009  */
/*  for every period in a simulation run                     */
/*                                                           */
/**************************************************************/
/**************************************************************/

// GIVEN:
// Read Project arrays
// - TxK        char KxT[KnowSize][TaskSize]
// - AxT        char AxT[ProjSize][TaskSize]
// - AxK        char AxK[ProjSize][KnowSize]
//
// Initialize
// - char or int ?  KnowledgeNeededTracking[KnowSize]
// - int TotalKnowledgeNeeded
//
// - PercentTaskComplete[TaskSize] to store percent knowledge possessed by
// agents assigned to complete a given task. It is calculated as:
// PercentTaskComplete = (knowledge possessed / total knowledge needed)
// (double) real number array
//
// Output:
// - double PercentProjectComplete =
avgProjectTaskComplete(PercentTaskComplete[])
//
#include <cstdlib>
#include <iostream>
#include <fstream>
#include <ctime>

using namespace std;

const int CustSize=28;    // 28 Customer agents
const int DevSize=7;      //  7 Developer agents
const int ProjSize = 35;  // 35 = CustSize+DevSize;
const int TaskSize = 17;  // 17 Tasks
const int KnowSize = 112; // 112 knowledge facts
const int RunPeriods = 100;  // the number of time periods in a simulation
run

// NETWORK CLASSES - CKxT, CAxT, and CAxK
/**************************************************************/
```

```
/*********   (K x T)  Knowledge - Task Network    *********/
/***********************************************************/
class CKxT
{
   private:
      ;
   public:
      CKxT(char KxT[KnowSize][TaskSize]);
      void ifileArray(char cArray[KnowSize][TaskSize]);
      void scrnArray(char cArray[KnowSize][TaskSize]);
      // void ofileArray(char KxT[KnowSize][TaskSize]);
};

CKxT::CKxT(char KxT[KnowSize][TaskSize])
{
   /********************************************************/
   /*  Initialize Knowledge - Task (K x T) Array  */
   /*             KnowSize x TaskSize             */
   /********************************************************/
   int row=0; int col=0;   // counters
   // initialize the KxT array to all 0's
   for(row=0; row<KnowSize; ++row){
      for(col=0; col<TaskSize; ++col){
         KxT[row][col]=  '0';
      }//end for
   }//end for
} // end CKxT constructor

/***********************************************************/
/*  Input an Array from a file  */
/***********************************************************/
void CKxT::ifileArray(char cArray[KnowSize][TaskSize])
{
   //  parameters:
   //    cArray   - the Array to input
   //    InFile   - input file name
   ifstream InFile("KxT.csv", ios::in); // input from file
   int row=0, col =0;         // counters

   if(InFile.fail())
   {
      cout << "Error opening input file." << endl << endl;
      exit(2);
   }

   for(row=0; row<KnowSize; ++row){
      for(col=0; col<TaskSize; ++col){
         InFile >> cArray[row][col];
         InFile.ignore(1);
      }//end for
   }//end for

   InFile.close();
} // end ifileArray()

/***********************************************************/
/*  Output an Array to the screen  */
```

```
/************************************************************/
void CKxT::scrnArray(char cArray[KnowSize][TaskSize])
{
   //  parameters:
   //    cArray   - the Array to output to screen
   int row=0; int col=0;

   cout << "KxT Network" << endl;
   for(row=0; row<KnowSize; ++row){
      for(col=0; col<TaskSize; ++col){
         cout << cArray[row][col];
         if(col<TaskSize-1)
            cout  << ',';     // Add comma between numbers
      }//end for
      cout << endl;           // Add New Line after last col in row
   }//end for
   cout << endl << "End of Screen Display." << endl;
} // end scrnArray() output array to screen


/************************************************************/
/***********   (A x T)  Developer - Task Network    ***********/
/************************************************************/
class CAxT
{
   private:
      ;
   public:
      CAxT(char AxT[ProjSize][TaskSize]);
      void ifileArray(char cArray[KnowSize][TaskSize]);
      void scrnArray(char cArray[KnowSize][TaskSize]);
      // void ofileArray(char AxT[ProjSize][TaskSize]);
};

CAxT::CAxT(char AxT[ProjSize][TaskSize])
{
   /*********************************************************/
   /*  Initialize Developer - Task (A x T) Array  */
   /*              ProjSize x TaskSize             */
   /*********************************************************/
   int row=0; int col=0;   // counters
   // initialize the AxT array to all 0's
   for(row=0; row<ProjSize; ++row){
      for(col=0; col<TaskSize; ++col){
         AxT[row][col]=  '0';
      }//end for
   }//end for
} // end CAxT constructor

/************************************************************/
/*  Input an Array from a file  */
/************************************************************/
void CAxT::ifileArray(char cArray[ProjSize][TaskSize])
{
   //  parameters:
   //    cArray   - the Array to input
   //    InFile   - input file name
```

```
   ifstream InFile("AxT.csv", ios::in); // input from file
   int row=0, col =0;         // counters

   if(InFile.fail())
   {
      cout << "Error opening input file." << endl << endl;
      exit(2);
   }

   for(row=0; row<ProjSize; ++row){
      for(col=0; col<TaskSize; ++col){
         InFile >> cArray[row][col];
         InFile.ignore(1);
      }//end for
   }//end for

   InFile.close();
} // end ifileArray()

/***************************************************************/
/*  Output an Array to the screen  */
/***************************************************************/
void CAxT::scrnArray(char cArray[ProjSize][TaskSize])
{
   //  parameters:
   //    cArray   - the Array to output to screen
   int row=0; int col=0;

   cout << "AxT Network" << endl;
   for(row=0; row<ProjSize; ++row){
      for(col=0; col<TaskSize; ++col){
         cout << cArray[row][col];
         if(col<TaskSize-1)
            cout  << ',';     // Add comma between numbers
      }//end for
      cout << endl;           // Add New Line after last col in row
   }//end for
   cout << endl << "End of Screen Display." << endl;
} // end scrnArray() output array to screen



/***************************************************************/
/*********   (A x K)  Agent - Knowledge Network       *********/
/***************************************************************/
class CAxK
{
   private:
      ;
   public:
      CAxK(char AxK[ProjSize][KnowSize]);
      void ifileArray(char cArray[ProjSize][KnowSize]);
      void scrnArray(char cArray[ProjSize][KnowSize]);
      void ofileArray(char AxK[ProjSize][KnowSize]);
};

CAxK::CAxK(char AxK[ProjSize][KnowSize])
```

```
{
   /**********************************************************/
   /*  Initialize Agent - Knowledge (A x K) Array  */
   /*             ProjSize x KnowSize             */
   /**********************************************************/
   int row=0; int col=0;   // counters
   // initialize the AxK array to all 0's
   for(row=0; row<ProjSize; ++row){
      for(col=0; col<KnowSize; ++col){
         AxK[row][col]=  '0';
      }//end for
   }//end for
} // end CAxK constructor

/*************************************************************/
/*  Input an Array from a file  */
/*************************************************************/
void CAxK::ifileArray(char cArray[ProjSize][KnowSize])
{
   //  parameters:
   //    cArray   - the Array to input
   //    InFile   - input file name
   ifstream InFile("AxK_Last.csv", ios::in); // input from file
   int row=0, col =0;         // counters

   if(InFile.fail())
   {
      cout << "Error opening input file." << endl << endl;
      exit(2);
   }

   for(row=0; row<ProjSize; ++row){
      for(col=0; col<KnowSize; ++col){
         InFile >> cArray[row][col];
         InFile.ignore(1);
      }//end for
   }//end for

   InFile.close();
} // end ifileArray()

/*************************************************************/
/*  Output an Array to the screen  */
/*************************************************************/
void CAxK::scrnArray(char cArray[ProjSize][KnowSize])
{
   //  parameters:
   //    cArray   - the Array to output to screen
   int row=0; int col=0;

   cout << "AxK Network" << endl;
   for(row=0; row<ProjSize; ++row){
      for(col=0; col<KnowSize; ++col){
         cout << cArray[row][col];
         if(col<KnowSize-1)
            cout  << ',';     // Add comma between numbers
      }//end for
```

```
      cout << endl;           // Add New Line after last col in row
   }//end for
   cout << endl << "End of Screen Display." << endl;
} // end scrnArray() output array to screen

/***************************************************************/
/*  Output AxK Array to an output file */
/***************************************************************/
void CAxK::ofileArray(char AxK[ProjSize][KnowSize])
{
   //  parameters:
   //    AxK      - the Array to output the file
   //    OutFile  - output file name
   ofstream OutFile("AxK_test.csv", ios::app);
   int row=0; int col=0;      // counters for loops

   if(OutFile.fail())
   {
      cout << "Error opening output file." << endl << endl;
      exit(2);
   }

   for(row=0; row<ProjSize; ++row){
      for(col=0; col<KnowSize; ++col){
         OutFile << AxK[row][col];
         if(col<KnowSize-1)
            OutFile  << ',';  // Add comma between numbers
      }//end for
      OutFile << endl;              // Add New Line after last col in row
   }//end for
   OutFile << endl; // extra newline between network arrays
   OutFile.close();
} // end ofileArray() output array to file
/***************************************************************/
/***************************************************************/

/***************************************************************/
/***************************************************************/
/***************************************************************/

/***************************************************************/
/********   (A x K)  Agent - Load ALL Knowledge Networks  *****/
/***************************************************************/
class CAxK_All
{
   private:
      ;
   public:
      CAxK_All(char AxK[RunPeriods][ProjSize][KnowSize]);
      void ifileArray(char cArray[RunPeriods][ProjSize][KnowSize]);
      void scrnArray(char cArray[RunPeriods][ProjSize][KnowSize]);
      void ioTest(char cArray[RunPeriods][ProjSize][KnowSize]);
      // void ofileArray(char AxK[RunPeriods][ProjSize][KnowSize]);
};

CAxK_All::CAxK_All(char AxK[RunPeriods][ProjSize][KnowSize])
{
```

```
   /*********************************************************/
   /*  Initialize Agent - Knowledge (A x K) Array  */
   /*           RunPeriods x ProjSize x KnowSize             */
   /*********************************************************/
   int row=0; int col=0; int n=0;  // counters

   // initialize the AxK array to all 0's
   for(n=0; n<RunPeriods; ++n){
      for(row=0; row<ProjSize; ++row){
         for(col=0; col<KnowSize; ++col){
            AxK[n][row][col]=  '0';
         }//end for columns
      }//end for rows
   } // end for run periods
} // end CAxK constructor

/************************************************************/
/*  Input an Array from a file  */
/************************************************************/
void CAxK_All::ifileArray(char cArray[RunPeriods][ProjSize][KnowSize])
{
   //  parameters:
   //    cArray   - the Array to input
   //    InFile   - input file name
   ifstream InFile("AxK_All.csv", ios::in); // input from file
   int row=0, col =0, n=0;          // counters

   if(InFile.fail())
   {
      cout << "Error opening input file." << endl << endl;
      exit(2);
   }

   for(n=0; n<RunPeriods; ++n){
      for(row=0; row<ProjSize; ++row){
         for(col=0; col<KnowSize; ++col){
            InFile >> cArray[n][row][col];
            InFile.ignore(1);
         }//end for columns
      }//end for rows
      InFile.ignore(1); // ignore blank line between networks in file
   } // end for run periods

   InFile.close();
} // end ifileArray()

/************************************************************/
/*  Output an Array to the screen  */
/************************************************************/
void CAxK_All::scrnArray(char cArray[RunPeriods][ProjSize][KnowSize])
{
   //  parameters:
   //    cArray   - the Array to output to screen
   int row=0; int col=0; int n=0;


   for(n=0; n<RunPeriods; ++n){
```

```
      cout << "AxK Network - Run: " << n+1 << endl;
      for(row=0; row<ProjSize; ++row){
         for(col=0; col<KnowSize; ++col){
            cout << cArray[n][row][col];
            if(col<KnowSize-1)
               cout  << ',';  // Add comma between numbers
         }//end for rows
         cout << endl;              // Add New Line after last col in row
      }//end for columns
      if(n<RunPeriods-1)
         cout << endl << endl;
   } // end for run periods
   cout << endl << "End of Screen Display." << endl;
} // end scrnArray() output array to screen

/**************************************************************/
/*  Input an Arrays and Compare   */
/**************************************************************/
void CAxK_All::ioTest(char cArray[RunPeriods][ProjSize][KnowSize])
{
   //  parameters:
   //    cArray   - the Array to input
   //    InFile and InFile2   - input file name
   ifstream InFile("AxK_All.csv", ios::in); // input from file
   ofstream OutFile("AxK_All_Test4.csv", ios::out);
   // ifstream InFile2("AxK_All2.csv", ios::in); // input from file
   // char ch=' ';
   int row=0, col =0, n=0;          // counters

   if(InFile.fail())
   {
      cout << "Error opening input file." << endl << endl;
      exit(2);
   }

   // input array of AxK networks
   for(n=0; n<RunPeriods; ++n){
      for(row=0; row<ProjSize; ++row){
         for(col=0; col<KnowSize; ++col){
            InFile >> cArray[n][row][col];
            InFile.ignore(1);
//            OutFile << *(*(*(cArray+row)+col)+n);
//            if(col<KnowSize-1)
//               OutFile << ',';
         }//end for columns
//         OutFile << endl;
      }//end for rows
      InFile.ignore(1);
//      OutFile << endl;
   } // end for run periods
   InFile.close();

   for(n=0; n<RunPeriods; ++n){
      for(row=0; row<ProjSize; ++row){
         for(col=0; col<KnowSize; ++col){
//            InFile >> *(*(*(cArray+row)+col)+n);
//            InFile.ignore(1);
```

```
            OutFile << cArray[n][row][col];
            if(col<KnowSize-1)
               OutFile << ',';
         }//end for columns
         OutFile << endl;
      }//end for rows
//      InFile.ignore(1);
      OutFile << endl;
   } // end for run periods

   // output array of AxK networks
//   for(n=0; n<RunPeriods; ++n){
//      for(row=0; row<ProjSize; ++row){
//         for(col=0; col<KnowSize; ++col){
//            OutFile << *(*(*(cArray+row)+col)+n);
//            if(col<KnowSize-1)
//               OutFile << ',';
//         }//end for columns
//         OutFile << endl;
//      }//end for rows
//      OutFile << endl;
//   } // end for run periods
   OutFile.close();

} // end ioTest()

/**************************************************************/
/**************************************************************/
/**************************************************************/


/**************************************************************/
/*********   Project Metric Class                    *********/
/**************************************************************/
class CProjectMetric
{
   private:
     // Define Networks - KxT, AxT, and AxK
     char KxT[KnowSize][TaskSize];   // define array to store K x T network
     char AxT[ProjSize][TaskSize];   // define array to store A x T network
     char AxK[ProjSize][KnowSize];   // define array to store A x K network
     char AxK_All[RunPeriods][ProjSize][KnowSize]; // array to store All A x
K
     // double PercentProjectComplete;

   public:
      CProjectMetric(void);
      void readNetworks(void);
      void readKT_AT_AK_All(void);
      double PercentCompKnow(void);
      void PercentCompKnowAll(void);
      void outProjectComplete(double);
      void outProjectComplete(char, double);
      void ofile_AK_All(void);
      void Test_All(void);
      // void scrnNetworks(void);
};
```

```
/************************************************************/
CProjectMetric::CProjectMetric(void){
    ;
} // end CProjectMetric constructor


/************************************************************/
void CProjectMetric::Test_All(void)
{
   CAxK_All aAxK_All(AxK_All);           // initialize AxK for All

   aAxK_All.ioTest(AxK_All);
}


/************************************************************/
// READ Networks: KxT, AxT, and AxK
void CProjectMetric::readNetworks(void)
{
     char ch_select=' ';

     // Initialize Networks
     CKxT aKxT(KxT);               // initialize KxT
     CAxT aAxT(AxT);               // initialize AxT
     CAxK aAxK(AxK);               // initialize AxK

     // Read Networks from Files
     aKxT.ifileArray(KxT);         // input K x T network
     aAxT.ifileArray(AxT);         // input A x T network
     aAxK.ifileArray(AxK);         // input A x K network

     cout << "KxT, AxT, and AxK networks read from file" << endl;
//     cout << endl << "Select option: D)isplay networks or any key to
continue ";
//     cin >> ch_select;
//     if(ch_select=='D'){
//        aKxT.scrnArray(KxT);
//        aAxT.scrnArray(AxT);
//        aAxK.scrnArray(AxK);
//     } // end if

     return;
}

/************************************************************/
// READ Networks: KxT, AxT, and AxK All
void CProjectMetric::readKT_AT_AK_All(void)
{
     char ch_select=' ';

     // Initialize Networks
     CKxT aKxT(KxT);               // initialize KxT
     CAxT aAxT(AxT);               // initialize AxT
     CAxK aAxK(AxK);               // initialize AxK
     CAxK_All aAxK_All(AxK_All);           // initialize AxK for All
```

```
     // Read Networks from Files
     aKxT.ifileArray(KxT);        // input K x T network
     aAxT.ifileArray(AxT);        // input A x T network
     aAxK_All.ifileArray(AxK_All); // input A x K network

     cout << "KxT, AxT, and AxK networks read from file" << endl;

     return;
}

/**************************************************************/
double CProjectMetric::PercentCompKnow(void)
{
   int i=0; int j=0; int m=0; int n=0; // counters for rows and columns
   int TotalKnowledgeNeeded=0; int TotalKnowledgePossessed=0;

   double PercentTaskComplete[TaskSize]={0.0}; // indiv task completion %
   double SumTaskPercentage=0.0; // used in step to calc avg. task comp %
   double PercentProjectComplete=0.0; // this is the avg. task comp %

   // used to track & compare knowledge needed with knowledge possessed
   char trackKxT[KnowSize];

   /* For each task - inc column ... loop KxT */
   for(j=0; j<TaskSize; ++j){
      /* Set the knowledge needed tracking array */
      /* Sum total the knowledge needed for the task */
      TotalKnowledgeNeeded=0;

      for(m=0; m<KnowSize; ++m){
         //  TotalKnowledgeNeeded+= atoi(KxT[m][j]); // Sum total knowledge
needed
         trackKxT[m]= KxT[m][j]; // set to current task knowledge needed
         if(trackKxT[m]=='1')
             TotalKnowledgeNeeded+=1;
         //cout << TotalKnowledgeNeeded << " ";
      }

      TotalKnowledgePossessed=0;  // (Re)Initialize total knowledge possessed

      /* For Agents assigned Tasks ... loop AxT */
      for(i=0; i<ProjSize; ++i){
         /* Find the agents assigned to the task using AxT */
         if(AxT[i][j]=='1'){ // For agent assigned this task
            // Compare KxT (Knowledge Needed) with AxK (Knowledge Possessed)
            for(m=0; m<KnowSize; ++m){ // Search for Knowledge
               /* Does the agent asssigned the task have the knowledge needed
*/
               // Knowledge is Needed trackKxT[m]=='1'
               // and Knowledge is Possessed && KxT[m][j]==aAxK[i][m]
               //                alternative(&& AxK[i][m]=='1')
               if(trackKxT[m]=='1' && KxT[m][j]==AxK[i][m]){
                  /* Flag the knowledge needed tracking array (remove the K
needed) */
                  /* once the knowledge is possessed by one agent it is no
longer  */
                  /* necessary to check for it among other agents */
```

```
                  trackKxT[m]='0';
                  ++ TotalKnowledgePossessed; // inc Knowledge Possessed
               } // end if (Task Knowledge Needed is possessed by Agent)
            } // end for
         } // end if (Agent is assigned Task)
      } // end for - check knowledge possessed by agents needed for this task

      /* For each Task Calculate the Percent Task Completion */
//      cout << endl << "Possessed: " << TotalKnowledgePossessed;
//      cout << endl << "Needed   : " << TotalKnowledgeNeeded << endl;
      PercentTaskComplete[j] = ((double)TotalKnowledgePossessed /
(double)TotalKnowledgeNeeded);

   } // end for - check all tasks

   /***************************************************************/
   /* Calculate the Percent Project Completion */
   /***************************************************************/
//   cout << endl << "Task Percent Complete:" << endl;
   for(i=0; i<TaskSize; ++i){
      SumTaskPercentage+=PercentTaskComplete[i];
//      cout << PercentTaskComplete[i] << "  ";
   }; // end for
   // Average of the Percent Complete for all Tasks in the project
   PercentProjectComplete = SumTaskPercentage/TaskSize;

//   cout << endl << "Project Percent Complete: " << PercentProjectComplete
<< endl;
   /***************************************************************/
   // Output results to file
   /***************************************************************/
   //outProjectComplete(PercentProjectComplete);
   return (PercentProjectComplete);
} // end PercentCompleteKnowlege()

/***************************************************************/
void CProjectMetric::PercentCompKnowAll(void)
{
   int row=0, col=0, n=0;  // counters

   // loop for all run periods
   for(n=0; n<RunPeriods; ++n){
      // copy a single network from AxK_All to AxK
      for(row=0; row<ProjSize; ++row){
         for(col=0; col<KnowSize; ++col){
            AxK[row][col] = AxK_All[n][row][col];
         }//end for columns
      }//end for rows

      // Calculate metrics and write to file for each period
      outProjectComplete('A', PercentCompKnow());
   } // end for run periods
   return;
} // end PercentCompKnowAll()

/***************************************************************/
// copies AxK a period at a time and writes to file
```

```
void CProjectMetric::ofile_AK_All(void)
{
   CAxK tmpAxK(AxK);
   int row=0, col=0, n=0;  // counters

   // loop for all run periods
   for(n=0; n<RunPeriods; ++n){
      // copy a single network from AxK_All to AxK
      for(row=0; row<ProjSize; ++row){
         for(col=0; col<KnowSize; ++col){
            AxK[row][col] = AxK_All[n][row][col];
         }//end for columns
      }//end for rows

      //  Write the network to a file for each period
      tmpAxK.ofileArray(AxK);
   } // end for run periods
   return;
} // end ofile_AK_All()


/**************************************************************/
/*  Output Percent Project Completion to an output file       */
/**************************************************************/
void CProjectMetric::outProjectComplete(double PercentProjectComplete)
{
   //  parameters:
   //    PercentProjectComplete
   //    OutFile  - output file name

   ofstream OutFile("ProjCompKnow_Last.csv", ios::out);

   if(OutFile.fail())
   {
      cout << "Error opening output file." << endl << endl;
      exit(2);
   }

   OutFile << PercentProjectComplete << endl;

   OutFile.close();
   return;
} // end ofileArray() output array to file
/**************************************************************/

/**************************************************************/
/*  Output Percent Project Completion to an output file       */
/**************************************************************/
void CProjectMetric::outProjectComplete(char fileflag, double
PercentProjectComplete)
{
   //  parameters:
   //    PercentProjectComplete
   //    OutFile  - output file name

   ofstream OutFile("ProjCompKnow_All.csv", ios::app);
```

```
   if(OutFile.fail())
   {
      cout << "Error opening output file." << endl << endl;
      exit(2);
   }

   OutFile << PercentProjectComplete << endl;

   OutFile.close();
   return;
} // end ofileArray() output array to file
/***************************************************************/



/***************************************************************/
/****************            main()           ****************/
/***************************************************************/
int main(int argc, char *argv[])
{
     char ch_select=' ';
     CProjectMetric aProjMetric;

     do{
        cout << endl << "Options currently available: \n"
             << "M - Calculate project completion for last period \n"
             << "N - Calculate project completion for last period \n"
             << "T - Test I/O for array of AxK networks" << endl
             << "x - Exit \n "
             << "Choice: ";
        cin >> ch_select;

        switch (ch_select)
        {
           case 'D':
                // aProjMetric.scrnNetworks();
                break;
           case 'M':
                // Initialize and Read Networks: KxT, AxT, and AxK
                aProjMetric.readNetworks();
                // Calculate Task and Project Completion Percentage, then
                // Output percentage to file

aProjMetric.outProjectComplete(aProjMetric.PercentCompKnow());
                break;
           case 'N':
                aProjMetric.readKT_AT_AK_All();
                // Calculate Task and Project Completion Percentage
                // for each run period using AxK_All
                aProjMetric.PercentCompKnowAll();
                break;
           case 'T':
                // test
                // read networks from file
                aProjMetric.readKT_AT_AK_All();
                // write network(s) to file
                aProjMetric.Test_All();
```

```
                break;
            case 'x':
                cout << "Goodbye ";
                break;
            default:
                cout << "Please make a valid selection & have a nice day. "
<< endl;
                break;
        } // end switch case
     }while(ch_select != 'x');

    system("PAUSE");
    return 1;
} // end main()
/***************************************************************/
/***************************************************************/
```

PERCENT COMPLETE ALGORITHM

The proportion of the project that is complete is calculated as an arithmetic mean of the proportion completion of the individual tasks that compose the project.

$$P_c = \frac{\sum \left(K_p \big/ K_r \right)}{n}$$, where

P_c: proportion of the project that is complete

K_r: knowledge that is required for a given task; derived from the knowledge requirement network (K x T)

K_p: knowledge possessed by an agent(s) assigned to perform a given task; derived from the task assignment network (A x T) and the knowledge network (A x K)

n: number of tasks within the project

Vita

Pierce Wesley Raymond Lee Hopkins was born in Miami, Florida, to Pierce Wesley Hopkins and Marjorie June Bautz. He graduated from the University of Florida in 1984 with a Bachelor of Science degree, having majored in mathematics. He also was awarded the rank of Shodan in 1984, in Cuong Nhu Martial Arts. He received his Master of Business Administration degree from Palm Beach Atlantic University in 1997. Pierce began the Information Systems and Decision Science doctoral program in the fall of 2002. Prior to entering the doctoral program Pierce worked in industry as an information systems manager. In anticipation to receiving his doctoral degree Pierce took a visiting instructor/professor position at the University of South Florida in the fall of 2008.