DISSERTATION

Ming-Chian Ken Wang

The Graduate School

University of Kentucky

1995

DECISION AGGREGATION

IN DISTRIBUTED DECISION MAKING

DISSERTATION

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
at the University of Kentucky

By

Ming-Chian Ken Wang

Lexington, Kentucky

Director: Dr. James R. Marsden

Professor of Decision Science and Information Systems

In the School of Business Administration

Lexington, Kentucky

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(Director of Dissertation)

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From an organizational perspective, the decision making process is often distributed across multiple participants, each of whom contributes to the decision. In this dissertation we focus on a special aspect of distributed decision making (DDM), the aggregation of collaborative group decision input. We address the usefulness of computerized laboratory experiments in analyzing group problem settings focusing on decision aggregation frameworks and experimentation in the context of *economically intelligent firms.*

This dissertation makes distinct contributions to the field of information systems. The contributions are primarily in two areas: research methodology in laboratory experimentation and the aggregation of individual decisions: We set up a decision aggregation problem and investigate how aggregation techniques may be used in a network setting to decide what variables to include and how they influence the decision making process. A set of incentive driven experiments enables us to investigate decision alternatives for the individual participant in a distributed decision making setting.

The results from the experiments are analyzed in the hypothesis testing. It offers insights in organizational decision making and automating decision aggregations. Further research is suggested in pushing forward the frontier of organizational decision aggregation.

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8-25-1995
(Date)

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This dissertation is dedicated to the celebration of the golden (plus three) anniversary of the author's parents, Yung and Tsao-Hsing Li Wang, and in memory of the author's eldest brother-in-law, Hsih-Yuan Huang, 1946-1990.

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Chapter 1

INTRODUCTION

1.1 Overview of the Research

With the advancement of technology, computers play an increasingly integral part in the operations of organizations. Problems in sharing information and making cooperative decisions are magnified in geographically dispersed organizations. Despite this, most decision support systems (DSS) currently in use are designed to support independent decisions (Marsden and Pingry, 1988a; Marsden, Pingry, and Wang, 1992; Holsapple and Whinston, 1988.) While many personal computers and terminals are interconnected, computer networks are primarily utilized for sharing printers and storage resources or for straightforward communication activities such as electronic mail. Such straightforward network utilizations may be beneficial, but they fall short of exploiting what networking can offer. As organizations grow and become more diversified and geographically dispersed, potential benefits from using networks to support distributed decision making increase significantly. It is to this area that we direct our efforts.

From an organizational perspective, there are many decisions that are not strictly individual. The decision making process is often distributed across multiple participants, each of whom contributes to the decision. In this research we focus on a special aspect of distributed decision making (DDM), the aggregation of group decision input. We address the usefulness of computerized laboratory experiments in analyzing group problem settings focusing on decision aggregation frameworks and experimentation in the context of *economically intelligent firms* (Marsden and Pingry, 1988a, Marsden, Pingry, and Wang, 1992).

Participants in distributed decision making must be able to communicate and coordinate with higher management and other decision makers in making requests and in offering responses (Holsapple and Whinston, 1988). To analyze the performance and design of alternative support systems, we address distributed decision making issues such as: (1) parallel decision making in situations of conflict; (2) serial linkage of independent decision support systems for geographically dispersed decision makers; (3) timing of on-line parallel decision making; and (4) decision aggregation in parallel and serial decision making.

As stated earlier, collaborative decisions are common in the context of organization. Different organization structures utilize different decision hierarchies. The quality of decisions depends upon not only the ability of the decision makers but also the structure of the decision aggregation process. Our study considers both generic decision aggregation rules and the impact of organizational structure on the performance of such rules.

This chapter gives an overview of the dissertation. In Chapter 2 we review relevant literature in four relevant areas: (1) Distributed Decision Making, (2) Experimental Economics, (3) Aggregation of Decision Making, and (4) Economic Organizations. The technical structure and methodology of our study are laid out in

Chapter 3. Chapter 3 also details our experimental process including the experimental shell we developed and its specific utilization in our research presented here. Chapter 4 presents the experimental results. In Chapter 5 we perform hypothesis tests on the experimental results. Chapter 6 discusses the decision rule simulation using our actual experimental data. We conclude with a summary of our contributions and a discussion of future research direction in Chapter 7.

In this chapter, we begin by emphasizing the multidisciplinary nature of this dissertation in Section 1.2. In Section 1.3 the framework of decision aggregation in a group decision support system is presented. Section 1.4 briefly introduces our methodology which is then presented in significantly more detail in Chapter 3. We rely heavily on experimental economics (Smith 1976, 1982). To shed light on the usefulness of our framework, we consider it in the organizational context in Section 1.5. The human subject incentive-driven computerized laboratory experiment design is briefly described in Section 1.6. We conclude this Chapter by briefly summarizing our contributions in Section 1.7.

1.2 A Multidisciplinary Study

In line with the interdisciplinary nature of the MIS field, we draw from various disciplines in this study: decision science, computer science, organizational theory, and microeconomics.

As in most disciplines, we have found that the literature relevant to our research contains many examples of terms with multiple definitions. We attempt to identify these differences in past research and clearly set forth the definitions we utilize.

The following three research groupings provide the "stepping off stones" for our efforts:

1. Distributed Decision Aggregation,
2. Experimental Microeconomics, and
3. Economic Organizations.

Our goal is to clearly establish the distinctiveness of our research and to indicate how it springs naturally from the foundations provided by efforts in these research arenas.

From the standpoint of Decision Science, decision aggregation commonly involves many essentials of multicriteria decision making (MCDM). In an organizational context, MCDM has been an issue of central concern to decision-making managers. This is particularly true when an organization is viewed as an entity that constantly strives to solve problems in order to adapt to environmental changes. As noted previously, the decision making process we focus on is one which is distributed across multiple participants in an organization. Research on MCDM to date has produced literature in two main arenas. One arena has approached MCDM from an operations research and management science perspective, resulting in optimization techniques for choice making (see Hwang and Lin, 1987; Zionts and Wallenius, 1976.) The other arena was tied to descriptive research regarding human choice behavior (Minch and Lawrence, 1986; Hong, Vogel, and Nunamaker, 1989.) Although these two approaches are complementary to each other and critical for any attempt at realistically modeling distributed decision making, this effort will focus on the latter, examining what knowledge can be compiled on the way people make choices. In doing so, we attempt to gain a useful perspective on how people evaluate decision alternatives.

1.3 A Distributed Decision Support System: Group Decision Aggregation

In the process of group decision making, aggregation of individual decisions or inputs to resolve conflicts and reach consensus plays a vital role to the success of the decision. There are many factors to be considered before and in the aggregation process: the number of alternatives to be evaluated by the decision makers, the mechanisms of aggregation, the optimal number of decision makers, and the number of iterations of the decision process performed. There are also a number of technical issues concerning the implementation of the process including the computer platform, the network adaptor, and the network software.

There are a number of aggregation mechanisms available in the literature. Some are implemented in software packages, even commercially available ones (for example, Alternative Evaluation in Ventana's GroupSystems). Some are discussed extensively in the literature (e.g., Analytic Hierarchy Process, Saaty 1980).

As a starting point, we implement various forms of voting and voting rules in our experiment platform in an attempt to gain insights from straightforward aggregation methods and use this as a foundation for subsequent analysis of more complicated structures. Chapter 3 will illustrate the technical structure in detail.

1.4 Experimental Economics

The foundation of our laboratory experiments draws heavily from the research of Vernon L. Smith (see, for example, 1976, 1982 and Plott and Smith, 1978) who largely developed the experimental microeconomics methodology. In his 1976 article, Smith details induced value theory, arguing that the study of the decision behavior of suitably motivated individuals and groups in the laboratory has important and significant application to the development and verification of theories of the economic system at large. Smith emphasizes that control is the essence of experimental methodology. In our experiments, through the use of the computer network, uniform video introduction presentation, on-line tutorial, and real-time practice, we can achieve significant environment control. By using a significant reward structure to induce prescribed monetary value on actions, the laboratory becomes a place "where real people earn real money for making real decisions about abstract claims that are just as 'real' as a share of General Motors" (Smith 1976, p. 275). An important message from this series of foundation work (articulated in Wilde 1980) is that laboratory microeconomies are real live economic systems, which can be richer than the systems parameterized in our theories. Smith's theory of induced valuation is employed as the basis for our generating software that creates the necessary experimental environments which are then calibrated to evaluate proposed hypotheses.

1.5 Organizational Context

As we stated previously, computers are playing an increasingly integral part in the operations of organizations. The need to share information and make cooperative decisions is intensified for organizations in competitive markets. Different organizations have different information needs and different decision-making hierarchies. Williamson [1975, 1981a, and 1981b] classifies different organizational structures. Marsden and Pingry [1988a] discussed the need to test whether or not advances in information technology would drive successful competitive firms toward more complex, flexible, and adaptable organizational structures (as had been suggested but not tested by Huber, 1984, and Huber and McDaniel, 1986). This argument is stressed again in Marsden, Pingry, and Wang [1992]:

> carefully structured and controlled laboratory experiments provide an excellent source for obtaining the knowledge necessary for organizations to strategically adapt. ..., such experiments should focus on determining relationships between organizational forms and information system constructs and on analyzing what mixes yield maximum performance in decision theoretic and game theoretic settings. ....., *optimal design involves determining the optimal mix of inputs (including intelligent information systems) and economic organization form*. (p. 226)

Researchers in organizational science recognized information processing as an integral organizational element (Lorsch and Lawrence, 1970). To date, however, their examples and analyses have covered only observations of existing firms and structures. In this era of rapid computer technology change, the usefulness of such empirical and case study analysis is limited. As pointed out in Marsden, Pingry, and Wang [1992], "to develop general principles of organizational structure and productivity, we must pursue methodologies that enable us to investigate the spectrum of structure/task possibilities."

By investigating aspects of the organizational decision making, our goal is to contribute to the design of intelligent information systems for future economic organizations. This dissertation serves as an illustration of the use of experimentation methodology for determining important man-machine-organization relationships.

1.6 Human Subject Incentive-driven Computerized Lab Experiments

Increasingly, laboratory experiments using human subjects are being employed to implement, test, and validate theories developed in social sciences, microeconomics, and MIS. Green & Kagel [1990] and Smith [1989] provide compilations of works done in the area of laboratory experiments with human subjects to analyze decision-making behavior under varying market conditions. Hoffman, Marsden, & Whinston [1990] provide a summary of results and emphasize that controlled laboratory experimentation can overcome limitations of field data including inadequacy, incompleteness, or even unavailability. Furthermore, laboratory experiments can be utilized where testing and validating is impossible or impractical using historical or field trial data.

As experimental economics has begun to take advantage of advancing computer and communication technology, the methodological approach used by this area has become more easily adaptable for studying the impact of technological advances on issues involving optimal organizational as well as intelligent information system design (Marsden, Pingry, & Wang, 1992).

In our analysis, we construct an experimental microeconomic system incorporating characteristics described by Smith [1982]. Using monetary rewards tied to subject performance, we observe the behavior of subjects under various combinations of aggregation processes and incentive mechanisms. Experimental outcomes are used to draw implications related to organizational structuring and aggregation rules in decision making within those structures.

1.7 Contribution

This dissertation makes distinct contributions to the field of information systems. The contributions are primarily in two areas:

1) research methodology in laboratory experimentation, and

2) the aggregation of individual decisions.

We set up a decision aggregation problem and investigate the use of aggregation techniques in a network setting for deciding what variables to include and how they influence the decision making process. We program and implement the experiment program on a network, recruit subjects for the incentive-driven experiments, and run the experiment sessions. We perform hypothesis tests on the data collected and elaborate on the insights learned from the tests. We then study the possible outcomes of the actual experiments if different decision rule sets were implemented for an automated manager in simulations of the experiment results. This research makes contributions to the study of decision making in an intelligent organization.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

We begin our analysis of aggregation of distributed decision making (DDM) by reviewing and summarizing key literature from the following four research groupings that provide the "stepping off stones" for our efforts:

1. Distributed Decision Making (DDM),
2. Experimental Economics
3. Aggregation of Decision Making and Experimental Design
4. Organizational Issues

Each of the following four sections is devoted to research in one of these segments. None of the sections is meant as a complete analysis of a research segment, but rather as a review of previous research sufficient to clearly establish the distinctiveness of our research and how it springs naturally from the foundations provided by efforts in the four chosen research arenas.

As noted in our introductory chapter, the decision making process we focus on is one which is distributed across multiple participants in an organization. Each of the participants contributes to the decision by solving one or more problems. In geographically dispersed organizations, the need to share information and make cooperative decisions is magnified. Furthermore, the problems facing decision makers often involve the choice of one or more alternatives by evaluating the alternatives according to criteria that may even involve conflicting objectives. The literature suggests that there are a host of choice strategies, or choice rules, that allow the decision makers to arrive at a decision. In our literature review and subsequent analysis we take a quite general approach to distributed decision making.

As in most disciplines, we have found that the literature relevant to our research is replete with differences in how terms are defined. In the review that follows we attempt to identify these conflicts in past research and clearly set forth the definitions we utilize. The summary of the literature review of each group appears at the end of this chapter.

2.2 Literature Review on Distributed Decision Making

Holsapple, Jarvenpaa, Marsden, and Whinston [1989] characterized the process of distributed decision making as being one "in which multiple entities (e.g., persons, group, computer systems) who are capable of playing various roles commit to performing specific problem-solving tasks relevant to the support of concurrently pending decisions." Burns, Rathwell, and Thomas [1987] suggested that "DDM extends the decision support system (DSS) concept to one that enables two or more decision-making parties to cooperate in employing DSS tools."

As a class, distributed decision support systems (DDSS) are separate and distinct from either individual DSS or traditional GDSS. The term distributed decision support system was coined by Scher [1981] when he discussed the implications of including communication support within DSS.

Offering a viewpoint different from Holsapple, Jarvenpaa, Marsden, and Whinston [1989], Swanson [1990] defines a distributed decision support system (DDSS) as a decision support system which supports distributed organizational decision making. Swanson argues that "DDSS constitutes one perspective, or view of organizational DSS." Swanson points out that the domain for distributed decision support involves situations in which decision models are semi-structured and decision criteria are semi-determined among decision makers. This domain may be usefully understood as juxtaposed between two other domains -- those of distributed communications and distributed computing. Alternative strategies for distributed decision support include decision ordering, information sharing, and negotiated choice. These strategies have distinctly different implications for system restrictiveness, guidance, and focus [Swanson 1990].

Distributed decision making involves much more than efficient communication among persons engaged in individual problem solving. It also requires an effective coordination of individual problem solving activities in the interest of solving larger problems than any one individual is capable of solving individually. This coordination has several aspects including planning (e.g., problem reduction, scheduling, synthesis), control (e.g., mediation, negotiation, execution), and review (e.g., evaluation, learning). Moreover, coordination occurs in a context of concurrent problem solving where multiple decisions are pending simultaneously. Thus, distributed decision making is based on the three elements of individual problem solving, communication, and coordination [Holsapple and Whinston 1988].

A Distributed Decision Making Framework -- the Knowledge-based Organizations (KBO) Framework

Holsapple and Whinston [1988] propose the knowledge-based organizations (KBO) framework for distributed decision making. They view distributed decision making as a coordinated effort of communicating individuals. Each individual possesses some specialized knowledge and an ability to process that knowledge in a manner that contributes to solving some problem or problems involved in the decision process. The individuals can interact with each other by communicating requests and responses. To avoid total anarchy and inefficiency, each individual's processing behavior must be coordinated with respect to every decision process that is currently active. This coordination may be explicit (i.e., actively expressed by an individual), implicit (i.e., inherent in roles that the participating individuals play), or a combination. It may adhere to one or a combination of the organization models.

The classic DSS framework of Bonczek, Holsapple, and Whinston [1981] provides one key to formalizing the above notion of distributed problem solving. Another is provided by the view that an organization is a structure of roles tied together by lines of communication. When these are combined, the result is a powerful and flexible framework for discussing distributed decision making [Holsapple and Whinston 1988]. An entity (e.g., person, computer system, group) in an organization is able to play one or more roles. Conversely, a role can be played by one or more entities. Roles can be related to each other in both a definitional and associative fashion [Bonczek, Holsapple, and Whinston 1981].

Holsapple and Whinston [1988] contend that each role and each entity has an internal structure identical to that of a DSS. It has a language system ("import schema", see Heimbigner and McLeod 1985) which defines the set of requests it can accept. It has a knowledge system which contains its own specialized knowledge (organized according to a "private schema", Heimbigner and McLeod, 1985). This can include descriptive (i.e., data, information), procedural (e.g., program), presentation ("export schema", Heimbigner and McLeod, 1985), linguistic, assimilative, and reasoning (e.g., rules) knowledge [Holsapple and Whinston, 1987b]. Such flexibility has far-reaching implications for distributed decision system design, prototyping, and testing. Each role or entity also has a problem processor that is able to comprehend any request existing in its language system, to take appropriate action for a request by drawing on its knowledge system contents, to respond to the issuer of the request, and to communicate with some other participant.

Holsapple and Whinston [1988] illustrate the KBO framework using the case where a customer of a financial institution desires financial assistance. A decision needs to be made about what financial assistance, if any, to offer. The ability to solve such a problem suggests the existence of the IB (investment banker) role. This role has certain properties that distinguish it from other roles in the organization. It is possible for a role to be related to other roles in a definitional fashion. A role that does not define a more specialized role can be filled by one or more entities. An entity not only inherits all properties of the role it can play, but also has a value for each of those properties.

In addition to planning and control, a role's coordination effort may also involve a review of what has been accomplished. This review can serve as a basis for improving the organization's performance over time by allowing roles to learn from experience. Learning is accomplished by changing a knowledge system's contents so that the role is better equipped to cope with future requests. The KBO framework recognizes the existence of at least two kinds of learning [Holsapple and Whinston 1988]. One is learning to better cope with the same situation when it is again faced in the future. The other is concerned with learning that prepares a role to cope with entirely new situations.

Classification of Distributed Decision Support Systems

We classify computer-mediated distributed decision support systems into the following categories:

A. Group Decision Support Systems (GDSS)
B. Negotiation Support Systems (NSS)
C. Cooperative Work Systems (CWS)
D. Distributed Artificial Intelligence (DAI)

Each category is eagerly pursued in the research and large volume of literature is generated every year. Furthermore, some systems in each category are developed and implemented. Since this research is in the context of group decision support, only the major important literature on GDSS will be reviewed in this study.

Group Decision Support Systems

First, the concept of a decision support system (DSS) has been widely discussed in the literature and many systems have been in use. Although various definitions have been proposed, there appears to have agreement that a DSS is an interactive computer-based system which facilitates solution of unstructured problems (Bonczek, Holsapple, and Whinston, 1979; Sprague, 1980).

A group decision support builds on the well-known idea of a DSS. A group decision support system (GDSS), as defined by Huber [1984b], "has hardware, software, language components and procedures that support a group of people, in a decision related meeting." DeSanctis and Gallupe [1985b] define GDSS as "an interactive computer-based system that facilitates the solution of unstructured problems by a set of decision makers working together as a group." Important characteristics of a GDSS are summarized as follows [DeSanctis and Gallupe 1985a]:

1) The GDSS is a specially designed system, not merely a configuration of already-existing system components;
2) A GDSS is designed with the goal of supporting groups of decision-makers in their work. As such, the GDSS should improve the decision making process and/or decision outcomes of groups over that which would occur if the GDSS were not present;
3) A GDSS is easy to learn and easy to use. It accommodates users with varying levels of knowledge regarding computing and decision support;
4) The GDSS may be "specific" (designed for one type, or class, of problems) or

"general" (designed for a variety of group-level organizational decisions); and

5) The GDSS contains built-in mechanisms which discourage development of negative group behaviors, such as destructive conflict, miscommunication, or "groupthink."

The need for GDSS, as pointed out by Sutherland and Crosslin [1989], is highlighted by the identification of a phenomenon in organizational behavior: networked organizations. By allowing individuals within and across organizations to share tasks through communication links, new networked organizations are being established.

Kraemer and King [1988a] broaden the definition of GDSS to include any computer and communications-based support of group work, including but not limited to decision making. Moreover, they suggest that the problems dealt with in GDSS are most often partially structured rather than unstructured. Consequently, their working definition is that a GDSS "involves a group of decision makers with access to a computer, viewing screen, database, decision model(s), and a 'facilitator' who supports the group in use of the technology, instructs them on the use of the decision model, coordinates the group's activity, and documents the group's work." Therefore, they argue, it is useful to conceive of GDSS's as a sociotechnical "package" comprised of (1) hardware, (2) software, (3) organizationware, and (4) people.

The literature reviews on distributed decision making are summarized as Table 2.2.1 which appears at the end of this chapter.

CITATION: Burns, A., M. A. Rathwell, and R. C. Thomas, (1987), "A Distributed Decision-Making System," *Decision Support Systems*, *3*(2), p. 121-131.

RELEVANCE: A message-based model of a distributed decision making (DDM) system is proposed.

SUMMARY: This model was developed from a survey of the needs of decision-making processes within organizations and distributed computer applications. It assumes a framework of organizational decision making that concentrates on the organization as a political system in which communication is important and conflict between groups is just as likely as consensus. Under UNIX on a single VAX 750 machine, a prototype implementation of the model is claimed to uphold the principles from which this particular DDM system is designed. The prototype incorporates an agent language containing explicit parallelism for programming distributed system functions. Although the model of DDM is distributed, physical distribution was not attempted in the prototype.

CITATION: Jacob, Varghese S. and Hasan Pirkul, (1992), "A Framework for Supporting Distributed Group Decision-Making," *Decision Support Systems*, *8*(1), January, p. 17-28.

RELEVANCE: A distributed group decision support system (DGDSS) is presented that would facilitate the exchange of information and expertise between group members without the need for a meeting or direct communication.

SUMMARY: The dynamic nature of the DGDSS is achieved by viewing an organization as being composed of a networked collection of human-computer information processors. The nodes in the network are either directly or indirectly linked to each other. The computer is considered as a knowledge-based system (KBS) that has the capabilities traditionally associated with a DSS, as well as those associated with an expert system. Both capabilities are utilized differently. The DSS capability is primarily for the human at the node; the expert system is used by other nodes. This networked KBS is utilized by the DGDSS to support the groups' activities. The interaction between the networked KBS and the DGDSS provides a framework for the group members to access relevant problem-solving information continuously rather than only at meetings.

CITATION: Turoff, Murray, Starr Roxanne Hiltz, Ahmed N. F. Bahgat, and Ajaz R. Rana, (1993), "Distributed Group Support Systems," *MIS Quarterly, 17*(4), December, p. 399-417.

RELEVANCE: Five case studies of different distributed group support systems developed over the last decade to support different types of tasks and to accommodate fairly large numbers of participants (tens to hundreds) are presented.

SUMMARY: Distributed group support systems are likely to be widely used in the future as a means for dispersed groups of people to work together through computer networks. They combine the characteristics of computer-mediated communications systems with the specialized tools and processes developed in the context of group decision support systems, to provide communications, a group memory, and tools and structures to coordinate the group process and analyze data. The case studies are placed within conceptual frameworks that aid in classifying and comparing such systems. The results of the case studies demonstrate that design requirements and the associated research issues for group support systems can be very different in the distributed environment as compared to the decision room approach.

2.3 Literature Review on Experimental Economics

The foundation of our laboratory experiments lies mainly in the research of Vernon L. Smith (1976, 1982) who largely developed the experimental microeconomics methodology. To motivate laboratory experiment subjects to perform the best they can, Smith (1976) suggested using sufficient monetary reward structures to induce prescribed monetary value on actions. The usefulness of induced valuation depends upon, among others, Smith's postulate of non-satiation:

Given a costless choice between two alternatives, identical except that the first yields more of the reward medium (usually currency) than the second, the first will always be chosen (preferred) over the second, by an autonomous individual.

Smith's theory is employed as the basis for our generating software that creates the necessary experimental environments which are then calibrated to evaluate proposed hypotheses. In this section, we review the literature on experimental microeconomics by citing important articles. A summary is provided in Table 2.3.1 which appears at the end of this chapter.

CITATION: Hoffman, Elizabeth, Marsden, J. R., & Whinston, A. B. (1990), "Laboratory Experiments and Computer Simulation: An Introduction to the Use of Experimental and Process Model Data in Economic Analysis," In L. Green & J. H. Kagel (Eds.), *Advances in Behavioral Economics (Volume 2)* (p. 1-27). Norwood, NJ: Ablex Publishing Company.

RELEVANCE: This article pointed out the following key advantages of using laboratory experiments: 1) the laboratory provides a controlled economic environment, which allows the researcher to directly manipulate preferences and institutions; and 2) laboratory experiments allow testing economic theories within the context of an environment that closely parallels the theoretical environment.

SUMMARY: A new generalized experimental technique which may significantly improve the quality of empirical research in economics was proposed. The basic experimental design is the process model, a logical representation of an economic process. This basic model can be used to simulate experiments on a computer and to conduct laboratory experiments with human subjects. It classified the types of data into four categories and stated their limitations: 1. field data (field study): provides direct information only on policies which have already been implemented and provides little information on the behavior or motivation underlying the observed data; 2. panel data (survey): tends to be unreliable because (a) respondents cannot always accurately predict their own behavior in hypothetical new economic situations, (b) there may be incentives to mispresent their preferences or expected behavior; 3. experimental data (laboratory experiments): artificial and simplified; 4. pseudo data (simulation): artificial and simplified. The authors presented an integrated analytical approach to combine the four data forms using advantages of each form and avoiding each form's problems. The authors provide a detailed summary of work in using laboratory experiments with human subjects to analyze decision-making behavior under varying market conditions.

CITATION: Smith, Vernon L. (1976), "Experimental economics: Induced value theory," *American Economic Review Proceedings*, *66*(2), May, p. 274-279.

RELEVANCE: Smith introduced the induced value theory into experimental economics in this concise article.

SUMMARY: Smith states that the results of laboratory studies can serve as a rigorous empirical pretest of economic theory prior to the use of field data tests and the results of experiments can be directly relevant to the study and interpretation of filed data. Control is the essence of experimental methodology. In experimental exchange studies it is important that one be able to state, as between two experiments, individual values either do or do not differ in a specified way. Such control can be achieved by using a reward structure to induce prescribed monetary value on actions. The concept of induced valuation depends upon the postulate of nonsatiation. There are three important qualifications to the nonsatiation postulate: 1. There may be subjective costs (or values) associated with market decisions. 2. Individuals may attach game value to experimental outcomes. 3. Individuals may not be autonomous own-reward maximizers and interpersonal utility criteria may qualify the theory of induced valuation.

CITATION: Smith, Vernon L. (1982), "Microeconomic Systems as an Experimental Science," *American Economic Review Proceedings*, *72*(5), December, p. 923-955.

RELEVANCE: Prior to this article, literature in experimental economics had mostly contained examples of experimental effort and very little in the way of theory or explanations of why and how these experiments should be conducted. With this article, Smith defines the nature of a microeconomic system and a methodology of laboratory experimentation. Smith states that "the important message of this paper is that laboratory microeconomies are real live economic systems, which are certainly richer, behaviorally, than the systems parameterized in our theories."

SUMMARY:

Part I of this article is devoted to microeconomic system theory. A microeconomic system is composed of two distinct components: an *environment* and an *institution*. The *environment* consists of a list of N economic agents $\{1, ..., N\}$, a list of K+1 commodities (including resources) $\{0, 1, ..., K\}$, and certain agent characteristics. The ith agent is characterized by the vector $e^i=(u^i, T^I, \omega^j)$ where the individual components are defined on the K+1 commodity space R^{K+1}, u^i is the agent's utility function, T^I is the agent's technology (knowledge) endowment, and ω^j is a commodity endowment vector. Smith defines a microeconomic *environment* as "the collection of characteristics $e=(e^1, ..., e^N)$." He clarifies that this specification defines the environment as a set of initial circumstances that cannot be altered by the agents or the institutions within which they interact. It is noted that an experimental environment e will include some circumstances that cannot be altered by the agents because they are control variables fixed by the experimenter.

The author emphasizes an important feature of the environment: "the superscript I on the characteristic of each agent I means that the initiating circumstances in an economic environment are *in their nature private*." This means that individual skills, knowledge, and willingness to work and buy are not publicly observable. Only their consequences are observable.

The *institution*, the other component of a microeconomic system, defines the rules of private property. Under those rules agents may communicate and exchange or transform commodities for the purpose of modifying initial endowments in accordance with private tastes and knowledge.

In Smith's language, the institution specifies:

a. A *language* $M = (M^1, \ldots, M^N)$ consisting of messages $m = (m^1, \ldots, m^N)$, where m^i is an element of M^i, the set of messages that can be sent by agent *I*.

b. A set $H = (h^1(m), \ldots, h^N(m))$ of *allocation rules* for each *I*. The rule $h^i(m)$ states the final commodity allocation to each *I* as a function of the messages sent by all agents.

c. A set $C = (c^1(m), \ldots, c^N(m))$ of cost *imputation rules*. The rule $c^i(m)$ states the payment to be made by each agent in numeraire units (money) as a function of the messages sent by all agents.

d. A set $G = (g^1(t_0, t, T), \ldots, g^N(t_0, t, T))$ of *adjustment process rules*.

In general, these rules consist of a *starting rule* $g^i(t_0, ., .)$ specifying the time or conditions under which the exchange of messages shall begin, a *transition rule* (or rules) $g^i(., t, .)$ governing the sequencing and exchange of messages, and a *stopping rule* $g^i(., ., T)$ under which the exchange of messages is terminated (and allocations are to begin).

Each agent *I*'s *property rights* in communication and in exchange are defined by I^I

$= (M^I, h^i(m), c^I(m), g^i(t_0, t, T))$, which specifies the messages that I has the right to send; the starting, transition, and stopping rules which govern these communication rights; and finally the right to claim commodities or payments in accordance with the outcome rules that apply to messages. A microeconomic *institution* is defined by the collection of all these individual property right characteristics $I = (I^1, \ldots, I^N)$.

Finally, putting the components together, a microeconomic environment along with a microeconomic institution, defines a *microeconomic system*, $S = (e, I)$.

Next the author discusses the behavior of agents. He states that a microeconomy is closed by the behavioral actions (choices) of agents in the message set M. There are static and dynamic descriptions of an economy. First, in the static description, the article defines agent's *outcome behavior*:

> Agent I's *outcome behavior* is defined by a function $\beta^i(e^i|I)$ which yields the allocation-determining message m^i sent by agent I with characteristic e^i, given the property rights of all agents defined by I.

It is noted that the mapping β^i may represent a single message transmission as in a sealed-bid auction, or it may constitute the final result of an exchange of messages in an iterative process. Smith illustrates the conceptual process in a microeconomic system with a triangle diagram: given the institution, the message m^i depends on agent characteristics e^i, and the messages sent by all I in turn determine, via the institution, the outcomes in X,

$$h^i(m) = h^i[\beta^1(e^1|I), \ldots, \beta^N(e^N|I)]$$

and $$c^I(m) = c^i[\beta^1(e^1|I), \ldots, \beta^N(e^N|I)].$$

It is further explained that agents do *not* choose direct commodity allocations.

Agents choose messages, and institutions determine allocations via the rules that carry messages into allocations.

In the dynamic or process description of an economy, the paper defines the *response behavior* of agents: Agent I's *response behavior* is defined generically by a function f^I in the following equation, $m^i(t) = f^i(m(t\text{-}1)|e^i, I)$, which gives I's message response $m^i(t)$, at sequence point t, to earlier messages $m(t\text{-}1)$ by all agents.

Rounding up the framework of microeconomic system theory, the article stresses *incentive compatibility* in the evaluation of a microeconomic system. An institution's rules are *incentive compatible* if the information and incentive conditions that it provides individual agents are compatible with the attainment of socially preferred outcomes. Smith emphasizes the following which bears on the relationship between laboratory experiments and the model of microeconomic system:

> The mapping $h^i[\beta^1(e^1|I), \ldots, \beta^N(e^N|I)]$: $e \rightarrow m \rightarrow x^I$, is generated by any microeconomy, particularly an experimental microeconomy, provided that we have a methodology for systematically varying the elements of E (and also I, if institutions as variables are to be studied) and observing the consequent elements in M and X. This is important because there may *not* exist in all contexts (or in any) a satisfactory theory or hypothesis allowing derivation of the β^i functions. If we can experiment, then we are not bound to study *only theoretical* systems that carry E into X. Experiments permit stable patterns of behavior in relation to institutions to be identified and to motivate more explicit theories. (p. 927)

The previous framework development is needed to make it possible to examine the role of the laboratory experiment in the study of microeconomic systems. In part II of this paper, the laboratory market or resource allocation experiment is developed and discussed as an example of a microeconomic system. Smith stated that the purpose of developing the framework in the paper was "for the purpose of defining exercises in measurement, hypothesis testing, and the comparative performance of institutions." Some of the observable elements of an economy are listed in the paper:

1. the list of agents,
2. the list of physical commodities and resources,
3. the physical commodity and resource endowments of individual agents,
4. the language and property right characteristics of institutions, and
5. outcomes.

Some elements that are not observable are:

6. preference orderings,
7. technological (knowledge, human capital) endowments, and
8. agent message behavior $\beta^i(e^i|I)$, I=1, ..., N.

Items 6 through 8 are private and often unrecorded elements and, as a result, are unobserved. Message behavior functions can't be observed because they are preferences which can't be observed.

Smith noted that "the fundamental objective behind a laboratory experiment in economics is to create a manageable microeconomic environment in the laboratory where adequate control can be maintained and accurate measurement of relevant variables guaranteed." He describes ways to operationally handle control, measurement, experimental design, and hypothesis testing within a laboratory experiment.

The methodology calls for controlling the elements of the microeconomic system $S=(e, I)=(u^i, T^i, w^i, M^i, h^i, c^i, g^i)$. A variable is controlled by maintaining it at a constant value, or by setting it at different levels across different experiments, or by setting it at different levels at different points in time within the same experiment. It is then necessary to observe and measure message responses of agents, m^i, and the outcomes h^i and c^i resulting from these messages. Outcomes are measured in order to evaluate the performance of the system S, and messages are measured in order to identify behavioral modes $[\beta^i(e^i|I)]$ by agents and to test hypotheses derived from theories about agent behavior.

Smith identifies a number of "precepts" or set of conditions that constitute sufficient conditions for a valid controlled microeconomic experiment. These precepts are:

Precept 1: Nonsatiation.

> Given a *costless* choice between two alternatives, identical (i.e., equivalent) except that the first yields more of a reward medium than the second, the first will always be chosen (i.e., preferred) over the second, by an *autonomous* individual. (p. 931)

Precept 2: Saliency.

> Individuals are guaranteed the right to claim a reward which is increasing(decreasing) in the goods (bads) outcomes, x^i, of an experiment; individual property rights in messages are to be translated into outcomes are defined by the institution of the experiment. (p. 931)

Precept 3: Dominance.

> The reward structure dominates any subjective costs (or values) associated with participation in the activities of an experiment. (p. 934)

Precept 4: Privacy.

> Each subject in an experiment is given information only on his/her own payoff alternatives. (p. 935)

Precept 5: Parallelism.

> Propositions about the behavior of individuals and the performance of institutions that have been tested in laboratory microeconomies apply also to non-laboratory microeconomies where similar *ceteris paribus* conditions hold. (p. 936)

Nonsatiation and saliency are sufficient conditions for the existence of an experimental microeconomy, that is, motivated individuals acting within the framework of an institution. In order to have a controlled microeconomic experiment, we must have dominance and privacy.

If we are only interested in testing hypotheses derived from theories, precepts 1-4 are enough since they "permit the study of laboratory microeconomic environments in which real economic agents exchange real messages through real property right institutions that yield outcomes redeemable in real money."

Since the laboratory experiment selects participants from the entire socioeconomic system (real world) and motivates them with real money, it is "a far richer and more complex set of circumstances than is parameterized in our theories." As a result, the laboratory experiment deals in abstractions much smaller than those of economic theory, and therefore makes the laboratory a very relevant place for falsifying theory.

With replicable results documented in laboratory experiments, it is now desirable to know if the results are transferable to the field. Parallelism is a sufficient condition for this transferability. The article points out that the appropriate way to falsify the parallelism precept is by showing that some replicable part of a theory or institution in a laboratory experiment can be falsified using field data.

Part III of the paper presents types of microeconomic system experiments. Smith considers only two broad classifications -- functional and methodological. The functional classification of experiments follows directly from the definition of a microeconomic system. The methodological classification is limited to only a few very comprehensive categories which can be readily identified in the experimental economics literature.

Finally, Smith suggests that laboratory research in microeconomics has focused on the simplest questions because very little microeconomic knowledge can be demonstrated. The mystery of economics is how the pricing system works without anyone being in charge. It is a product of culture, but it also makes culture possible. The roots of economics need to be reexamined. There is a need for a body of knowledge that differentiates between theory and discovery.

CITATION: Smith, Vernon L. (1962), "An Experimental Study of Competitive Market Behavior," *Journal of Political Economy*, ***70***, p. 111-137.

RELEVANCE: In this paper Smith defines the basic methodology of experimental economics. It precedes his development of "incentive driven" experimentation methodology (Smith, 1976). This serves as an example of an early, straightforward application of laboratory experimentation.

SUMMARY: An actual auction mechanism used in the commodity markets was implemented in the experiments in this research. The experiments had buyers, sellers, and the experimenter. In the process of an experiment, the buyers in the markets were asked to submit oral bids and the sellers were asked to submit oral offers. The experimenter facilitated all the activities, including acting as an auctioneer, recording all the bids and offers, and confirming when the trades were done. The activities were controlled manually. In the experiments, fourteen students were divided into two equal groups as buyers and sellers. The buyers could not buy at a price higher than its value. The sellers could not sell at a price less than its cost. The buyers' profit was the difference between redemption value and the purchase cost, and the sellers' profit was the difference between the selling price and the cost of the object. Every player was rewarded their profit in real money at the end of the experiment. There were ten experiments conducted. In these experiments, all trades approached optimal or equal trading prices from below. All trades reached these prices closely after three or four periods.

CITATION: Roth, Alvin E., (1988), "Laboratory Experimentation in Economics: A Methodological Overview," *The Economic Journal*, ***98***(393), December, p. 974-1031.

RELEVANCE: This article surveys several sets of experiments to show how series of experiments can be constructed to allow us to draw reliable conclusions. Roth argues that experimentation is not only a sum of facts but is a method of investigation. It is important to know how experiments are conducted, how it is decided what experiments to conduct, and how results are interpreted. The article indicates that computer controlled laboratories are not necessary for economic experiments but can facilitate many kinds of control and record keeping saving both time and energy.

SUMMARY: Laboratory experiments in economics are those in which the economic environment is fully controlled by the experimenter, who has relatively unimpeded access to the subjects. Economists have used experiments to investigate 2-person bargaining. These experiments illustrate the difficulty in creating an environment in which the theories being tested give unambiguous predictions and of controlling or measuring the subjects' preferences. The free rider problem and the prisoner's dilemma have also been studied using experiments, concentrating on both single and repeated decisions. Experiments have been used to study auction behavior, suggesting that the problem can be studied in field data by observing certain qualitative relationships identified in the laboratory setting. Individual choice behavior has been experimentally studied, including from the point of view of expected utility theory.

CITATION: Marimon, Ramon, Stephen E. Spear, and Shyam Sunder, (1993), "Expectationally Driven Market Volatility: An Experimental Study," *Journal of Economic Theory*, ***61***(1), October, p. 74-103.

RELEVANCE: The article discussed that the existence of multiple equilibria in economic models has been a persistent embarrassment to theorists and a source of controversy in the formulation of macroeconomic policy.

SUMMARY: In models of dynamic economies, indeterminacies frequently manifest themselves as so-called sunspot equilibria. In these equilibria, the expectation that extrinsic random events matter becomes self-fulfilling, and causes extrinsic uncertainty to have real allocative effects. A study conducted finds that excess market volatility can be sustained by expectations alone, although subjects must be conditioned to expect cyclic movements in prices before they will consistently forecast such movements. A version of the overlapping generations model is analyzed. The model exhibits a monetary steady-state equilibrium, 2-period cyclic equilibria, and 2-state Markovian sunspot equilibria. The experiment suggests that this phenomenon is more likely to occur if the conditioning events are known to have been associated in the past with market movements.

CITATION: Roth, Alvin E., (1991), "Game Theory as a Part of Empirical Economics," *Economic Journal*, ***101***(404), Jan. p. 107-114.

RELEVANCE: This article states that experimental economics is a fairly new line of research, having originated more or less contemporaneously with game theory. The next step in the development of game theory is to bring to the fore the empirical questions associated with strategic environments. Experimental economics will play a growing role in this effort.

SUMMARY: Game theory has achieved important insights into such issues as the design of contracts and allocation mechanisms. However, if economists do not take steps to add a solid empirical base to game theory, it is likely that, long before a hundred years hence, game theory will have experienced sharply diminishing returns. Empirical work in economics has focused disproportionately on economically important questions. There are many questions for which laboratory experimentation will be the most direct way to test theory and to explore the effects of variables that are difficult to control in any other way.

2.4 Literature Review on Aggregation of Decision Making and Experimental Design

In this section, we review relevant literature on the design, development and implementation of laboratory experiments. We also review the articles on the aggregation of decision making, such as the voting mechanism. The criticism and examination of laboratory experiment as a research tool are also included. All the citations in this section are summarized in Table 2.4.1 at the end of this chapter.

CITATION: Gardner, C., Marsden, J. R., and D. Pingry, (1993) "The design and use of laboratory experiments for DSS evaluation," *Decision Support Systems*, *9*(4), p. 369-379.

RELEVANCE: This article implemented induced value laboratory experiments involving individual subjects facing decision on determination of production level. These individual experiments formed a basic pattern that we extended to a group decision making setting.

SUMMARY: In an individual decision making setting, subjects had the opportunity to purchase expert forecasts. Forecasts had to be purchased in order with each forecast yielding a more accurate (but more costly) predictions. Optimal search patterns based upon maximization of expected monetary return were obtained for each game structure. The key issue addressed was whether or not subjects who paid for information and who were rewarded based upon their performance would identify the optimal search pattern. The consistent pattern observed was that subjects did approach an optimal search as the number of iterations increased. Further, in experiments with a larger number of expert forecasts available, subjects actually performed closer to the optimal information search. A striking and consistent result was that subjects approached the optimum from below, that is, they did not oversearch. The results provide evidence contrary to popularly held views that as individuals are faced with increasing amounts of information they will tend to search more and will oversearch. A key factor in the experiments appears to have been that subjects had to pay both to search information and for the time taken in searching.

CITATION: Sol, Henk G., (1985), "Aggregating Data for Decision Support," *Decision Support Systems*, ***1***(2), April, p. 111-121.

RELEVANCE: A simulation analysis of decision making in a hypothetical multi-divisional firm suggests that global decision effectiveness will be damaged by the use of aggregated local decision data.

SUMMARY: Frequently, decision models incorporating definitions or behavioral equations and based on aggregated data are used to support decision-making coordination throughout an organization, particularly for strategic and tactical planning. The simulation analysis performed in this study calls into question the validity of aggregated management information. Decision support systems should incorporate system description and simulation to improve model problem-solving environments. Through simulation-based DSS, the effects of global decisions can be disaggregated to assess their local-level impacts, allowing for better decision-making coordination.

CITATION: Beauclair, Renee A., (1989), "An Experimental Study of GDSS Support Application Effectiveness," *Journal of Information Science Principles & Practice*, ***15***(6), p. 321-332.

RELEVANCE: This study examines the effect of two computerized applications - voting-rating and brainstorming - on small decision-making groups.

SUMMARY: A theoretical rationale for predictive hypotheses based on social psychological theories of small group interaction is developed, and an experimental design to test the hypotheses is presented. Four sets of small groups receive different treatments. Group level dependent variables are decision time and quality of decision. Individual level dependent variables are quality of interaction, proclivity to participate, and attitude toward decision. The individual dependent variables are analyzed using the MANOVA procedure, while the group dependent variables are analyzed using the Kruskal-Wallis procedure. With alpha set at 0.05, no significant results were found for any of the analyses.

CITATION: Dobbins, Gregory H., Irving M. Lane, and Dirk D. Steiner (1988), "A Note on the Role of Laboratory Methodologies in Applied Behavioural Research: Don't Throw out the Baby with the Bath Water" *Journal of Organizational Behavior*, ***9***, p. 281-286.

RELEVANCE: This article refuted several criticisms of laboratory research. It refuted the "artificiality" criticism by arguing that "a well-conducted and meaningful laboratory study allows an investigator to make stronger statements concerning cause and effect relationships between theoretical constructs than usually can be made in field research."

SUMMARY: An examination of the purpose of research, the use of college students as subjects, and the use of artificial experimental procedures shows that: 1. laboratory research with undergraduates does have external validity, and 2. laboratory experiments are useful in testing theoretical predictions and increasing understanding of organizational behavior. Basing rewards wholly or partially on subjects used would cause a decline in laboratory research, which is a powerful tool for testing work behavior theories. The choice of research strategy should be based on the purpose of the research and on the researcher's preference or orientation.

CITATION: Steckel, Joel H, (1990), "Committee Decision Making in Organizations: An Experimental Test of the Core," *Decision Sciences*, ***21***(1), p. 204-215.

RELEVANCE: The applicability of experiments on predicting the outcome of majority-rule voting committees to organizations is limited by a set of rigid controls intended to ensure that these experiments are internally valid. A concept is tested in a laboratory experiment that relaxes these controls.

SUMMARY: The Core is a concept that has been widely supported in experiments on predicting the outcome of majority-rule voting committees. The Core is a set of alternatives that cannot be defeated by any other in a binary contest. It is shown that the applicability of these experiments to organizations is limited by a set of rigid controls intended to ensure that these experiments are internally valid. The Core is tested in a laboratory experiment that relaxes these controls. The Core is found to be highly predictive under these relaxed conditions, thereby enhancing confidence in its external validity. Future research directions should include empirical investigation of models under decision structures other than simple majority rule.

CITATION: Hoffman, Elizabeth and J. R. Marsden, (1986), "Testing Informational Assumptions in Common Value Bidding Models" *Scandinavian Journal of Economics*, *88*(4), p. 627-641.

RELEVANCE: This article provided an example of a means of linking mathematical theory, laboratory experiments, and standard empirical work.

SUMMARY: It is argued that theories, by necessity, must abstract from the naturally occurring environment, and experiments designed to test theories must incorporate those abstractions. However, empirical tests are generally performed on naturally occurring data, which may not reflect those same abstractions. The proposed methodology is applied to US data on offshore oil leasing to investigate whether the signals that firms use in bidding decisions are unbiased in relation to the underlying distribution of leased plots that later actually produced oil. The results strongly suggest that bidders who have similar risk characteristics and who make many bids do so on the basis of information that is unbiased relative to the actual distribution of productive wells. Some small bidders consistently bid on producing wells, while others consistently bid on nonproducing wells. The results also suggest that experiments can be used to examine the usefulness of existing theory and experiments can be used to test and refine theory as it is developed.

CITATION: Lind, Barry and Charles R. Plott, (1991), "The Winner's Curse: Experiments with Buyers and with Sellers," *American Economic Review*, ***81***(1), March, p. 335-346.

RELEVANCE: The experiments produced the following results: 1. the winner's curse was observed in both experimental settings, 2. the winner's curse observed by Kagel and Levin (1986) was not a consequence of their experimental procedures, 3. the winner's curse might diminish in size or frequency but does not completely dissipate over time, and 4. the winner's curse is a general phenomenon exhibited by most agents.

SUMMARY: Kagel and Levin's (1986) and Dyer, Kagel, and Levin's (1989) experiments with the winner's curse were replicated and extended. The phenomenon was sought using procedures that avoid the bankruptcy problems. The winner's curse experiment in which subjects might lose money was conducted simultaneously with a second experiment in which subjects were making money. A second set of procedures involved competitors as sellers in a common-value auction. In addition to the results listed above in the

"RELEVANCE" part, Lind and Plott indicate that theories of suboptimal behavior advanced as explanations of the phenomenon do not explain the data as well as does the completely rational model in which the phenomenon does not exist at all theoretically.

CITATION: Ramanathan, R. and L. S. Ganesh, (1994), "Group Preference Aggregation Methods Employed in AHP: An Evaluation and an Intrinsic Process for Deriving Members' Weightages," *European Journal of Operational Research*, *79*(2), December 8, p. 249-265.

RELEVANCE: The analytical hierarchy process (AHP) is one of the popular techniques for decision making and decision aggregation. A simple and intuitively appealing eigenvector-based method to intrinsically determine the weightages for group members using their own subjective opinions is proposed.

SUMMARY: A detailed survey of the literature revealed that there exists no formal evaluation of the group preference aggregation methods currently employed in AHP. Such an evaluation is provided using well established social choice axioms, which govern the process of combining individual opinions to obtain a single group opinion. The geometric mean method (GMM) and the weighted arithmetic mean method are the two methods evaluated. It is shown, using counter-examples, that the GMM does not always satisfy the Pareto optimality axiom, which is one of the prominent and widely accepted social choice axioms. This finding is significant as the

GMM has been the most commonly used method in AHP for combining individual opinions to form a group opinion. A simple and intuitively appealing eigenvector-based method to intrinsically determine the weightages for group members using their own subjective opinions is proposed. The superiority of the proposed method over the previous methods is brought out.

2.5 Literature Review on Organizational Issues in Distributed Decision Aggregation

Different organizations have different information needs and different decision-making hierarchies. Marsden and Pingry [1988a] discussed the need to test whether or not advances in information technology would drive successful competitive firms toward more complex, flexible, and adaptable organizational structures. This argument is stressed again in Marsden, Pingry, and Wang [1992].

As we had pointed out in Chapter 1, researchers in organizational science recognized information processing as an integral organizational element. To date, however, their examples and analyses have covered only observations of existing firms and structures. Here we review the relevant articles in organizational issues related to our study and also summarize them in Table 2.5.1 at the end of the chapter.

CITATION: Ouchi, William. G. (1980). "Markets, Bureaucracies, and Clans," *Administrative Science Quarterly*, *25*(1), March, p. 129-141.

RELEVANCE: Evaluating organizations according to an efficiency criterion would make it possible to predict the form organizations will take under certain conditions. The transactions cost approach provides a framework for describing organizational efficiency in microscopic terms.

SUMMARY: Organization theory has not developed an efficiency criterion because it has lacked a conceptual scheme capable of describing organizational efficiency in sufficiently microscopic terms. The transactions cost approach provides such a framework because it permits identification of the conditions which give rise to the costs of mediating exchanges between individuals: goal incongruence and performance ambiguity. Different combinations of these causes distinguish three basic mechanisms of mediation or control: 1. markets, which are efficient when performance ambiguity is low and goal incongruence is high; 2. bureaucracies, which are efficient when both goal incongruence and performance ambiguity are moderately high; and 3. clans, which are efficient when goal incongruence is low and performance ambiguity is high.

CITATION: Williamson, Oliver E. (1981a), "The Modern Corporation: Origins, Evolution, Attributes," *Journal of Economic Literature*, *19*(4), December, p. 1537-1568.

RELEVANCE: In the transaction-cost approach presented in this analysis, structural differences are assumed to arise primarily to promote economy in transaction costs.

SUMMARY: The neoclassical theory of the firm maintains that the corporation's structural features are irrelevant and describes the firm as a production function with a profit maximization objective. Distinctive structural features of the corporation are believed to be the result of unwanted (anti-competitive) intrusions into market processes. The application of the transaction-cost approach requires: 1. the transaction be the principal unit of analysis, 2. an appreciation of human nature, 3. transactions dimensionalized, 4. rudimentary principles of market and hierarchical organization be recognized, and 5. the guiding principle be the hypothesis that transactions are assigned to and organized within governance structures in a discriminating way. A succession of organizational innovations occurring over the past 150 years, out of which the modern corporation emerged, is examined and explained by the hypothesis of transaction cost.

CITATION: Ciborra, C. U., (1985), "Reframing the Role of Computers in Organizations: The Transaction Costs Approach," *Proceedings of the International Conference on Information Systems*, p. 57-69.

RELEVANCE: This paper proposed a more realistic approach to the analysis and design of information systems. It discussed the potential use of Williamson's [1975, 1981b] transaction costs approach in analyzing the role of computers in organizations.

SUMMARY: Organizations are seen as networks of contracts which govern exchange transactions between members having only partially overlapping goals. Conflict of interests is explicitly admitted to be a factor affecting information and exchange costs. Information technology is seen as a means to streamline exchange transactions, thus enabling economic organizations to operate more efficiently. Examples are given of MIS, data base and office automation systems, where both the organization and its information system were jointly designed.

CITATION: Williamson, Oliver E., (1991), "Comparative Economic Organization: The Analysis of Discrete Structural Alternatives," *Administrative Science Quarterly*, *36*(2), June, p. 269-296.

RELEVANCE: In this article, institutional economics is combined with aspects of contract law and organization theory to identify and explain the key differences that distinguish three generic forms of economic organization: 1) market, 2) hybrid, and 3) hierarchy.

SUMMARY: The three generic forms are shown to be distinguished by different coordinating and control mechanisms and by different abilities to adapt to disturbances. Each generic form is supported and defined by a distinctive type of contract law. The cost-effective choice of organization form is shown to vary systematically with the attributes of transactions. Two disjunct areas of institutional economics - the institutional environment and the institutions of governance - are unified by treating the institutional environment as a locus of parameters, changes in which parameters bring about shifts in the comparative costs of governance. Changes in property rights, contract law, reputation effects, and uncertainty are investigated.

CITATION: Marsden, J. R. and D. E. Pingry, (1988a), "The Intelligent Organization: Some Observations and Alternative Views," *Proceeding of the Twenty-First Annual Hawaii International Conference on System Sciences, Vol. III*, p. 19-24.

RELEVANCE: In order to survive, the economically intelligent firm must select a technically efficient and cost efficient machine-manual process mix. Technical efficiency exists when a given machine-manual mix is used to the fullest or to the "production frontier." Cost efficiency exists when the least cost combination of machine and manual processes is selected for providing a given level of production.

SUMMARY: It is argued that the survivability of a firm cannot be measured by any index relating only to its use of communications/computer (CC) technology or any other limited subset of inputs. The success of the firm is a function of the overall quality of its production input choices. Predictions about the organizational design characteristics of the "firm of the future" must make assumptions about the market environment in which these firms will be operating. Relative prices, demand conditions, and other macro and micro market relationships all can impact the "firm of the future's" optimal input mix choice. Any general predictions about the organizational characteristics of the "firm of the future" rely upon the accuracy of the implicit assumption that market conditions will be the same for all firms and the implicit assumption that the CC technology advances can only facilitate certain organizational forms.

CITATION: Marsden, J. R., D. E. Pingry, and M. C. Ken Wang, (1992), "An Experimental Approach to Intelligent Organizational Design," *Journal of Organizational Computing*, *2*, p. 225-242.

RELEVANCE: The authors argue that the intelligent firm must understand the relationship between its structure, its production inputs, and its productivity. When market and technological conditions dictate that a change in structure is optimal, the intelligent and successful firm will change. Carefully structured and controlled laboratory experiments provide an excellent source for obtaining the knowledge necessary for organizations to strategically adapt.

SUMMARY: Advances in communication/computer technology make it easier to use laboratory experiments as a methodological approach to achieve various research objectives. The article suggested that the reward payment based on subject performance is a key control in experimentation and used an example experiment with a fixed, hierarchical organization facing uncertain market demand for its single product to illustrate the methodology the authors suggested for use in analyzing organization structure. This illustrated how such experiments can be used in determining the relationships between organizational forms and information system constructs and in analyzing what mixes yield maximum performance in decision theoretic and game theoretic settings.

CITATION: Zeffane, Rachid, (1994), "Utility Theory and Organization Design: The Usefulness of Indifference Curves for Structural Control," *American Business Review*, *12*(1), January, p. 66-75.

RELEVANCE: THe author articulates that utility theory in general, and its indifference curves postulate in particular, could assist in explaining organization design choices and options.

SUMMARY: Structural control, and its concomitant organization design options, revolves around choices along the centralization/formalization continuum. Indifference curve analysis is an alternative method of demonstrating the concepts of consumer equilibrium in microeconomics theory. Organizations may face structural control options on a continuum of trade-offs between varying degrees of centralization and formalization. Here, the indifference curves approach helps in transcribing the notion of purposive structural choices by individuals in the real world of organizations. The approach can also help provide better clues to the positioning of the size effects in a fundamental trade-off paradigm and illuminate discontinuities and quantum moves.

Table 2.2.1. Summary of Literature Review on Distributed Decision Making

Author(s) (Year)	Title	Relevance
Holsapple, Jarvenpaa, Marsden, and Whinston (1989)	"A Coordination Theory for Distributed Decision Making"	In distributed decision making (DDM), multiple entities (e.g., persons, group, computer systems) who are capable of playing various roles commit to performing specific problem-solving tasks relevant to the support of concurrently pending decisions.
Burns, Rathwell, and Thomas (1987)	"A Distributed Decision-Making System"	DDM extends the decision support system (DSS) concept to one that enables two or more decision-making parties to cooperate in employing DSS tools.
Scher (1981)	"Distributed Decision Support Systems for Management and Organizations"	Coined the term *distributed decision support system* when he discussed the implications of including communication support within DSS.
Swanson (1990)	"Distributed Decision Support Systems: A Perspective"	Defines a distributed decision support system (DDSS) as a decision support system which supports distributed organizational decision making.
Holsapple and Whinston (1988)	"Distributed Decision Making: A Research Agenda"	DDM requires an effective coordination of individual problem solving activities in the interest of solving larger problems than any one individual is capable of solving individually. Thus, DDM is based on the three elements of individual problem solving, communication, and coordination. They propose the knowledge-based organizations (KBO) framework for DDM.
Bonczek, Holsapple, and Whinston (1981)	*Foundations of Decision Support Systems*	The book introduces a formal, generic description of decision support systems that views a DSS as having three principal components: a language system, a knowledge system, and a problem-processing system.
Burns, Rathwell, and Thomas, (1987)	"A Distributed Decision-Making System"	A message-based model of a distributed decision making (DDM) system is proposed. Although the model of DDM is distributed, physical distribution was not attempted in the prototype.

Author(s) (Year)	Title	Relevance
Huber (1984b)	"The Decision-Making Paradigm of Organizational Design"	A group decision support system (GDSS) has hardware, software, language components and procedures that support a group of people, in a decision related meeting.
DeSanctis and Gallupe (1985b)	"GDSS: A Brief Look at a New Concept in Decision Support"	Defines GDSS as an interactive computer-based system that facilitates the solution of unstructured problems by a set of decision makers working together as a group.
Sutherland and Crosslin (1989)	"Group Decision Support Systems: Factors in a Software Implementation"	The need for GDSS is highlighted by the identification of a phenomenon in organizational behavior: networked organizations. By allowing individuals within and across organizations to share tasks through communication links, new networked organizations are being established.
Kraemer and King (1988a)	"Computer-Based Systems for Cooperative Work and Group Decision Making"	A GDSS involves a group of decision makers with access to a computer, viewing screen, database, decision model(s), and a 'facilitator' who supports the group in use of the technology, instructs them on the use of the decision model, coordinates the group's activity, and documents the group's work. Therefore, it is useful to conceive of GDSS's as a sociotechnical "package" comprised of (1) hardware, (2) software, (3) organizationware, and (4) people.
Jacob and Pirkul (1992)	"A Framework for Supporting Distributed Group Decision-Making"	A distributed group decision support system (DGDSS) is presented that would facilitate the exchange of information and expertise between group members without the need for a meeting or direct communication.
Turoff, et. al. (1993)	"Distributed Group Support Systems"	Five case studies of different distributed group support systems developed over the last decade to support different types of tasks and to accommodate fairly large numbers of participants (tens to hundreds) are presented.

Table 2.3.1. Summary of Literature Review on Experimental Economics

Author(s) (Year)	Title	Relevance
Hoffman, Marsden, and Whinston (1990)	"Laboratory Experiments and Computer Simulation: An Introduction to the Use of Experimental and Process Model Data in Economic Analysis"	This article pointed out the following key advantages of using laboratory experiments: 1. the laboratory provides a controlled economic environment, which allows the researcher to directly manipulate preferences and institutions; and 2. laboratory experiments allow testing economic theories within the context of an environment that closely parallels the theoretical environment.
Smith (1976)	"Experimental economics: Induced value theory"	Smith introduces the induced value theory into experimental economics in this concise article.
Smith (1982)	"Microeconomic Systems as an Experimental Science"	Smith defines the nature of a microeconomic system theory and a methodology of laboratory experimentation. The important message of this paper is that laboratory microeconomies are real live economic systems, which are certainly richer, behaviorally, than the systems parameterized in our theories. A number of "precepts" or set of conditions that constitute sufficient conditions for a valid controlled microeconomic experiment are introduced. These precepts are nonsatiation, saliency, dominance, privacy, and parallelism.
Smith (1962)	"An Experimental Study of Competitive Market Behavior"	The basic methodology of experimental economics is defined. This article preceded the author's development of "incentive driven" experimentation methodology and served as an example of an early, straightforward application of laboratory experimentation.
Roth (1988)	"Laboratory Experimentation in Economics: A Methodological Overview"	This article surveyed several sets of experiments to show how series of experiments can be constructed to allow us to draw more reliable conclusions. The article indicates that computer controlled laboratories are not necessary for economic experiments but can facilitate many kinds of control and record keeping hence save a lot of time and energy.
Marimon, Spear, and Sunder (1993)	"Expectationally Driven Market Volatility: An Experimental Study"	The article discussed that the existence of multiple equilibria in economic models has been a persistent embarrassment to theorists and a source of controversy in the formulation of macroeconomic policy.

Author(s) (Year)	Title	Relevance
Roth (1991)	"Game Theory as a Part of Empirical Economics"	This article states that experimental economics is a fairly new line of research, having originated more or less contemporaneously with game theory. The next step in the development of game theory is to bring to the fore the empirical questions associated with strategic environments. Experimental economics will play a growing role in this effort.

Table 2.4.1. Summary of Literature Review on Aggregation of Decision Making and Experimental Design

Author(s) (Year)	Title	Relevance
Sol (1985)	"Aggregating Data for Decision Support"	A simulation analysis of decision making in a hypothetical multidivisional firm suggests that global decision effectiveness will be damaged by the use of aggregated local decision data.
Beauclair (1989)	"An Experimental Study of GDSS Support Application Effectiveness"	This study examines the effect of two computerized applications - voting-rating and brainstorming - on small decision-making groups.
Dobbins, Lane, and Steiner (1988)	"A Note on the Role of Laboratory Methodologies in Applied Behavioural Research: Don't Throw out the Baby with the Bath Water"	This article refuted several criticisms of laboratory research. It argued that a well-conducted and meaningful laboratory study allows an investigator to make stronger statements concerning cause and effect relationships between theoretical constructs than usually can be made in field research.
Gardner, Marsden, and Pingry (1993)	"The design and use of laboratory experiments for DSS evaluation"	Induced value laboratory experiments involving individual subjects facing decision on determination of production level. These individual experiments formed a basic pattern that we extended to a group decision making setting.
Hoffman and Marsden, (1986)	"Testing Informational Assumptions in Common Value Bidding Models"	This article provided an example of a means of linking mathematical theory, laboratory experiments, and standard empirical work.
Lind and Plott (1991)	"The Winner's Curse: Experiments with Buyers and with Sellers"	The experiments produced the following results: 1. The winner's curse was observed in both experimental settings. 2. The winner's curse observed by Kagel and Levin (1986) was not a consequence of their experimental procedures. 3. The winner's curse might diminish in size or frequency but does not completely dissipate over time. 4. The winner's curse is a general phenomenon exhibited by most agents.

Author(s) (Year)	Title	Relevance
Steckel (1990)	"Committee Decision Making in Organizations: An Experimental Test of the Core"	The applicability of experiments on predicting the outcome of majority-rule voting committees to organizations is limited by a set of rigid controls intended to ensure that these experiments are internally valid. A concept is tested in a laboratory experiment that relaxes these controls.
Ramanathan and Ganesh (1994)	"Group Preference Aggregation Methods Employed at AHP: An Evaluation and an Intrinsic Process for Deriving Members' Weightages"	The analytical hierarchy process (AHP) is one of the popular and powerful techniques for decision making and decision aggregation. We review this recent paper. A simple and intuitively appealing eigenvector-based method to intrinsically determine the weightages for group members using their own subjective opinions is proposed.

Table 2.5.1. Literature Review on Organizational Issues in Distributed Decision Aggregation

Author(s) (Year)	Title	Relevance
Ouchi (1980)	"Markets, Bureaucracies, and Clans"	Evaluating organizations according to an efficiency criterion would make it possible to predict the form organizations will take under certain conditions. The transactions cost approach provides a framework in describing organizational efficiency in sufficiently microscopic terms.
Williamson (1981a)	"The Modern Corporation: Origins, Evolution, Attributes"	In the transaction-cost approach presented in this analysis, structural differences are assumed to arise primarily to promote economy in transaction costs.
Ciborra (1985)	"Reframing the Role of Computers in Organizations: The Transaction Costs Approach"	This paper proposed a more realistic approach to the analysis and design of information systems. It discussed the potential use of Williamson's (1975, 1981b) transaction costs approach in analyzing the role of computers in organizations.
Marsden and Pingry (1988a)	"The Intelligent Organization: Some Observations and Alternative Views"	In order to survive, the economically intelligent firm must select a technically efficient and cost efficient machine-manual process mix. Technical efficiency exists when a given machine-manual mix is used to the fullest or to the "production frontier." Cost efficiency exists when the least cost combination of machine and manual processes is selected for providing a given level of production.
Marsden, Pingry, and Wang (1992)	"An Experimental Approach to Intelligent Organizational Design"	When market and technological conditions dictate that a change in structure is optimal, the intelligent and successful firm will change. Carefully structured and controlled laboratory experiments provide an excellent source for obtaining the knowledge necessary for organizations to strategically adapt. Experiments with reward payments based on subject performance can be used in determining the relationships between organizational forms and information system constructs and in analyzing what mixes yield maximum performance in decision theoretic and game theoretic settings.

Author(s) (Year)	Title	Relevance
Williamson (1991)	"Comparative Economic Organization: The Analysis of Discrete Structural Alternatives"	In this article, institutional economics is combined with aspects of contract law and organization theory to identify and explicate the key differences that distinguish 3 generic forms of economic organization: 1. market, 2. hybrid, and 3. hierarchy.
Zeffane (1994)	"Utility theory and organization design: The usefulness of indifference curves for structural control"	It is articulated that the utility theory in general, and its indifference curves postulate in particular, could assist in explaining organization design choices and options.

Chapter 3

GROUP DECISION AGGREGATION IN DISTRIBUTED DECISION SUPPORT

3.1 Introduction

In this chapter we lay out in detail the technical structure and methodology of our decision aggregation framework. In section 3.2 we discuss the managerial decision making. The decision aggregation variables that are operationalized in our controlled laboratory experimentation shell are set out in section 3.3. In section 3.4 we detail the forms of our experimental shell. The prototyping process is reviewed and the screen layouts for the manager's and the subordinates' workstations are displayed.

3.2 Managerial Decision Making

As we noted in our introductory remarks in Chapter 1, decision processes in modern firms often involve inputs from many individuals. This is especially so for multinational firms operating in a global economy. Yet we have found little structured, scientific investigation of the relationships between decision processes (including aggregation techniques) in multiple input settings and decision quality. As we detail below, controlled laboratory experiments offer us a flexible tool set for such analyses.

Though lacking in structured analysis, the works of several previous authors do provide summaries that can serve as starting points for our analysis. Vroom and Yetton

[1973] identified five methods that managers might utilize in differing decision situations:

i) manager makes decision alone using the information available at that time;
ii) manager obtains necessary information from subordinates, then makes decision. Subordinates provide information, but are not involved in evaluating alternatives;
iii) manager shares the decision problem with subordinates, obtaining data and suggestions. The manager makes decision which may or may not reflect subordinates' inputs;
iv) manager shares the problem with subordinates as a group, obtaining their collective ideas and suggestions. Manager makes the decision which, again, may or may not reflect subordinates' inputs; and
v) manager shares problems with subordinates as a group. Together they generate and evaluate alternatives and reach agreement (consensus) on solution.

Rowe and Boulgarides [1992] offered a quite similar list of alternative ways that a decision maker can "decide to decide":

i) make the decision alone (and not inform subordinates);
ii) make the decision alone and inform subordinates;
iii) consult subordinates before making decision;
iv) consult other managers before making decision;
v) utilize subordinates for input to the decision; and
vi) make the decision jointly with subordinates.

The choice between decision processes was addressed in Maier [1963]. While not fully operationalizing key terms, Maier did suggest the following factors for choosing between differing decision processes:

i) effectiveness of decision;
ii) quality required in decision;
iii) acceptance of decision; and
iv) time taken to make decision.

Vroom and Yetton, cited above, also offered their version of a list of factors to consider when choosing among decision processes:

i) importance of the quality of the decision;
ii) extent to which the manager possesses the information or expertise to make a high quality decision;
iii) extent to which subordinates have the information necessary to generate a high quality decision;
iv) extent to which a problem is structured;
v) extent to which acceptance or commitment on the part of the subordinates is critical to the effective implementation of the decision;
vi) probability that manager's decision will be accepted by subordinates;
vii) extent to which subordinates are motivated to achieve organizational goals; and
viii) extent to which subordinates are likely to be in conflict over preferred solutions.

Such lists, while perhaps emoting sensations of agreement or disagreement, provide no basis for action. They do not provide reliable information on how well differing mechanisms perform on alternative decision problems. Our purpose here is not to argue the strength of any such list or to discuss elements of agreement emoted by the verbal descriptions of the decision processes or evaluation of those processes. Rather, we seek to structure a mechanism to formally investigate specific decision processes in specific decision problem settings. To do so, we need to put sufficient controls into place to insure that what we measure relates to what is under study. We begin with analyses of uncomplicated decision problems and non-complex decision mechanisms. We then work to build on these analyses to structure studies of more complex decision and input aggregation processes.

In the preceding chapter, we carefully summarized a key set of literature from the area of experimental economics. Our investigatory process makes direct use of the induced value approach, adapting to the controlled laboratory approach to a form appropriate for studying alternative decision making processes, input aggregation techniques, and individual incentive mechanisms.

The scenario of our study is decision making under uncertainty. In such a setting, one knows the options available, but cannot determine precise final outcomes because of uncertainty as to which state of nature will occur. One rather straightforward example of such a setting is where we are faced with choosing one level of production (low, medium, or high) but are uncertain as to the level of demand (low, medium, or high) for that production (Ahituv and Wand 1984). A decision making manager might attempt to analyze all information himself, making an individual decision based on this analysis. Alternatively, the manager may look to subordinates (marketing staff, sales staff, company forecasters) for various inputs, then makes the decision individually. A third option might involve the manager relying upon inputs or recommendations from subordinates and then utilizing a predetermined aggregation mechanism for mapping these inputs into a decision choice. In each setting, we might also study the impact of various individual incentive mechanisms (manager incentives, subordinate incentives) on the decision outcome.

To perform such analyses we need a platform which is flexible enough to incorporate a variety of combinations of decision problems, decision making process, and incentive mechanism alternatives. We began our development of this platform using the pioneering work of Gardner [1991], and Gardner, Pingry, and Marsden [1993]. These efforts focused on individual decision making under uncertainty and involved analyses of the ability of individuals to optimally search through a set of information signals (with differing reliability) and to optimally react to differing incentive mechanisms. In their experimentation, costs were charged both for information searched and for time taken to make a decision. Decision quality was measured as "profit realized" and determined using a set of mappings related to the correspondence of decision choice and state of nature. One of the key issues addressed was whether or not subjects who paid for information and who were rewarded based upon their performance would identify the optimal search pattern. The consistent pattern observed was that subjects did approach optimal searches as the number of iterations increased. Further, in experiments with a larger number of expert forecasts available, subjects actually performed closer to the optimal information search. A striking and consistent result was that subjects approached the optimum from below, that is, they did not oversearch. The results provide evidence contrary to popularly held views that as individuals are faced with increasing amounts of information they will tend to search more and will oversearch. A key factor in the experiments appears to have been that subjects had to pay both to search information and for the time taken in searching.

3.3 Operationalization

We began by developing a prototype implementing collaborative group decision making processes. The setup has a manager relying upon inputs from subordinates. The manager then utilizes a predetermined aggregation mechanism for mapping these inputs into a decision choice.

To operationalize our framework, we introduce a tuple of platform variables as follows:

Principal, P, is the manager who makes the final decision in our experiment.

Agents, α_i, are the subordinates who submit inputs or recommendations to the manager. A group of agents is denoted by $\alpha = (\alpha_1, \alpha_2, \ldots, \alpha_{|\alpha|})$.

An incentive mechanism, I^m, exists for the manager.

An incentive mechanism, I^s, exists for the subordinates.

An aggregation method, A, exists, having been selected by the manager.

We define our experimental platform, denoted by E, as a five-tuple:

$$E = \{ P, \alpha, I^m, I^s, A \}$$

In experiments, two forms of manager are used, a human manager and a machine manager. In the case of machine manager we automate the functions of the manager. That is, the experimental software uses a predetermined aggregation method to make a production level decision after all subordinates have submitted recommendations or when the decision time for subordinate inputs expires. When a human manager is in place, the system prompts the manager with the recommendation calculated according to a specified aggregation mechanism. The manager then makes the final decision by following the recommendation or acting on his/her instinct.

The number of agents, or subordinates, ranges from three to six persons. Typically groups vary in their degree of homogeneity in characteristics such as educational background. For example, one group may consist of subjects recruited from MBA classes. Another group may have a mix of MBA students and undergraduate upper-division students.

Our experimental platform provides the means to analyze numerous distinct incentive mechanisms. The mechanisms used in this study are presented in detail in Chapter 4. In the initial experiments the same payoff (profit) matrix is used for manager and subordinates, that is, $I^m = I^s$. An individual's profit or loss is tied only to the individual's own performance. In subsequent experiments, the payoff for subordinates is a function of the manager's profit, that is, the profit or loss of subordinates is tied to the performance of the manager. Our experiments used the majority vote as an aggregation method. Key components of our platform include:

DL a finite set of demand levels, i.e., actual sales, $DL = \{ dl_1, dl_2, ..., dl_{|DL|} \}$. These are the *events* which might occur. In this study $DL = \{ L, M, H \}$, where L, M, and H denote *low*, *medium*, and *high* demand levels respectively.

IL a finite set of input levels, $IL = \{ il_1, il_2, ..., il_{|IL|} \}$. These are the recommendations the subordinates submit to the manager. In our experiments $IL = \{ L, M, H \}$, where L, M, and H denote *low*, *medium*, and *high* input levels respectively.

PL a finite set of production levels, $PL = \{ pl_1, pl_2, ..., pl_{|PL|} \}$. These are the *actions* the manager might take after receiving inputs from the subordinates. Here, $PL = \{ L, M, H \}$, where L, M, and H denote *low*, *medium*, and *high* production levels respectively.

SG a predetermined set of information signals, $SG = \{ sg_1, sg_2, \ldots, sg_{|SG|} \}$. These are the signals of production level provided to the subordinates when they purchase the information systems. In our experiments, $SG = \{ L, M, H \}$, where L, M, and H denote signals of *low*, *medium*, and *high* demand levels respectively.

π *a priori* probability vector. This is the prior probability of demand levels, i.e., the prior occurrences of market demand.

$$\pi = \begin{bmatrix} \pi_1 \\ \pi_2 \\ \cdot \\ \cdot \\ \cdot \\ \pi_{|\pi|} \end{bmatrix} = \begin{bmatrix} \pi_L \\ \pi_M \\ \pi_H \end{bmatrix}$$

in this study, where π_L, π_M, and π_H denote the prior probabilities of *low*, *medium*, and *high* levels of demand respectively. If $\pi_L = \pi_M = \pi_H$, then the market is called neutral, otherwise it is called a biased market.

IS information structure matrix. This provides the reliability of the forecasting information systems available to the subordinates for purchasing. The element $IS_{dl,sg}$ designates the probability that a demand level (actual sales), dl, results in an information signal sg.

PM profit matrix for manager. This is one of the forms of incentive mechanism for manager. ***PM***: $DL \times PL \rightarrow R$ (R is the real number set), whose element $PM_{pl,dl}$ is profit being gained by taking an action (making production level decision) *pl* at the occurrence of an event (demand level) *dl*.

PS payoff array for subordinates. This is one of the forms of incentive mechanism for subordinates. ***PS***: $DL \times PL \times IL \rightarrow R$ (R is the real number set), whose element $PS_{il,\, pl,\, dl}$ is the payoff gained by submitting an input *il* to help manager make a production level decision, *pl*, at the occurrence of an event (demand level) *dl*. ***PS*** can be viewed as a tensor of rank 3. Several schemes of subordinate payoffs are used in the experiments and discussed in detail in Chapter 4.

DR decision rule matrix for subordinates, whose element $DR_{sg,il}$ designates the probability that action *il* is taken after signal *sg* has been observed. It may vary across time.

The information structure ***IS*** is a stochastic matrix whose elements are non-negative and for which each row sums to one. For our 3-level working model, the 3x3 matrix is:

$$\boldsymbol{IS} = \begin{bmatrix} IS_{L,L} & IS_{L,M} & IS_{L,H} \\ IS_{M,L} & IS_{M,M} & IS_{M,H} \\ IS_{H,L} & IS_{H,M} & IS_{H,H} \end{bmatrix}$$

where the first subscript is an actual demand level *dl* and the second subscript is information signal *sg*. For the experiments, a number of unique ***IS*** matrices are created by assigning different values to $IS_{i,j}$ with the restriction that

$$0 \le IS_{i,j} \le 1 \text{ and } \Sigma_j IS_{i,j} = 1.$$

A specific information system matrix, say $\boldsymbol{IS}^p$, is said to be more reliable than another matrix $\boldsymbol{IS}^q$ if

$$\text{for all } I,\ IS^p_{i,i} \ge IS^q_{i,i} \text{ and}$$

$$\text{for all } I, j,\ I \ne j,\ IS^p_{i,j} \le IS^q_{i,j}$$

For example, consider the following three rank-ordered information matrices:

$$\boldsymbol{IS}^1 = \begin{bmatrix} .85 & .10 & .05 \\ .10 & .80 & .10 \\ .05 & .10 & .85 \end{bmatrix} \quad \boldsymbol{IS}^2 = \begin{bmatrix} .70 & .25 & .05 \\ .20 & .60 & .20 \\ .05 & .25 & .70 \end{bmatrix} \quad \boldsymbol{IS}^3 = \begin{bmatrix} .34 & .33 & .33 \\ .33 & .34 & .33 \\ .33 & .33 & .34 \end{bmatrix}$$

Applying the reliability concept, we say that $\boldsymbol{IS}^1$ is more reliable than $\boldsymbol{IS}^2$ and $\boldsymbol{IS}^2$ is more reliable than $\boldsymbol{IS}^3$. In another word, $\boldsymbol{IS}^1$ is relatively accurate, $\boldsymbol{IS}^2$ is more obscure but still distinguishes between the demand level, $\boldsymbol{IS}^3$ is practically equivalent to not having any information. A complete listing of information structure matrices used in the experiments is shown in Appendix F.

The experiments use five *a priori* probability vectors. They are:

$$\pi^1 = \begin{bmatrix} 1/3 \\ 1/3 \\ 1/3 \end{bmatrix} \quad \pi^2 = \begin{bmatrix} .2 \\ .5 \\ .3 \end{bmatrix} \quad \pi^3 = \begin{bmatrix} .3 \\ .2 \\ .5 \end{bmatrix} \quad \pi^4 = \begin{bmatrix} .1 \\ .6 \\ .3 \end{bmatrix} \quad \pi^5 = \begin{bmatrix} .5 \\ .2 \\ .3 \end{bmatrix}$$

As noted above, π^1 represents neutral markets. The other probability vectors represent markets in which one demand level dominates, i.e., biased markets.

For the subordinates, the expected payoff of employing a decision rule ***DR*** is:

$$E\,[\,\boldsymbol{DR}, \boldsymbol{PS}\,] \qquad = \Sigma_{dl,sg,il}\, \pi_{dl}\, IS_{dl,sg}\, DR_{sg,il}\, PS_{il,pl,dl} \tag{1}$$

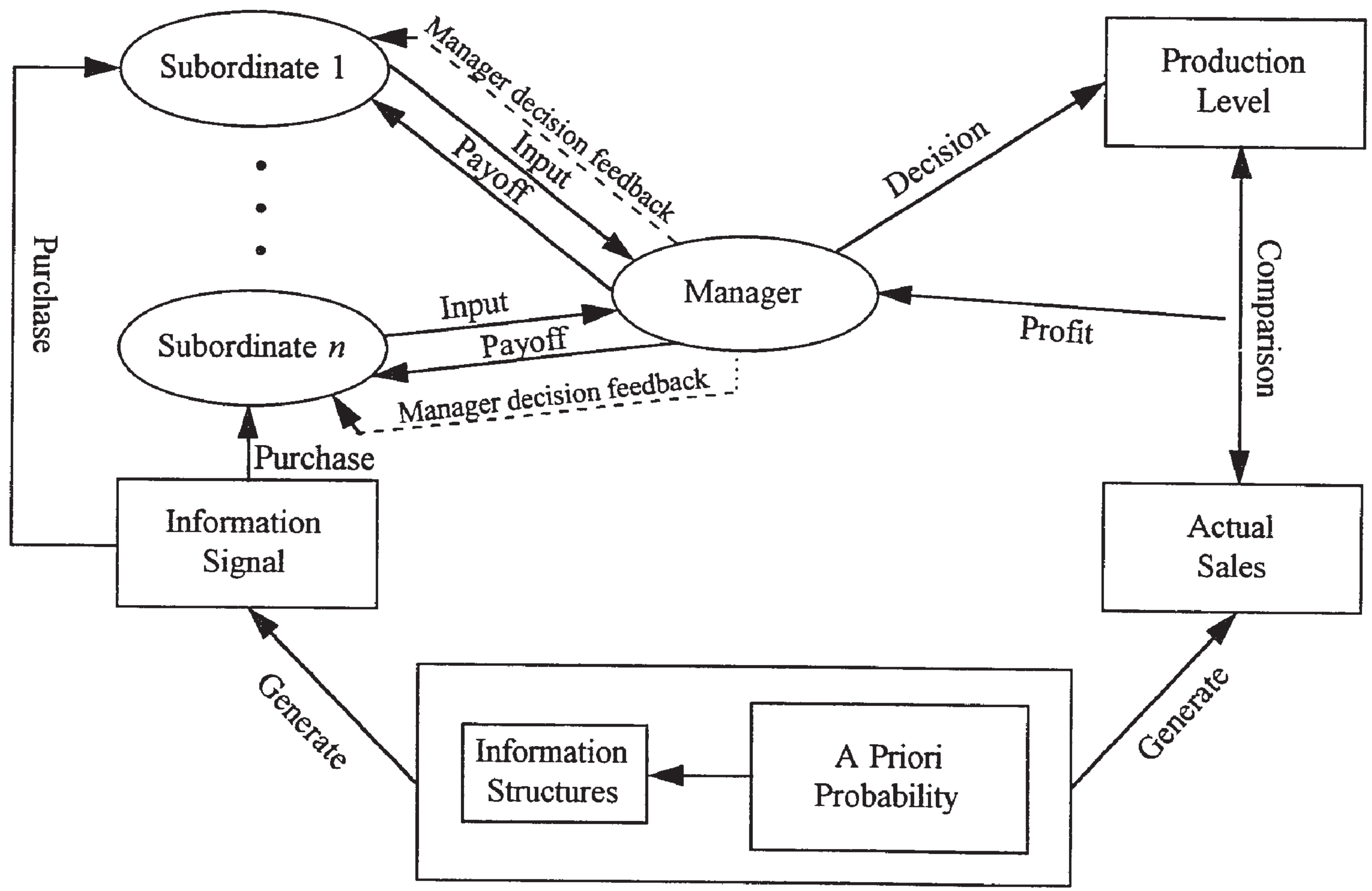
The determination of expected subordinate payoff and expected manager profit is vital to the computation of actual dollar amounts paid to the participating experiment subjects in addition to the control and outcomes of the experiment.

To calculate the *optimal expected subordinate payoff* (OESP) for every available information structure ***IS***, an identity decision rule matrix is used. An identity matrix has diagonal elements equal to one and off-diagonal elements equal to zero. Using an identity matrix for a decision rule means that the action taken (submission from subordinate, *il*) would always follow the signal *sg* in ***IS***. We note that during an experiment, subjects determine their own decision rule ***DR*** which might differ from an identity matrix.

The actual demand level *dl* for a specific experimental period was randomly generated independently and has nothing to do with that of the previous period. It is generated by the experimental program using the *a priori* probability π.

Figure 3.3.1 is a schematic representation of the decision aggregation framework. The subordinates each may independently consult sequentially a number of information signals generated from the information structures and *a priori* probability implemented in the experiment shell. The information signals provide forecasts of demand. The subordinate must pay for each information signal consulted and for the time taken in consulting them. The task of each subordinate is, within a specified time, to submit to the manager a recommended level of production. The less time a subordinate spends in making a decision, the less time cost an individual is charged. When the allotted decision time expires, even if a subordinate has not submitted a recommendation, that individual is charged for the time cost and for any information purchase cost. The manager then has a specified amount of time to make the final production decision. The experiment shell then compares this production level to the actual level of demand. A profit or loss will then be awarded to the manager and, in turn, the manager will then pay off the subordinates according to the individual's recommendation by the payoff scheme prescribed for the experiment. The manager can access a history of the recommendations of each subordinate at any time of the experiment. At the end of each decision period, all relevant variable values are updated to reflect profits dispersed and costs incurred. In addition, the shell maintains running histories that can be accessed later by the researcher to aid in learning and in analyzing alternative incentives and rewards for decision rule simulation.

Figure 3.3.1. Schematic representation of the decision aggregation framework



3.4 Prototyping

In this section, we discuss the prototyping process of the experiment shell and explain the experiment screens for the manager and the subordinates.

The experiment programs were written in C language. There are a manager program and a subordinate program. The NETBIOS commands are used for the communications between the manager workstation and the subordinate workstations. The automated manager program was developed first, where the manager's production level decision was computed automatically after all subordinates submitted their recommendations. At first, the subordinate's payoff was only a function of the individual's decision and manager's profit was also only a function of the manager's decision. Both manager and subordinate program use the same data file for parameter inputs. Reception of a message between the manager and subordinates is always acknowledged. If a workstation does not receive a particular message because of the volume of traffic through the network, it remains "in waiting", and the message will be resent until an acknowledgment is received by the sender. In the process of system prototyping, significant effort was directed toward ensuring that the message transmission would be done properly and effectively. When an operational prototype had been developed and undergone several revisions, we began trial runs using volunteer subjects. A group of doctoral students in the department volunteered and were asked to test the prototype in a setting structured to parallel an actual experiment. We solicited suggestions for further improvements, including, among other things, the screen layout, the flow of the experiment, and the computerized tutorial. Numerous runs were completed and led to numerous suggested interface screen modifications. after several alterations, subjects (new and return volunteers) indicated satisfaction with the format and no further changes were done.

In addition to the human trial runs, we also used a remote keyboard utility to test the prototype. The utility enabled the control of all the subordinate workstations simultaneously. After the automated manager program was working as hoped, the human manager procedures were programmed and incorporated. Different payoff schemes were implemented as needed. In addition to the experiment programs, a tutorial introduction and practice program used for training were also developed. I wrote all the programs.

Figures 3.4.1 to 3.4.5 show the screen layout for the subordinate's workstation. Figure 3.4.1 shows the whole screen layout. The **CURRENT PERIOD** window (explained in Figure 3.4.2) displays the activity of a subordinate. The **HISTORY** window, explained in Figure 3.4.3, shows one previous period of a subordinate's decision making, but the subordinate can also scroll back to any earlier completed period. The **SESSION SUMMARY** window, as displayed in Figure 3.4.4, shows information such as the cash balance and the number of subordinates in the experiment. The **OPTIONS** menu bar (explained in Figure 3.4.5) indicates the options currently available to a subordinate.

Figures 3.4.6 to 3.4.11 display the screen layout on the manager's workstation. The **CURRENT PERIOD** window, as explained in Figure 3.4.7, shows the activity of the current period. Figure 3.4.8 explains the **HISTORY** window. It enables a human manager to scroll back to an earlier period. The SESSION SUMMARY window shows the manager's current cash balance and other information, as explained in Figure 3.4.9. The menu bar at the bottom of the manager's screen, as seen in Figure 3.4.10, indicates the current stage in the experiment. Figure 3.4.11 shows a different layout of the CURRENT PERIOD window when a human manager is implemented. When an automated manager is in operating, the HISTORY window enables the researcher (experimenter) to review the previous periods of subordinate actions while an experiment is in session.

Figure 3.4.1. Subordinate's screen layout: the functions of each window are explained in the following figures.

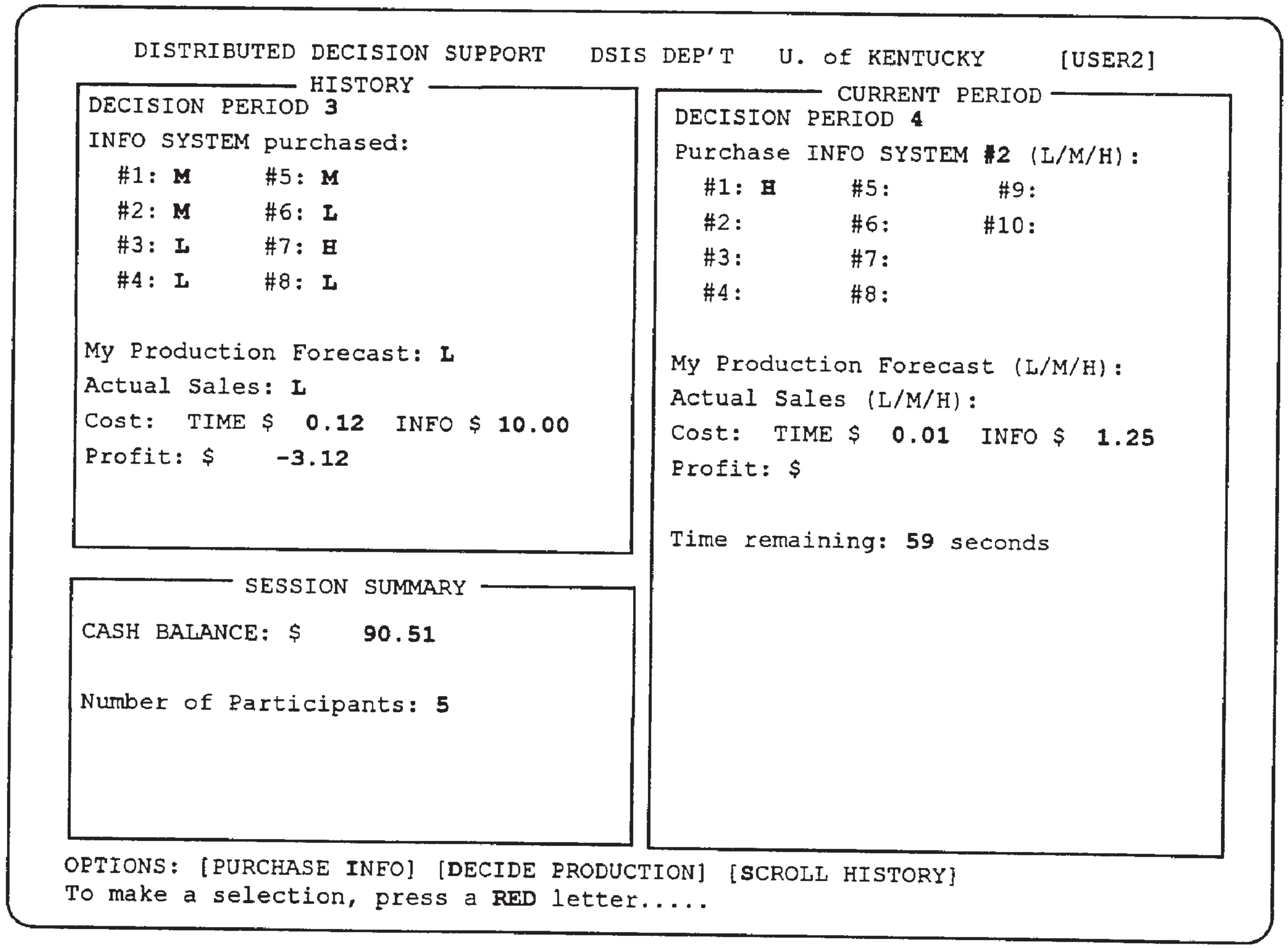


Figure 3.4.2. Subordinate's screen layout: CURRENT PERIOD window

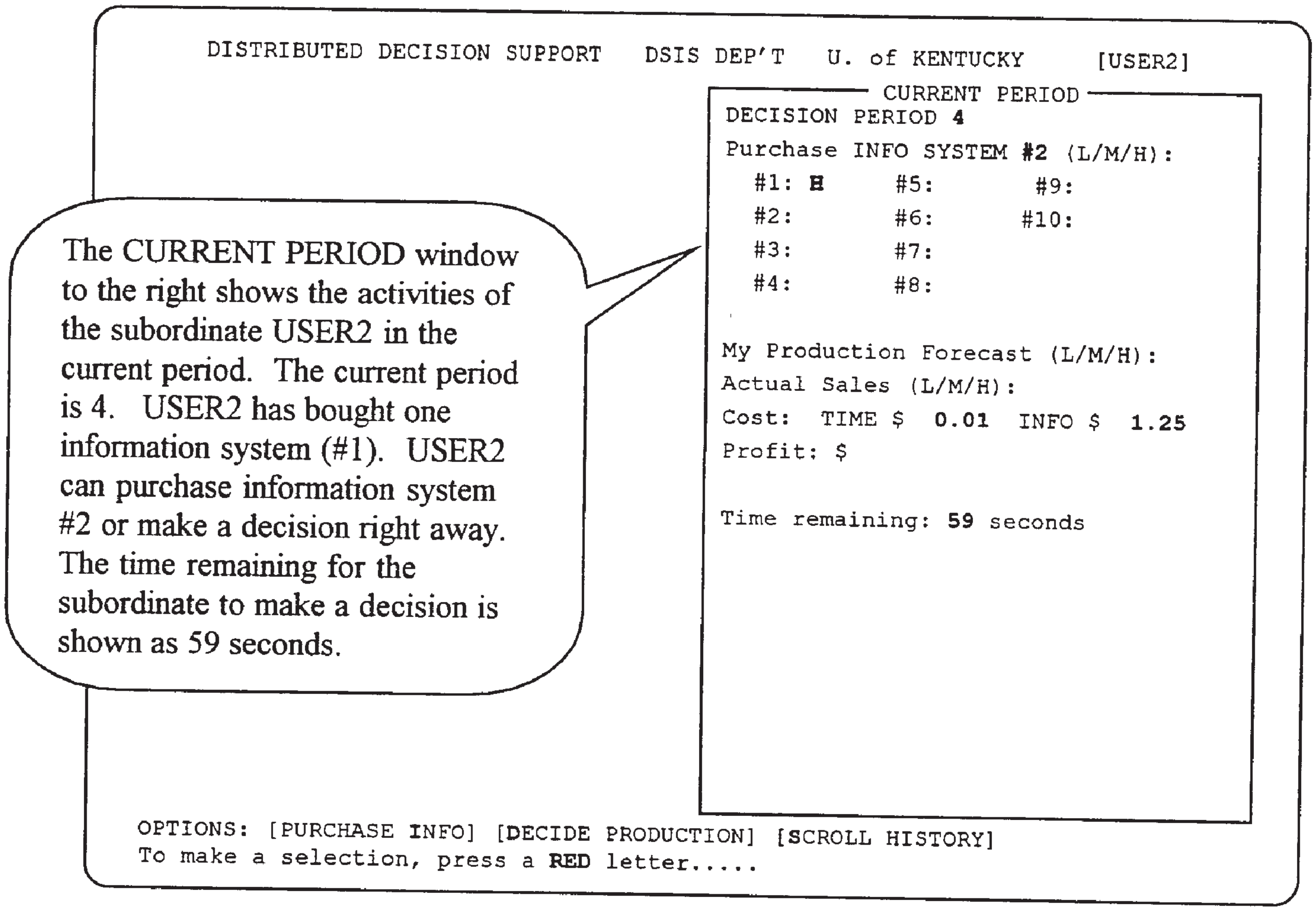


Figure 3.4.3. Subordinate's screen layout: HISTORY window

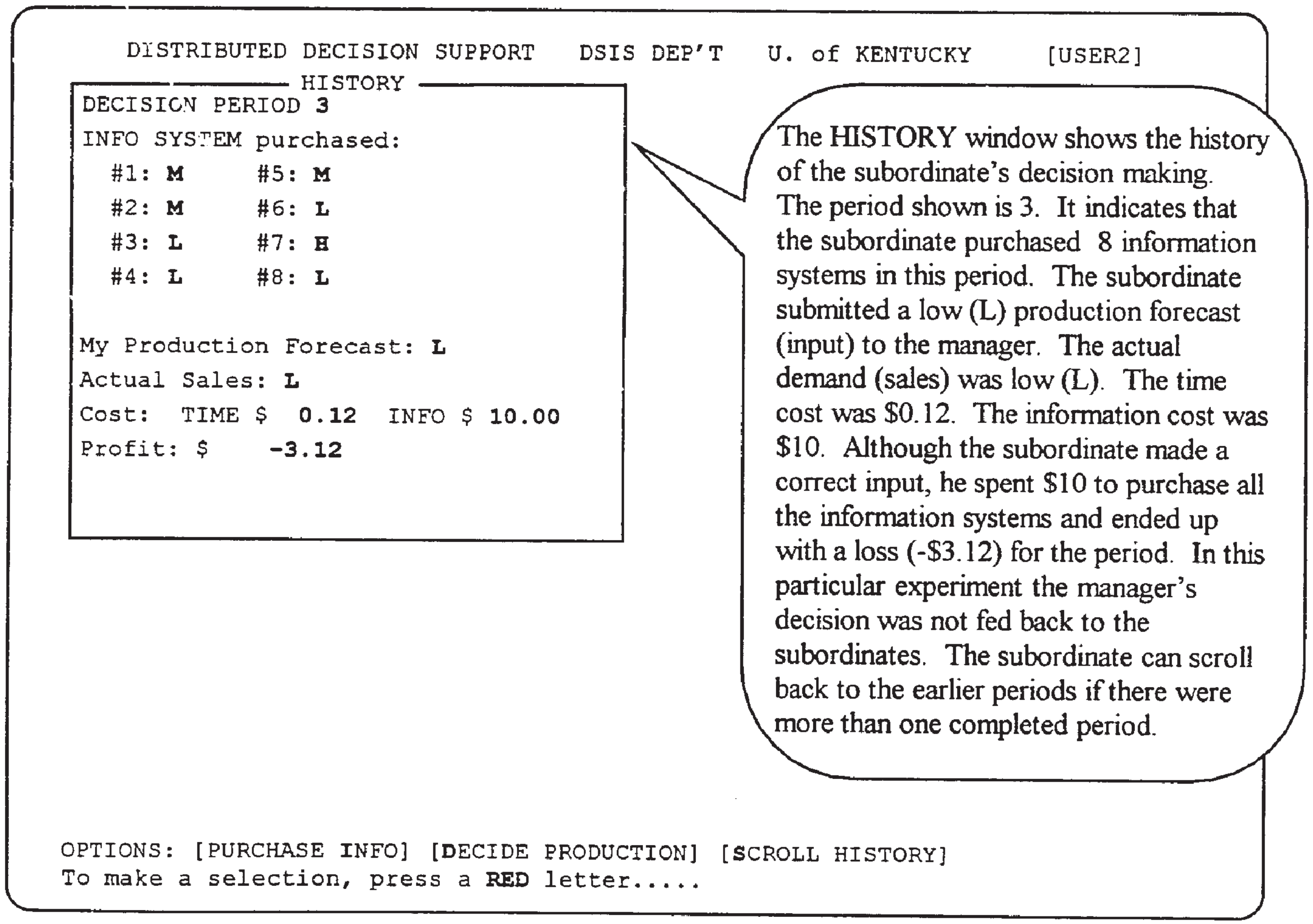


Figure 3.4.4. Subordinate's screen layout: SESSION SUMMARY window

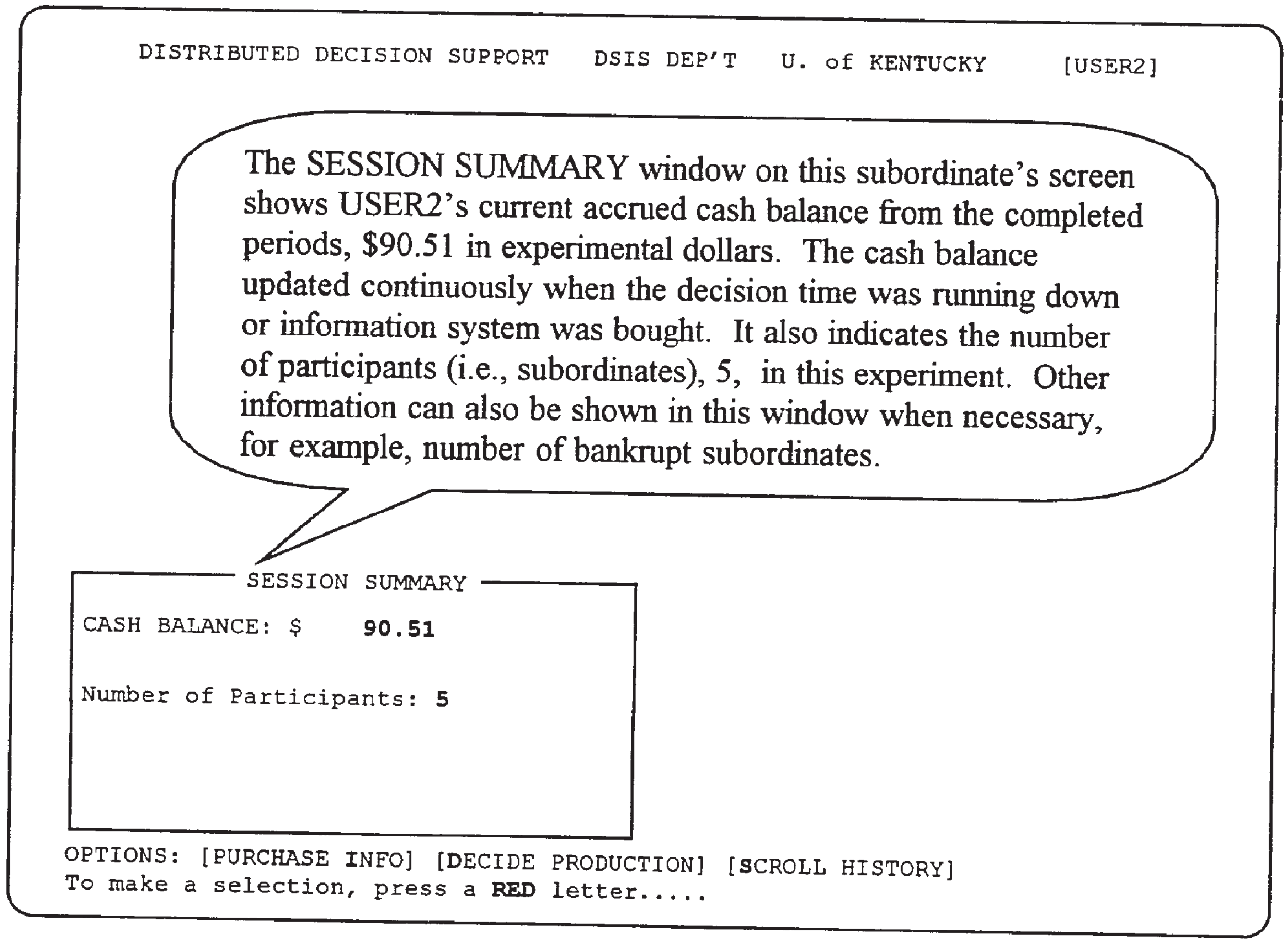


Figure 3.4.5. Subordinate's screen layout: OPTIONS menu bar

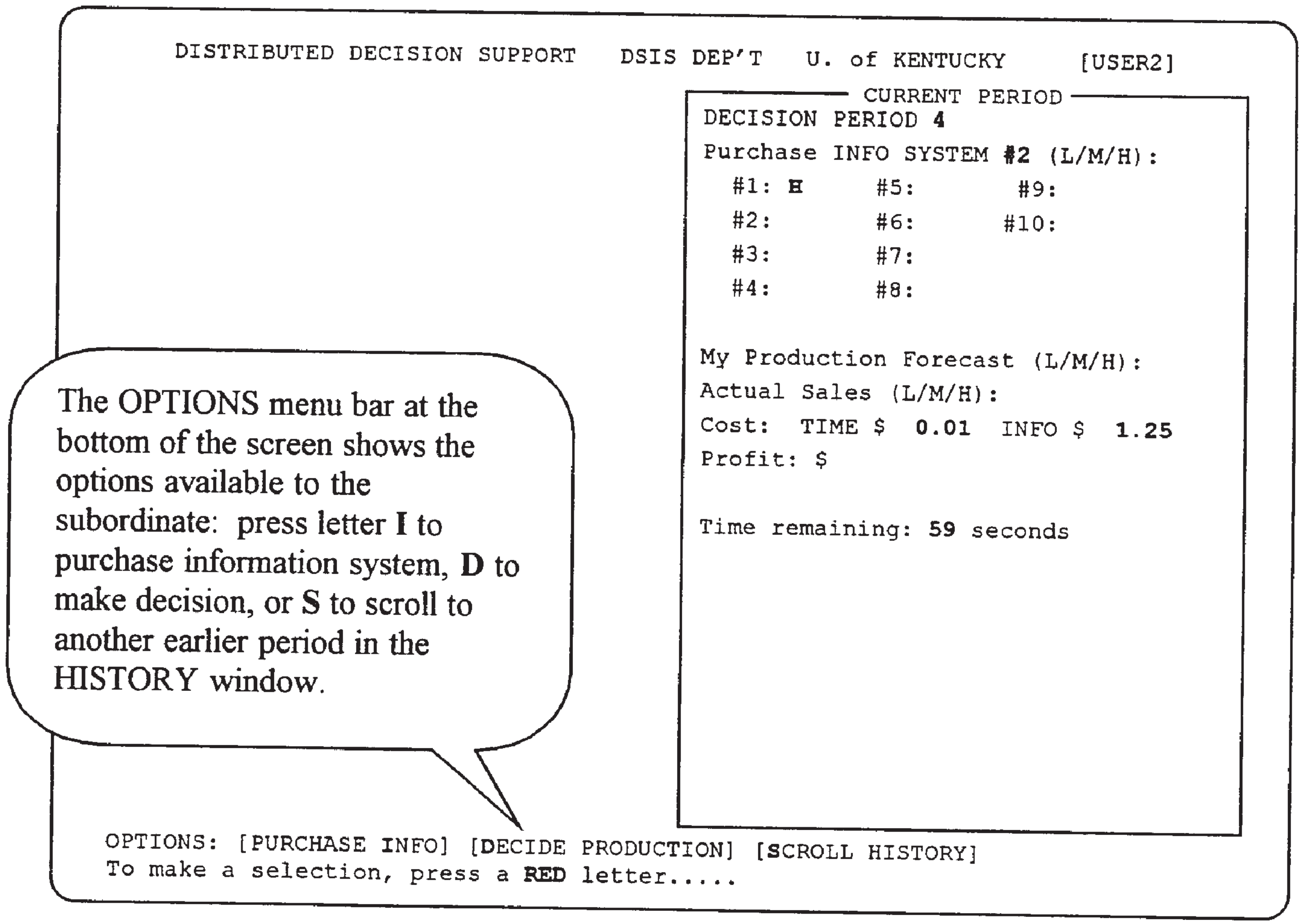


Figure 3.4.6. Manager's screen layout: the functions of each window are explained in the following figures.

```
DISTRIBUTED DECISION SUPPORT   DSIS DEP'T   U. of KENTUCKY     [Manager]

---------- HISTORY ----------          ---------- CURRENT PERIOD ----------
DECISION PERIOD 3                      DECISION PERIOD 4 OF 50
User's Production Forecast (L/M/H):    User's Production Forecast (L/M/H):
 10: M  5  3  2: L  8 12                 2: H  2  3
 12: M  2  4                             8: H  3  4
  8: L 10  9                            12: H  3  4
 14: M  5 12                            10: H  6  5

Manager's Decision: M                  Manager's Decision:
Actual Sales: L                        Actual Sales (L/M/H):
Cost:   TIME $  0.00                   Cost:   TIME $
Profit: $    -12.50                    Profit: $

                                       Subordinate's time remaining: 52 secs
-------- SESSION SUMMARY --------
CASH BALANCE: $   905.00               Info. sys. available to users: 10
Number of Subordinates: 5                H H H M H H H H H H
Roster:12  8 14  2 10
Bankrupt Subordinate: (None)
Decision Mechanism: Majority Vote

Waiting for feedback from participants... (Press S to scroll history)
```

Figure 3.4.7. Manager's screen layout: CURRENT PERIOD window

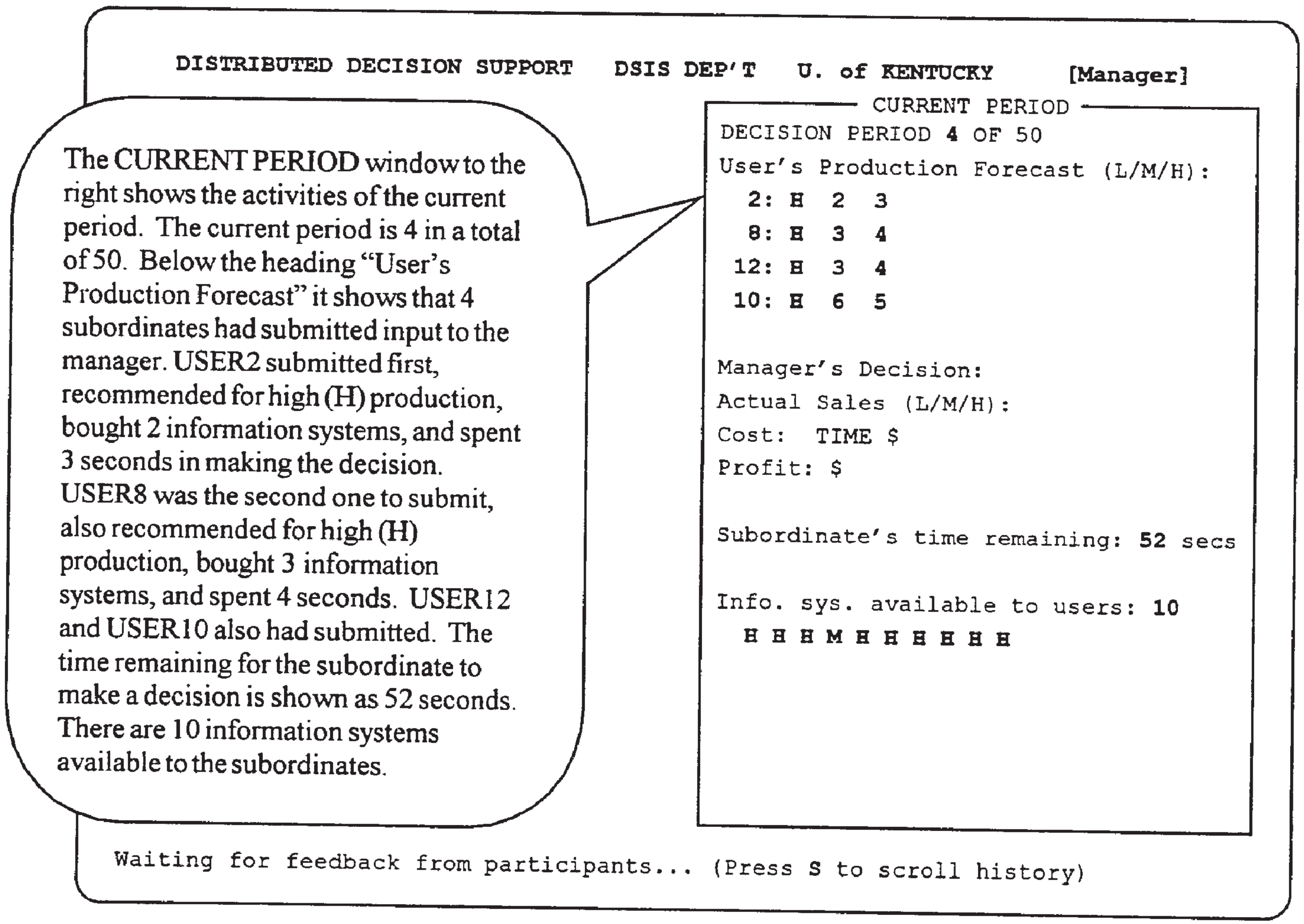


Figure 3.4.8. Manager's screen layout: HISTORY window

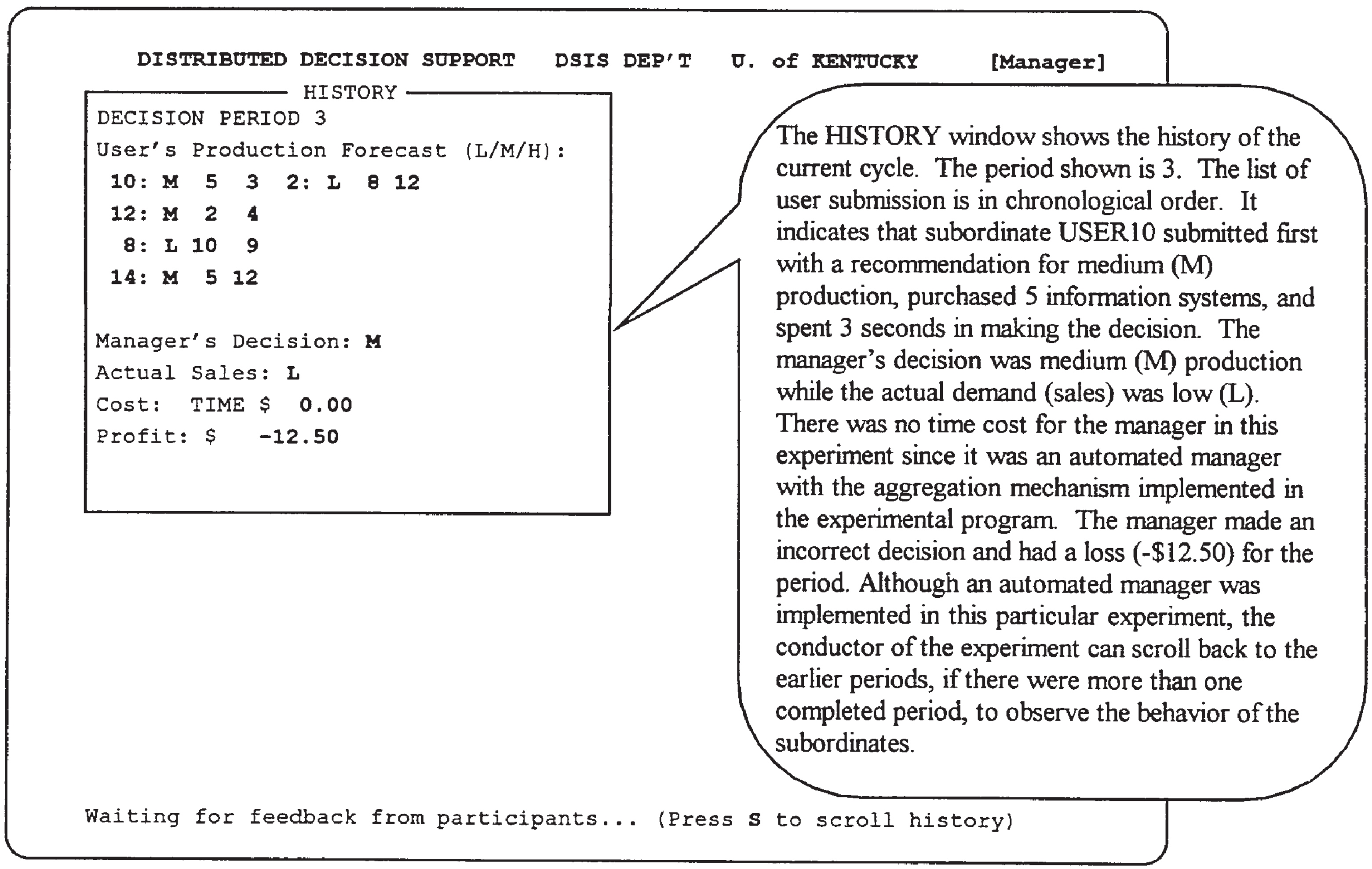


Figure 3.4.9. Manager's screen layout: SESSION SUMMARY window

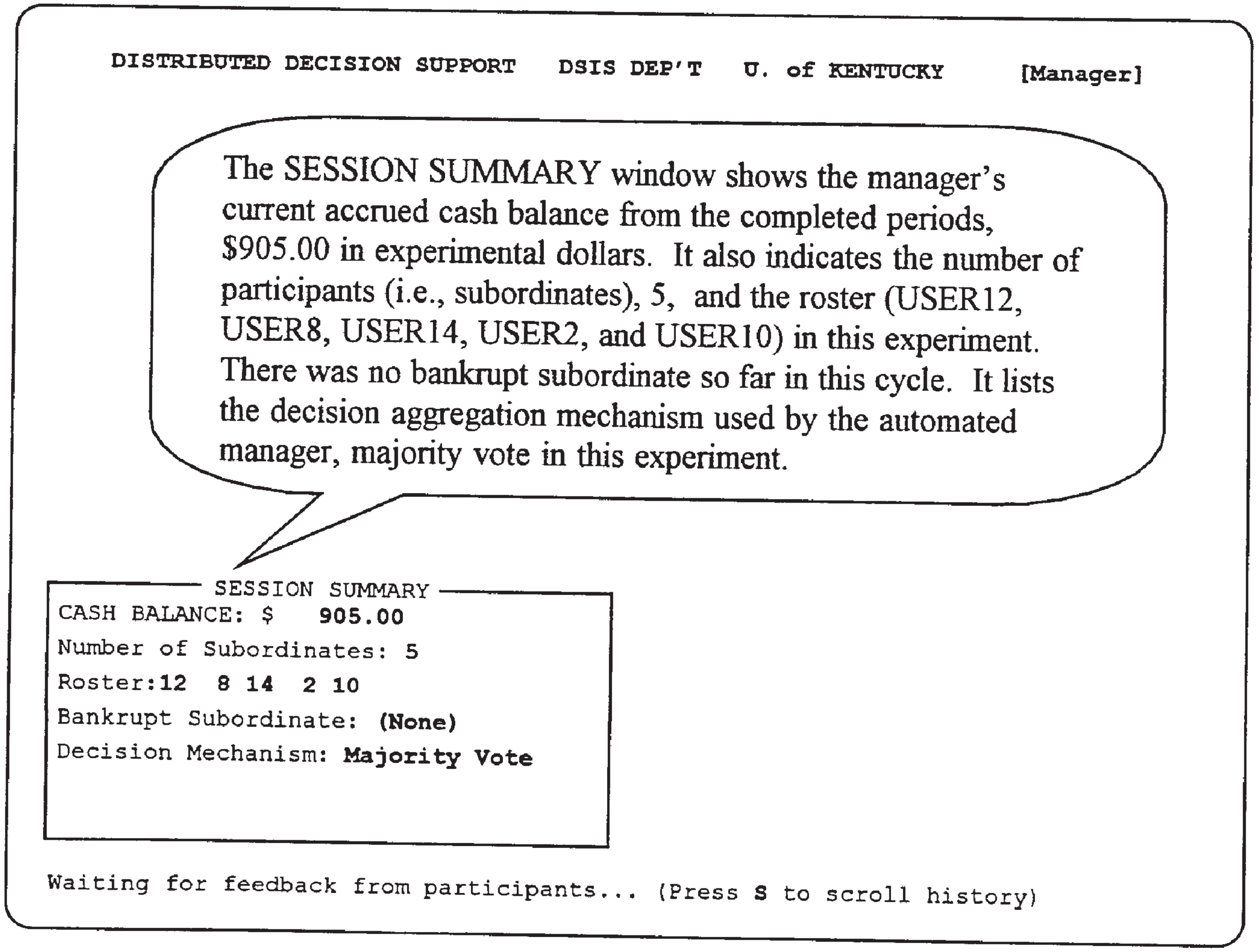


Figure 3.4.10. Manager's screen layout: OPTIONS menu bar

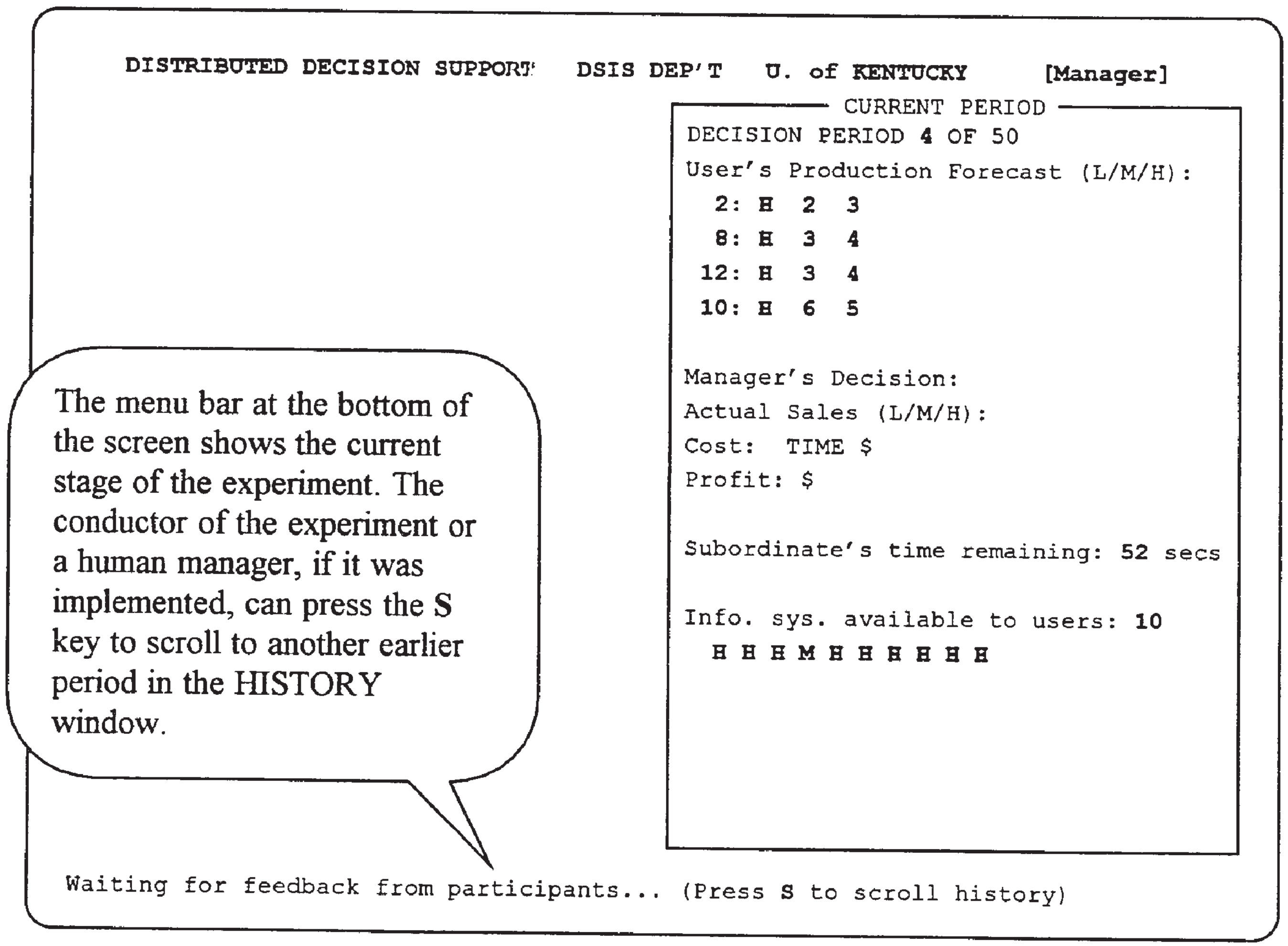
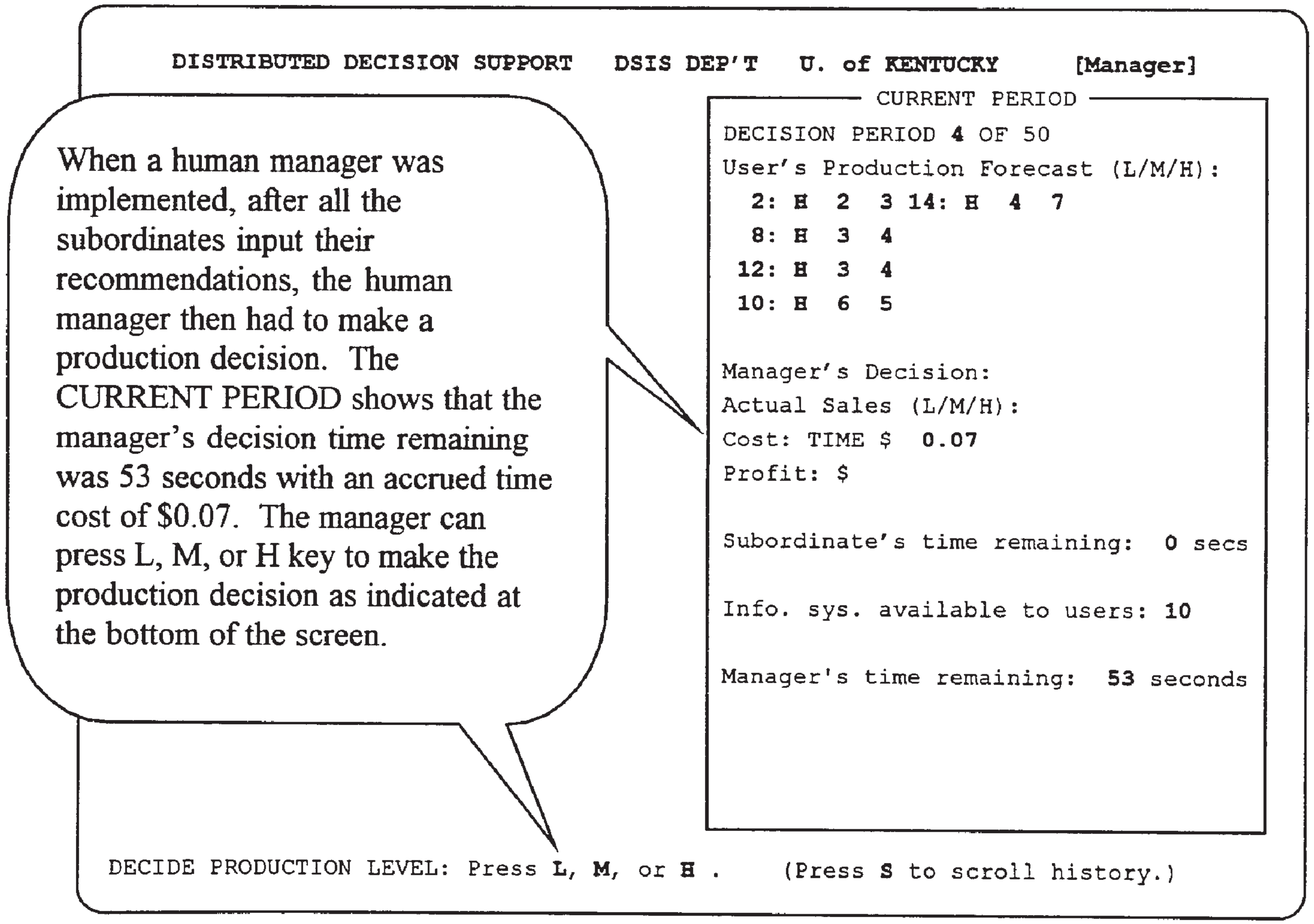


Figure 3.4.11. Manager's screen layout: Human manager making a decision



Chapter 4

EXPERIMENTS AND RESULTS

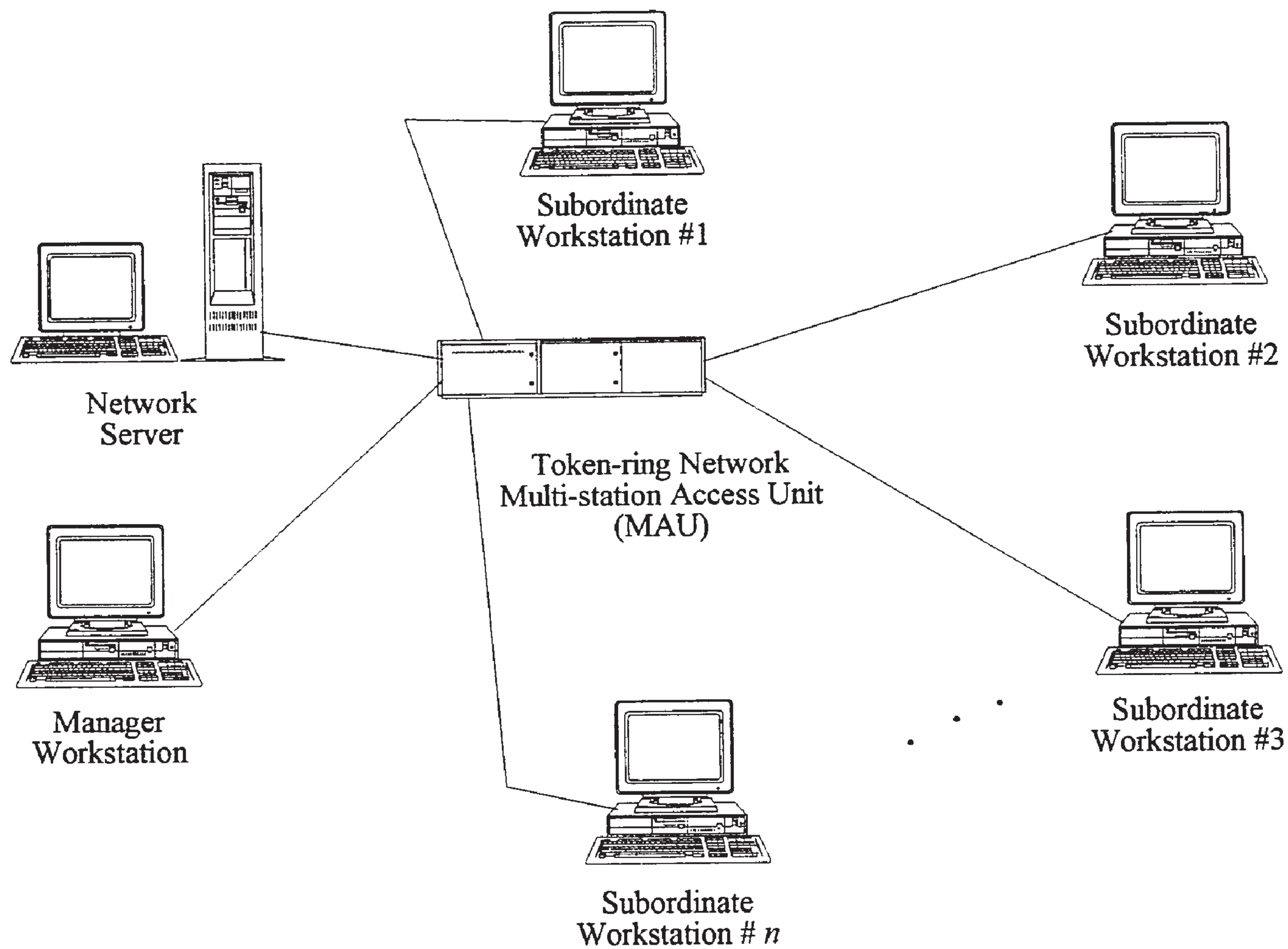
4.1 Logistics of the Experiment

The experiments were conducted in the MIS Research Laboratory of the Department of Decision Science and Information Systems, College of Business and Economics at the University of Kentucky. The MIS Research Lab consists of 18 IBM PS/2 computers connected in a token ring network through three Multi-Station Access Unit. The main file server and secondary server are PS/2 model 80's. The 16 workstations are PS/2 model 50's. Figure 4.1.1 is a schematic layout of the experimental lab environment.

Since human subjects were used in the experiments, a formal filing of intent was required by the university under federal and state law. A "Request for Waiver" application form with necessary description of the experimental design and procedures was filed with the University of Kentucky Human Subjects Review committee of the Department of Research and Graduate Studies. The waiver was granted before experimentation began. The documentation of the waiver request is attached as Appendix A.

Doctoral and MBA graduate students as well as upper division undergraduate students in the business college were recruited as human subjects. The recruiting process started with the distribution of a handout (Appendix B) describing the computerized group decision game. The students were given a list of time slots to pick from. If they

Figure 4.1.1. Layout of the experimental lab environment



wanted to participate but were not available for the time slots specified, they had the option of writing down time periods when they would be available and attempts would be made to schedule experiments for them. In the recruiting of doctoral students, we asked them to pick a mutually agreeable time.

When the subjects reported to the lab for the experiment, they were greeted and presented with an information sheet (Appendix C) prepared by the experimenter stating:

--- This experiment is conducted by Ming-Chian Ken Wang, a Ph.D. candidate in the Department of Decision Science and Information Systems, College of Business & Economics of the University of Kentucky.

--- Participation in this experiment is voluntary and anonymous. The identity of the participant will not and cannot be related to the experiment results.

--- The personal information obtained from the participant is only for the purpose of completing the experiment expense report to the University.

--- This experiment is approved by and on file with Research Subjects Office of Research and Graduate Studies, University of Kentucky.

--- The participation payment and performance bonus, if any, were established by the conductor of this experiment and will be paid after a participant has completed the experiment.

Subjects were also asked to fill out a 1099 information sheet (Appendix D) required by the University for the payment of a participation fee and a performance bonus, if any.

After all scheduled participants completed the sign-in process, a 10-minute video presentation of the experiment process was shown. The video explained the nature of the decision tasks and the flow of the experiment. It also emphasized the keystrokes used in the experiments. Subjects could ask questions following the video presentation.

After the video, the subjects had a hands-on practice session. The tutorial in the practice set reinforced the video presentation. As in the video presentation, "information" or forecasts provided by the information systems in the practice were just white noises. This was done so that the subjects could not learn game strategy in the practice stage. The conductor remains on hand to answer any questions. If a question is of a general nature, the experimenter calls it to the attention of all subjects. It is essential to the control of experiment that no single subject receives private information that might affect the outcome of the experiment.

After the video presentation and practice sessions the real experiment begins. Subjects are identified only by the workstations they are using, (USER*n* where *n* is the id number of a workstation.)

Although our experimental program used NETBIOS commands and did not need to run on top of the PC LAN software program, the experiment is conducted with the PC LAN program running. The purpose is to simplify the installation of the experimental programs and to facilitate the collection of results. All the experiment programs reside on the hard disk of the main file server. All results are also written to that hard disk. A remote keyboard utility was used to start the experiment for every participant from the conductor's workstation. This control eliminates possible errors from subjects starting up the program and ensures a steady flow of the process.

Each experiment had three to six cycles with 20 to 50 periods in each cycle. When each cycle ends, the results are written to the hard disk of the main file server. The performance bonus is converted into the equivalent U.S. Dollar amount and recorded along with the experimental results. When the experiment ends, the performance bonuses for individual cycles are added together. While the participants are filling out the post-experiment survey (Appendix E), the payment checks are completed. After a participant completes the survey, he or she leaves the lab with payment check in hand.

In sessions using a human manager, the manager is selected by a random draw after the video presentation. The chosen subject is then given additional instruction in the practice stage relating to the decision and acting options available to the manager.

When the experimental program on the subordinate workstation starts, it sends a sign-in message to the manager workstation. If the manager program is not started yet on the manager station, the subordinate station keeps trying to sign in until the manager program accepts the sign-in. After all subordinate stations are signed in, the manager program indicates that every station is ready to begin the first decision period. In the case of an automated manager, the conductor presses the 'starting period' key to start the decision period. When a human manager is present, the conductor asks the manager to start the decision period.

4.2 Overview of the Conducted Experiments

This section lists the set of seventeen induced-value experiments conducted for this research. Table 4.2.1 lists the experiments in chronological order and summarizes the relevant parameters and their values used in each experiment session. The legends used in the table are explained in the page following Table 4.2.1. We assigned a designation to each experiment for easy reference. The first experiment was designated Experiment 1A, with the letter "A" indicating that it was an experiment with an automated machine manager. The next experiment with an automated manager was assigned 2A, and so on, so forth. If an experiment used a human manager, we use an "H" designation, e.g., 11H. Certain experimental pairs were constructed for and used in direct comparison of performance of a human manager and an automated manager. They are designated in pairs. For example, Experiments 11A and 11H provide comparison of the performance of a group of subjects in both a human manager environment and an automated manager environment.

Decision Agreement Frequency

We define "decision agreement frequency" as the frequency of agreement between subordinate's input, manager's decision, and actual sales (i.e., actual demand) using the following categories:

(1) Subordinate's input, manager's decision, and actual sales are the same. This category includes three combinations.

	Subordinate's input	Manager's decision	Actual sales
Combination 1:	H	H	H
Combination 2:	M	M	M
Combination 3:	L	L	L

(2) Subordinate's input is equal to manager's decision, but different from actual sales. This category includes six combinations.

	Subordinate's input	Manager's decision	Actual sales
Combination 4:	H	H	M
Combination 5:	H	H	L
Combination 6:	M	M	H
Combination 7:	M	M	L
Combination 8:	L	L	H
Combination 9:	L	L	M

(3) Manager's decision is equal to actual sales, but different from the subordinate's input. This category includes six combinations.

	Subordinate's input	Manager's decision	Actual sales
Combination 10:	M	H	H
Combination 11:	L	H	H
Combination 12:	H	M	M
Combination 13:	L	M	M
Combination 14:	H	L	L
Combination 15:	M	L	L

(4) Subordinate's input is equal to actual sales, but different from the manager's decision. This category includes six combinations.

	Subordinate's input	Manager's decision	Actual sales
Combination 16:	H	M	H
Combination 17:	H	L	H
Combination 18:	M	H	M
Combination 19:	M	L	M
Combination 20:	L	H	L
Combination 21:	L	M	L

(5) Subordinate's input, manager's decision, and actual sales are all different. This category includes six combinations.

	Subordinate's input	Manager's decision	Actual sales

Combination 22:	H	M	L
Combination 23:	H	L	M
Combination 24:	M	H	L
Combination 25:	M	L	H
Combination 26:	L	H	M
Combination 27:	L	M	H

The starting cash balance for the manager was set at a level so that it was not expected that the manager would go bankrupt. The starting cash balance for the subordinates was set at a level that the subordinate could go bankrupt in a cycle by making sufficient number of incorrect decisions. If a subordinate did go bankrupt in a cycle, that subject's experiment program was terminated for that cycle. Unless it was the last cycle, the subordinate rejoined the experiment in the next cycle. When a subordinate went bankrupt, we classified the remaining periods in the cycle as Category 0 for that individual subordinate. For example, in an experiment cycle with 30 periods, if a subordinate goes bankrupt in period 12, then that subordinate will have 18 periods in Category 0.

Subordinates can only purchase the information systems sequentially. They can purchase the second information system only after they have bought the first information system, and so on.

In an experiment with an automated manager, the decision rule implemented for the automated machine manager in this experiment was as follows: The automated manager makes the decision by following the most identical inputs (not necessarily majority) from the subordinates. The automated manager is risk averse, i.e., if there are identical number of subordinate inputs recommending different levels of production, the automated manager would choose the *lower* level of production to lessen the possible loss from overproduction. The automated manager always makes a decision as long as there is at least one input from the subordinates. There might not be an input from a subordinate since a subordinate may fail to make a decision within the time limit.

Following Table 4.2.1, which lists details of all experiments completed, individual sections are used to provide individual summaries for each experiment conducted. Included are discussions of input parameters. Outcomes are discussed. We tabulate the results in table form extensively. In this chapter we only summarize experimental structures, processes, and numerical results. Analysis of results and hypothesis testing are presented in the next chapter.

Table 4.2.1. List of experiments

Exp't	*CYN*	*NOU*	*NOP*	π	*NIS*	*ISI*	*TC*	*WTI*	*IC*	*POM*	*AGM*	*MGR*	*TOP*	*MFB*	*SPS*
	1	3	20	(1)	5	(1)	$0.01	0	$2.00	(1)	(1)	auto	MBA students	Y	(1)
	2	3	20	(2)	5	(2)	$0.01	0	$2.00	(1)	(1)	auto	MBA students	Y	(1)
1A	3	3	20	(1)	10	(3)	$0.01	0	$2.00	(1)	(1)	auto	MBA students	Y	(1)
	4	3	20	(3)	10	(4)	$0.01	0	$2.00	(1)	(1)	auto	MBA students	Y	(1)
	5	3	20	(4)	6	(5)	$0.01	0	$2.00	(1)	(1)	auto	MBA students	Y	(1)
	6	3	20	(1)	5	(1)	$0.01	0	$2.00	(1)	(1)	auto	MBA students	Y	(1)
	1	4	30	(1)	10	(6)	$0.01	0	$2.00	(1)	(1)	auto	MBA students	Y	(1)
	2	4	40	(1)	10	(7)	$0.01	0	$1.25	(1)	(1)	auto	MBA students	Y	(1)
2A	3	4	40	(4)	6	(8)	$0.01	0	$1.50	(1)	(1)	auto	MBA students	Y	(1)
	4	4	30	(3)	10	(4)	$0.01	0	$1.50	(1)	(1)	auto	MBA students	Y	(1)
	5	4	40	(3)	10	(4)	$0.01	0	$1.50	(1)	(1)	auto	MBA students	Y	(1)
	6	4	30	(2)	8	(9)	$0.01	0	$1.50	(1)	(1)	auto	MBA students	Y	(1)
	1	3	30	(3)	10	(6)	$0.01	0	$1.75	(1)	(1)	auto	MBA students	Y	(1)
	2	3	40	(1)	10	(7)	$0.01	0	(a)	(1)	(1)	auto	MBA students	Y	(1)
3A	3	3	40	(4)	6	(8)	$0.01	0	$2.50	(1)	(1)	auto	MBA students	Y	(1)
	4	3	30	(1)	10	(4)	$0.01	0	$1.50	(1)	(1)	auto	MBA students	Y	(1)
	5	3	40	(3)	8	(10)	$0.01	0	$1.50	(1)	(1)	auto	MBA students	Y	(1)
	6	3	30	(1)	8	(9)	$0.01	0	(a)	(1)	(1)	auto	MBA students	Y	(1)
	1	5	40	(1)	10	(6)	$0.01	0	$1.75	(1)	(1)	auto	MBA students	Y	(1)
	2	5	40	(5)	10	(7)	$0.01	0	(a)	(1)	(1)	auto	MBA students	Y	(1)
4A	3	5	40	(4)	6	(8)	$0.01	0	$2.50	(1)	(1)	auto	MBA students	Y	(1)
	4	5	40	(1)	10	(4)	$0.01	0	$2.00	(1)	(1)	auto	MBA students	Y	(1)
	5	5	50	(1)	8	(10)	$0.01	0	$1.50	(1)	(1)	auto	MBA students	Y	(1)
	6	5	50	(1)	8	(9)	$0.01	0	(a)	(1)	(1)	auto	MBA students	Y	(1)
	1	5	40	(4)	6	(8)	$0.01	0	$2.50	(1)	(1)	auto	Staff	Y	(1)
5A	2	5	40	(1)	10	(4)	$0.01	0	$2.00	(1)	(1)	auto	Staff	Y	(1)
	3	5	50	(1)	8	(10)	$0.01	0	$1.50	(1)	(1)	auto	Staff	Y	(1)
	4	5	50	(1)	8	(9)	$0.01	0	(a)	(1)	(1)	auto	Staff	Y	(1)

Table 4.2.1. List of experiments

Exp't	*CYN*	*NOU*	*NOP*	π	*NIS*	*ISI*	*TC*	*WFI*	*IC*	*POM*	*AGM*	*MGR*	*TOP*	*MFB*	*SPS*
	1	5	40	(1)	10	(6)	$0.01	0	$1.75	(1)	(1)	auto	Doctoral students	Y	(1)
	2	5	40	(5)	10	(7)	$0.01	0	(a)	(1)	(1)	auto	Doctoral students	Y	(1)
6A	3	5	40	(4)	6	(8)	$0.01	0	$1.50	(1)	(1)	auto	Doctoral students	Y	(1)
	4	5	40	(1)	10	(4)	$0.01	0	$2.00	(1)	(1)	auto	Doctoral students	Y	(1)
	5	5	30	(1)	8	(10)	$0.10	4	Free	(1)	(1)	auto	Doctoral students	Y	(1)
	6	5	40	(1)	8	(9)	$0.10	5	Free	(1)	(1)	auto	Doctoral students	Y	(1)
	1	5	30	(2)	5	(1)	$0.01	0	$1.75	(1)	(1)	auto	Undergrad	N	(1)
7A	2	5	50	(2)	6	(11)	$0.01	0	$2.00	(1)	(1)	auto	Undergrad	N	(1)
	3	5	30	(5)	10	(3)	$0.01	0	$2.00	(1)	(1)	auto	Undergrad	N	(1)
	4	5	20	(2)	6	(11)	$0.10	5	Free	(1)	(1)	auto	Undergrad	N	(1)
	1	5	50	(2)	5	(1)	$0.01	0	$1.75	(1)	(1)	auto	(a)	N	(1)
	2	5	50	(2)	6	(11)	$0.01	0	$2.00	(1)	(1)	auto	(a)	N	(1)
8A	3	5	50	(5)	10	(3)	$0.01	0	$2.00	(1)	(1)	auto	(a)	N	(1)
	4	5	20	(2)	6	(11)	$0.10	5	Free	(1)	(1)	auto	(a)	N	(1)
	5	5	25	(5)	10	(3)	$0.10	4	Free	(1)	(1)	auto	(a)	N	(1)
	1	6	50	(3)	10	(12)	$0.01	0	$1.75	(1)	(1)	auto	Doctoral students	N	(1)
	2	6	50	(1)	10	(14)	$0.01	0	$2.00	(1)	(1)	auto	Doctoral students	N	(1)
9A	3	6	50	(3)	8	(13)	$0.01	0	(b)	(1)	(1)	auto	Doctoral students	N	(1)
	4	6	30	(3)	10	(12)	$0.35	5	Free	(1)	(1)	auto	Doctoral students	N	(1)
	5	6	20	(1)	10	(14)	$0.50	4	Free	(1)	(1)	auto	Doctoral students	N	(1)
	1	6	50	(1)	10	(15)	$0.01	0	$1.25	(1)	(1)	auto	Doctoral students	N	(1)
10A	2	6	50	(3)	10	(12)	$0.01	0	$1.75	(1)	(1)	auto	Doctoral students	N	(1)
	3	6	50	(2)	8	(16)	$0.45	5	Free	(1)	(1)	auto	Doctoral students	N	(1)
	4	6	50	(2)	8	(16)	$0.01	0	$2.25	(1)	(1)	auto	Doctoral students	N	(1)
	1	4	50	(1)	10	(15)	$0.01	0	$1.25	(1)	(2)	human	Doctoral students	Y	(1)
11H	2	4	50	(1)	10	(15)	$0.01	0	$1.25	(1)	(2)	human	Doctoral students	Y	(2)
	3	4	50	(1)	10	(15)	$0.01	0	$1.25	(1)	(2)	human	Doctoral students	Y	(3)
	4	4	50	(1)	8	(16)	$0.01	0	$2.25	(1)	(2)	human	Doctoral students	Y	(3)

Table 4.2.1. List of experiments

Exp't	*CYN*	*NOU*	*NOP*	π	*NIS*	*ISI*	*TC*	*WFI*	*IC*	*POM*	*AGM*	*MGR*	*TOP*	*MFB*	*SPS*
11A	1	4	50	(1)	8	(16)	$0.01	0	$2.25	(1)	(1)	auto	Doctoral students	Y	(2)
	2	4	50	(1)	10	(15)	$0.01	0	$1.25	(1)	(1)	auto	Doctoral students	Y	(2)
	3	4	50	(1)	10	(15)	$0.01	0	$1.25	(1)	(1)	auto	Doctoral students	Y	(3)
	4	4	50	(1)	8	(16)	$0.01	0	$2.25	(1)	(1)	auto	Doctoral students	Y	(3)
12H	1	4	50	(1)	10	(15)	$0.01	0	$1.25	(1)	(2)	human	MBA students	Y	(1)
	2	4	50	(1)	10	(15)	$0.01	0	$1.25	(1)	(2)	human	MBA students	Y	(2)
	3	4	50	(1)	10	(15)	$0.01	0	$1.25	(1)	(2)	human	MBA students	Y	(3)
	4	4	50	(1)	8	(16)	$0.01	0	$2.25	(1)	(2)	human	MBA students	Y	(3)
12A	1	4	50	(1)	8	(16)	$0.01	0	$2.25	(1)	(1)	auto	MBA students	Y	(2)
	2	4	50	(1)	10	(15)	$0.01	0	$1.25	(1)	(1)	auto	MBA students	Y	(2)
	3	4	50	(1)	10	(15)	$0.01	0	$1.25	(1)	(1)	auto	MBA students	Y	(3)
	4	4	50	(1)	8	(16)	$0.01	0	$2.25	(1)	(1)	auto	MBA students	Y	(3)
13H	1	4	50	(1)	10	(15)	$0.01	0	$1.25	(1)	(2)	human	Doctoral students	Y	(1)
	2	4	50	(1)	10	(14)	$0.01	0	$1.25	(1)	(2)	human	Doctoral students	Y	(1)
	3	4	50	(1)	8	(16)	$0.01	0	$1.25	(1)	(2)	human	Doctoral students	Y	(1)
	4	4	50	(1)	8	(16)	$0.01	0	$1.25	(1)	(2)	human	Doctoral students	Y	(1)
	5	4	50	(1)	10	(14)	$0.01	0	$1.25	(1)	(2)	human	Doctoral students	Y	(1)
14H	1	4	50	(1)	10	(15)	$0.01	0	$1.25	(1)	(2)	human	Doctoral students	Y	(4)
	2	4	50	(1)	10	(14)	$0.01	0	$1.25	(1)	(2)	human	Doctoral students	Y	(4)
	3	4	50	(1)	8	(16)	$0.01	0	$1.25	(1)	(2)	human	Doctoral students	Y	(4)
	4	4	50	(1)	8	(16)	$0.01	0	$1.25	(1)	(2)	human	Doctoral students	Y	(4)
	5	4	50	(1)	10	(14)	$0.01	0	$1.25	(1)	(2)	human	Doctoral students	Y	(4)
14A	1	4	50	(1)	10	(15)	$0.01	0	$1.25	(1)	(1)	auto	Doctoral students	Y	(4)
	2	4	50	(1)	10	(14)	$0.01	0	$1.25	(1)	(1)	auto	Doctoral students	Y	(4)
	3	4	50	(1)	8	(16)	$0.01	0	$1.25	(1)	(1)	auto	Doctoral students	Y	(4)
	4	4	50	(1)	8	(16)	$0.01	0	$1.25	(1)	(1)	auto	Doctoral students	Y	(4)
	5	4	50	(1)	10	(14)	$0.01	0	$1.25	(1)	(1)	auto	Doctoral students	Y	(4)

Legend for Table 4.2.1:

CYN: *CY*cle *N*umber in each experiment session.

NOU: *N*umber *Of* subordinates (or *U*sers).

NOP: *N*umber *Of* *P*eriods.

π: a priori probability.

(1) {1/3, 1/3, 1/3} (2) {.2, .5, .3}
(3) {.3, .2, .5} (4) {.1, .6, .3}
(5) {.5, .2, .3}

NIS: *N*umber of *I*nformation *S*ystems available to subordinates.

ISI: *I*nformation *S*ystem *I*dentification numbers. (Listed in Table 4.2.2.)

TC: *T*ime *C*ost per second.

WFI: *W*ait *f*or *I*nformation (in seconds). When the forecast information is free, the waiting time for the subordinates to receive the next forecast information.

IC: *I*nformation *C*ost (each).

(a) {.50, .75, 1.00, 1.25, 1.50, 1.75, 2.00, 2.25, 2.25, 2.25}
(b) {1.00, 1.25, 1.50, 1.75, 2.00, 2.25, 2.50, 2.75, 3.00, 3.25, 3.50, 3.75}

POM: Manager's *P*ay*O*ff *M*atrix

(1)

		Event (Sales)		
		L	M	H
Action	L	7	-12.5	-32
(Production	M	-12.5	17.5	-2
Decision)	H	-32	-2	28

AGM: *AG*gregation *M*ethods.

(1) Automated majority vote
(2) Human manager decision

MGR: *M*ana*G*e*R*'s decision.

Auto: Decision computed by the experiment program automatically.

Human: Manager decides individually -- creates own decision process or lack of process.

TOP: Type of Subjects.

Staff: Clerical staff in B&E College
Undergrad: Undergraduate upper division
(a): 3 staff (2 new, 1 repeated), 2 doctoral students

MFB: *M*anager's *F*eed*B*ack.

Y: Subordinates receive feedback of manager's decision.
N: Subordinates have no feedback of manager's decision.

SPS: *S*ubordinate's *P*ayoff *S*cheme. (Explained in later sections.)

4.3 Experiment 1A: First Experiment

After the experiment program had been tried in numerous test-runs to ensure it ran without bugs, we ran our initial experiment using real subjects and incentive mechanisms. This initial session was also intended to aid the experimenter in gaining experience in conducting experiments.

Experiment 1A used 3 MBA students as subordinates. There were six cycles, each with 20 periods. Each information purchase cost $2.00. The experiment program implemented an automated machine manager. Five information systems were available in Cycles 1, 2, and 6. Six information systems were available in Cycle 5. Ten information systems were available in Cycles 3 and 4. Cycle 6 had the same parameter values as Cycle 1. A subordinate's profit was a function of the individual's own decision in all the cycles. Table 4.2.1 provides the specific experimental parameter values used in this experiment.

The decision rule implemented for the automated machine manager in this experiment was as follows: <u>The automated manager makes the decision by following the most identical inputs (not necessarily majority) from the subordinates</u>. The automated manager was risk averse, i.e., if there are identical number of subordinate inputs recommending different levels of production, the automated manager would choose the *lower* level of the equally preferred production rates to lessen the possible loss from overproduction.

The starting cash balance for the automated manager was set at $900. The starting cash balance for the subordinate was set at $100.

Experiment Results

Table 4.3.1 lists the average number of information systems purchased by the subordinates, average time spent by the subordinates in making a decision, and average profit made by the subordinates. In Cycle 1, there were five information systems available for the subordinate to purchase, Subordinates 1 and 2 each bought 3.2 on average, while Subordinate 3 bought 3.0 information systems. Subordinate 1 used 6.20 seconds per period to make a decision. Subordinate 2 spent 5.90 seconds to make a decision. Subordinate 3 spent 4.40 seconds to make a decision. Subordinate 1 made an average profit of $5.96 per period. Subordinate 2 made $5.97 and Subordinate 3 made $2.48 per period. In Cycle 4, the subordinates' profits were low. Subordinate 1 made $1.04 per period. Subordinate 2 had an average loss of $0.14 per period and Subordinate 3 made a profit of $1.42 per period. In Cycle 3, Subordinates 1 and 2 also had considerable low profits, $0.06 and $1.83 per period separately.

It took the subordinates progressively less time to make a decision. The average decision time from Cycle 1 to Cycle 6 was 5.50, 4.25, 3.85, 3.55, 2.80, and 2.28 per period separately. It is noted that Cycle 6 has the same parameter values as Cycle 1. All 3 subordinates showed improved profit in Cycle 6 while Subordinates 1 and 2 purchased less information systems on average and Subordinate 3 bought one more information systems on average per period. The average of the profit for the 3 subordinates increased from $4.80 to $6.43 per period.

Six cycle average data, as shown in the last row of Table 4.3.1, was calculated by *dividing the sum of the per-period value in each cycle with the number of cycles.* In calculating the average over the cycles this way, we treated each cycle as an independent cycle.

Table 4.3.2 shows the decision agreement frequency in Experiment 1. For Subordinate 1, the subordinate's decision was the same as that of the manager and the actual sales (Category 1) in 95 periods out of the total of 120 periods (79.2%). For Subordinate 2, it was 98 in 120 periods (81.7%). For subordinate 3, it was 100 in 120 periods (83.3%). Overall, the agreement frequency of Category 1 for all the subordinates in all the periods was 81.4%. The overall percentage for Category 2 (the subordinate's input equal to the manager's decision, but different from the actual sales) was 9.4%, 6.1% for Category 3 (the manager's decision equal to the actual sales, but different from the subordinate's input), 2.5% for Category 4 (the subordinate's input equal to the actual sales, but different from the manager's decision), and 0.6% for Category 5 (the subordinate's input, the manager's decision, and the actual sales were all different.)

Table 4.3.3 compares the per-period profit of the subordinates to that of the automated manager. The average per-period profit of the manager was $12.21, while the average profit of the three subordinates over the six cycles was $4.27. The average number of information systems purchased by the subordinates was 3.7 ($2.00 per information system). The average time taken by the subordinates in making a decision was 3.71 seconds at a cost of $0.01 per second. The subordinates would have made an average of $11.71 (i.e., $4.27+$2.00x3.7+$0.01x3.71) if they had not incurred the information cost and time cost. This was lower than the per-period average profit of the manager ($12.21). Figure 4.3.1. compares the average per-period profit made by the automated manager and the subordinates in a line chart. It is noted that in Cycle 4, even when the subordinates had low profit or loss, the manager had higher profit than in four cycles.

Table 4.3.1. Experiment 1A: Average information systems purchased by the subordinates, average time spent by the subordinates in making a decision, and average profit made by the subordinates.

Cycle Number	Info Available	Subordinate 1			Subordinate 2			Subordinate 3			All Subordinates		
		Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit
Cycle 1	5	3.2	6.20	$5.96	3.2	5.90	$5.97	3.0	4.40	$2.48	3.1	5.50	$4.80
Cycle 2	5	3.3	4.30	$4.06	3.5	4.80	$6.13	3.7	3.65	$5.19	3.5	4.25	$5.13
Cycle 3	10	3.0	3.70	$0.06	4.6	4.15	$1.83	4.7	3.70	$4.19	4.1	3.85	$2.03
Cycle 4	10	2.7	3.15	$1.04	4.8	4.15	($0.14)	6.5	3.35	$1.42	4.7	3.55	$0.77
Cycle 5	6	2.8	2.85	$6.02	3.5	2.75	$6.65	4.7	2.80	$6.72	3.7	2.80	$6.46
Cycle 6	5	2.6	2.30	$7.20	2.9	2.10	$6.50	4.1	2.45	$5.60	3.2	2.28	$6.43
All Cycles		2.9	3.75	$4.06	3.8	3.98	$4.49	4.5	3.39	$4.27	3.7	3.71	$4.27

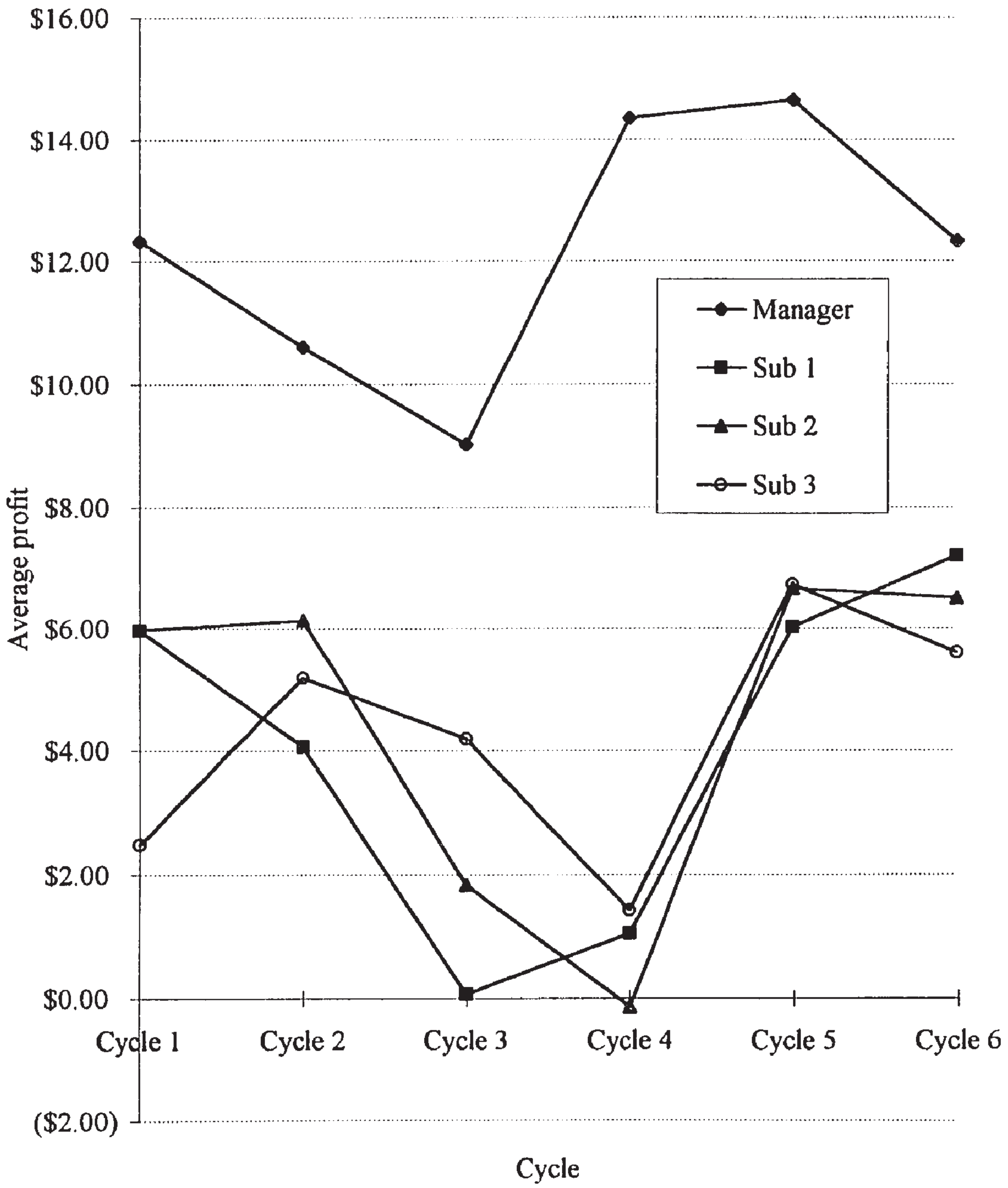
Table 4.3.2. Experiment 1A: Decision agreement frequency.

Cycle Number	Periods	Subordinate 1 Category					Subordinate 2 Category					Subordinate 3 Category					All Subordinates Category				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Cycle 1	20	19	1	0	0	0	19	1	0	0	0	15	1	4	0	0	53	3	4	0	0
Cycle 2	20	15	5	0	0	0	14	3	1	2	0	14	3	1	2	0	43	11	2	4	0
Cycle 3	20	13	3	3	0	1	15	2	1	1	1	16	2	0	2	0	44	7	4	3	2
Cycle 4	20	15	0	5	0	0	16	0	4	0	0	20	0	0	0	0	51	0	9	0	0
Cycle 5	20	14	4	2	0	0	15	4	1	0	0	16	3	0	1	0	45	11	3	1	0
Cycle 6	20	19	1	0	0	0	19	1	0	0	0	19	0	0	1	0	57	2	0	1	0
All Cycles	120	95	14	10	0	1	98	11	7	3	1	100	9	5	6	0	293	34	22	9	2
All Cycles (in %)		79.2	11.7	8.3	0.0	0.8	81.7	9.2	5.8	2.5	0.8	83.3	7.5	4.2	5.0	0.0	81.4	9.4	6.1	2.5	0.6

Table 4.3.3. Experiment 1A: Average profit made by the automated manager and the subordinates.

Exp't	Cycle	Periods	Manager	Sub 1	Sub 2	Sub 3	All Subs
1A	Cycle 1	20	$12.33	$5.96	$5.97	$2.48	$4.80
	Cycle 2	20	$10.60	$4.06	$6.13	$5.19	$5.13
	Cycle 3	20	$9.03	$0.06	$1.83	$4.19	$2.03
	Cycle 4	20	$14.35	$1.04	($0.14)	$1.42	$0.77
	Cycle 5	20	$14.65	$6.02	$6.65	$6.72	$6.46
	Cycle 6	20	$12.33	$7.20	$6.50	$5.60	$6.43
	All Cycles		$12.21	$4.06	$4.49	$4.27	$4.27

Figure 4.3.1. Experiment 1A: Average per-period profit made by the automated manager and the subordinates.



4.4 Experiment 2A: Four MBA Student Subordinates in Six Cycles

This experiment used four subordinates and an automated manager. The subordinate subjects were MBA students. There were six cycles. The number of periods in each cycle was increased to 30 or 40 periods instead of the 20 periods in Experiment 1A. Cycles 1, 4, and 6 had 30 periods each and Cycles 2, 3, and 5 each had 40 periods. The information costs were varied from cycle to cycle. The subordinate's profit was a function of the individual's own decision. Table 4.2.1 provides the specific experimental parameter values used in this experiment.

The decision rule implemented for the automated manager was the same as in Experiment 1A, most identical inputs (not necessarily majority) from all subordinates with risk averse choice as explained earlier.

Experiment Results

Tables 4.4.1 outlines the average information systems purchased by the subordinates, average time spent by the subordinates in making a decision, and average profit made by the subordinates. The upper table includes data of Subordinate 4 before that subordinate went bankrupt in Period 12 of Cycle 1. The averaged data for Subordinate 4, calculated over all the cycles and shown in the last row, include the data from Cycle 1. The averaged data for all subordinates, shown in the last three columns, also include the data of Subordinate 4. The lower table does not include data of Subordinate 4 in Cycle 1. The averaged data for Subordinate 4 calculated over all the cycles, shown in the last row, include only data of Cycles 2 to 5. The averaged data for all subordinates in Cycle 1 includes only the data of Subordinates 1 to 3.

In Cycle 1, Subordinate 4 purchased only 1.4 information systems on average and went bankrupt in Period 12. For all the cycles, Subordinate 4 purchased only 2.9 information systems on average and ended up with the lowest per-period profit ($5.85) among the four subordinates. Subordinate 2 purchased the most information systems (5.0), and had the highest average profit ($10.54.)

Table 4.4.2 lists the decision agreement frequency between each subordinate, the automated manager, and the actual sales. Overall, Subordinate 1 has 84.3% of the decisions in Category 1. Subordinate 2 has 88.1% in Category 1. Subordinate 3 has 79.5% in Category 1. And Subordinate 4 has 71.0% in Category 1. The average of the Category 1 frequency for all the four subordinates was 80.7%, while it was 81.4% in Experiment 1A. Subordinate 4 was bankrupt in Period 12 of Cycle 1. Other subordinates did not have bankruptcy in the entire experiment. As shown in Table 4.4.2, Category 0 is used to account for the number of periods a subordinate did not participate because of bankruptcy. Since Subordinate 4 became bankrupt in Period 12 of Cycle 1, the table indicates that Subordinate 4 has 18 Category 0 frequencies in Cycle 1.

Tables 4.4.3 compares the profit of the subordinates to that of the automated manager. The upper table includes the average loss of Subordinate 4 in Cycle 1 before that subordinate went bankrupt in Period 12. The average profit of Subordinate 4 calculated over all cycles, $5.85, includes the loss from this cycle. The average profit of all subordinates, $0.79, also includes the loss of Subordinate 4 in Cycle 1. The lower table does not include the loss of Subordinate 4 in Cycle 1. The average profit of Subordinate 4 calculated over all cycles, $8.73, includes only per-period profits of Cycles 2 to 5. The average profit of all subordinates in Cycle 1, $3.90, includes only the profits of Subordinates 1 to 3.

Table 4.4.1 Experiment 2A: Average information systems purchased, average time spent in making a decision, and average profit made by the subordinates.

This table includes data of Subordinate 4 before bankruptcy occurred in Period 12 of Cycle 1.

Cycle Number	Info Available	Subordinate 1			Subordinate 2			Subordinate 3			Subordinate 4			All Subordinates		
		Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit
Cycle 1	10	2.2	4.57	$0.99	6.9	6.70	$6.85	3.6	4.60	$3.85	1.4	7.42	($8.53)	3.5	5.82	$0.79
Cycle 2	10	3.6	4.80	$10.81	6.7	4.48	$9.67	3.8	3.30	$5.82	4.6	4.55	$4.51	4.7	4.28	$7.70
Cycle 3	6	3.0	3.40	$15.14	3.6	3.13	$12.78	3.4	1.88	$11.78	2.7	1.95	$14.03	3.2	2.59	$13.43
Cycle 4	10	3.3	3.83	$12.26	4.4	3.10	$12.92	3.7	1.97	$12.38	2.9	2.10	$9.28	3.6	2.75	$11.71
Cycle 5	10	3.6	3.83	$11.05	4.0	2.78	$11.40	4.1	1.85	$7.28	2.7	2.00	$8.18	3.6	2.62	$9.48
Cycle 6	8	5.1	4.37	$10.46	4.4	4.73	$9.60	4.1	2.37	$7.08	2.9	1.93	$7.63	4.1	3.35	$8.69
All Cycles		3.5	4.13	$10.12	5.0	4.15	$10.54	3.8	2.66	$8.03	2.9	3.33	$5.85	3.8	3.57	$8.64

This table does not include data of Subordinate 4 in Cycle 1, in which Subordinate 4 went bankrupt in Period 12.

Cycle Number	Info Available	Subordinate 1			Subordinate 2			Subordinate 3			Subordinate 4			All Subordinates		
		Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit
Cycle 1	10	2.2	4.57	$0.99	6.9	6.70	$6.85	3.6	4.60	$3.85	N/A	N/A	Bankrupt (12)	4.2	5.29	$3.90
Cycle 2	10	3.6	4.80	$10.81	6.7	4.48	$9.67	3.8	3.30	$5.82	4.6	4.55	$4.51	4.7	4.28	$7.70
Cycle 3	6	3.0	3.40	$15.14	3.6	3.13	$12.78	3.4	1.88	$11.78	2.7	1.95	$14.03	3.2	2.59	$13.43
Cycle 4	10	3.3	3.83	$12.26	4.4	3.10	$12.92	3.7	1.97	$12.38	2.9	2.10	$9.28	3.6	2.75	$11.71
Cycle 5	10	3.6	3.83	$11.05	4.0	2.78	$11.40	4.1	1.85	$7.28	2.7	2.00	$8.18	3.6	2.62	$9.48
Cycle 6	8	5.1	4.37	$10.46	4.4	4.73	$9.60	4.1	2.37	$7.08	2.9	1.93	$7.63	4.1	3.35	$8.69
All Cycles		3.5	4.13	$10.12	5.0	4.15	$10.54	3.8	2.66	$8.03	3.2	2.51	$8.73	3.9	3.36	$9.36

Table 4.4.2. Experiment 2A: Decision agreement frequencies.

Cycle Number	Periods	Subordinate 1					Subordinate 2					Subordinate 3					Subordinate 4						All Subordinates					
		Category					Category					Category					Category						Category					
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5
Cycle 1	30	13	10	7	0	0	20	0	0	10	0	19	10	1	0	0	18	5	2	3	0	2	18	57	22	11	10	2
Cycle 2	40	36	3	1	0	0	37	1	0	2	0	29	2	8	0	1	0	30	2	7	1	0	0	132	8	16	3	1
Cycle 3	40	37	1	0	2	0	37	3	0	0	0	35	2	2	1	0	0	36	2	1	1	0	0	145	8	3	4	0
Cycle 4	30	27	2	1	0	0	28	0	0	2	0	27	1	1	1	0	0	24	2	4	0	0	0	106	5	6	3	0
Cycle 5	40	35	3	1	1	0	35	2	1	2	0	32	3	4	1	0	0	31	4	5	0	0	0	133	12	11	4	0
Cycle 6	30	29	0	0	1	0	28	0	1	1	0	25	1	4	0	0	0	23	1	6	0	0	0	105	2	11	2	0
All Cycles	210	177	19	10	4	0	185	6	2	17	0	167	19	20	3	1	18	149	13	26	2	2	18	678	57	58	26	3
All Cycles (in %)		84.3	9.0	4.8	1.9	0.0	88.1	2.9	1.0	8.1	0.0	79.5	9.0	9.5	1.4	0.5	8.6	71.0	6.2	12.4	1.0	1.0	2.1	80.7	6.8	6.9	3.1	0.4

Table 4.4.3 Experiment 2A: Average profit made by the automated manager and the subordinates.

This table includes per-period loss of Subordinate 4 before bankruptcy occurred in Period 12 of Cycle 1.

Expt.	Cycle	Periods	Manager	Sub 1	Sub 2	Sub 3	Sub 4	All Subs
2A	Cycle 1	30	$11.75	$0.99	$6.85	$3.85	($8.53)	$0.79
	Cycle 2	40	$15.81	$10.81	$9.67	$5.82	$4.51	$7.70
	Cycle 3	40	$18.14	$15.14	$12.78	$11.78	$14.03	$13.43
	Cycle 4	30	$17.95	$12.26	$12.92	$12.38	$9.28	$11.71
	Cycle 5	40	$16.64	$11.05	$11.40	$7.28	$8.18	$9.48
	Cycle 6	30	$16.20	$10.46	$9.60	$7.08	$7.63	$8.69
	All Cycles		$16.08	$10.12	$10.54	$8.03	$5.85	$8.64

This table does not include per-period loss of Subordinate 4 in Cycle 1, in which Subordinate 4 went bankrupt in Period 12.

Expt.	Cycle	Periods	Manager	Sub 1	Sub 2	Sub 3	Sub 4	All Subs
2A	Cycle 1	30	$11.75	$0.99	$6.85	$3.85	Bankrupt (12)	$3.90
	Cycle 2	40	$15.81	$10.81	$9.67	$5.82	$4.51	$7.70
	Cycle 3	40	$18.14	$15.14	$12.78	$11.78	$14.03	$13.43
	Cycle 4	30	$17.95	$12.26	$12.92	$12.38	$9.28	$11.71
	Cycle 5	40	$16.64	$11.05	$11.40	$7.28	$8.18	$9.48
	Cycle 6	30	$16.20	$10.46	$9.60	$7.08	$7.63	$8.69
	All Cycles		$16.08	$10.12	$10.54	$8.03	$8.73	$9.36

4.5 Experiment 3A: Three MBA Student Subordinates in Six Cycles

This experiment used three MBA students as subordinate subjects. There were six cycles. Cycles 1, 4, and 6 had 30 periods each. Cycles 2, 3, and 5 each had 40 periods. An automated manager was implemented. In Cycles 2 and 6, information cost was progressively higher for each additional information purchase in a period. It cost $0.50 to purchase the first information system, $0.75 for the second one, $1.00 for the third one, $1.25 for the fourth one, $1.50 for the fifth one, $1.75 for the sixth one, $2.00 for the seventh one, and $2.25 for the eighth, ninth, and tenth information systems. The subordinate's profit was a function of the individual's own decision. Table 4.2.1 provides the specific experimental parameter values used in this experiment.

The decision rule implemented for the automated machine manager was the same as in Experiment 1A. The automated manager follows the most identical inputs (not necessarily majority) from all subordinates. The automated manager is risk averse. The automated manager always makes a decision if there is at least one input from the subordinates.

Experiment Results

Table 4.5.1 summarizes the average information systems purchased by the subordinates, average time spent by the subordinates in making a decision, and average profit made by the subordinates. Subordinate 2 purchased the least information systems on average (2.7) and had the highest per-period profit ($9.16) overall, while Subordinate 1 bought the most information systems (4.4) and had the lowest per-period profit, $5.02.

The decision agreement frequency for each subordinate is shown in Table 4.5.2. No bankruptcy occurred in this experiment. The overall frequency of Category 1 for Subordinate 1 was 71.4%. It was 81% for Subordinate 2 and 84.8% for Subordinate 3. The overall Category 1 frequency of all three subordinates was 79%.

Table 4.5.3 summarizes the per-period earnings of the manager and the subordinates. These data will be used when we perform hypothesis testing in Chapter 5.

Table 4.5.1. Experiment 3A: Average information systems purchased, average time spent in making a decision, and average profit made by the subordinates.

Cycle Number	Info Available	Subordinate 1			Subordinate 2			Subordinate 3			All Subordinates		
		Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit
Cycle 1	10	4.0	3.63	$3.21	2.8	2.77	$8.31	3.8	4.77	$6.49	3.5	3.72	$6.00
Cycle 2	10	5.6	2.70	$3.87	2.9	2.13	$4.87	4.4	4.00	$4.22	4.3	2.94	$4.32
Cycle 3	6	3.8	2.48	$5.40	2.6	1.60	$12.61	3.9	2.53	$9.54	3.4	2.20	$9.18
Cycle 4	10	4.3	2.37	$2.13	2.7	1.63	$11.58	4.0	2.77	$10.22	3.7	2.26	$7.98
Cycle 5	8	4.1	2.08	$7.95	2.6	1.50	$8.45	3.5	2.23	$8.74	3.4	1.94	$8.38
Cycle 6	8	4.7	1.93	$7.56	2.8	1.47	$9.16	4.1	2.63	$7.42	3.9	2.01	$8.05
All Cycles		4.4	2.53	$5.02	2.7	1.85	$9.16	4.0	3.16	$7.77	3.7	2.51	$7.32

Table 4.5.2. Experiment 3A: Decision agreement frequencies.

Cycle Number	Periods	Subordinate 1					Subordinate 2					Subordinate 3					All Subordinates				
		Category					Category					Category					Category				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Cycle 1	30	20	4	6	0	0	24	4	2	0	0	25	4	1	0	0	69	12	9	0	0
Cycle 2	40	27	6	3	4	0	25	6	5	1	3	29	9	1	1	0	81	21	9	6	3
Cycle 3	40	29	2	8	1	0	37	3	0	0	0	36	2	1	1	0	102	7	9	2	0
Cycle 4	30	19	1	9	1	0	26	2	2	0	0	27	1	1	1	0	72	4	12	2	0
Cycle 5	40	32	2	3	3	0	33	5	2	0	0	35	4	0	1	0	100	11	5	4	0
Cycle 6	30	23	1	4	2	0	25	3	2	0	0	26	3	1	0	0	74	7	7	2	0
All Cycles	210	150	16	33	11	0	170	23	13	1	3	178	23	5	4	0	498	62	51	16	3
All Cycles (in %)		71.4	7.6	15.7	5.2	0.0	81.0	11.0	6.2	0.5	1.4	84.8	11.0	2.4	1.9	0.0	79.0	9.8	8.1	2.5	0.5

Table 4.5.3. Experiment 3A: Average profit made by the automated manager and the subordinates.

Exp't	Cycle	Periods	Manager	Sub 1	Sub 2	Sub 3	All Subs
3A	Cycle 1	30	$15.25	$3.21	$8.31	$6.49	$6.00
	Cycle 2	40	$8.58	$3.87	$4.87	$4.22	$4.32
	Cycle 3	40	$19.19	$5.40	$12.61	$9.54	$9.18
	Cycle 4	30	$16.90	$2.13	$11.58	$10.22	$7.98
	Cycle 5	40	$13.30	$7.95	$8.45	$8.74	$8.38
	Cycle 6	30	$13.15	$7.56	$9.16	$7.42	$8.05
	All Cycles		$14.39	$5.02	$9.16	$7.77	$7.32

4.6 Experiment 4A: Five MBA Student Subordinates in Six Cycles

This is the first experiment using five subordinate subjects. They were MBA students. There were six cycles. Cycles 1 to 4 had 40 periods. Cycles 5 and 6 had 50 periods. The parameter values used in this experiment were similar to Experiment 3A. The information cost in Cycle 4 was different from that in Cycle 4 of Experiment 3A. The information systems purchase cost $2.00 each in Cycle 4 now. As in Experiment 3A, the information systems cost was progressively higher in Cycles 2 and 6. The subordinate's profit was a function of the individual's own decision. Table 4.2.1 provides the specific experimental parameter values used in this experiment.

The decision rule implemented for the automated machine manager was the same as in the previous experiment. The automated manager follows the most identical inputs (not necessarily majority) from all subordinates. The automated manager is risk averse. The automated manager always makes a decision if there is at least one input from the subordinates.

Experiment Results

As shown in Table 4.6.3, two subordinates became bankrupt in this experiment. Subordinate 1 was bankrupt in Period 6 of Cycle 1. Subordinate 2 was bankrupt in Period 5 of Cycle 1 and Period 13 of Cycle 2. Due to the bankruptcy, Subordinate 1 did not participate in 13.1% of the total 260 periods. Likewise, Subordinate 2 did not participate in 23.8% of the total 260 periods. Because of the bankruptcy, Subordinate 1 had only

62.3% category 1 frequency in decision agreement. Similarly, Subordinate 2 had only 45% in category 1. The other three subordinates, however, had high frequency in Category 1, namely, 89.6% for Subordinate 3, 84.6% for Subordinate 4, and 87.3% for Subordinate 5.

Table 4.6.1 includes values from the two subordinates' bankrupt cycles. With a per-period loss of $24.94 in Cycle 1, for example, Subordinate 2 had an average loss of $3.31 over the six cycles. As in other experiments, this average was calculated by dividing the sum of the per-period value in each cycle with the number of cycles, (-$24.94-$2.13+$2.72-$8.56+$7.70+$5.33) / 6 = -$3.31. Table 4.6.2 does not include values from the two subordinates' bankrupt cycles. For example, the average profit of Subordinate 2 over the six cycles, $3.41, was calculated by totaling the per-period profit from Cycles 2, 3, 5, and 6, and then dividing the total by the number of cycles (4), i.e., (-$2.13+$2.72+$7.70+$5.33) / 4 = $3.41.

Table 4.6.4 summarizes the per-period profit of the manager and the subordinates. The upper table includes the bankrupt subordinate's loss in the cycles with bankruptcy. The lower table does not include these losses.

Table 4.6.1. Experiment 4A: Average information systems purchased, average time spent in making a decision, and average profit made by the subordinates.
This table includes data of subordinate's bankrupt cycles.

Cycle Number	Info Available	Subordinate 1			Subordinate 2			Subordinate 3			Subordinate 4			Subordinate 5			All Subordinates		
		Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit
Cycle 1	10	2.5	13.33	($16.76)	0.4	4.40	($24.94)	6.9	4.98	$5.11	8.4	4.60	$1.60	6.1	6.03	$4.15	4.9	6.67	($6.17)
Cycle 2	10	3.3	6.55	$7.35	0.9	3.15	($2.13)	6.9	3.88	$5.38	6.0	3.78	$6.58	6.8	5.13	$5.69	4.8	4.50	$4.57
Cycle 3	6	2.5	4.10	$2.91	2.5	2.70	$2.72	4.1	3.18	$6.41	4.0	2.85	$7.77	4.4	3.23	$4.84	3.5	3.21	$4.93
Cycle 4	10	2.8	4.13	$4.20	1.5	2.31	($8.56)	5.3	3.35	$7.43	4.1	2.50	$4.98	5.5	3.65	$6.33	3.8	3.19	$2.88
Cycle 5	8	1.8	2.80	$9.01	1.2	2.10	$7.70	3.5	2.88	$10.45	3.7	2.44	$7.43	4.2	2.52	$9.94	2.9	2.55	$8.91
Cycle 6	8	2.0	2.98	$9.81	1.0	1.74	$5.33	3.4	2.68	$11.63	2.6	1.86	$10.91	4.2	2.64	$13.28	2.6	2.38	$10.19
All Cycles		2.5	5.65	$2.75	1.3	2.73	($3.31)	5.0	3.49	$7.74	4.8	3.01	$6.55	5.2	3.87	$7.37	3.8	3.75	$4.22

Table 4.6.2. Experiment 4A: Average information systems purchased, average time spent in making a decision, and average profit made by the subordinates. *This table does not include data of subordinate's bankrupt cycles.*

Cycle Number	Info Available	Subordinate 1			Subordinate 2			Subordinate 3			Subordinate 4			Subordinate 5			All Subordinates		
		Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit
Cycle 1	10	N/A	N/A	Bankrupt (6)	N/A	N/A	Bankrupt (5)	6.9	4.98	$5.11	8.4	4.60	$1.60	6.1	6.03	$4.15	7.1	5.20	$3.62
Cycle 2	10	3.3	6.55	$7.35	0.9	3.15	($2.13)	6.9	3.88	$5.38	6.0	3.78	$6.58	6.8	5.13	$5.69	4.8	4.50	$4.57
Cycle 3	6	2.5	4.10	$2.91	2.5	2.70	$2.72	4.1	3.18	$6.41	4.0	2.85	$7.77	4.4	3.23	$4.84	3.5	3.21	$4.93
Cycle 4	10	2.8	4.13	$4.20	N/A	N/A	Bankrupt (13)	5.3	3.35	$7.43	4.1	2.50	$4.98	5.5	3.65	$6.33	4.4	3.41	$5.74
Cycle 5	8	1.8	2.80	$9.01	1.2	2.10	$7.70	3.5	2.88	$10.45	3.7	2.44	$7.43	4.2	2.52	$9.94	2.9	2.55	$8.91
Cycle 6	8	2.0	2.98	$9.81	1.0	1.74	$5.33	3.4	2.68	$11.63	2.6	1.86	$10.91	4.2	2.64	$13.28	2.6	2.38	$10.19
All Cycles		2.5	4.11	$6.66	1.4	2.42	$3.41	5.0	3.49	$7.74	4.8	3.01	$6.55	5.2	3.87	$7.37	3.8	3.38	$6.35

Table 4.6.3. Experiment 4A: Decision agreement frequencies.

Cycle		Subordinate 1						Subordinate 2						Subordinate 3					Subordinate 4					Subordinate 5					All Subordinates					
		Category						Category						Category					Category					Category					Category					
Number	Periods	0	1	2	3	4	5	0	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	0	1	2	3	4	5
Cycle 1	40	34	0	1	5	0	0	35	0	0	4	0	1	39	1	0	0	0	37	0	2	1	0	35	1	4	0	0	69	111	3	15	1	1
Cycle 2	40	0	31	3	6	0	0	0	18	2	19	1	0	36	1	1	2	0	36	3	1	0	0	35	1	2	2	0	0	156	10	29	5	0
Cycle 3	40	0	27	2	10	1	0	0	27	2	10	1	0	37	3	0	0	0	37	1	0	2	0	35	2	2	1	0	0	163	10	22	5	0
Cycle 4	40	0	29	4	7	0	0	27	5	0	8	0	0	36	1	0	3	0	31	3	5	1	0	35	1	1	3	0	27	136	9	21	7	0
Cycle 5	50	0	40	2	7	0	1	0	38	0	9	1	2	46	2	1	1	0	41	3	6	0	0	47	2	0	1	0	0	212	9	23	3	3
Cycle 6	50	0	35	9	5	0	1	0	29	8	11	1	1	39	8	1	2	0	38	7	2	1	2	40	3	0	7	0	0	181	35	19	11	4
All Cycles	260	34	162	21	40	1	2	62	117	12	61	4	4	233	16	3	8	0	220	17	16	5	2	227	10	9	14	0	96	959	76	129	32	8
All Cycles (in %)		13.1	62.3	8.1	15.4	0.4	0.8	23.8	45.0	4.6	23.5	1.5	1.5	89.6	6.2	1.2	3.1	0.0	84.6	6.5	6.2	1.9	0.8	87.3	3.8	3.5	5.4	0.0	7.4	73.8	5.8	9.9	2.5	0.8

Table 4.6.4. Experiment 4A: Average profit made by the automated manager and the subordinates.

This table includes the per-period loss of Subordinate 1 before bankruptcy occurred in Period 6 of Cycle 1 and the per-period loss of Subordinate 2 before bankruptcy occurred in Period 5 of Cycle 5 and Period 13 of Cycle 4.

Expt.	Cycle	Periods	Manager	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	All Subs
4A	Cycle 1	40	$17.28	($16.76)	($24.94)	$5.11	$1.60	$4.15	($6.17)
	Cycle 2	40	$14.46	$7.35	($2.13)	$5.38	$6.58	$5.69	$4.57
	Cycle 3	40	$16.56	$2.91	$2.72	$6.41	$7.77	$4.84	$4.93
	Cycle 4	40	$15.81	$4.20	($8.56)	$7.43	$4.98	$6.33	$2.88
	Cycle 5	50	$15.91	$9.01	$7.70	$10.45	$7.43	$9.94	$8.91
	Cycle 6	50	$14.02	$9.81	$5.33	$11.63	$10.91	$13.28	$10.19
	All Cycles		$15.67	$2.75	($3.31)	$7.74	$6.55	$7.37	$4.22

This table does not include per-period loss of subordinate's bankrupt cycles.

Expt.	Cycle	Periods	Manager	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	All Subs
4A	Cycle 1	40	$17.28	Bankrupt (6)	Bankrupt (5)	$5.11	$1.60	$4.15	$3.62
	Cycle 2	40	$14.46	$7.35	($2.13)	$5.38	$6.58	$5.69	$4.57
	Cycle 3	40	$16.56	$2.91	$2.72	$6.41	$7.77	$4.84	$4.93
	Cycle 4	40	$15.81	$4.20	Bankrupt (13)	$7.43	$4.98	$6.33	$5.74
	Cycle 5	50	$15.91	$9.01	$7.70	$10.45	$7.43	$9.94	$8.91
	Cycle 6	50	$14.02	$9.81	$5.33	$11.63	$10.91	$13.28	$10.19
	All Cycles		$15.67	$6.66	$3.41	$7.74	$6.55	$7.37	$6.35

4.7 Experiment 5A: Five Subordinates in Six Cycles

The subjects used in this experiment were clerical staff in the College of B&E. There were five subordinates. As before, an automated human manager was implemented. The automated manager follows the most identical inputs (not necessarily majority) from all subordinates. The automated manager is risk averse. The automated manager always makes a decision if there is at least one input from the subordinates. The subordinate's profit was a function of the individual's own decision.

To compare the performance of different types of subjects, this experiment had parameter values similar to those in Experiment 4A. Cycle 1 had the same parameter values as in Cycle 3 of Experiment 4A. Cycle 2 had the same parameter values as in Cycle 4 of Experiment 4A. Cycle 3 had the same parameter values as in Cycle 5 of Experiment 4A. Cycle 4 had the same parameter values as in Cycle 6 of Experiment 4A. As in Experiment 4A, the information systems cost was progressively higher in Cycle 4.

Experiment Results

Table 4.7.2 lists the decision agreement frequencies in this experiment. No subordinate became bankrupt in any cycle. The Category 1 frequencies, however, were lower than those in previous experiments. All cycles combined, the Category 1 frequency of Subordinate 1 was 63.3%, 53.3% for Subordinate 2, 71.1% for Subordinate 3, 71.7% for Subordinate 4, and 67.2% for Subordinate 5. The average of all subordinates was 65.3%.

Although no subordinate became bankrupt in any cycle, Subordinates 1 and 2 did have a loss in Cycle 2, as shown in Table 4.7.1. Table 4.7.3 summarizes the average per-period profits made by the automated manager and the subordinates.

Table 4.7.1. Experiment 5A: Average information systems purchased, average time spent in making a decision, and average profit made by the subordinates.

Cycle Number	Info Available	Subordinate 1			Subordinate 2			Subordinate 3			Subordinate 4			Subordinate 5			All Subordinates		
		Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit
Cycle 1	6	2.3	2.93	$4.72	3.3	4.30	$0.01	2.8	4.55	$4.24	2.9	5.63	$5.74	3.4	5.33	$3.81	2.9	4.55	$3.70
Cycle 2	10	2.5	2.28	($0.82)	3.0	2.48	($0.56)	2.9	2.85	$0.87	4.1	4.63	$6.90	3.6	4.15	$0.92	3.2	3.28	$1.46
Cycle 3	8	2.2	1.78	$6.92	3.0	2.16	$5.33	3.7	2.70	$8.71	2.7	3.50	$7.69	3.2	3.60	$5.82	3	2.75	$6.89
Cycle 4	8	2.6	2.30	$8.50	2.7	1.94	$10.50	3.1	1.82	$10.82	2.7	2.76	$11.20	2.5	2.66	$11.29	2.7	2.30	$10.46
All Cycles		2.4	2.32	$4.83	3.0	2.72	$3.82	3.1	2.98	$6.16	3.1	4.13	$7.88	3.2	3.94	$5.46	3	3.22	$5.63

Table 4.7.2. Experiment 5A: Decision agreement frequencies.

Cycle		Subordinate 1					Subordinate 2					Subordinate 3					Subordinate 4					Subordinate 5					All Subordinates				
		Category					Category					Category					Category					Category					Category				
Number	Periods	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Cycle 1	40	26	9	4	1	0	7	5	2	17	9	26	6	4	3	1	28	6	2	4	0	28	5	2	3	2	115	31	14	28	12
Cycle 2	40	20	10	6	3	1	19	10	7	3	1	22	12	4	2	0	25	4	1	10	0	23	10	3	2	2	109	46	21	20	4
Cycle 3	50	37	7	6	0	0	35	5	8	0	2	42	4	1	2	1	38	6	5	1	0	34	5	9	2	0	186	27	29	5	3
Cycle 4	50	31	7	8	4	0	35	8	4	2	1	38	10	1	1	0	38	10	1	1	0	36	9	3	2	0	178	44	17	10	1
All Cycles	180	114	33	24	8	1	96	28	21	22	13	128	32	10	8	2	129	26	9	16	0	121	29	17	9	4	588	148	81	63	20
All Cycles (in %)		63.3	18.3	13.3	4.4	0.6	53.3	15.6	11.7	12.2	7.2	71.1	17.8	5.6	4.4	1.1	71.7	14.4	5.0	8.9	0.0	67.2	16.1	9.4	5.0	2.2	65.3	16.4	9.0	7.0	2.8

Table 4.7.3. Experiment 5A: Average profit made by the automated manager and the subordinates.

Expt.	Cycle	Periods	Manager	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	All Subs
5A	Cycle 1	40	$11.61	$4.72	$0.01	$4.24	$5.74	$3.81	$3.70
	Cycle 2	40	$6.66	($0.82)	($0.56)	$0.87	$6.90	$0.92	$1.46
	Cycle 3	50	$13.72	$6.92	$5.33	$8.71	$7.69	$5.82	$6.89
	Cycle 4	50	$13.42	$8.50	$10.50	$10.82	$11.20	$11.29	$10.46
	All Cycles		$11.35	$4.83	$3.82	$6.16	$7.88	$5.46	$5.63

4.8 Experiment 6A: Five Doctoral Students in Six Cycles; Waiting for Free Information in Two Cycles

This experiment used five doctoral students in the College of B&E as subordinate subjects. There were six cycles. In Cycle 4 the subordinates had to wait four seconds for a free information system. The waiting cost was $0.10 per second. In Cycle 5 the subordinates had to wait five seconds for a free information system. The waiting cost was also $0.10 per second. The decision rule implemented for the automated machine manager was the same as that in previous experiments. A subordinate's profit was a function of the individual's own decision. Table 4.2.1 provides the specific experimental parameter values used in this experiment. The information systems cost was progressively higher in Cycle 4.

Experiment Results

Tables 4.8.1 lists the average information systems purchased by the subordinates, average time spent by the subordinates in making a decision, and average profit made by the subordinates. In Cycle 5, the subordinates waited for an average of 15.64 seconds (with a time cost of $1.56) to obtain an average of 3.4 free information systems. In Cycle 6, the subordinates waited for an average of 22.98 seconds (with a time cost of $2.30) to obtain an average of 4.3 information systems. In Cycles 1 to 4, where there was no waiting to purchase the information systems, the average decision time taken by the subordinates was 6.11, 2.63, 2.77, and 3.72 respectively.

In observing the proceeding of this experiment, we noted that the subordinates were impatient in waiting for a free information system. After the experiment the subjects expressed their dislike of the waiting.

Table 4.8.2 shows the decision agreement frequencies between the subordinate's, manager's, and the actual sales. All five subordinates had more than 80% of Category 1 agreement. There was no bankrupt subordinate in this experiment, as shown in Table 4.8.3.

Table 4.8.1. Experiment 6A: Average information systems purchased, average time spent in making a decision, and average profit made by the subordinates.

Cycle Number	Info Available	Subordinate 1			Subordinate 2			Subordinate 3			Subordinate 4			Subordinate 5			All Subordinates		
		Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit
Cycle 1	10	3.2	4.95	$4.12	2.0	7.85	$0.58	6.0	4.80	$3.33	4.7	5.55	$5.81	3.9	7.40	$4.41	4	6.11	$3.65
Cycle 2	10	3.3	3.23	$6.04	1.4	2.58	$0.21	4.8	3.35	$8.14	4.4	3.73	$8.24	3.9	5.23	$7.20	3.6	3.62	$5.97
Cycle 3	6	3.4	3.43	$13.64	1.7	2.73	$12.04	3.7	2.18	$12.49	2.5	1.88	$13.81	2.8	3.65	$12.40	2.8	2.77	$12.88
Cycle 4	10	3.6	3.60	$5.59	3.6	4.33	$5.27	4.4	2.75	$7.22	4.2	3.23	$6.56	3.6	4.68	$5.89	3.9	3.72	$6.11
Cycle 5	8	4.5	19.77	$10.92	3.8	17.53	$8.55	2.7	12.47	$9.00	2.8	12.87	$8.61	3.4	15.57	$8.34	3.4	15.64	$9.08
Cycle 6	8	4.7	25.55	$11.31	4.4	24.35	$9.70	4.1	21.48	$9.73	3.7	19.43	$7.50	4.4	24.10	$9.95	4.3	22.98	$9.64
All Cycles		3.8	10.09	$8.60	2.8	9.9	$6.06	4.3	7.84	$8.32	3.7	7.78	$8.42	3.7	10.11	$8.03	3.7	9.14	$7.89

Table 4.8.2. Experiment 6A: Decision agreement frequencies.

Cycle Number	Periods	Subordinate 1 Category					Subordinate 2 Category					Subordinate 3 Category					Subordinate 4 Category					Subordinate 5 Category					All Subordinates Category				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Cycle 1	40	28	8	4	0	0	20	8	12	0	0	29	3	3	5	0	31	5	1	3	0	29	7	3	1	0	137	31	23	9	0
Cycle 2	40	32	2	6	0	0	22	2	16	0	0	38	2	0	0	0	37	2	1	0	0	34	2	4	0	0	163	10	27	0	0
Cycle 3	40	39	0	0	1	0	34	1	5	0	0	38	0	1	1	0	38	1	1	0	0	36	1	3	0	0	185	3	10	2	0
Cycle 4	40	33	2	4	1	0	32	2	5	1	0	37	2	0	1	0	36	2	1	1	0	34	3	3	0	0	172	11	13	4	0
Cycle 5	30	24	4	1	1	0	22	5	3	0	0	22	5	3	0	0	22	5	3	0	0	21	3	4	2	0	111	22	14	3	0
Cycle 6	40	38	1	0	1	0	36	2	2	0	0	36	2	2	0	0	32	2	6	0	0	36	1	2	1	0	178	8	12	2	0
All Cycles	230	194	17	15	4	0	166	20	43	1	0	200	14	9	7	0	196	17	13	4	0	190	17	19	4	0	946	85	99	20	0
All Cycles (in %)		84.3	7.4	6.5	1.7	0.0	72.2	8.7	18.7	0.4	0.0	87.0	6.1	3.9	3.0	0.0	85.2	7.4	5.7	1.7	0.0	82.6	7.4	8.3	1.7	0.0	82.3	7.4	8.6	1.7	0.0

Table 4.8.3. Experiment 6A: Average profit made by the automated manager and the subordinates.

Expt.	Cycle	Periods	Manager	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	All Subs
6A	Cycle 1	40	$12.55	$4.12	$0.58	$3.33	$5.81	$4.41	$3.65
	Cycle 2	40	$13.11	$6.04	$0.21	$8.14	$8.24	$7.20	$5.97
	Cycle 3	40	$18.33	$13.64	$12.04	$12.49	$13.81	$12.40	$12.88
	Cycle 4	40	$15.25	$5.59	$5.27	$7.22	$6.56	$5.89	$6.11
	Cycle 5	30	$12.90	$10.92	$8.55	$9.00	$8.61	$8.34	$9.08
	Cycle 6	40	$13.11	$11.31	$9.70	$9.73	$7.50	$9.95	$9.64
	All Cycles		$14.21	$8.60	$6.06	$8.32	$8.42	$8.03	$7.89

4.9 Experiment 7A: Subordinates Have No Feedback on the Automated Manager's Decision

This experiment used five undergraduate subjects as subordinates. There were four cycles. The major difference of this experiment from the previous ones was that the subordinates had no feedback on the manager's decision. A subordinate's profit was a function of the individual's own decision. The decision rule implemented for the automated manager was the same as in previous experiments.

This is the first experiment using undergraduate students and the first one with no manager's decision feedback for the subordinates. There were four cycles. The first cycle had 30 periods. Cycle 2 had 50 periods and Cycle 3 had 30 periods. In Cycle 4 the subordinates had to wait five seconds for a free information system. This cycle had 20 periods. It had less periods because the waiting ate up time and, therefore, it took longer for a subordinate to make a decision. Table 4.2.1 provides the specific experimental parameter values used in this experiment.

Experiment Results

In Cycle 2 and 4 the subordinates were provided with the same set of information systems. There were six information systems in the set. It turned out that the subordinates used an average of 2.2 information systems in both cycles, as shown in Table 4.9.1.

Subordinate 2 accessed an average of 0.9 information system in the experiment and had a per-period profit of $2.74. Subordinate 3 purchased only an average of 1.6 information systems and had the lowest profit of $1.54 among the subordinates. Subordinate 3 had the lowest Category 1 agreement frequency at 43.1%, as listed in Table 4.9.2. No subordinate went bankrupt in this experiment. In Cycle 3, the per-period profits of the subordinates were generally low, as shown in Table 4.9.3. Subordinates 2 and 3 ended up with a loss for the cycle.

In Cycle 4, where the subordinates had to wait five seconds for a free information system, the subordinates waited for an average of 12.19 seconds (with a time cost of $1.22) to obtain an average of 2.2 free information systems per period.

Compared to other subjects in previous experiments, the undergraduate subjects in this experiment appeared reluctant in purchasing information systems. They purchased an average of 2.2 information systems per period across all the cycles.

Table 4.9.1. Experiment 7A: Average information systems purchased, average time spent in making a decision, and average profit made by the subordinates.

Cycle Number	Info Available	Subordinate 1			Subordinate 2			Subordinate 3			Subordinate 4			Subordinate 5			All Subordinates		
		Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit
Cycle 1	5	2.4	2.17	$13.54	1.0	2.77	$7.97	0.5	5.77	$3.87	2.7	2.87	$13.65	2.4	1.87	$12.48	1.8	3.09	$10.30
Cycle 2	6	2.7	2.74	$4.22	1.0	2.30	$2.28	1.1	5.48	$1.11	3.3	4.02	$4.80	2.8	2.04	$4.94	2.2	3.32	$3.47
Cycle 3	10	2.6	2.07	$1.68	0.9	2.80	($1.06)	2.7	4.73	($3.25)	3.6	3.83	$0.01	3.2	2.90	$1.54	2.6	3.27	($0.22)
Cycle 4	6	3.3	17.80	$12.35	0.5	4.25	$1.78	2.1	12.45	$4.41	2.5	13.45	$6.86	2.4	13.00	$9.38	2.2	12.19	$6.96
All Cycles		2.8	6.2	$7.95	0.9	3.03	$2.74	1.6	7.11	$1.54	3.0	6.04	$6.33	2.7	4.95	$7.09	2.2	5.47	$5.13

Table 4.9.2. Experiment 7A: Decision agreement frequencies.

Cycle Number	Periods	Subordinate 1					Subordinate 2					Subordinate 3					Subordinate 4					Subordinate 5					All Subordinates				
		Category					Category					Category					Category					Category					Category				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Cycle 1	30	27	3	0	0	0	18	2	9	1	0	11	1	16	2	0	25	1	2	2	0	26	3	1	0	0	107	10	28	5	0
Cycle 2	50	33	13	3	1	0	23	11	13	3	0	23	7	13	4	3	31	8	5	5	1	34	12	2	2	0	144	51	36	15	4
Cycle 3	30	21	5	2	1	1	9	3	14	3	1	12	2	11	4	1	19	4	4	2	1	22	6	1	1	0	83	20	32	11	4
Cycle 4	20	13	4	0	3	0	8	5	5	1	1	10	6	3	1	0	11	6	2	1	0	12	6	1	1	0	54	27	11	7	1
All Cycles	130	94	25	5	5	1	58	21	41	8	2	56	16	43	11	4	86	19	13	10	2	94	27	5	4	0	388	108	107	38	9
All Cycles (in %)		72.3	19.2	3.8	3.8	0.8	44.6	16.2	31.5	6.2	1.5	43.1	12.3	33.1	8.5	3.1	66.2	14.6	10.0	7.7	1.5	72.3	20.8	3.8	3.1	0.0	59.7	16.6	16.5	5.8	1.7

Table 4.9.3. Experiment 7A: Average profit made by the automated manager and the subordinates.

Expt.	Cycle	Periods	Manager	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	All Subs
7A	Cycle 1	30	$17.70	$13.54	$7.97	$3.87	$13.65	$12.48	$10.30
	Cycle 2	50	$10.39	$4.22	$2.28	$1.11	$4.80	$4.94	$3.47
	Cycle 3	30	$8.20	$1.68	($1.06)	($3.25)	$0.01	$1.54	($0.22)
	Cycle 4	20	$8.65	$12.35	$1.78	$4.41	$6.86	$9.38	$6.96
	All Cycles		$11.24	$7.95	$2.74	$1.54	$6.33	$7.09	$5.13

4.10 Experiment 8A: Mixed Types of Subordinates in Five Cycles

The Subjects in this experiment were three experienced clerical staff members in the College of Business and Economics and two experienced doctoral students. They participated in the experiment as the subordinates. There were five cycles. The subordinates had no feedback of the automated manager's decision. The subordinate's profit was a function of the individual's own decision. The decision rule implemented for the automated machine manager was the same as in Experiment 1A.

The experimental parameter values in Cycle 1 were the same as those in Cycle 1 of Experiment 7A except for the number of periods. The parameter values in Cycle 2 were the same as those of Cycle 2 in Experiment 7A. Cycle 3 had the same parameter values as Cycle 3 in Experiment 7A except for the number of periods. Cycle 4 had different parameter values from Cycle 2 in this experiment in the number of periods, the time cost, and the information cost. Cycle 5 had different parameter values from Cycle 3 in this experiment in the number of periods, the time cost, and the information cost.

In Cycle 4 the subordinates had to wait five seconds for a free information system. The waiting cost was $0.10 per second. There were 20 periods. In Cycle 5 the subordinates had to wait four seconds for a free information system. The waiting cost was also $0.10 per second. There were 25 periods. As indicated in Experiment 7A, Cycles 4 and 5 had less periods because the waiting ate up time and, therefore, it took longer for a subordinate to make a decision.

Experiment Results

Table 4.10.1. lists average information systems purchased, average time spent in making a decision, and average profit made by the subordinates. In Cycle 3, Subordinate 4 went bankrupt in Period 42 and Subordinate 5 in Period 43. The upper table in Table 4.10.1 includes per-period data of Subordinates 4 and 5 before bankruptcy occurred in Cycle 3. The lower table does not include those data.

In Cycle 4, the subordinates waited for an average of 15.49 seconds (with a time cost of $1.55) to obtain an average of 2.8 free information systems. In Cycle 5, the subordinates waited for an average of 15.74 seconds (with a time cost of $1.57) to obtain an average of 3.6 information systems. In Cycles 1 to 3, where there was no waiting to purchase the information systems, the average decision time taken by the subordinates was 2.69, 2.60, and 2.50 respectively.

Table 4.10.2 summarizes the decision agreement frequencies. We noted that Subordinate 5 had the lowest Category 1 frequencies (62.1%) in the five cycles. The subordinate had the lowest per-period profit, $3.51, when the bankrupt Cycle 3 was accounted for. The subordinate also had the lowest per-period profit, $5.04, when the bankrupt Cycle 3 was not included, as shown in Table 4.10.3.

Table 4.10.1. Experiment 8A: Average information systems purchased, average time spent in making a decision, and average profit made by the subordinates.

This table includes per-period data of Subordinates 4 and 5 before bankruptcy occurred in Cycle 3.																			
		Subordinate 1			Subordinate 2			Subordinate 3			Subordinate 4			Subordinate 5			All Subordinates		
Cycle Number	Info Available	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit
Cycle 1	5	2.1	2.22	$9.51	2.2	1.78	$10.09	4.1	3.76	$11.48	2.2	2.34	$8.99	3.0	3.34	$8.35	2.7	2.69	$9.68
Cycle 2	6	2.4	2.12	$4.11	2.9	1.84	$4.57	4.3	3.40	$4.33	2.2	1.80	$2.26	3.3	3.86	$2.75	3	2.60	$3.60
Cycle 3	10	3.5	2.62	$3.26	3.1	2.04	$0.71	3.8	2.84	$0.20	2.5	2.48	($2.87)	3.3	3.07	($2.60)	3.2	2.61	($0.26)
Cycle 4	6	3.0	16.60	$9.54	2.8	14.90	$6.71	3.0	16.55	$10.00	2.7	15.25	$5.63	2.4	14.15	$5.21	2.8	15.49	$7.42
Cycle 5	10	3.8	16.28	$11.91	4.0	16.48	$13.45	2.8	12.72	$6.75	4.5	19.68	$9.17	2.8	13.52	$3.85	3.6	15.74	$9.03
All Cycles		3.0	7.97	$7.67	3.0	7.41	$7.11	3.6	7.85	$6.55	2.8	8.31	$4.64	3.0	7.59	$3.51	3.1	7.83	$5.90

This table does not include per-period data of Subordinates 4 and 5 before bankruptcy occurred in Cycle 3.																			
		Subordinate 1			Subordinate 2			Subordinate 3			Subordinate 4			Subordinate 5			All Subordinates		
Cycle Number	Info Available	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit
Cycle 1	5	2.1	2.22	$9.51	2.2	1.78	$10.09	4.1	3.76	$11.48	2.2	2.34	$8.99	3.0	3.34	$8.35	2.7	2.69	$9.68
Cycle 2	6	2.4	2.12	$4.11	2.9	1.84	$4.57	4.3	3.40	$4.33	2.2	1.80	$2.26	3.3	3.86	$2.75	3	2.60	$3.60
Cycle 3	10	3.5	2.62	$3.26	3.1	2.04	$0.71	3.8	2.84	$0.20	N/A	N/A	Bankrupt (42)	N/A	N/A	Bankrupt (43)	3.5	2.50	$1.39
Cycle 4	6	3.0	16.60	$9.54	2.8	14.90	$6.71	3.0	16.55	$10.00	2.7	15.25	$5.63	2.4	14.15	$5.21	2.8	15.49	$7.42
Cycle 5	10	3.8	16.28	$11.91	4.0	16.48	$13.45	2.8	12.72	$6.75	4.5	19.68	$9.17	2.8	13.52	$3.85	3.6	15.74	$9.03
All Cycles		3.0	7.97	$7.67	3.0	7.41	$7.11	3.6	7.85	$6.55	2.9	9.77	$6.51	2.9	8.72	$5.04	3.1	8.34	$6.58

Table 4.10.2. Experiment 8A: Decision agreement frequencies.

Cycle		Subordinate 1					Subordinate 2					Subordinate 3					Subordinate 4						Subordinate 5						All Subordinates					
		Category					Category					Category					Category						Category						Category					
Number	Periods	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5
Cycle 1	50	40	5	5	0	0	42	5	3	0	0	45	0	0	5	0	0	39	3	6	2	0	0	40	4	5	1	0	0	206	17	19	8	0
Cycle 2	50	31	14	4	1	0	34	14	1	1	0	33	8	2	7	0	0	28	11	7	3	1	0	29	12	6	3	0	0	155	59	20	15	1
Cycle 3	50	32	9	0	8	1	32	14	0	3	1	30	11	2	5	2	8	25	10	4	1	2	7	26	11	3	1	2	15	145	55	9	18	8
Cycle 4	20	11	5	2	2	0	11	7	2	0	0	13	6	0	1	0	0	11	5	2	1	1	0	11	5	2	1	1	0	57	28	8	5	2
Cycle 5	25	22	3	0	0	0	22	2	0	1	0	18	2	4	0	1	0	21	3	1	0	0	0	15	1	7	0	2	0	98	11	12	1	3
All Cycles	195	136	36	11	11	1	141	42	6	5	1	139	27	8	18	3	8	124	32	20	7	4	7	121	33	23	6	5	15	661	170	68	47	14
All Cycles (in %)		69.7	18.5	5.6	5.6	0.5	72.3	21.5	3.1	2.6	0.5	71.3	13.8	4.1	9.2	1.5	4.1	63.6	16.4	10.3	3.6	2.1	3.6	62.1	16.9	11.8	3.1	2.6	1.5	67.8	17.4	7.0	4.8	1.8

Table 4.10.3. Experiment 8A: Average profit made by the automated manager and the subordinates.

This table includes per-period loss of Subordinates 4 and 5 before bankruptcy occurred in Cycle 3.									
Expt.	Cycle	Periods	Manager	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	All Subs
8A	Cycle 1	50	$15.58	$9.51	$10.09	$11.48	$8.99	$8.35	$9.68
	Cycle 2	50	$10.60	$4.11	$4.57	$4.33	$2.26	$2.75	$3.60
	Cycle 3	50	$5.17	$3.26	$0.71	$0.20	($2.87)	($2.60)	($0.26)
	Cycle 4	20	$10.15	$9.54	$6.71	$10.00	$5.63	$5.21	$7.42
	Cycle 5	25	$13.54	$11.91	$13.45	$6.75	$9.17	$3.85	$9.03
	All Cycles		$11.01	$7.67	$7.11	$6.55	$4.64	$3.51	$5.90

This table does not include per-period loss of Subordinates 4 and 5 before bankruptcy occurred in Cycle 3.									
Expt.	Cycle	Periods	Manager	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	All Subs
8A	Cycle 1	50	$15.58	$9.51	$10.09	$11.48	$8.99	$8.35	$9.68
	Cycle 2	50	$10.60	$4.11	$4.57	$4.33	$2.26	$2.75	$3.60
	Cycle 3	50	$5.17	$3.26	$0.71	$0.20	Bankrupt (42)	Bankrupt (43)	$1.39
	Cycle 4	20	$10.15	$9.54	$6.71	$10.00	$5.63	$5.21	$7.42
	Cycle 5	25	$13.54	$11.91	$13.45	$6.75	$9.17	$3.85	$9.03
	All Cycles		$11.01	$7.67	$7.11	$6.55	$6.51	$5.04	$6.58

4.11 Experiment 9A: Six Doctoral Student Subordinates in Five Cycles, Waiting for Free Information in Two Cycles

This was the first experiment using six subjects as subordinates. They were doctoral students in the College of Business and Economics and had never participated in our experiment before. There were five cycles in this experiment. The subordinate's profit was a function of the individual's own decision. In Cycle 4, the subordinates had to wait five seconds to receive a piece of free information. Each second cost $0.35. The parameter values were the same as those in Cycle 1 except for the time cost, information cost, and the number of periods. In Cycle 5, the subordinates had to wait four seconds to receive a piece of free information. Each second cost $0.50. The parameter values were the same as those in Cycle 2 except for time cost, information cost, and the number of periods. There were 50 periods in Cycles 1, 2, and 3. There were 30 periods in Cycle 4 and 20 periods in Cycle 5. In Cycle 3, the information cost was progressively higher in each information system, starting from $1.00 for the first information system and going up to $2.75 for the last (#8) information system. The decision rule implemented for the automated machine manager was the same as in Experiment 1A.

Experiment Results

There were many bankruptcies in this experiment. Subordinate 3 became bankrupt in Period 4 of Cycle 4, as seen in Table 4.11.1. Subordinate 5 went bankrupt in Period 41 of Cycle 1 and again in Period 5 of Cycle 5. Subordinate 6 went bankrupt in Period 8 of

Cycle 1, Period 5 of Cycle 3, Period 17 of Cycle 4, and Period 15 of Cycle 5. As a result, Subordinate 6 did not participate in 105 periods (52.5%) of the total of 200 periods (see Table 4.11.2) and has the least profit in this experiment.

Table 4.11.1 are twin tables. The upper one includes per-period data of the subordinates in bankrupt cycles. The lower one does not include those data. In Cycle 4, excluding the data of Subordinate 6, the other five subordinates spent an average of 23.45 seconds (with a time cost of $8.21) for 4.4 free information systems per period, as shown in the lower table. Again, in Cycle 5, excluding the data of Subordinate 6, the other five subordinates spent an average of 18.47 seconds per period (with a time cost of $9.24) for 4.3 free information systems. The high cost of waiting time cut deeply into their profit. For example, the average profit of the five non-bankrupt subordinates in Cycle 5 was a mere $1.32. The time cost in Cycles 4 and 5 was the highest so far in these conducted experiments and it proved to be costly for the subordinates.

Table 4.11.1. Experiment 9A: Average information systems purchased, average time spent in making a decision, and average profit made by the subordinates.

This table includes per-period data of Subordinate 3 in Cycle 1, those of Subordinate 5 in Cycles 1 and 3, and those of Subordinate 6 in Cycles 1, 3, 4, and 5 before bankruptcy occurred.

Cycle Number	Info Available	Subordinate 1			Subordinate 2			Subordinate 3			Subordinate 4			Subordinate 5			Subordinate 6			All Subordinates		
		Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit
Cycle 1	10	4.1	3.20	$5.08	4.9	3.30	$4.56	2.0	6.50	($25.82)	4.3	5.18	$3.08	2.0	8.00	($3.12)	0.9	5.00	($12.58)	3	5.20	($4.80)
Cycle 2	10	4.9	3.20	$3.19	4.9	3.10	$1.53	3.0	6.52	$5.26	5.1	6.76	$1.64	4.8	6.46	$2.21	4.4	4.10	$0.63	4.5	5.02	$2.41
Cycle 3	8	5.4	3.24	$8.63	5.4	3.46	$6.76	3.5	5.56	$8.60	4.6	5.10	$7.27	4.4	6.60	($22.87)	4.2	5.00	($22.40)	4.6	4.83	($2.34)
Cycle 4	10	3.9	20.10	$4.27	4.9	26.33	$4.08	4.8	26.60	$4.29	3.6	19.50	$4.53	4.7	24.73	$0.99	3.2	17.53	($7.25)	4.2	22.47	$1.82
Cycle 5	10	2.8	12.00	$0.70	4.8	21.05	$0.60	5.3	22.50	$1.90	4.5	19.20	$1.08	4.2	17.60	$2.33	3.5	15.80	($6.90)	4.2	18.03	($0.05)
All Cycles		4.2	8.35	$4.37	5.0	11.45	$3.51	3.7	13.54	($1.15)	4.4	11.15	$3.52	4.0	12.68	($4.09)	3.2	9.49	($9.70)	4.1	11.11	($0.59)

This table does not include per-period data of Subordinate 3 in Cycle 1, those of Subordinate 5 in Cycles 1 and 3, and those of Subordinate 6 in Cycles 1, 3, 4, and 5. Those individual subordinates went bankrupt in those cycles

Cycle Number	Info Available	Subordinate 1			Subordinate 2			Subordinate 3			Subordinate 4			Subordinate 5			Subordinate 6			All Subordinates		
		Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit
Cycle 1	10	4.1	3.20	$5.08	4.9	3.30	$4.56	N/A	N/A	Bankrupt (4)	4.3	5.18	$3.08	N/A	N/A	Bankrupt (41)	N/A	N/A	Bankrupt (8)	4.4	3.89	$4.24
Cycle 2	10	4.9	3.20	$3.19	4.9	3.10	$1.53	3.0	6.52	$5.26	5.1	6.76	$1.64	4.8	6.46	$2.21	4.4	4.10	$0.63	4.5	5.02	$2.41
Cycle 3	8	5.4	3.24	$8.63	5.4	3.46	$6.76	3.5	5.56	$8.60	4.6	5.10	$7.27	N/A	N/A	Bankrupt (5)	N/A	N/A	Bankrupt (5)	4.7	4.34	$7.82
Cycle 4	10	3.9	20.10	$4.27	4.9	26.33	$4.08	4.8	26.60	$4.29	3.6	19.50	$4.53	4.7	24.73	$0.99	N/A	N/A	Bankrupt (17)	4.4	23.45	$3.63
Cycle 5	10	2.8	12.00	$0.70	4.8	21.05	$0.60	5.3	22.50	$1.90	4.5	19.20	$1.08	4.2	17.60	$2.33	N/A	N/A	Bankrupt (15)	4.3	18.47	$1.32
All Cycles		4.2	8.35	$4.37	5.0	11.45	$3.51	4.2	15.3	$5.01	4.4	11.15	$3.52	4.6	16.26	$1.84	4.4	4.1	$0.63	4.5	11.1	$3.15

Table 4.11.2. Experiment 9A: Decision agreement frequencies.

Cycle Number	Periods	Subordinate 1 Category					Subordinate 2 Category					Subordinate 3 Category						Subordinate 4 Category					Subordinate 5 Category						Subordinate 6 Category						All Subordinates Category					
		1	2	3	4	5	1	2	3	4	5	0	1	2	3	4	5	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5
Cycle 1	50	36	12	0	1	1	35	9	1	4	1	46	0	1	3	0	0	33	12	3	2	0	9	17	9	11	1	3	42	1	3	4	0	0	97	122	46	22	8	5
Cycle 2	50	38	4	4	4	0	40	8	2	0	0	0	41	7	1	0	1	36	4	6	4	0	0	36	3	6	4	1	0	36	6	6	2	0	0	227	32	25	14	2
Cycle 3	50	42	5	0	3	0	39	5	3	3	0	0	39	7	3	1	0	38	5	4	3	0	45	1	1	2	0	1	45	1	1	2	0	1	90	160	24	14	10	2
Cycle 4	30	20	6	2	2	0	20	4	2	4	0	0	22	5	0	3	0	21	5	1	2	1	0	17	5	5	3	0	13	8	5	2	0	2	13	108	30	12	14	3
Cycle 5	20	11	4	5	0	0	14	3	2	1	0	0	15	3	1	1	0	13	3	3	1	0	0	15	4	1	0	0	5	7	3	5	0	0	5	75	20	17	3	0
All Cycles	200	147	31	11	10	1	148	29	10	12	1	46	117	23	8	5	1	141	29	17	12	1	54	86	22	25	8	5	105	53	18	19	2	3	205	692	152	90	49	12
All Cycles (in %)		73.5	15.5	5.5	5.0	0.5	74.0	14.5	5.0	6.0	0.5	23.0	58.5	11.5	4.0	2.5	0.5	70.5	14.5	8.5	6.0	0.5	27.0	43.0	11.0	12.5	4.0	2.5	52.5	26.5	9.0	9.5	1.0	1.5	17.1	57.7	12.7	7.5	4.1	1.0

Table 4.11.3. Experiment 9A: Average profit made by the automated manager and the subordinates.

This table includes per-period loss of subordinates in bankrupt cycles.											
Expt.	Cycle	Periods	Manager	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	Sub 6	All Subs
9A	Cycle 1	50	$11.26	$5.08	$4.56	($25.82)	$3.08	($3.12)	($12.58)	($4.80)
	Cycle 2	50	$12.10	$3.19	$1.53	$5.26	$1.64	$2.21	$0.63	$2.41
	Cycle 3	50	$14.65	$8.63	$6.76	$8.60	$7.27	($22.87)	($22.40)	($2.34)
	Cycle 4	30	$11.30	$4.27	$4.08	$4.29	$4.53	$0.99	($7.25)	$1.82
	Cycle 5	20	$12.63	$0.70	$0.60	$1.90	$1.08	$2.33	($6.90)	($0.05)
	All Cycles		$12.39	$4.37	$3.51	($1.15)	$3.52	($4.09)	($9.70)	($0.59)

This table does not include per-period loss of subordinates in bankrupt cycles.										
Expt.	Cycle	Periods	Manager	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	Sub 6	All Subs
9A	Cycle 1	50	$11.26	$5.08	$4.56	Bankrupt (4)	$3.08	Bankrupt (41)	Bankrupt (8)	$4.24
	Cycle 2	50	$12.10	$3.19	$1.53	$5.26	$1.64	$2.21	$0.63	$2.41
	Cycle 3	50	$14.65	$8.63	$6.76	$8.60	$7.27	Bankrupt (5)	Bankrupt (5)	$7.82
	Cycle 4	30	$11.30	$4.27	$4.08	$4.29	$4.53	$0.99	Bankrupt (17)	$3.63
	Cycle 5	20	$12.63	$0.70	$0.60	$1.90	$1.08	$2.33	Bankrupt (15)	$1.32
	All Cycles		$12.39	$4.37	$3.51	$5.01	$3.52	$1.84	$0.63	$3.15

4.12 Experiment 10A: Six Doctoral Student Subordinates in Four Cycles

This experiment employed six experienced doctoral students as subordinates. They did four cycles of experiment. The subordinate's profit was a function of the individual's own decision. There were many bankruptcies in the previous experiment. The parameter values used in Cycle 2 were the same as those in Cycle 1 of Experiment 9A. The parameter values in Cycle 3 and Cycle 4 were the same except that in Cycle 3 the subordinates had to wait five seconds for a free information with each second costing $0.45 and in Cycle 4 the information was $2.25 each with no waiting. We wanted to investigate whether there would be many bankruptcies in this experiment. There were 50 periods in each cycle.

The decision rule implemented for the automated machine manager was the same as in Experiment 1A. The subordinates had no feedback of the manager's production level decision.

Experiment Results

There were two bankruptcies in this experiment while there were seven bankruptcies in Experiment 9A. Both Subordinates 2 and 3 became bankrupt in Cycle 3, as seen in Table 4.12.1. This is the cycle in which the subordinates had to wait five seconds for a free information with each second costing $0.45. Subordinate 2 went bankrupt in Period 29 and Subordinate 3 in Period 10. Table 4.12.1 are twin tables. The upper one includes per-period data of Subordinates 2 and 3 in a bankrupt cycle (Cycle 3). The lower one does not include those data. In Cycle 3, excluding the data of Subordinates 2 and 3, the other four subordinates spent an average of 17.00 seconds (with a time cost of $7.65) for 3.2 free information systems per period, as shown in the lower table of Table 4.12.1. Although Subordinate 5 did not become bankrupt in Cycle 3, the subject had a per-period loss of $0.14. In Cycle 4, the non-bankrupt subordinates purchased an average of 4.4 information systems per period, with a cost of $9.90, and had a higher per-period profit of $5.21, as shown in the lower table of Table 4.12.1, while in Cycle 3 the non-bankrupt subordinates managed to have an average profit of $2.57 per period. The extra 1.2 average information systems (4.4 minus 3.2) bought by the non-bankrupt subordinates appear to have been vital for the accuracy of their input to the manager and for their own profit. That also seems to have made a difference in the manager's profit. The manager's profit per period was $11.95 in Cycle 3 and $16.12 in Cycle 4, as shown in Table 4.12.3.

Table 4.12.1. Experiment 10A: Average information systems purchased, average time spent in making a decision, and average profit made by the subordinates.

This table includes per-period data of Subordinates 2 and 3 in Cycle 3 before bankruptcy occurred.

		Subordinate 1			Subordinate 2			Subordinate 3			Subordinate 4			Subordinate 5			Subordinate 6			All Subordinates		
Cycle Number	Info Available	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit
Cycle 1	10	4.9	4.48	$5.18	4.9	5.54	$1.18	5.8	4.76	$7.23	5.6	3.36	$5.28	4.4	4.82	$3.95	4.8	6.22	$4.43	5.1	4.86	$4.54
Cycle 2	10	5.4	3.70	$5.27	5.6	4.60	$4.42	7.6	5.16	$4.02	5.3	2.98	$4.71	6.2	5.32	$3.05	5.5	3.68	$3.22	5.9	4.24	$4.12
Cycle 3	8	4.0	21.64	$2.81	3.6	19.41	($3.70)	3.5	18.80	($10.01)	3.3	16.58	$4.49	1.9	11.86	($0.14)	3.4	17.92	$3.11	3.3	17.70	($0.57)
Cycle 4	8	5.1	2.72	$5.10	3.7	3.48	$3.79	5.4	3.96	$4.83	4.3	1.82	$6.13	3.4	2.42	$5.18	4.5	2.44	$6.23	4.4	2.81	$5.21
All Cycles		4.9	8.14	$4.59	4.5	8.26	$1.42	5.6	8.17	$1.52	4.6	6.19	$5.15	4.0	6.11	$3.01	4.6	7.57	$4.25	4.7	7.41	$3.32

This table does not include per-period data of Subordinates 2 and 3 in Cycle 3 before bankruptcy occurred.

		Subordinate 1			Subordinate 2			Subordinate 3			Subordinate 4			Subordinate 5			Subordinate 6			All Subordinates		
Cycle Number	Info Available	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit
Cycle 1	10	4.9	4.48	$5.18	4.9	5.54	$1.18	5.8	4.76	$7.23	5.6	3.36	$5.28	4.4	4.82	$3.95	4.8	6.22	$4.43	5.1	4.86	$4.54
Cycle 2	10	5.4	3.70	$5.27	5.6	4.60	$4.42	7.6	5.16	$4.02	5.3	2.98	$4.71	6.2	5.32	$3.05	5.5	3.68	$3.22	5.9	4.24	$4.12
Cycle 3	8	4.0	21.64	$2.81	N/A	N/A	Bankrupt (29)	N/A	N/A	Bankrupt (10)	3.3	16.58	$4.49	1.9	11.86	($0.14)	3.4	17.92	$3.11	3.2	17.00	$2.57
Cycle 4	8	5.1	2.72	$5.10	3.7	3.48	$3.79	5.4	3.96	$4.83	4.3	1.82	$6.13	3.4	2.42	$5.18	4.5	2.44	$6.23	4.4	2.81	$5.21
All Cycles		4.9	8.14	$4.59	4.7	4.54	$3.13	6.3	4.63	$5.36	4.6	6.19	$5.15	4.0	6.11	$3.01	4.6	7.57	$4.25	4.8	6.2	$4.25

Table 4.12.2. Experiment 10A: Decision agreement frequencies.

Cycle		Subordinate 1					Subordinate 2						Subordinate 3						Subordinate 4					Subordinate 5					Subordinate 6					All Subordinates					
		Category					Category						Category						Category					Category					Category					Category					
Number	Periods	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	0	1	2	3	4	5
Cycle 1	50	36	6	4	4	0	0	32	9	8	0	1	0	40	5	0	5	0	38	8	2	2	0	36	10	4	0	0	38	9	2	1	0	0	220	47	20	12	1
Cycle 2	50	40	8	0	2	0	0	38	7	2	3	0	0	40	3	0	7	0	38	9	2	1	0	39	8	1	2	0	38	10	2	0	0	0	233	45	7	15	0
Cycle 3	50	38	7	2	3	0	21	19	5	5	0	0	40	6	1	3	0	0	40	10	0	0	0	27	8	13	1	1	38	10	2	0	0	61	168	41	25	4	1
Cycle 4	50	47	2	0	1	0	0	39	2	8	1	0	0	46	0	1	3	0	46	3	1	0	0	42	3	5	0	0	46	2	1	1	0	0	266	12	16	6	0
All Cycles	200	161	23	6	10	0	21	128	23	23	4	1	40	132	9	4	15	0	162	30	5	3	0	144	29	23	3	1	160	31	7	2	0	61	887	145	68	37	2
All Cycles (in %)		80.5	11.5	3.0	5.0	0.0	10.5	64.0	11.5	11.5	2.0	0.5	20.0	66.0	4.5	2.0	7.5	0.0	81.0	15.0	2.5	1.5	0.0	72.0	14.5	11.5	1.5	0.5	80.0	15.5	3.5	1.0	0.0	5.1	73.9	12.1	5.7	3.1	0.2

Table 4.12.3. Experiment 10A: Average profit made by the automated manager and the subordinates.

This table includes per-period loss of subordinates in bankrupt cycles.										
Expt.	Cycle	Periods	Manager	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	Sub 6	All Subs
10A	Cycle 1	50	$11.32	$5.18	$1.18	$7.23	$5.28	$3.95	$4.43	$4.54
	Cycle 2	50	$13.63	$5.27	$4.42	$4.02	$4.71	$3.05	$3.22	$4.12
	Cycle 3	50	$11.95	$2.81	($3.70)	($10.01)	$4.49	($0.14)	$3.11	($0.57)
	Cycle 4	50	$16.12	$5.10	$3.79	$4.83	$6.13	$5.18	$6.23	$5.21
	All Cycles		$13.26	$4.59	$1.42	$1.52	$5.15	$3.01	$4.25	$3.32

This table does not include per-period loss of subordinates in bankrupt cycles.										
Expt.	Cycle	Periods	Manager	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	Sub 6	All Subs
10A	Cycle 1	50	$11.32	$5.18	$1.18	$7.23	$5.28	$3.95	$4.43	$4.54
	Cycle 2	50	$13.63	$5.27	$4.42	$4.02	$4.71	$3.05	$3.22	$4.12
	Cycle 3	50	$11.95	$2.81	Bankrupt (29)	Bankrupt (10)	$4.49	($0.14)	$3.11	$2.57
	Cycle 4	50	$16.12	$5.10	$3.79	$4.83	$6.13	$5.18	$6.23	$5.21
	All Cycles		$13.26	$4.59	$3.13	$5.36	$5.15	$3.01	$4.25	$4.25

4.13 Same Group of Subjects in Both Human Manager Environment and Automated Machine Manager Environment -- Experiments 11A and 11H

A group of subjects participated in both human manager environment and automated machine manager environment in this set of experiments. The experiment with an automated manager was designated Experiment 11A. The experiment with a human manager was designated 11H. Consistent with our intention to compare performance of the same participants in both environments, five doctoral students in the Department of Decision Science and Information Systems participated in each of these sets of experiments. The experiment using a human manager (Experiment 11H) was conducted first. Four subjects were subordinates while one subject was randomly chosen to play the role of manager. A lottery was held to assign roles. When all other subjects were in the tutorial session for subordinates, the single human manager subject was given separate instructions on the mechanics of acting as a manager.

The experiment using an automated machine manager (Experiment 11A) was conducted four days later. The four subjects acting as subordinates were invited back to participate. Since they were already familiar with the process of the experiment, no video presentation and practice preceded the experiment. The decision rule implemented for the experiment with an automated machine manager was the same as in Experiment 1A.

Subordinate Payoff Schemes

We used three different subordinate payoff schemes, the first of which was independent of the manager's decision making success:

Scheme 1:

> The subordinate's payoff is based only on the quality of the individual's recommendation (forecast) and is independent of the manager's decision and payoff. The subordinate's payoff matrix is the same as the manager's.

The next two subordinate payoff schemes, Schemes 2 and 3, are dependent upon the manager's decision employing two sets of percentages that we felt were representative of business activity. Payoff Scheme 4 structured that the subordinate's payoff as a function of only the manager's performance.

Scheme 2:

> The subordinate's payoff is dependent upon the manager's decision. The manager-to-subordinate payoff percentages are set as:
>
> (a) If actual sales = manager's decision = subordinate's decision, then subordinate's payoff = 100% of the manager's payoff.
> (b) If actual sales ≠ manager's decision, and actual sales = subordinate's decision, then subordinate's payoff = -50% of manager's payoff. (Since the manager's payoff matrix has off-diagonal elements less than zero.)
> (c) If actual sales = manager's decision, and actual sales ≠ subordinate's decision, then subordinate's payoff = -50% of the manager's payoff.
> (d) If actual sales ≠ manager's decision, and subordinate's decision = manager's decision, then subordinate's payoff = 100% of the manager's payoff.
> (e) If actual sales, manager's decision, and subordinate's decision are all different, then subordinate's payoff = 50% of the manager's payoff.

Scheme 3:

> The subordinate's payoff is dependent upon the manager's decision. This scheme is similar to scheme 2 above except that the manager-to-subordinate payoff percentage is half of that in scheme 2.

(a) If actual sales = manager's decision = subordinate's decision, then subordinate's payoff = 50% of the manager's payoff.

(b) If actual sales ≠ manager's decision, and actual sales = subordinate's decision, then subordinate's payoff = -25% of the manager's payoff. (Since the manager's payoff matrix has off-diagonal elements less than zero.)

(c) If actual sales = manager's decision, and actual sales ≠ subordinate's decision, then subordinate's payoff = -25% of the manager's payoff.

(d) If actual sales ≠ manager's decision, and subordinate's decision = manager's decision, then subordinate's payoff = 50% of the manager's payoff.

(e) If actual sales, manager's decision, and subordinate's decision are all different, then subordinate's payoff = 25% of the manager's payoff.

Scheme 4:

The subordinate's payoff is a function of only the manager's performance. The subordinate receives the same amount of profit as the manager does, i.e., the subordinate's payoff is independent of the individual's own recommendation.

Schemes 2 and 3 were used in Experiments 11A and 11H, as indicated in Table 4.2.1. Scheme 4 will be used in Experiment 14A and 14H and discussed in Section 4.16.

Part of this set of experiments was designed to compare the performance of the human manager environment with that of the automated machine manager. Cycle 2 of the human-manager group had the same experimental parameter values as Cycle 2 of the automated-manager group. Cycle 3 of the human-manager group had the same experimental parameter values as Cycle 3 of the automated-manager group. Cycle 4 of the human-manager group had the same experimental parameter values as Cycle 4 of the automated-manager group. Table 4.2.1 provides the specific experimental parameter values used in this experiment. Both Experiments 11H and 11A had four cycles with 50 periods in a cycle.

Experiment Results

As in the previous experiment, in each cycle the manager started with a balance of $900.00 experimental dollars and the subordinates started with a balance of $100.00 experimental dollars. Table 4.13.3 shows the manager's and subordinates' final profits in each cycle. As in the previous experiments, the number in the parenthesis after "Bankrupt" entries indicates the period in which the subordinate went bankrupt. Many bankruptcies occurred in this experiment. We started the manager with a balance of $900.00 experimental dollars to avoid bankruptcy, as in the previous experiments,

Figures 4.13.1 and 4.13.2 show the human and automated managers' accrued profit (current balance minus starting balance) for all four cycles. In Experiment 11H, even when there were as many as 3 bankrupt subordinates out of the game in Cycles 3 and 4, the human manager still had a profit at the end of the cycles, as shown in Table 4.13.3.

Figures 4.13.3 through 4.13.5 provide a graphical representation comparing the performances of the human manager and the automated manager in Cycles 2, 3, and 4 where both were making decisions in the experiments with the same parameter values. In corresponding Cycle 2, the human manager ($845.67, see Table 4.13.3) did not do as well as the automated manager ($885.50). In Cycle 3, The human manager ($417.72) was also outperformed by the automated manager ($620.00). In Cycle 4, however, the human manager ($680.49) outperformed the automated manager ($305.00). In Cycle 4, both managers ended up with only one non-bankrupt subordinate.

Tables 4.13.1 and 4.13.2 illustrate the relationship between the decision agreement frequency, number of information systems purchased by the subordinates, and the profits earned by the subordinates. Table 4.13.2 shows the decision agreement frequencies. As an example, in the five-category distributions for Cycle 1, Subordinate 1 of the human-manager group had 34 periods in category 1, 2 periods in category 2, 13 periods in category 3, 1 period in category 4, and no period in category 5.

In Cycle 1, Subordinate 1 of the human-manager group had 35 valid periods because this subordinate went bankrupt in period 35. Subordinate 4 also went bankrupt in Period 40 of Cycle 1. Consequently, both Subordinates 1 and 4 had no profit for the cycle in addition to having lost the $100 starting balance. Experimental subjects received a performance bonus for the cycle only if the final net balance was greater than zero, as Subordinates 2 and 3 had.

There were many bankruptcies in Cycles 3 and 4 in both human- and automated-manager groups. The poor performance of the subordinates in these two cycles was reflective of the composition of the input data and the payoff scheme used (Scheme 3). The input data was drawn from the same data set as that drawn for Cycle 2, but payoff scheme 3 was used in both cycles (see Table 4.2.1). If a subordinate made the correct input and the manager also made the correct decision, then the subordinate's profit was only half of manager's profit. In Cycle 2 a subordinate's profit was 100% of manager's profit if both were correct. This rule in the scheme significantly reduced the profit of subordinates.

Table 4.13.1. Experiments 11A and 11H: Average information systems purchased, average time spent in making a decision, and average profit made by the subordinates.
This table includes per-period loss of subordinate's bankrupt cycles.

Experiment 11A: With an automated machine manager																
		Subordinate 1			Subordinate 2			Subordinate 3			Subordinate 4			All Subordinates		
Cycle Number	Info Available	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit
Cycle 1	8	3.3	3.64	$2.46	6.1	3.62	$4.26	4.5	2.36	$7.14	5.1	3.52	$5.36	4.8	3.29	$4.81
Cycle 2	10	5.3	4.10	$4.90	7.5	3.60	$8.06	6.9	2.70	$8.48	6.9	3.24	$7.45	6.7	3.41	$7.22
Cycle 3	10	5.0	4.30	($0.74)	7.4	3.47	($2.35)	5.2	2.09	($2.25)	5.8	2.80	($1.64)	5.9	3.17	($1.75)
Cycle 4	8	2.7	2.00	($3.70)	6.0	2.68	($4.67)	1.4	0.84	($0.15)	3.3	1.94	($3.49)	3.4	1.87	($3.00)
All Cycles		4.1	3.51	$0.73	6.8	3.34	$1.33	4.5	2.00	$3.31	5.3	2.88	$1.92	5.2	2.93	$1.82

Experiment 11H: With a human manager																
		Subordinate 1			Subordinate 2			Subordinate 3			Subordinate 4			All Subordinates		
Cycle Number	Info Available	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit
Cycle 1	10	1.4	3.17	($2.97)	6.1	3.58	$6.02	4.8	2.68	$0.50	0.1	1.45	($2.71)	3.1	2.72	$0.21
Cycle 2	10	3.7	5.08	$4.60	6.2	4.48	$8.51	5.8	3.44	$8.95	5.7	4.70	$4.23	5.4	4.43	$6.57
Cycle 3	10	5.0	5.83	($2.12)	5.3	3.95	($2.65)	5.9	3.05	($2.63)	2.9	3.34	($1.10)	4.8	4.04	($2.13)
Cycle 4	8	1.6	4.86	($4.79)	4.7	3.33	($2.35)	3.0	2.51	($2.07)	1.1	2.54	($1.39)	2.6	3.31	($2.65)
All Cycles		2.9	4.74	($1.32)	5.6	3.84	$2.38	4.9	2.92	$1.19	2.5	3.01	($0.24)	4.0	3.63	$0.50

Table 4.13.2. Experiments 11A & 11H: Decision agreement frequencies.

Experiment 11A: With an automated machine manager

Cycle Number	Periods	Subordinate 1 Category						Subordinate 2 Category						Subordinate 3 Category						Subordinate 4 Category						All Subordinates Category					
		0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5
Cycle 1	50	0	34	2	13	1	0	0	47	1	0	2	0	0	46	3	1	0	0	0	45	2	2	1	0	0	172	8	16	4	0
Cycle 2	50	0	37	0	13	0	0	0	49	0	1	0	0	0	49	0	1	0	0	0	47	0	3	0	0	0	182	0	18	0	0
Cycle 3	50	0	37	9	4	0	0	5	36	3	0	6	0	3	30	8	8	1	0	0	37	7	4	2	0	8	140	27	16	9	0
Cycle 4	50	4	14	4	7	1	2	10	18	0	0	4	0	0	18	6	5	2	1	0	22	8	1	0	1	14	72	18	13	7	4
All Cycles	200	4	122	15	37	2	2	15	150	4	1	12	0	3	143	17	15	3	1	0	151	17	10	3	1	22	566	53	63	20	4
All Cycles (in %)		2.0	61.0	7.5	18.5	1.0	1.0	7.5	75.0	2.0	0.5	6.0	0.0	1.5	71.5	8.5	7.5	1.5	0.5	0.0	75.5	8.5	5.0	1.5	0.5	2.8	70.8	6.6	7.9	2.5	0.5

Experiment 11H: With a human manager

Cycle Number	Periods	Subordinate 1 Category						Subordinate 2 Category						Subordinate 3 Category						Subordinate 4 Category						All Subordinates Category					
		0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5
Cycle 1	50	15	15	1	18	0	1	0	44	5	0	1	0	0	32	5	12	1	0	10	13	2	24	0	1	25	104	13	54	2	2
Cycle 2	50	0	31	1	17	1	0	0	46	1	2	1	0	0	46	1	2	1	0	0	38	1	10	1	0	0	161	4	31	4	0
Cycle 3	50	2	27	7	6	8	0	12	24	7	5	2	0	9	28	9	1	3	0	0	22	6	11	6	5	23	101	29	23	19	5
Cycle 4	50	29	6	0	12	2	1	7	37	2	0	3	1	1	29	3	10	4	3	0	15	1	25	7	2	37	87	6	47	16	7
All Cycles	200	46	79	9	53	11	2	19	151	15	7	7	1	10	135	18	25	9	3	10	88	10	70	14	8	85	453	52	155	41	14
All Cycles (in %)		23.0	39.5	4.5	26.5	5.5	1.0	9.5	75.5	7.5	3.5	3.5	0.5	5.0	67.5	9.0	12.5	4.5	1.5	5.0	44.0	5.0	35.0	7.0	4.0	10.6	56.6	6.5	19.4	5.1	1.8

Table 4.13.3.Experiments 11H and 11A: Manager's and subordinate's final net profits in each cycle.

Exp't	Cycle	Manager's Profit	Subordinates' Profit			
			Sub 1	Sub 2	Sub 3	Sub 4
11H	1	$643.09	Bankrupt (35)	$301.21	$24.91	Bankrupt (40)
	2	$845.67	$229.96	$425.51	$447.28	$211.40
	3	$417.72	Bankrupt (48)	Bankrupt (38)	Bankrupt (41)	-$55.04
	4	$680.49	Bankrupt (21)	Bankrupt (43)	Bankrupt (49)	-$69.39
Exp't	Cycle	Manager's Profit	Subordinates' Profit			
			Sub 1	Sub 2	Sub 3	Sub 4
11A	1	$879.50	$123.18	$213.19	$357.07	$267.99
	2	$885.50	$244.95	$403.20	$424.15	$372.63
	3	$626.00	-$37.15	Bankrupt (45)	Bankrupt (47)	-$82.15
	4	$305.00	Bankrupt (28)	Bankrupt (22)	-$7.55	Bankrupt (32)

Figure 4.13.1. Experiment 11H: Human manager's accrued profit over the periods in each cycle.

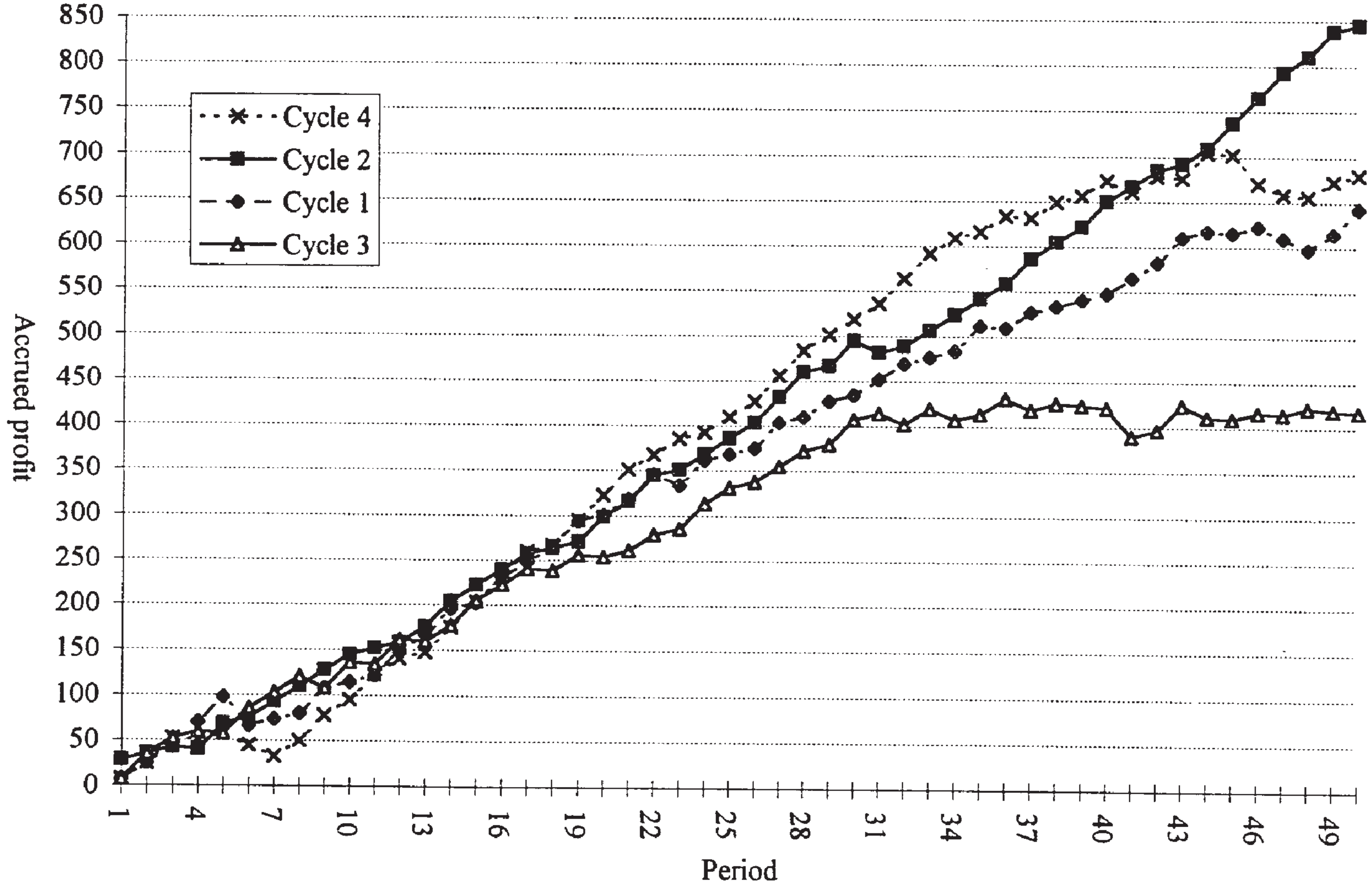


Figure 4.13.2. Experiment 11A: Automated manager's accrued profit over the periods in each cycle.

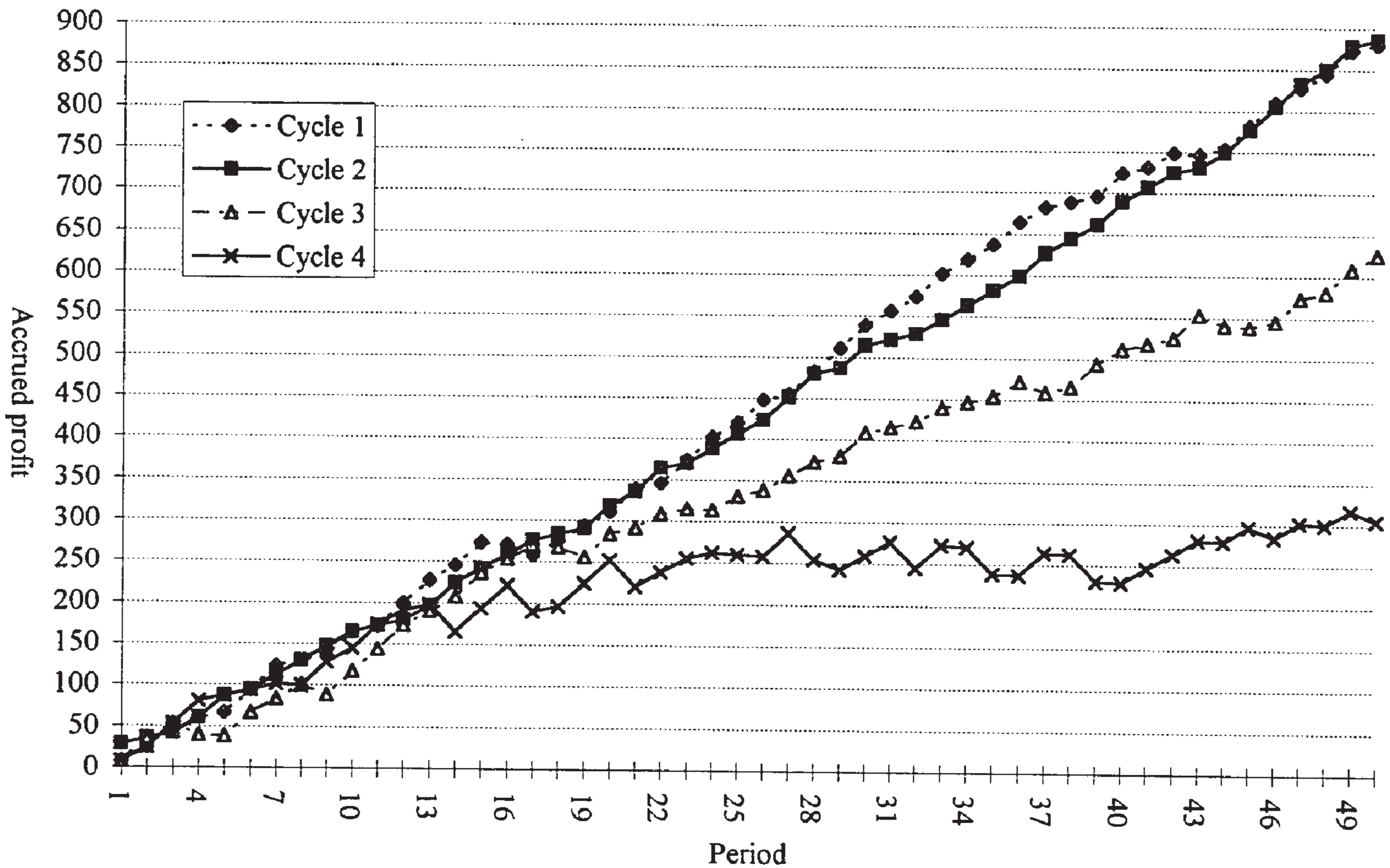


Figure 4.13.3. Experiments 11A & 11H: Automated and human managers' accrued profit over the periods in cycle 2.

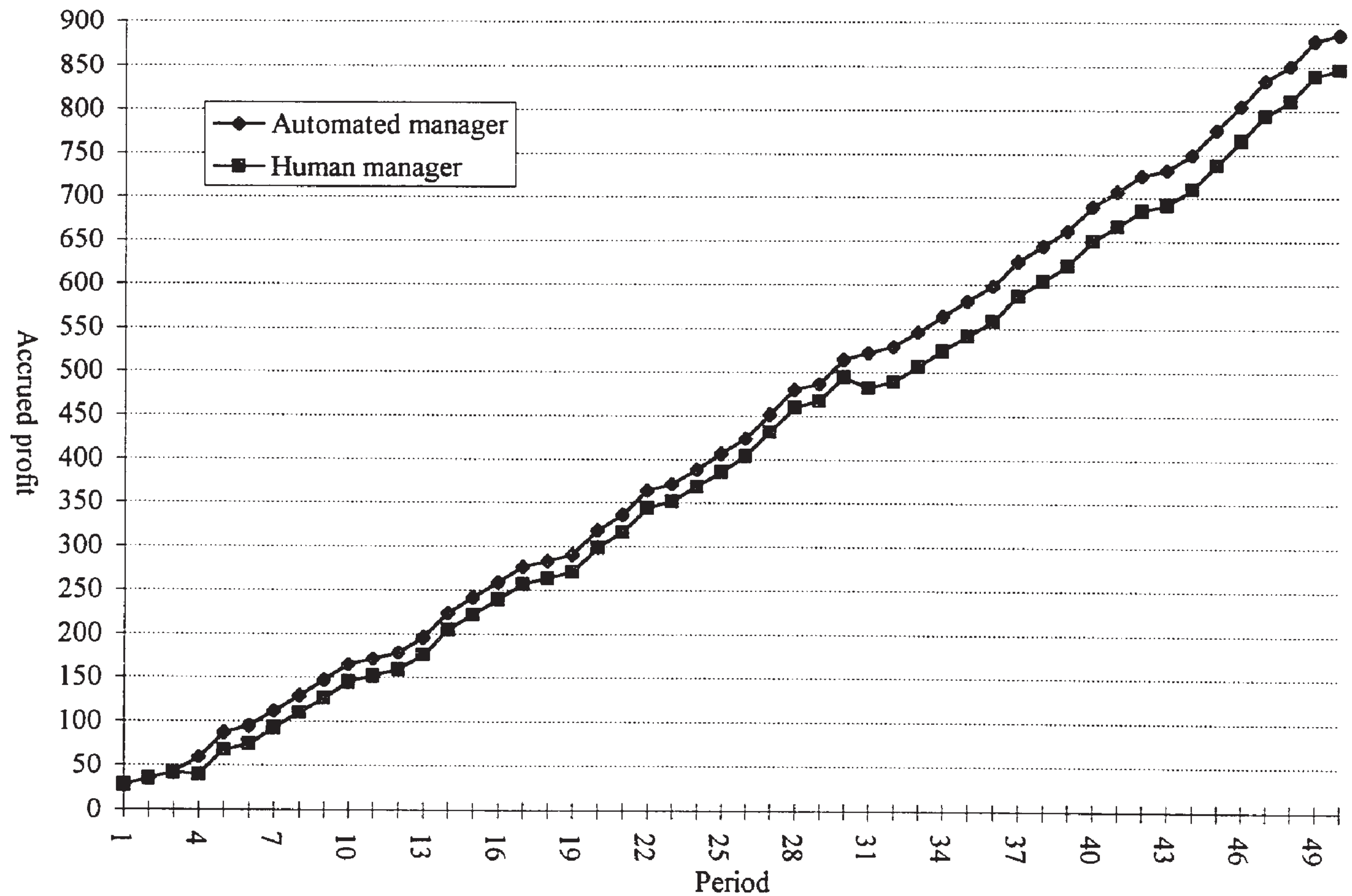


Figure 4.13.4. Experiments 11A & 11H: Automated and human managers' accrued profit over the periods in cycle 3.

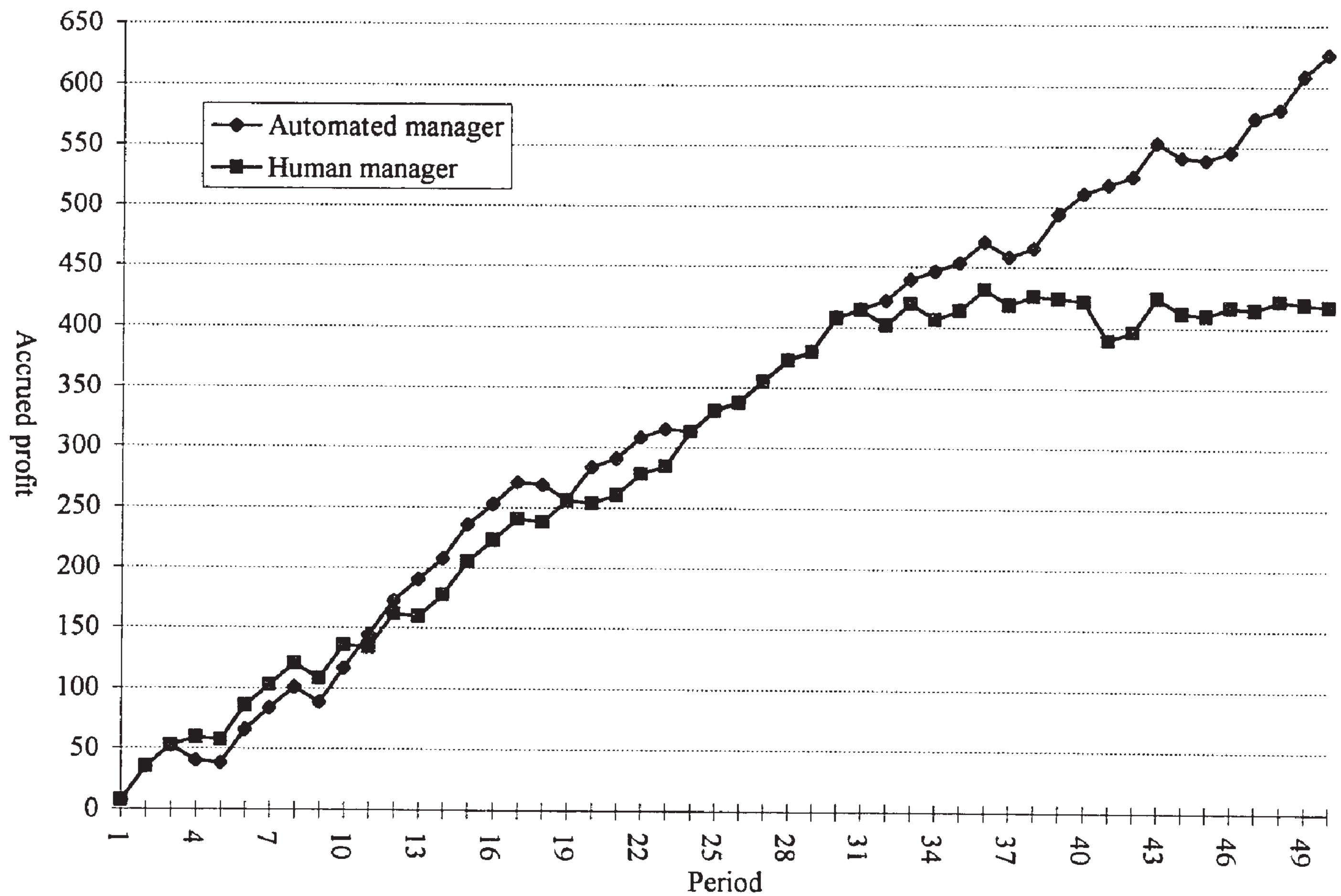
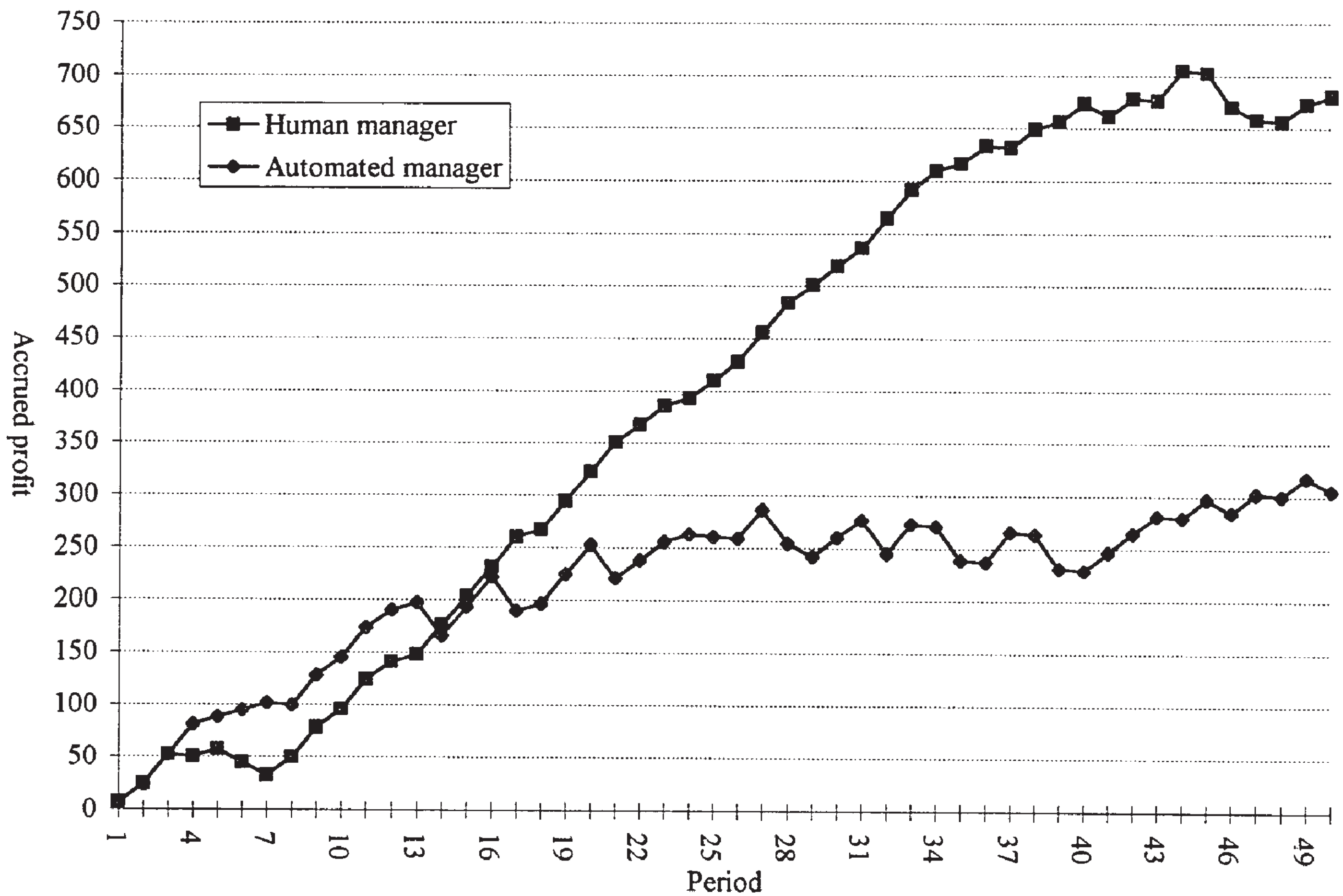


Figure 4.13.5. Experiments 11A & 11H: Automated and human managers' accrued profit over the periods in cycle 4.



4.14 Simultaneous Experiments: Experiment 12A -- With an Automated Machine Manager Experiment 12H -- With A Human Manager

This set of experiments was conducted using nine MBA students and was designed to run two groups of experiments in the same lab simultaneously. This allowed us to use identical input data facilitating group comparison while avoiding the possibility of knowledge transfer if the sessions occurred at different times. Experiment 12A consisted of four subjects, while Experiment 12H had five subjects. All subjects in Experiment 12A were subordinates with an automated machine manager. Four subjects in Experiment 12H were subordinates while one subject was randomly chosen to play the role of manager.

After the subjects watched the presentation video, a lottery was held to assign roles. When all other subjects were in the tutorial session for subordinates, the single human manager subject was given separate instructions on the mechanics of acting as a manager.

Table 4.2.1 provides the specific experimental parameter values used in this experiment. Each experiment had four cycles with 50 periods in a cycle. The decision rule implemented for the experiment with an automated machine manager was as before. As in the previous section we also used three different subordinate payoff schemes. There were Schemes 1, 2, and 3 as listed in the pervious section.

Similar to Experiments 11A and 11H, part of this set of experiments was designed to compare the performance of the human manager environment with that of the automated machine manager. Cycle 2 of the human-manager group had the same experimental parameter values as Cycle 2 of the automated-manager group. Cycle 3 of the human-manager group had the same experimental parameter values as Cycle 3 of the automated-manager group. Cycle 4 of the human-manager group had the same experimental parameter values as Cycle 4 of the automated-manager group.

Experiment Results

Table 4.14.3 shows the manager's and subordinates' final profits in each cycle. As in previous experiments, we started the manager with a balance of $900.00 experimental dollars to avoid bankruptcy. Figures 4.14.1 and 4.14.2 show the human and automated managers' accrued profit (current balance minus starting balance) for all four cycles. In the experiment with an automated manager (Experiment 12A), even when there were as many as 3 bankrupt subordinates out of the game, the automated manager still had profit at the end of the cycle.

Figures 4.14.3 through 4.14.5 provide a graphical representation comparing the performances of a human manager and an automated manager in Cycles 2, 3, and 4 where both were making decisions over the same problem sets. The human manager outperformed the automated manager and finished the cycles with a higher profit.

We prepared Tables 4.14.1 and 4.14.2 to help illustrate the relationship between the decision agreement frequency, number of information systems purchased by the subordinates, and the profits earned by the subordinates.

Table 4.14.2 shows the decision agreement frequencies. As an example, in the five-category distributions for Cycle 2, Subordinate 1 of the human-manager group had 27 periods in category 1, 14 periods in category 2, 5 periods in category 3, 4 periods in category 4, and no period in category 5. In Cycle 2, Subordinate 5 of the automated-manager group had only 12 valid periods because this subordinate went bankrupt in period 12. Consequently, Subordinate 5 had no profit for the cycle in addition to having lost the $100 starting balance. All the other subordinates in this cycle earned some profit.

It is interesting to observe the total number of correct inputs (recommendations) from each subordinate. For example, in Cycle 2, Subordinate 1 made the correct input 31 times (27 times in category 1 plus 4 times in category 4) out of the total of 50 periods. Subordinate 8 in the automated-manager group made 34 correct inputs and, not surprisingly, had the highest profit in this cycle.

Here we continue by analyzing the results from Cycle 3. There were three bankrupt subordinates in Experiment 12A. In addition, two subordinates in Experiment 12H and one subordinate in 12A ended up with a loss. The loss reflected that the balance fell below the $100 starting balance, but didn't fall to zero (bankrupt).

The poor performance of the subordinates in this cycle was reflective of the composition of the input data and the payoff scheme used, as was also true in the previous experiment. The input data was drawn from the same data set as that drawn for Cycle 2, but payoff scheme 3 was used in this cycle (see Table 4.2.1). If a subordinate made the right input and the manager also made the right decision, then the subordinate's profit was only half of manager's profit. In Cycle 2 the subordinate's profit was 100% of the manager's profit if both were correct in their decision. This rule in the scheme significantly reduced the profit of the subordinates.

Table 4.14.1. Experiments 12A and 12H: Average information systems purchased, average time spent in making a decision, and average profit made by the subordinates.
This table includes per-period loss of subordinate's bankrupt cycles.

Experiment 12H: With a human manager																
		Subordinate 1			Subordinate 2			Subordinate 3			Subordinate 4			All Subordinates		
Cycle Number	Info Available	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit
Cycle 1	8	3.3	3.64	$2.46	6.1	3.62	$4.26	4.5	2.36	$7.14	5.1	3.52	$5.36	4.8	3.29	$4.81
Cycle 2	10	5.3	4.10	$4.90	7.5	3.60	$8.06	6.9	2.70	$8.48	6.9	3.24	$7.45	6.7	3.41	$7.22
Cycle 3	10	5.0	4.30	($0.74)	7.4	3.47	($2.35)	5.2	2.09	($2.25)	5.8	2.80	($1.64)	5.9	3.17	($1.75)
Cycle 4	8	2.7	2.00	($3.70)	6.0	2.68	($4.67)	1.4	0.84	($0.15)	3.3	1.94	($3.49)	3.4	1.87	($3.00)
All Cycles		4.1	3.51	$0.73	6.8	3.34	$1.33	4.5	2.00	$3.31	5.3	2.88	$1.92	5.2	2.93	$1.82

Experiment 12A: With an automated machine manager																
		Subordinate 5			Subordinate 6			Subordinate 7			Subordinate 8			All Subordinates		
Cycle Number	Info Available	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit
Cycle 1	8	1.5	14.00	($10.57)	2.8	4.38	($12.73)	3.9	2.70	$1.84	3.1	4.40	($10.64)	2.8	6.37	($8.03)
Cycle 2	10	2.8	7.25	($8.76)	3.9	2.24	$1.36	3.4	2.28	$1.50	4.0	3.04	$3.30	3.5	3.70	($0.65)
Cycle 3	10	2.7	6.04	($2.22)	3.0	2.50	($0.99)	3.8	2.42	($4.39)	3.9	2.58	($2.33)	3.4	3.39	($2.48)
Cycle 4	8	2.6	4.79	($2.65)	0.9	1.64	$0.30	3.8	2.30	($5.05)	2.7	1.86	($2.41)	2.5	2.65	($2.45)
All Cycles		2.4	8.02	($6.05)	2.7	2.69	($3.02)	3.7	2.43	($1.53)	3.4	2.97	($3.02)	3.1	4.03	($3.41)

Table 4.14.2. Experiments 12A & 12H: Decision agreement frequencies.

Experiment 12H: With a human manager																															
Cycle Number	Periods	Subordinate 1						Subordinate 2						Subordinate 3						Subordinate 4						All Subordinates					
		Category						Category						Category						Category						Category					
		0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5
Cycle 1	50	0	27	15	5	3	0	0	28	16	4	1	1	0	30	11	2	7	0	0	26	13	6	4	1	0	111	55	17	15	2
Cycle 2	50	0	27	14	5	4	0	0	25	11	7	5	2	0	30	16	2	1	1	0	29	15	3	2	1	0	111	56	17	12	4
Cycle 3	50	0	22	12	14	2	0	0	24	9	12	2	3	0	27	11	9	2	1	0	33	13	3	1	0	0	106	45	38	7	4
Cycle 4	50	4	33	11	1	1	0	22	14	4	7	3	0	0	25	8	12	3	2	0	29	10	8	2	1	26	101	33	28	9	3
All Cycles	200	4	109	52	25	10	0	22	91	40	30	11	6	0	112	46	25	13	4	0	117	51	20	9	3	26	429	189	100	43	13
All Cycles (in %)		2.0	54.5	26.0	12.5	5.0	0.0	11.0	45.5	20.0	15.0	5.5	3.0	0.0	56.0	23.0	12.5	6.5	2.0	0.0	58.5	25.5	10.0	4.5	1.5	3.3	53.6	23.6	12.5	5.4	1.6

Experiment 12A: With an automated machine manager																															
Cycle Number	Periods	Subordinate 5						Subordinate 6						Subordinate 7						Subordinate 8						All Subordinates					
		Category						Category						Category						Category						Category					
		0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5
Cycle 1	50	39	2	4	4	0	1	42	4	3	1	0	0	0	33	14	0	3	0	40	3	3	3	0	1	121	42	24	8	3	2
Cycle 2	50	38	1	4	6	1	0	0	28	14	3	3	2	0	25	16	6	3	0	0	28	11	3	6	2	38	82	45	18	13	4
Cycle 3	50	4	17	15	8	5	1	0	25	16	4	4	1	26	10	10	3	0	1	5	21	13	4	5	2	35	73	54	19	14	5
Cycle 4	50	12	23	9	2	2	2	0	22	9	9	4	6	30	11	3	4	2	0	8	24	11	2	3	2	50	80	32	17	11	10
All Cycles	200	93	43	32	20	8	4	42	79	42	17	11	9	56	79	43	13	8	1	53	76	38	12	14	7	244	277	155	62	41	21
All Cycles (in %)		46.5	21.5	16.0	10.0	4.0	2.0	21.0	39.5	21.0	8.5	5.5	4.5	28.0	39.5	21.5	6.5	4.0	0.5	26.5	38.0	19.0	6.0	7.0	3.5	30.5	34.6	19.4	7.8	5.1	2.6

Table 4.14.3:Experiments 12A and 12H: Manager's and subordinate's final profits in each cycle.

Exp't	Cycle	Manager's Profit	Subordinates' Profit			
			Sub 1	Sub 2	Sub 3	Sub 4
12H	1	$328.15	$52.24	$10.70	$246.89	$153.55
	2	$429.98	$155.72	$133.25	$86.90	$132.52
	3	$518.64	-$83.04	$21.49	-$38.84	-$33.57
	4	$600.70	Bankrupt (46)	Bankrupt (28)	$4.58	-$79.46

Exp't	Cycle	Manager's Profit	Subordinates' Profit			
			Sub 5	Sub 6	Sub 7	Sub 8
12A	1	$413.00	Bankrupt (11)	Bankrupt (8)	$92.15	Bankrupt (10)
	2	$360.50	Bankrupt (12)	$68.13	$74.86	$164.98
	3	$260.00	Bankrupt (46)	-$49.37	Bankrupt (24)	Bankrupt (45)
	4	$321.50	Bankrupt (38)	$14.80	Bankrupt (20)	Bankrupt (42)

Figure 4.14.1. Experiment 12H: Human manager's accrued profit over the periods in each cycle.

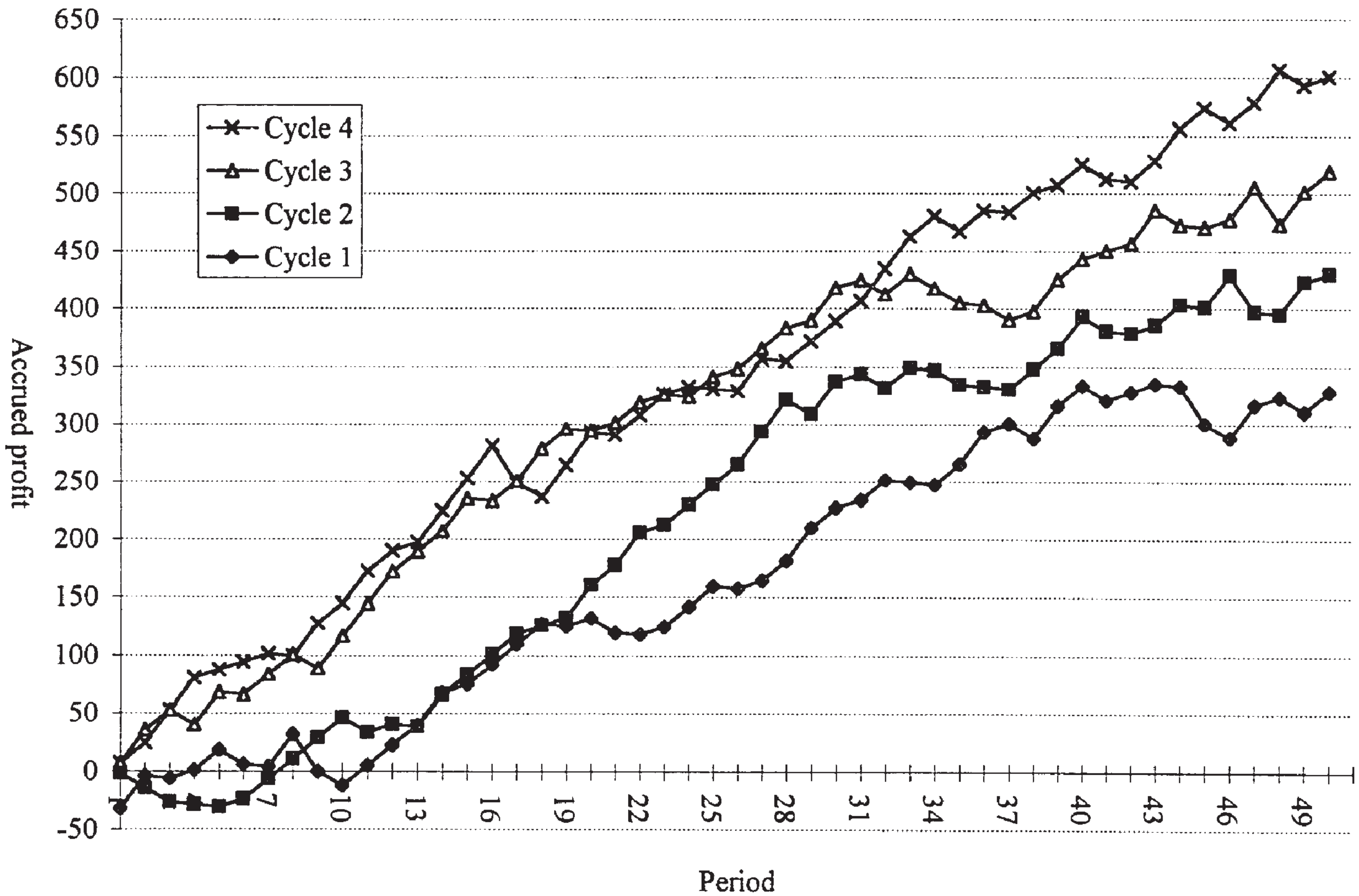


Figure 4.14.2. Experiment 12A: Automated manager's accrued profit over the periods in each cycle.

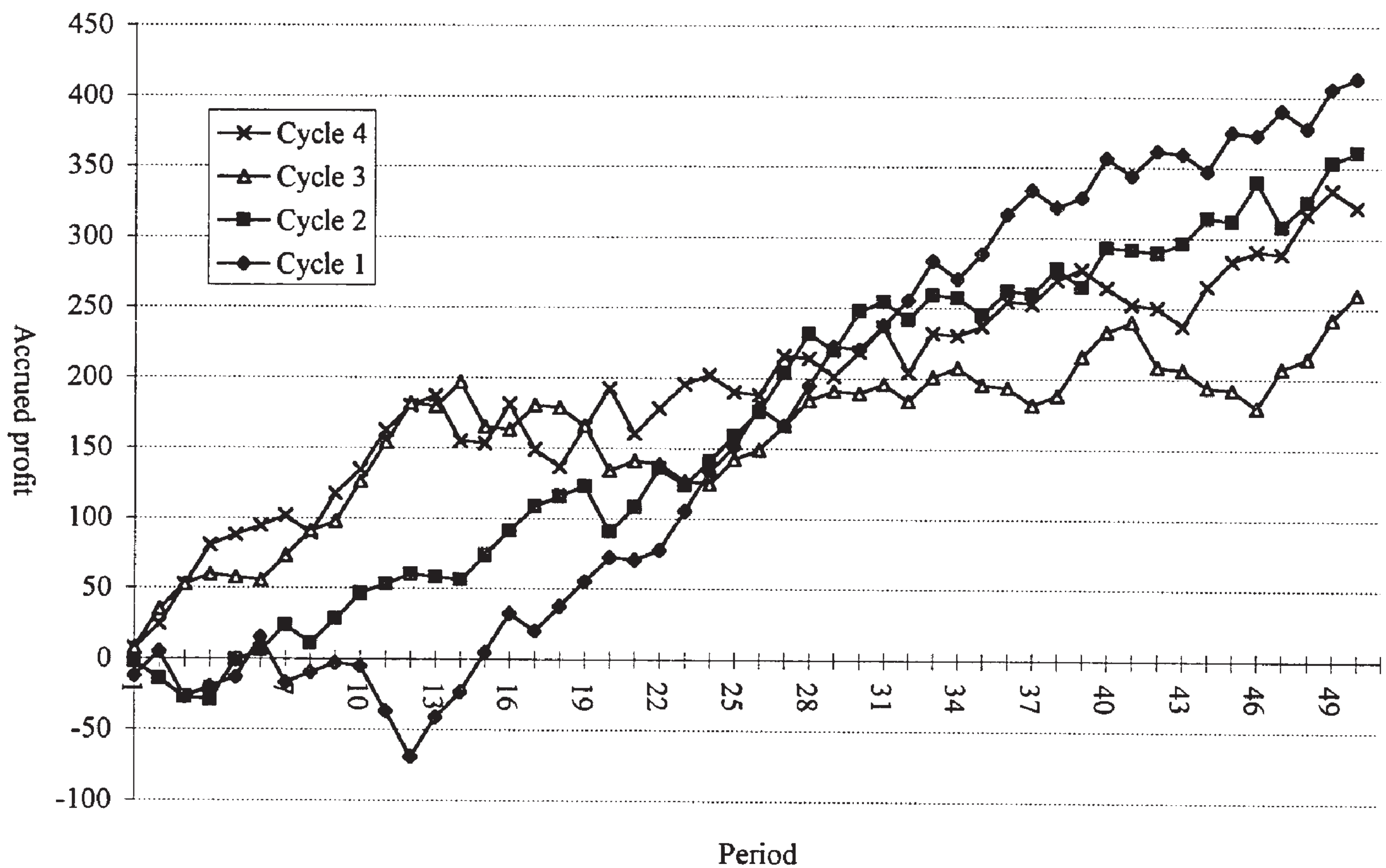


Figure 4.14.3. Experiments 12A & 12H: Automated and human managers' accrued profit over the periods in cycle 2.

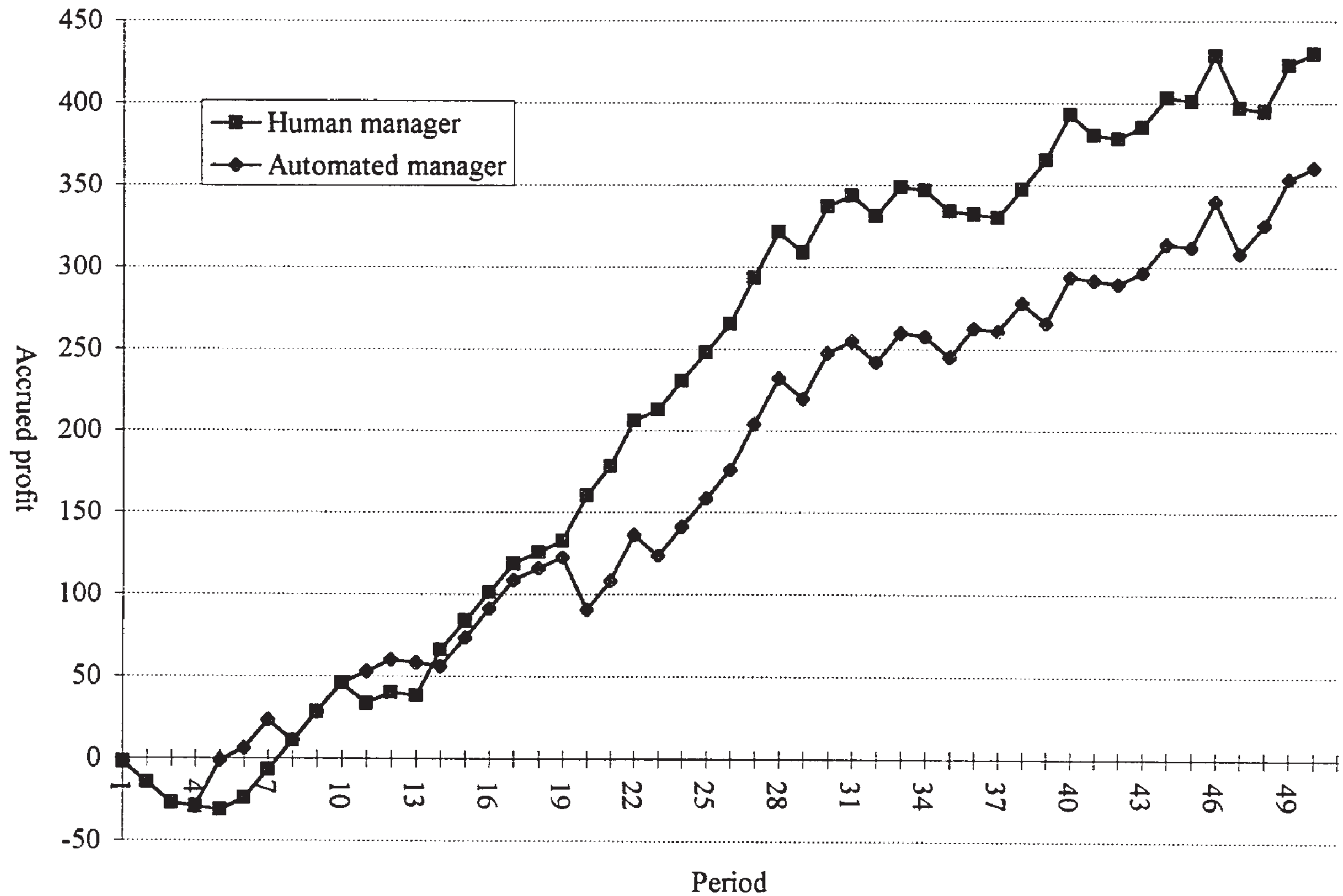


Figure 4.14.4. Experiments 12A & 12H: Automated and human managers' accrued profit over the periods in cycle 3.

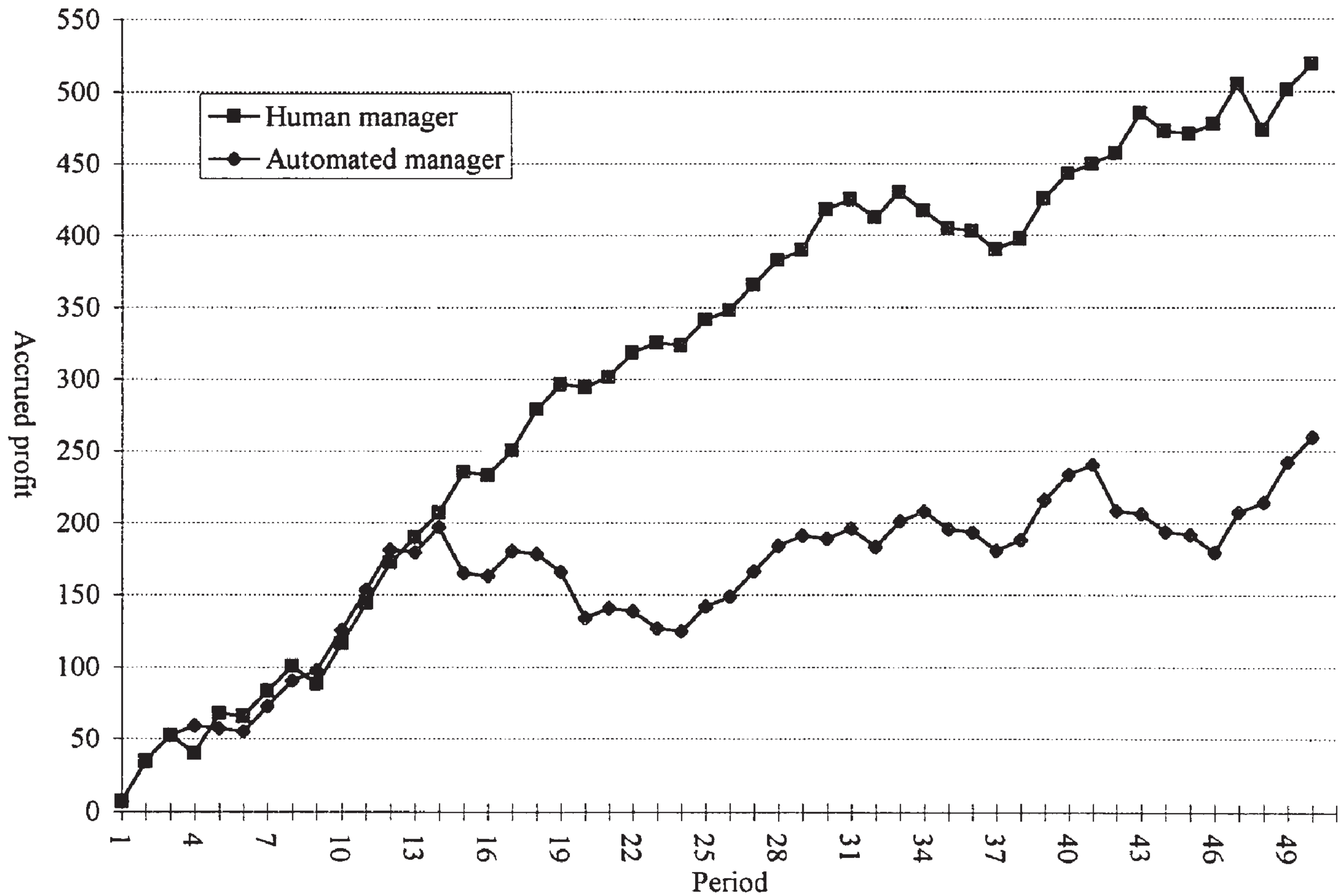
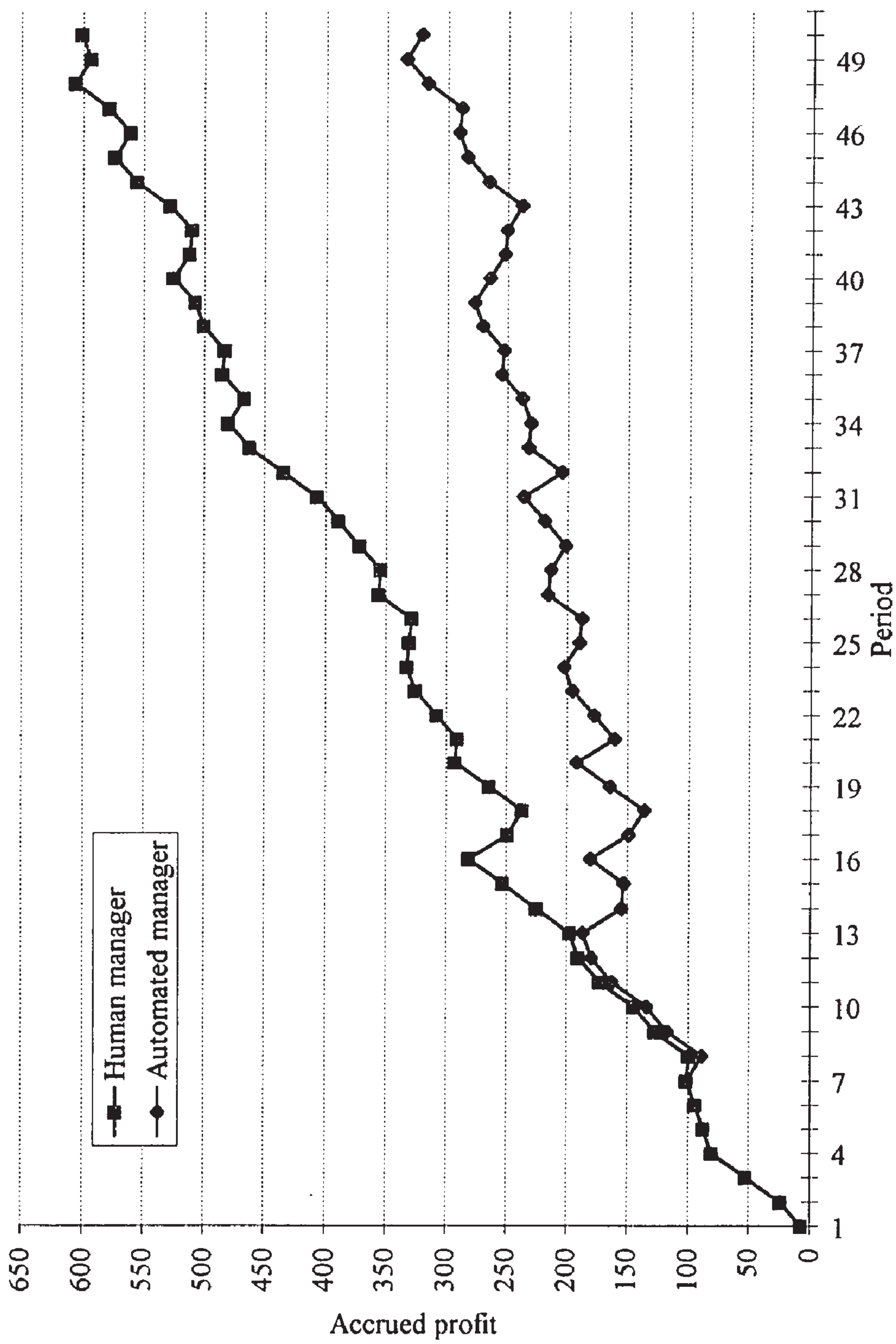


Figure 4.14.5. Experiments 12A & 12H: Automated and human managers' accrued profit over the periods in cycle 4.



4.15 Experiment 13H: No Occurrence of Subordinate Bankruptcy by Design

This experiment was designed to have no bankrupt subordinate. Five subjects were used in this experiment, a human manager and four subordinates. The experimental data from this session was used in the comparison of performance of automated and human managers. Unlike the previous experiments where the subordinate's starting balance was set at $100 experimental dollars, the starting balance for the subordinates in this set of experiments was set at $900 experimental dollars to prevent them from bankruptcy, thus allowing for application of decision rules for the automated machine manager to all experimental periods.

The payoff scheme for the subordinates was independent of the manager's performance. This allows for application of different payoff schemes in the aggregation analyses. The human manager used his own decision rule to make a decision.

The experimental parameter values used in Cycle 2 and Cycle 5 were the same. There were 10 information systems available for the subordinates to purchase. The parameter values used were also the same in Cycle 3 and Cycle 4. There were 8 information systems for the subordinates to purchase.

Experiment Results

Table 4.15.1 shows the average information systems purchased, average time spent in making a decision, and average profit made by the subordinates. Subordinate 1 purchased the most information systems (an average of 7.1) and had the highest Category 1 decision agreement frequency (91.6%, as shown in the last row of Table 4.15.2). Subordinate 1 did not, however, have the highest profit ($6.60, see Tables 4.15.1 and 4.15.3) because the subject spent more in purchasing the information systems.

As indicated earlier, the experimental parameter values were the same in both Cycles 2 and 5. It turned out that the average profit of the four subordinates in Cycle 2 was $4.17 (as seen in the last column of Table 4.15.1, also in the last column of Table 4.15.3) while it was $4.15 in Cycle 5. The experimental parameter values were the same in both Cycles 3 and 4, but the average profit of the four subordinates was $10.14 in Cycle 3 and dropped to $8.99 in Cycle 4.

Table 4.15.1. Experiment 13H: Average information systems purchased, average time spent in making a decision, and average profit made by the subordinates.

Cycle Number	Info Available	Subordinate 1			Subordinate 2			Subordinate 3			Subordinate 4			All Subordinates		
		Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit
Cycle 1	10	5.9	3.28	$6.11	5.5	3.84	$7.80	4.9	3.94	$3.19	5.9	6.18	$5.92	5.6	4.31	$5.76
Cycle 2	10	8.4	3.86	$4.36	7.1	3.16	$4.84	5.8	2.44	$4.94	7.7	6.64	$2.52	7.3	4.03	$4.17
Cycle 3	8	6.4	2.92	$9.56	5.4	2.54	$11.57	4.9	2.08	$10.06	4.6	4.54	$9.37	5.3	3.02	$10.14
Cycle 4	8	6.3	2.38	$9.39	5.3	2.54	$8.82	5.0	2.10	$8.26	5.3	4.24	$9.50	5.5	2.82	$8.99
Cycle 5	10	8.3	3.08	$3.57	6.9	3.14	$5.12	6.2	2.58	$3.76	7.0	4.78	$4.14	7.1	3.40	$4.15
All Cycles		7.1	3.1	$6.60	6.0	3.04	$7.63	5.4	2.63	$6.04	6.1	5.28	$6.29	6.1	3.51	$6.64

Table 4.15.2. Experiment 13H: Decision agreement frequencies.

Cycle Number	Periods	Subordinate 1					Subordinate 2					Subordinate 3					Subordinate 4					All Subordinates				
		Category					Category					Category					Category					Category				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Cycle 1	50	45	2	3	0	0	45	1	3	1	0	39	2	9	0	0	44	2	4	0	0	173	7	19	1	0
Cycle 2	50	45	4	1	0	0	41	3	5	1	0	38	3	8	1	0	39	4	7	0	0	163	14	21	2	0
Cycle 3	50	48	0	2	0	0	49	0	1	0	0	45	0	5	0	0	43	0	7	0	0	185	0	15	0	0
Cycle 4	50	49	0	0	1	0	46	1	3	0	0	44	0	5	1	0	48	1	1	0	0	187	2	9	2	0
Cycle 5	50	42	6	1	1	0	40	5	3	2	0	37	5	6	2	0	39	5	4	2	0	158	21	14	7	0
All Cycles	250	229	12	7	2	0	221	10	15	4	0	203	10	33	4	0	213	12	23	2	0	866	44	78	12	0
All Cycles (in %)		91.6	4.8	2.8	0.8	0.0	88.4	4.0	6.0	1.6	0.0	81.2	4.0	13.2	1.6	0.0	85.2	4.8	9.2	0.8	0.0	86.6	4.4	7.8	1.2	0.0

Table 4.15.3. Experiment 13H: Average profit made by the human manager and the subordinates.

Expt.	Cycle	Periods	Manager	Sub 1	Sub 2	Sub 3	Sub 4	All Subs
13H	Cycle 1	50	$15.91	$6.11	$7.80	$3.19	$5.92	$5.76
	Cycle 2	50	$15.52	$4.36	$4.84	$4.94	$2.52	$4.17
	Cycle 3	50	$18.76	$9.56	$11.57	$10.06	$9.37	$10.14
	Cycle 4	50	$16.90	$9.39	$8.82	$8.26	$9.50	$8.99
	Cycle 5	50	$13.93	$3.57	$5.12	$3.76	$4.14	$4.15
	All Cycles		$16.20	$6.60	$7.63	$6.04	$6.29	$6.64

4.16 Experiments 14A and 14H: Subordinate's Profit as A Function Only of The Manager's Performance

In our previous experiments, the profit for the subordinates was either a function of the subordinates' own performance or a joint function of the subordinate's and the manager's performances. In the following two experiments we ran experimental sessions with the gross profit for the subordinates as a function only of the manager's performance. One experiment used four subjects as subordinates and an automated machine manager. The other experiment used five subjects, one acting as a manager and four acting as the subordinates.

These two experiments were designed to test the effect of performance ambiguity as defined in Williamson [1975].

The experiment with a human manager was run first. It has five cycles. Each cycle has 50 periods. The experiment with an automated machine manager was run right after the experiment with a human manager. It also has five cycles with 50 periods in each cycle. The subjects were three doctoral students from the Department of Decision Science and Information Systems and two doctoral students from the School of Accountancy. None previously participated in any of our experiments. After sign-in, they watched the tutorial video and went through the practice session. The human manager was drawn randomly from the five subjects.

The initial cash balance for the subordinates was set at $900 experimental dollars to prevent them from bankruptcy. Although the subordinate's profit (subordinate payoff scheme) from the production decision itself is a function of only the manager's decision, each subordinate incurred the individual's own information cost and the time cost. Thus, the profits made by the subordinates can be different from subordinate to subordinate. The subjects were informed of the payoff scheme before the experiment started. The decision made and the number of information systems purchased by the subordinates were shown on the display of the manager's workstation. The sequence that the subordinate's recommendation was submitted was also shown on the screen of the manager's workstation.

Experiment 14H: Human Manager

The cost of the time taken by individual subordinates to make a decision did not tend to differ much among the subordinates. It cost $0.01 per second for the subordinates to buy each information system. As shown in Table 4.16.1, on average over the five cycles, Subordinate 1 took 5.1 seconds to make up the decision in the experiment session with a human manager; Subordinate 2 took 6.3 seconds; Subordinate 3 took merely 0.93 second; and Subordinate 4 took 3.7 seconds.

The information cost, however, could make a big difference in their final profit. Consequently, Subordinate 3 never purchased any information system in either experiment. The human manager had to rely on the input of the other subordinates. Subordinate 2 constantly bought almost all the information systems in the first three cycles. The subordinate purchased an average of 8.5 information systems in Cycle 1, in which there were ten information systems available for purchase. Subordinate 2 again purchased an average of 8.6 information systems in Cycle 2, where there were ten information systems available for purchase. In Cycle 3, Subordinate 2 purchased 6.8 information systems on average, where 8 information systems were available for purchase

With the payoff scheme in this experiment, the profit made by Subordinate 3 was constantly higher than that by Subordinate 2. The 5-cycle average per-period profit made Subordinate 2 was $7.31, while Subordinate 3 averaged $15.20. Subordinate 4 constantly took more time to purchase information and make decisions. This subordinate took an average of 18.74 seconds per period in the first cycle and 12.22 in the second cycle. Most of the time, the human manager was ready to make a decision based on the inputs of Subordinate 1 and Subordinate 2, when still waiting for Subordinate 4 to submit the input. By cycle 3, Subordinate 4 speeded up his decision process, but was still the last one to submit.

Table 4.16.2 shows the decision agreement frequency in this experiment. As mentioned above, Subordinate 2 purchased most of the available information systems in the first three cycles. Consequently, Subordinate 2 had 49 periods out of the total of 50 in Category 1 in Cycle 1, 46 periods in Cycle 2, and 49 periods again in Cycle 3. Subordinate 3 never purchased any information system and therefore has only 30.0% in Category 1. Subordinate 3, however, had 60.4% in Category 3. The percentage that Subordinate 3 had a correct guess was 33.2 (30.0% in Category 1 and 3.2% in Category 4.) It was expected because the subordinate was guessing among three choices (high, medium, and low productions.)

Experiment 14A: Automated Manager

The experimental parameter values were the same as those in Experiment 14H. The four original subordinate subjects in Experiment 14H participated in this experiment. Having gained experience in Experiment 14H, this session with an automated manager went smoothly and quickly.

Table 4.16.3 lists the average information systems purchased by the subordinates, average time spent by the subordinates in making a decision, and average profit made by the subordinates. Just as in the experiment with a human manager, Subordinate 3 did not buy a single information system in the entire experiment and, consequently, had the highest profits. Subordinate 3 spent less than one second on average to make a decision. Therefore, the profit of Subordinate 3 was the same as that of the automated manager, as shown in Table 4.16.5.

Table 4.16.1. Experiment 14H: Average information systems purchased, average time spent in making a decision, and average profit made by the subordinates.

Cycle Number	Info Available	Subordinate 1			Subordinate 2			Subordinate 3			Subordinate 4			All Subordinates		
		Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit
Cycle 1	10	5.0	6.04	$10.38	8.5	5.38	$5.99	0.0	1.02	$16.68	3.8	18.74	$11.70	4.3	7.80	$11.19
Cycle 2	10	5.0	4.42	$9.28	8.6	3.34	$4.76	0.0	1.00	$15.51	4.1	12.22	$10.32	4.4	5.25	$9.97
Cycle 3	8	4.7	2.90	$12.28	6.8	3.12	$9.60	0.0	0.56	$18.15	3.3	7.80	$13.93	3.7	3.60	$13.49
Cycle 4	8	4.9	3.94	$8.78	3.8	2.82	$10.17	0.0	0.96	$14.91	3.1	7.60	$10.97	3.0	3.83	$11.21
Cycle 5	10	5.7	4.48	$3.59	3.8	3.42	$6.05	0.0	1.12	$10.77	4.1	8.84	$5.62	3.4	4.47	$6.51
All Cycles		5.1	4.36	$8.86	6.3	3.62	$7.31	0.0	0.93	$15.20	3.7	11.04	$10.51	3.8	4.99	$10.47

Table 4.16.2. Experiment 14H: Decision agreement frequencies.

Cycle Number	Periods	Subordinate 1 Category					Subordinate 2 Category					Subordinate 3 Category					Subordinate 4 Category					All Subordinates Category				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Cycle 1	50	39	0	10	0	1	49	0	0	0	1	12	0	37	1	0	36	1	13	0	0	136	1	60	1	2
Cycle 2	50	34	2	12	2	0	46	4	0	0	0	14	2	32	0	2	35	1	11	3	0	129	9	55	5	2
Cycle 3	50	45	1	4	0	0	49	1	0	0	0	19	0	30	1	0	39	1	10	0	0	152	3	44	1	0
Cycle 4	50	43	5	2	0	0	38	1	7	3	1	18	3	27	1	1	35	1	10	3	1	134	10	46	7	3
Cycle 5	50	32	10	5	3	0	25	8	12	5	0	12	3	25	5	5	33	7	4	5	1	102	28	46	18	6
All Cycles	250	193	18	33	5	1	207	14	19	8	2	75	8	151	8	8	178	11	48	11	2	653	51	251	32	13
All Cycles (in %)		77.2	7.2	13.2	2.0	0.4	82.8	5.6	7.6	3.2	0.8	30.0	3.2	60.4	3.2	3.2	71.2	4.4	19.2	4.4	0.8	65.3	5.1	25.1	3.2	1.3

Table 4.16.3. Experiment 14A: Average information systems purchased by the subordinates, average time spent by the subordinates in making a decision, and average profit made by the subordinates

Cycle Number	Info Available	Subordinate 1			Subordinate 2			Subordinate 3			Subordinate 4			All Subordinates		
		Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit	Avg. Info Purchased	Avg. Decision Time	Avg. Profit
Cycle 1	10	5.8	3.30	$3.34	3.9	2.40	$5.62	0.0	0.96	$10.56	3.4	2.66	$6.27	3.3	2.33	$6.45
Cycle 2	10	6.3	3.54	$3.10	5.5	2.70	$4.11	0.0	0.32	$10.99	4.0	2.10	$5.99	4	2.17	$6.05
Cycle 3	8	4.8	2.80	$6.40	3.7	1.76	$7.76	0.0	0.78	$12.42	4.0	1.82	$7.39	3.1	1.79	$8.49
Cycle 4	8	5.0	2.90	$6.92	4.0	2.08	$8.18	0.0	1.16	$13.14	3.9	1.88	$8.23	3.2	2.01	$9.12
Cycle 5	10	6.5	3.20	$4.42	5.3	2.56	$5.90	0.0	0.40	$12.58	4.0	1.98	$7.51	4	2.04	$7.60
All Cycles		5.7	3.15	$4.84	4.5	2.3	$6.31	0.0	0.72	$11.94	3.9	2.09	$7.08	3.5	2.07	$7.54

Table 4.16.4. Experiment 14A: Decision agreement frequencies.

Cycle Number	Periods	Subordinate 1 Category					Subordinate 2 Category					Subordinate 3 Category					Subordinate 4 Category					All Subordinates Category				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Cycle 1	50	38	3	1	6	2	34	10	5	1	0	12	3	27	3	5	30	10	9	1	0	114	26	42	11	7
Cycle 2	50	31	3	7	9	0	35	11	3	1	0	13	2	25	4	6	28	12	10	0	0	107	28	45	14	6
Cycle 3	50	37	5	1	7	0	35	10	3	2	0	18	3	20	3	6	33	12	5	0	0	123	30	29	12	6
Cycle 4	50	39	2	3	6	0	40	7	2	1	0	14	2	28	3	3	33	7	9	0	1	126	18	42	10	4
Cycle 5	50	33	6	6	5	0	38	11	1	0	0	14	3	25	3	5	23	7	16	4	0	108	27	48	12	5
All Cycles	250	178	19	18	33	2	182	49	14	5	0	71	13	125	16	25	147	48	49	5	1	578	129	206	59	28
All Cycles (in %)		71.2	7.6	7.2	13.2	0.8	72.8	19.6	5.6	2.0	0.0	28.4	5.2	50.0	6.4	10.0	58.8	19.2	19.6	2.0	0.4	57.8	12.9	20.6	5.9	2.8

Table 4.16.5. Experiments 14A & 14H: Average profit made by the managers and the subordinates.

Exp't	Cycle	Manager	Sub 1	Sub 2	Sub 3	Sub 4	All Subs
14H	Cycle 1	$16.68	$10.38	$5.99	$16.68	$11.70	$11.19
	Cycle 2	$15.51	$9.28	$4.76	$15.51	$10.32	$9.97
	Cycle 3	$18.15	$12.28	$9.60	$18.15	$13.93	$13.49
	Cycle 4	$14.91	$8.78	$10.17	$14.91	$10.97	$11.21
	Cycle 5	$10.77	$3.59	$6.05	$10.77	$5.62	$6.51
	All Cycles	$15.20	$8.86	$7.31	$15.20	$10.51	$10.47
14A	Cycle 1	$10.57	$3.34	$5.62	$10.56	$6.27	$6.45
	Cycle 2	$10.99	$3.10	$4.11	$10.99	$5.99	$6.05
	Cycle 3	$12.43	$6.40	$7.76	$12.42	$7.39	$8.49
	Cycle 4	$13.15	$6.92	$8.18	$13.14	$8.23	$9.12
	Cycle 5	$12.58	$4.42	$5.90	$12.58	$7.51	$7.60
	All Cycles	$11.94	$4.84	$6.31	$11.94	$7.08	$7.54

Chapter 5

HYPOTHESIS TESTING

5.1 Hypotheses

In this chapter we present the results of hypothesis tests performed using the experimental data outlined in the previous chapter.

As discussed in Chapter 2, Marsden and Pingry [1991] address the problem of selecting an optimal portfolio of DSS for a profit maximizing firm. They argue that the problem of DSS design involves deciding what unstructured problems to assign to a DSS, what unstructured problems to do manually, and what unstructured problems to ignore. They also contend that empirical testing is one way toward structuring the DSS design evaluation problem.

My work extends their approach into the area of distributed multi-participant decision making. We propose the subordinate-manager decision aggregation model as detailed in Chapter 3 and provide empirical testing in computerized laboratory experiments.

The hypotheses tested are listed below:

H1: *The human manager performs better in aggregating the subordinates' recommendations and making a production decision.*

Thus, we test the null hypothesis that the per-period profit made by a human manager is different from that made by an automated machine manager. It is tested in section 5.2.

H2: *The per-period profits of the subordinates are different among different kinds of subordinates.*

For this hypothesis, we tested the following as an example:

H2.1: *The per-period profits of the subordinates are different between groups comprising of doctoral students and groups comprising of MBA students.*

H3: *The per-period profits of the manager are different among different kinds of subordinates.*

For this hypothesis, to be consistent with H2, we tested the following as an example:

H3.1: *The per-period profits of the managers are different between groups comprising of doctoral students and groups comprising of MBA students.*

The tests of H2 and H3 are performed in section 5.3.

H4: *The per-period profits of the subordinates are different in the cycles where they pay for the forecast information without waiting for it from those in the cycles where they have to wait and are charged with time cost before the free forecast information becomes available.*

H5: *The per-period profits of the manager are different in the cycles where the subordinates pay for the forecast information without waiting for it from those in the cycles where the subordinates have to wait and are charged with time cost before the free forecast information becomes available.*

The tests of H4 and H5 are illustrated in section 5.4.

H6: *The per-period profits of the subordinates are different in a larger group of subordinates and in a smaller group of subordinates.*

For this hypothesis, we tested the following group sizes as examples:

H6.1 *The per-period profits of the subordinates are different in a group of six subordinates and in a group of five subordinates.*

H6.2 *The per-period profits of the subordinates are different in a group of five subordinates and in a group of four subordinates.*

H7: *The per-period profits of the manager are different in a larger group of* *subordinates from those in a smaller group of subordinates.*

For this hypothesis, we tested the same group sizes as in H6 as examples:

H7.1 *The per-period profits of the manager are different in a group of six subordinates and in a group of four subordinates.*

H7.2 *The per-period profits of the manager are different in a group of five subordinates and in a group of four subordinates.*

We perform the tests of H6 and H7 in section 5.5.

To test the difference between two means, we use a nonparametric test, the *U* test. With this test we are able to test the null hypothesis that the two means are equal without having to assume that the populations sampled have roughly the shapes of normal distributions. The test requires only that the populations be continuous (in order to avoid ties). In practice it does not matter whether this assumption is satisfied or not, so long as the number of ties is small (Conover, 1971). We illustrate the procedure of the *U* test in testing our hypothesis in the next section.

We conclude the chapter in section 5.6 with a summary of the tests performed in this chapter and elaborate on the implications of the results.

5.2 Hypotheses Tests H1: Comparison of the Performance of the Human and Automated Managers

To compare the performance (per-period profits) of a human manager and an automated manager in our experiments, we used the *U* test. We tested the null hypothesis that the per-period profit made by a human manager was equal to that made by an automated machine manager.

The data for this test appear in Tables 5.2.1 and 5.2.2. There were three experimental sessions with a human manager, Experiments 11H, 12H, and 13H. Experiments 11H and 12H had four cycles each and Experiment 13H had five cycles. The parameters used in the sessions of Experiments 11H and 12H were also used in the experiments with an automated manager, Experiments 11A and 12A. All the periods from the five experiments (three with a human manager and two with an automated manager) are included in Table 5.2.1. Table 5.2.2 does not include those periods in which there was at least one bankrupt subordinate. The per-period profit was obtained from dividing the total profit in a cycle by the number of periods. The mean per-period profit of the eight cycles for the human manager in Table 5.2.1 was \$11.16 and, for the automated manager, \$10.13. The mean per-period profit of the 13 cycles for the human manager in Table 5.2.1 was \$13.11. The mean per-period profit of the eight cycles for the human manager in Table 5.2.2 was \$12.20 and, for the automated manager, \$9.58. The mean per-period profit of the 13 cycles for the human manager in Table 5.2.2 was \$13.75.

We perform the *U* test by first arranging the data jointly, as if they comprise one sample, in an increasing order of magnitude. Next the data in this order were assigned the ranks 1, 2, 3, and so on. If the hypothesis is true, we would expect that more of the smaller ranks will go to the values of the automated-manager sample, while more of the higher ranks will go to those of the human-manager sample.

Hypothesis Tests H1.1 and H1.2: All Experiment Periods Are Included in the Test

Two *U* tests were performed on the data in Table 5.2.2. Test H1.1 uses all of the 13 human-manager cycles and the eight automated-manager cycles, while Test H1.2 uses the eight human-manager cycles and their corresponding eight automated-manager cycles. These eight corresponding cycles have identical experiment parameter values. We call the sample with an automated manager Sample 1 and the one with a human manager Sample 2. We use 95% confidence interval, i.e., α=0.05, in all the tests.

TEST H1.1:

Eight automated-manager cycles and 13 human-manager cycles. All periods in each cycle are included.

H_0: $\mu_1 = \mu_2$
H_1: $\mu_1 \neq \mu_2$

The rank orders are listed in Table 5.2.3. The sum of rank orders of the automated-manager sample, W_1, is 67, while that of the human-manager sample, W_2, is 164. The decision in this test is now based on either of the following related statistics, instead of on the rank sums when it was first proposed as a nonparametric alternative to the two-sample *t* test.

$$U_1 = W_1 - \frac{n_1(n_1+1)}{2}$$

or

$$U_2 = W_2 - \frac{n_2(n_2+1)}{2}$$

where n_1 and n_2 are the sizes of Sample 1 and Sample 2. The statistic U_1 is 31. The statistic U_2 is 73. For this two-tailed test with the alternative H_1: $\mu_1 = \mu_2$, we reject the null hypothesis if the observed value of U_1 is less than the lower critical value or greater than the higher critical value. By consulting a table of critical values for the two-sided U test at the 0.05 level of significance (α level), with $n_1 = 8$ and $n_2 = 13$, the critical value ($U_{\alpha=0.05}$) is 24. Since $U = 31$ and is greater than the critical value (i.e., 24), the null hypothesis cannot be rejected and there is no evidence of significance at the 0.05 level that the mean per-period profit made by the human manager is different from that made by the automated manager.

TEST H1.2:

Eight automated-manager cycles and eight human-manager cycles. All periods in each cycle are included.

H_0: $\mu_1 = \mu_2$
H_1: $\mu_1 \neq \mu_2$

Summary of the computed data:

Sum of rank order:	$W_1 = 59$, $W_2 = 77$
Statistics:	$U_1 = 23$, $U_2 = 41$
Test statistic U:	$U = 23$
Two-sided critical value:	$U_{\alpha=0.05} = 13$

Since $U = 23$ and exceeds $U_{\alpha=0.05}$, the null hypothesis cannot be rejected. Again, there is no evidence of significance at the 0.05 level that the mean per-period profit made by a human manager is not equal to that made by an automated manager.

Hypothesis Tests H1.3 and H1.4: Experiment Periods with Bankrupt Subordinate Are Not Included in the Test

Next the profits for a human manager and an automated manager are tallied only for the periods with no bankrupt subordinate as shown in Table 5.2.2. The per-period profits are used in Tests H1.3 and H1.4.

TEST H1.3:

Eight automated-manager cycles and 13 human-manager cycles. Periods with bankrupt subordinate are not included.

H_0: $\mu_1 = \mu_2$
H_1: $\mu_1 \neq \mu_2$

TEST H1.4:

Eight automated-manager cycles and eight human-manager cycles. Periods with bankrupt subordinate are not included.

H_0: $\mu_1 = \mu_2$
H_1: $\mu_1 \neq \mu_2$

The test results are tabulated in Table 5.2.4 along with other tests. Again, these two tests failed to reject the null hypothesis. By applying the U test, there is no evidence of significance at the 0.05 level that the mean per-period profit made by a human manager is different from that made by an automated manager. The simple rule implemented for the automated manager enabled it to perform as well as a human manager did. This promising performance by the automated manager points the way to a more intelligent implementation of the rule set for the automated manager.

When we first set up the experiments comparing the performance between an automated machine manager and a human manager, we might have expected that a human manager would fair better than an automated machine manager implemented with a simple set of rules to rely upon in making the decisions. It turned out that statistically both kinds of manager perform at a compatible level. Although one may argue that the sample size cannot justify a general conclusion, we are encouraged by the research direction this hypothesis test leads. It can be stipulated that a computer-based collaborative decision support system will help an organization in making effective decisions, thus pushing the boundary of intelligent organization.

Table 5.2.1. Data set for U tests H1.1 and H1.2: Per-period profit for human and automated manager in a cycle. Periods with bankrupt subordinates are included in the tests.

Per-period profit	Total profit in a cycle	Total periods in the cycle	Type of manager	Mean per-period profit	
$6.56	$328.15	50	human manager		
$8.60	$429.98	50	human manager		
$10.37	$518.64	50	human manager		
$12.01	$600.70	50	human manager	Mean	
$12.86	$643.09	50	human manager	$11.16	
$16.91	$845.67	50	human manager		
$8.35	$417.72	50	human manager		Mean
$13.61	$680.49	50	human manager		$13.11
$15.91	$795.50	50	human manager		
$15.52	$776.00	50	human manager		
$18.76	$938.00	50	human manager		
$16.90	$845.00	50	human manager		
$13.99	$699.50	50	human manager		
$8.26	$413.00	50	auto manager		
$7.21	$360.50	50	auto manager		
$5.20	$260.00	50	auto manager		
$6.43	$321.50	50	auto manager	Mean	
$17.59	$879.50	50	auto manager	$10.13	
$17.71	$885.50	50	auto manager		
$12.52	$626.00	50	auto manager		
$6.10	$305.00	50	auto manager		

Table 5.2.2. Data set for U tests H1.3 and H1.4: Per-period profit for human and automated manager in a cycle. Periods with bankrupt subordinates are not included in the tests.

Per-period profit	Total profit in a cycle	Total non-bankrupt periods in the cycle	Type of manager	Mean per-period profit	
$6.56	$328.15	50	human manager	Mean $12.20	Mean $13.75
$8.60	$429.98	50	human manager		
$10.37	$518.64	50	human manager		
$12.66	$354.43	28	human manager		
$14.61	$511.43	35	human manager		
$16.91	$845.67	50	human manager		
$11.21	$425.82	38	human manager		
$16.70	$350.61	21	human manager		
$15.91	$795.50	50	human manager		
$15.52	$776.00	50	human manager		
$18.76	$938.00	50	human manager		
$16.90	$845.00	50	human manager		
$13.99	$699.50	50	human manager		
($1.25)	($10.00)	8	auto manager	Mean $9.58	
$5.00	$60.00	12	auto manager		
$5.19	$124.50	24	auto manager		
$9.63	$192.50	20	auto manager		
$17.59	$879.50	50	auto manager		
$17.71	$885.50	50	auto manager		
$11.97	$538.50	45	auto manager		
$10.82	$238.00	22	auto manager		

Table 5.2.3. Rank order, sum of ranks, and statistics in Test H1.1.

Rank	Auto manager	Human manager	Rank 1	Rank 2
1	$5.20		1	
2	$6.10		2	
3	$6.43		3	
4		$6.56		4
5	$7.21		5	
6	$8.26		6	
7		$8.35		7
8		$8.60		8
9		$10.37		9
10		$12.01		10
11	$12.52		11	
12		$12.86		12
13		$13.61		13
14		$13.99		14
15		$15.52		15
16		$15.91		16
17		$16.90		17
18		$16.91		18
19	$17.59		19	
20	$17.71		20	
21		$18.76		21
Average	$10.13	$13.11		
Sum of Ranks, W			67	164
Sample size, n			8	13
Statistic, U			31	73
Two-tailed critical value			24	

Table 5.2.4. Hypothesis tests H1: Results of mean per-period profits between sample 1, experiment with an automated manager, and sample 2, experiment with a human manager.

Test #	Hypothesis	n_1	n_2	W_1	W_2	U_1	U_2	U	$U_{\alpha=0.05}$	Test result
Test H1.1	H_0: $\mu_1 = \mu_2$ H_1: $\mu_1 \neq \mu_2$	8	13	67	164	31	73	31	24	**Failed to reject H_0**
Test H1.2	H_0: $\mu_1 = \mu_2$ H_1: $\mu_1 \neq \mu_2$	8	8	59	77	23	41	23	13	**Failed to reject H_0**
Test H1.3	H_0: $\mu_1 = \mu_2$ H_1: $\mu_1 \neq \mu_2$	8	13	69	162	33	71	33	24	**Failed to reject H_0**
Test H1.4	H_0: $\mu_1 = \mu_2$ H_1: $\mu_1 \neq \mu_2$	8	8	61	75	25	39	25	13	**Failed to reject H_0**

5.3 Hypothesis Tests H2 and H3: MBA Student Subordinate Groups vs. Doctoral Student Subordinate Groups.

In general, we might expect doctoral student subjects to outperform MBA student subjects in a decision-making situation like our experiments. In this section we first compare the performance of these two subject groups in subordinate decision making activities. Again, we use the *U* test to avoid making assumptions regarding the normality of the population distribution. The data used is from the MBA student experiments (2A, 3A, and 4A) and the corresponding doctoral student experiments (6A, 9A, 10A, and 11A) which used the same parameter value sets.

H2.1: Comparison of Subordinates' Profits:

A total of 12 MBA student subordinates and 21 doctoral student subordinates participated in these experiments. The number of cycles for MBA student subordinates was 18 and for doctoral student subordinates it was 19. Table 5.3.1 provides the relevant data for the observation set. The average per-period profit of a subordinate used in this test was the mean calculated from all the cycles in an experiment. The MBA student subordinates' per-period profits ranged from -\$3.31 to +\$10.54 yielding a range of \$13.85. The doctoral student subordinates' profits varied from -\$9.70 to +\$8.60 yielding a range of \$18.30. The mean per-period profit for MBA's was \$6.47 and the mean for doctoral students' was \$3.01. The hypothesis is that the per-period profits of the subordinates are different between groups comprising of doctoral students and groups comprising of MBA students:

$$H_0: \quad \mu_1 = \mu_2$$
$$H_1: \quad \mu_1 \neq \mu_2$$

The rank orders are provided in Table 5.3.1. The sum of rank orders of the MBA student sample, W_1, is 267, while that of the doctoral student sample, W_2, is 294. The following statistics, rather than the originally proposed rank sums, are now used to perform the U-test:

$$U_1 = W_1 - \frac{n_1(n_1+1)}{2}$$

or

$$U_2 = W_2 - \frac{n_2(n_2+1)}{2}$$

where n_1 and n_2 are the sizes of Sample 1 and Sample 2. In this test n_1 is 12 and n_2 is 21. Since n_1 and n_2 are both greater than 8, the sampling distribution of the statistic can be approximated closely by a normal distribution. The large-sample U test may be based on either U_1 or U_2, but since the resulting tests are equivalent and it does not matter which sample we denote sample 1 and which sample we denote sample 2, we shall use the statistic U_1. Thus, we base the test of the null hypothesis $\mu_1 = \mu_2$ on the following statistic:

$$z = \frac{U_1 - \mu_{U_1}}{\sigma_{U_1}}$$

For this two-tailed test with the alternative H_1: $\mu_1 \neq \mu_2$, we reject the null hypothesis if the observed z value is lower than the lower critical bound or higher than the upper critical bound. The following results are obtained:

Statistics: $U_1 = 189$
Mean of the sampling distribution of the statistics: $\mu = 126$
Standard deviations of the sampling distribution of the statistics: $\sigma = 26.721$
z test statistic: $z = 2.358$
Two-tailed critical value: $z_{\alpha=0.05} = 1.960$

The null hypothesis is rejected. The average per-period profit made by the MBA student subordinates is statistically significantly different from (greater than) that of the doctoral student subordinates.

The test results suggest that educational level is only one of the factors affecting a subordinate's decision making. Higher educational level does not guarantee better decision making in an organizational decision making hierarchy. Exposure to broader and deeper knowledge body such as one would expect in the case of a doctoral student, may not help the person in a decision making process such as that implemented in our experiments.

H3.1: Comparison of the Automated Manager's Profits:

The manager's per-period profit in each cycle was used in this test. The number of cycles for MBA student subordinates was 18 and for doctoral student subordinates it was 19. The automated manager's profits in groups with MBA student subjects ranged from \$8.58 to \$19.19 yielding a range of \$10.61. The mean per-period profit was \$15.38. The manager's profits in groups with doctoral student subjects varied from \$6.10 to \$18.33 yielding a range of \$12.23. The mean per-period profit was \$13.38, as shown in Table

5.3.2.

Since the size of both samples is greater than eight, this is also a large-sample U test. We proceeded with the same procedure as in the testing of the subordinates' performance. The hypothesis is that the per-period profits of the managers are different between groups comprising of doctoral students and groups comprising of MBA students:

H_0: $\mu_1 = \mu_2$
H_1: $\mu_1 \neq \mu_2$

The rank order is listed in Table 5.3.2. The following results were obtained in this test:

Statistics: $U_1 = 249$
Mean of the sampling distribution of the statistics: $\mu = 171$
Standard deviations of the sampling distribution of the statistics: $\sigma = 32.909$
z test statistic: $z = 2.370$
Two-tailed critical value: $z_{\alpha=0.05} = 1.960$

The null hypothesis is rejected. We conclude that the average per-period profit made by the managers with groups of MBA student subordinates is statistically significantly different from (greater than) that made by the managers with groups of doctoral student subordinates.

The test results indicate that educational level of the subordinates is only one of the factors affecting a manager's decision making based on inputs from a group of subordinates. Higher educational level in the subordinates does not guarantee better decision making in an organizational decision making hierarchy.

Table 5.3.1. Hypothesis test H2.1: Results of MBA student subordinates' profit vs. doctoral student subordintes' profit in groups with an automated machine manager.

Rank	Per-period profit		Rank 1	Rank 2	Type of subordinate
	MBA	Doctoral			
1		-$9.70		1	doctoral students
2		-$4.09		2	doctoral students
3	-$3.31		3		MBA students
4		-$1.15		4	doctoral students
5		$.73		5	doctoral students
6		$1.33		6	doctoral students
7		$1.42		7	doctoral students
8		$1.52		8	doctoral students
9		$1.92		9	doctoral students
10	$2.75		10		MBA students
11		$3.01		11	doctoral students
12		$3.31		12	doctoral students
13		$3.51		13	doctoral students
14		$3.52		14	doctoral students
15		$4.25		15	doctoral students
16		$4.37		16	doctoral students
17		$4.59		17	doctoral students
18	$5.02		18		MBA students
19		$5.15		19	doctoral students
20	$5.85		20		MBA students
21		$6.06		21	doctoral students
22	$6.55		22		MBA students
23	$7.37		23		MBA students
24	$7.74		24		MBA students
25	$7.77		25		MBA students
26	$8.03		26		MBA students
27		$8.03		27	doctoral students
28		$8.32		28	doctoral students
29		$8.42		29	doctoral students
30		$8.60		30	doctoral students
31	$9.16		31		MBA students
32	$10.12		32		MBA students
33	$10.54		33		MBA students
Average	$6.47	$3.01			
Sum of Ranks, *W*			267	294	
Sample size, *n*			12	21	
Statistic, *U*			189	63	
Mean of the sampling distribution of *U*			126.000		
Std dev of the sampling distribution of *U*			26.721		
z-test			2.358		
Two-tailed critical value $z_{\alpha=0.05}$			1.960		

Table 5.3.2. Hypothesis test H3.1: Results of the automated machine manager's profits in groups with MBA student subjects as subordinates vs. group with doctoral student subjects as subordintes.

Rank	Manager's per-period profit		Rank of MBA group	Rank of doctoral group
	MBA group	Doctoral group		
1		$6.10		1
2	$8.58		2	
3		$11.26		3
4		$11.30		4
5		$11.32		5
6	$11.75		6	
7		$11.95		7
8		$12.10		8
9		$12.52		9
10		$12.55		10
11		$12.63		11
12		$12.90		12
13		$13.11		13
14		$13.11		14
15	$13.15		15	
16	$13.30		16	
17		$13.63		17
18	$14.02		18	
19	$14.46		19	
20		$14.65		20
21	$15.25		21	
22		$15.25		22
23	$15.81		23	
24	$15.81		24	
25	$15.91		25	
26		$16.12		26
27	$16.20		27	
28	$16.56		28	
29	$16.64		29	
30	$16.90		30	
31	$17.28		31	
32		$17.59		32
33		$17.71		33
34	$17.95		34	
35	$18.14		35	
36		$18.33		36
37	$19.19		37	
Average	$15.38	$13.38		
Sum of Ranks, *W*			420	283
Sample size, *n*			18	19
Statistic, *U*			249	93
Mean of the sampling distribution of *U*			171	
Std dev of the sampling distribution of *U*			32.909	
z-test			2.370	
Two-tailed critical value $z_{\alpha=0.05}$			1.960	

5.4 Hypothesis Tests H4 and H5: Experiments with Free Information vs. Experiments with with-cost Information

In this section we investigated the performance of subordinates and managers in decision making situations where the subordinates pay for the forecast information without waiting for it and in the decision making situation where they have to wait and are charged with time cost before the free forecast information becomes available. In the experiments with free forecast information we observed that the subordinates were impatient in waiting for the information and some of them realized that the cost of waiting time could be expensive.

There were eight cycles in the conducted experiments in which the information was free. For these eight free-information cycles, there were 14 corresponding cycles with the same experimental parameter values except for the information cost. Sample 1 were the cycles with free information and Sample 2 were those cycles in which the forecast information was not free.

H4: Comparison of the Subordinates' Profit

Here we first tested the performance of the subordinates. We operationalize the hypothesis and state that the per-period profits of the subordinates are different in the cycles where they pay for the forecast information without waiting for it from those in the cycles where they have to wait and are charged with time cost before the free forecast information becomes available. The hypothesis is stated as follows:

H_0: $\mu_1 = \mu_2$
H_1: $\mu_1 \neq \mu_2$

Since there were eight points in Sample 1 and 14 points in Sample 2, we perform a small-sample U test. The per-period profit used in this test is the *average* profit of all the subordinates in a cycle. The subordinates' profit in cycles with free information ranged from -\$0.57 to +\$9.64 yielding a range of \$10.21. The mean per-period profit was \$5.41. The subordinates' profit in cycles with non-free information varied from -\$4.80 to +\$12.88 yielding a range of \$17.68. The mean per-period profit was \$4.34, as shown in Table 5.4.1. The rank orders and the test results are also shown in Table 5.4.1:

Sum of rank order:	$W_1 = 98$, $W_2 = 155$
Statistics:	$U_1 = 62$, $U_2 = 50$
Test statistic U:	$U = 50$
Two-sided critical value:	$U_{\alpha=0.05} = 26$

Since the test statistic is greater than the critical value, we are unable to reject the null hypothesis. There is no statistical evidence that a subordinate with access to free information (but having to wait for the free information) performed better than a subordinate who had to purchase the information.

H5: Comparison of the Manager's Profit

We tested that the per-period profits of the manager are different in the cycles where the subordinates pay for the forecast information without waiting for it and those in the cycles where the subordinates have to wait and are charged with time cost before the free forecast information becomes available. The hypothesis is stated as follows:

H_0: $\mu_1 = \mu_2$
H_1: $\mu_1 \neq \mu_2$

As in the test of subordinates' profit, since there were eight data in Sample 1 and 14 data in Sample 2, we perform a small-sample U test. The manager's profit in cycles with free information ranged from \$8.65 to \$13.54 yielding a range of \$4.89. The mean per-period profit was \$11.78. The manager's profit in cycles with non-free information varied from \$5.17 to \$18.33 yielding a range of \$13.16. The mean per-period profit was \$12.73, as shown in Table 5.4.2. The rank orders and the test results are also shown in Table 5.4.2:

Sum of rank order:	$W_1 = 83$, $W_2 = 170$
Statistics:	$U_1 = 47$, $U_2 = 65$
Test statistic U:	$U = 47$
Two-sided critical value:	$U_{\alpha=0.05} = 26$

We do not reject the null hypothesis. There is no statistical evidence that a manager with inputs from subordinates who had access to free information (but who had to wait for the free information) performed better than a manager with inputs from subordinates who had to purchase the information.

The lesson we can learn from this test is that appropriate purchase of timely information may offset the cost. Free information has a cost, the cost of waiting and possible loss of the timeliness of the decision in the operations of an organization. The cost incurred in waiting is used as a practical and reasonable simulations of the lost opportunities and the incurred operations cost.

Table 5.4.1. Hypothesis test H4: The subordinates' profits in free-information cycles vs. with-cost information cycles.

Rank	Per-period profit		Rank 1	Rank 2
	Cycles with free information	Cycles with with-cost information		
1		-$4.80		1
2	-$0.57		2	
3		-$0.26		3
4		-$0.22		4
5	-$0.05		5	
6	$1.82		6	
7		$2.41		7
8		$3.47		8
9		$3.60		9
10		$3.65		10
11		$4.12		11
12		$4.54		12
13		$5.21		13
14		$6.11		14
15	$6.96		15	
16	$7.42		16	
17	$9.03		17	
18	$9.08		18	
19	$9.64		19	
20		$9.68		20
21		$10.30		21
22		$12.88		22
Average	$5.41	$4.34		
Sum of Ranks, W			98	155
Sample size, n			8	14
Statistic, U			62	50
Two-tailed critical value			26	

Table 5.4.2. Hypothesis test H5: The managers' profits in free-information cycles vs. with-cost information cycles.

Rank Order	Per-period profit: Cycles with free information	Per-period profit: Cycles with with-cost information	Rank 1	Rank 2
1		$5.17		1
2		$8.20		2
3	$8.65		3	
4	$10.15		4	
5		$10.39		5
6		$10.60		6
7		$11.26		7
8	$11.30		8	
9		$11.32		9
10	$11.95		10	
11		$12.10		11
12		$12.55		12
13	$12.63		13	
14	$12.90		14	
15	$13.11		15	
16	$13.54		16	
17		$13.63		17
18		$15.25		18
19		$15.58		19
20		$16.12		20
21		$17.70		21
22		$18.33		22
Average	$11.78	$12.73		
Sum of Ranks, W			83	170
Sample size, n			8	14
Statistic, U			47	65
Two-tailed critical value			26	

5.5 Hypothesis Tests H6 and H7: Experiments with Input from Larger Group of Subordinates vs. Experiments with Input from Smaller Group of Subordinates.

As outlined in section 5.1, we might expect that the per-period profits of the manager are different in a larger group of subordinates from those in a smaller group of subordinates. For this hypothesis, we tested the following group sizes as examples:

H6.1 *The per-period profits of the manager are different in a group of six subordinates and in a group of four subordinates.*

H6.2 *The per-period profits of the manager are different in a group of five subordinates and in a group of four subordinates.*

Similarly, we propose that the per-period profits of the subordinates are different in a larger group of subordinates and in a smaller group of subordinates. For this hypothesis, we tested the same group sizes as in H6:

H7.1 *The per-period profits of the subordinates are different in a group of six subordinates and in a group of five subordinates.*

H7.2 *The per-period profits of the subordinates are different in a group of five subordinates and in a group of four subordinates.*

H6.1 Comparison of the Subordinates' Profit: Six-Subordinate Group vs. Four-Subordinate Group

First we test the proposition that the per-period profits of the subordinates are different in a group of six subordinates from those in a group of four subordinates. We denote the six-subordinate group as Sample 1 and the four-subordinate group as Sample 2. There were nine subordinates in Sample 1 used in this test. There were 13 corresponding subordinates used in this test for Sample 2. We perform small-sample U and set up the hypothesis as follows:

$$H_0: \quad \mu_1 = \mu_2$$
$$H_1: \quad \mu_1 \neq \mu_2$$

The average per-period profit of a subordinate used in this test was the mean calculated from all the cycles in an experiment. The subordinates' profit in a 6-subordinate group ranged from -\$4.80 to +\$5.21 yielding a range of \$10.01. The mean per-period profit was \$1.15. The subordinates' profit in a 4-subordinate group varied from -\$8.03 to +\$2.54 yielding a range of \$10.57. The mean per-period profit was -\$1.59, i.e., a loss, as shown in Table 5.5.1. The rank orders and test results are tabulated in Table 5.5.1 and summarized below:

Sum of rank order:	$W_1 = 133$, $W_2 = 120$
Statistics:	$U_1 = 88$, $U_2 = 29$
Test statistic U:	$U = 29$
Two-sided critical value:	$U_{\alpha=0.05} = 28$

We do not reject the null hypothesis. In other words, we conclude that there was no difference in the subordinate's mean profits between the six-subordinate group and four-subordinate group.

H6.2 Comparison of the Subordinates' Profit: Five-Subordinate Group vs. Four-Subordinate Group

Here we test that the per-period profits of the subordinates are different in a group of five subordinates and in a group of four subordinates. We denote the five-subordinate groups as Sample 1 and the four-subordinate groups as Sample 2. There were 25 subordinates in the five-subordinate groups and 13 subordinates in the four-subordinate groups used in this test. Therefore, we performed a large-sample U test on the following hypothesis:

H_0: $\mu_1 = \mu_2$
H_1: $\mu_1 \neq \mu_2$

The average per-period profit of a subordinate used in this test was the mean calculated from all the cycles in an experiment. As shown in Table 5.5.2, the subordinates' profit in a 5-subordinate group ranged from -\$6.17 to +\$12.88 yielding a range of \$19.05. The mean per-period profit was \$5.81. The subordinates' profit in a 4-subordinate group, as shown in the previous test, varied from -\$8.03 to +\$2.54 yielding a range of \$10.57. The mean per-period profit was -\$1.59, i.e., a loss. The rank order and test results are tabulated in Table 5.5.2 and summarized below:

Statistics: $U_1 = 305$
Mean of the sampling distribution of the statistics: $\mu = 162.5$
Standard deviations of the sampling distribution of the statistics: $\sigma = 32.5$
z test statistic: $z = 4.385$
Two-tailed critical value: $z_{\alpha=0.05} = 1.960$

We reject the null hypothesis and conclude that there is statistical evidence that the subordinate's profit in a 5-subordinate group is different from (higher than) that in a 4-subordinate group.

H7.1 Comparison of the Manager's Profit: Six-Subordinate Group vs. Four-Subordinate Group

The manager's per-period profit in a cycle was used as the test data here. The number of cycles for the 6-subordinate groups was nine and for the 4-subordinate groups the number of cycles with corresponding experimental parameter values was 17. Therefore, there was a total of 26 data in this test. The manager's profits in 6-subordinate groups ranged from \$11.26 to \$16.12 yielding a range of \$4.86. The mean per-period profit was \$12.77. The manager's profits in 4-subordinate groups varied from \$5.20 to \$16.91 yielding a range of \$11.71. The mean per-period profit was \$10.36, as shown in Table 5.5.3.

Since the size of both samples is greater than eight, this is also a large-sample U test. We propose that the per-period profits of the manager are different in a group of six subordinates and in a group of four subordinates and set up the hypothesis accordingly:

H_0: $\mu_1 = \mu_2$
H_1: $\mu_1 \neq \mu_2$

The rank orders and the test results are listed in Table 5.5.3 and summarized here:

Statistics: $U_1 = 112$
Mean of the sampling distribution of the statistics: $\mu = 76.5$
Standard deviations of the sampling distribution of the statistics: $\sigma = 18.554$
z test statistic: $z = 1.913$
Two-tailed critical value: $z_{\alpha=0.05} = 1.960$

The test statistic was less than the two-tailed critical value for a 95% confidence interval, therefore, we do not reject the null hypothesis and there was no evidence of significance that the mean profit for a 6-subordinate group and a 4-subordinate group were not equal.

H7.2 Comparison of the Manager's Profit: Five-Subordinate Group vs. Four-Subordinate Group

Here we test that the per-period profits of the managers are different in a group of five subordinates and in a group of four subordinates. We denote the five-subordinate groups as Sample 1 and the four-subordinate groups as Sample 2. There were 25 cycles in the five-subordinate groups and 17 cycles in the four-subordinate groups used in this test. Therefore, we performed a large-sample U test on the following hypothesis:

$$H_0: \quad \mu_1 = \mu_2$$
$$H_1: \quad \mu_1 \neq \mu_2$$

The manager's per-period profit in a cycle was used as the test data here. As shown in Table 5.5.5, the managers' profit in a 5-subordinate group ranged from \$5.17 to \$18.33 yielding a range of \$13.16. The mean per-period profit was \$12.99. The managers' profit in a 4-subordinate group, as shown in the previous test, varied from \$5.20 to \$16.91 yielding a range of \$11.71. The mean per-period profit was \$10.36. The rank order and test results are tabulated in Table 5.5.1 and summarized below:

Statistics: $U_1 = 636$
Mean of the sampling distribution of the statistics: $\mu = 212.5$
Standard deviations of the sampling distribution of the statistics: $\sigma = 39.025$
z test statistic: $z = 2.524$
Two-tailed critical value: $z_{\alpha=0.05} = 1.960$

The test statistic is greater than the two-tailed critical value at the 0.05 level, therefore, we reject the null hypothesis and conclude that there is statistical evidence that the managers' profit in a 5-subordinate group is different from (higher than) that in a 4-subordinate group.

In this section we asked the question whether the performance of manager and subordinate was better in a group of larger size. The results were mixed. In the tests of 6-subordinate groups against 4-subordinate groups, we found no difference between performance of subjects in one group size and those in another group size. In the tests of 5-subordinate groups against 4-subordinate groups, we found statistically significant difference, that is, the 5-subordinate groups performed significantly better than those in the 4-subordinate groups.

When we started out to compare the performance of the manager in the experiments with different group size, we might expect that the managers would perform better and earn more profits with inputs from a larger group of subordinates. But we were unable to draw such conclusion from our tests.

Issues relating to group size and performance are important and we suggest this area as one for future study. Issue of optimal group size, including marginal net contribution of additional members, is important for organizations. While our results are mixed, we have provided a means for conducting the necessary analyses and we intend to pursue this research area.

Table 5.5.1. Hypothesis test H6.1: The subordinates' profits in six-subordinate groups vs. four-subordinate groups.

Order	Per-period profit: 6-subordinate group	Per-period profit: 4-subordinate group	Rank 1	Rank 2
1		-$8.03		1
2	-$4.80		2	
3		-$3.00		3
4		-$2.65		4
5		-$2.48		5
6		-$2.45		6
7	-$2.34		7	
8		-$2.13		8
9		-$1.88		9
10		-$1.75		10
11		-$0.67		11
12		-$0.65		12
13	-$0.57		13	
14	-$0.05		14	
15		$0.21		15
16	$1.82		16	
17		$2.32		17
18	$2.41		18	
19		$2.54		19
20	$4.12		20	
21	$4.54		21	
22	$5.21		22	
Average	$1.15	-$1.59		
Sum of Ranks, *W*			133	120
Sample size, *n*			9	13
Statistic, *U*			88	29
Two-tailed critical value			28	

Table 5.5.2. Hypothesis test H6.2: The subordinates' profits in five subordinate groups vs. four-subordinate groups.

Order	Per-period profit: 5-subordinate group	Per-period profit: 4-subordinate group	Rank 1	Rank 2
1		-\$8.03		1
2	-\$6.17		2	
3		-\$3.00		3
4		-\$2.65		4
5		-\$2.48		5
6		-\$2.45		6
7		-\$2.13		7
8		-\$1.88		8
9		-\$1.75		9
10		-\$0.67		10
11		-\$0.65		11
12	-\$0.26		12	
13	-\$0.22		13	
14		\$0.21		14
15	\$1.46		15	
16		\$2.32		16
17		\$2.54		17
18	\$2.88		18	
19	\$3.47		19	
20	\$3.60		20	
21	\$3.65		21	
22	\$3.70		22	
23	\$4.57		23	
24	\$4.93		24	
25	\$5.97		25	
26	\$6.11		26	
27	\$6.89		27	
28	\$6.96		28	
29	\$7.42		29	
30	\$8.91		30	
31	\$9.03		31	
32	\$9.08		32	
33	\$9.64		33	
34	\$9.68		34	
35	\$10.19		35	
36	\$10.30		36	
37	\$10.46		37	
38	\$12.88		38	
Average	\$5.81	-\$1.59		
Sum of Ranks, W			630	111
Sample size, n			25	13
Statistic, U			305	20
Mean of the sampling distribution of U			162.5	
Std dev of the sampling distribution of U			32.500	
z-test			4.385	
Two-tailed critical value $z_{\alpha=0.05}$			1.96	

Table 5.5.3. Hypothesis test H7.1: The managers' profits in six-subordinate groups vs. four-subordinate groups.

Order	Per-period profit		Rank 1	Rank 2
	6-subordinate group	4-subordinate group		
1		$5.20		1
2		$6.43		2
3		$6.56		3
4		$7.21		4
5		$8.26		5
6		$8.35		6
7		$8.60		7
8		$10.37		8
9		$10.57		9
10		$10.99		10
11	$11.26		11	
12	$11.30		12	
13	$11.32		13	
14	$11.95		14	
15		$12.01		15
16	$12.10		16	
17		$12.43		17
18		$12.58		18
19	$12.63		19	
20		$12.86		20
21		$13.15		21
22		$13.61		22
23	$13.63		23	
24	$14.65		24	
25	$16.12		25	
26		$16.91		26
Average	$12.77	$10.36		
Sum of Ranks, W			157	194
Sample size, n			9	17
Statistic, U			112	41
Mean of the sampling distribution of U			76.5	
Std dev of the sampling distribution of U			18.554	
z-test			1.913	
Two-tailed critical value $z_{\alpha=0.05}$			1.96	

Table 5.5.4. Hypothesis test 7.2: The managers' profits in five-subordinate groups vs. four-subordinate groups.

Order	Per-period profit: 5-subordinate group	Per-period profit: 4-subordinate group	Rank 1	Rank 2
1	\$5.17		1	
2		\$5.20		2
3		\$6.43		3
4		\$6.56		4
5	\$6.66		5	
6		\$7.21		6
7	\$8.20		7	
8		\$8.26		8
9		\$8.35		9
10		\$8.60		10
11	\$8.65		11	
12	\$10.15		12	
13		\$10.37		13
14	\$10.39		14	
15		\$10.57		15
16	\$10.60		16	
17		\$10.99		17
18	\$11.61		18	
19		\$12.01		19
20		\$12.43		20
21	\$12.55		21	
22		\$12.58		22
23		\$12.86		23
24	\$12.90		24	
25	\$13.11		25	
26	\$13.11		26	
27		\$13.15		27
28	\$13.42		28	
29	\$13.54		29	
30		\$13.61		30
31	\$13.72		31	
32	\$14.02		32	
33	\$14.46		33	
34	\$15.25		34	
35	\$15.58		35	
36	\$15.81		36	
37	\$15.91		37	
38	\$16.56		38	
39		\$16.91		39
40	\$17.28		40	
41	\$17.70		41	
42	\$18.33		42	
Average	\$12.99	\$10.36		
Sum of Ranks, W			636	267
Sample size, n			25	17
Statistic, U			311	114
Mean of the sampling distribution of U			212.5	
Std dev of the sampling distribution of U			39.025	
z-test			2.524	
Two-tailed critical value $z_{\alpha=0.05}$			1.96	

5.6 Conclusion from the Hypothesis Testing

We performed a series of hypothesis tests using our experimental data. The test results are summarized in Table 5.6.1. In all we tested twelve hypotheses. The first four related to performance comparisons between an automated manager and a human manager with different sample sizes. We also considered the cases of bankrupt subordinates. In all four tests we found no statistically significant performance difference between the automated manager and the human manager. The automated manager used simplistic decision rules. This suggests that even a simple computer-based "collaborative decision support system" may provide organizations with decision making as effective as a human manager.

Next we tested the performance of managers and subordinates in groups comprising of different kind of subordinates. The MBA student subjects and doctoral student subjects were used as an example. The test results indicated that the managers and the subordinates performed better in groups with MBA student subjects. We concluded that educational level of the subordinates is only one of the factors affecting a manager's decision making based on inputs from a group of subordinates as well as the subordinates' decision making. Higher educational level in the subordinates does not guarantee better decision making in an organization.

The third set of tests examined the performance of subordinates and managers in the decision making situation where the subordinates pay for the forecast information without waiting for it and in the situation where they have to wait and are charged with time cost before free forecast information becomes available. There is no statistical evidence that a subordinate with access to free information (but who had to wait for the free information) performed better than a subordinate who had to purchase the information. There is also no statistical evidence that a manager with inputs from subordinates who had access to free information (but who had to wait for the free information) performed better than a manager with inputs from subordinates who had to purchase the information. Cost of information and its timeliness are factors that must be balanced. As noted in the discussion in Section 5.4, appropriate purchase of timely information may offset the cost. Free information has a cost, the cost of waiting and possible loss of the timeliness of the decision in the operations of an organization.

In the final set of tests, we investigated whether the performances of a manager and subordinates were better in groups of larger size. In the tests of 6-subordinate groups against 4-subordinate groups, we found no statistical significant difference. In the tests of 5-subordinate groups against 4-subordinate groups, we found statistical significant differences, that is, the subjects in the 5-subordinate groups performed better than those in the 4-subordinate groups.

We were unable to draw the conclusion that the managers would perform better and earned more profits with inputs from a larger group of subordinates. Similar to the test for subordinate's profit, in the tests of 6-subordinate groups against 4-subordinate groups, we found no statistical significant difference. In the tests of 5-subordinate groups against 4-subordinate groups, however, we found statistical significant differences, that is, the manager in the 5-subordinate groups performed better than that in the 4-subordinate groups.

Although one might argue that the sample sizes in these hypothesis tests are not large enough and, therefore, cannot justify a general conclusion, we are encouraged by the research direction these hypothesis tests lead. We argue that a computer-based collaborative decision support system can provide an organization a cost effective means for making effective decisions.

Table 5.6.1. Hypothesis tests: Summary of test results.

Test #	H_0	H_1	Mean, μ	n_1	n_2	Sample size	Small sample: U, Large sample: z test	Critical value α=0.05	Test result
H1.1	Auto manager	Human manager	Manager's profit	8	13	small	31	24	**Failed to reject H_0**
H1.2	Auto manager	Human manager	Manager's profit	8	8	small	23	13	**Failed to reject H_0**
H1.3	Auto manager	Human manager	Manager's profit	8	13	small	33	24	**Failed to reject H_0**
H1.4	Auto manager	Human manager	Manager's profit	8	8	small	25	13	**Failed to reject H_0**
H2.1	MBA students	Doctoral students	Sub's profit	12	21	Large	2.358	1.96	**reject H_0**
H3.1	MBA students	Doctoral students	Manager's profit	18	19	Large	2.37	1.96	**reject H_0**
H4	Free info	Non-free info	Sub's profit	8	14	Small	50	26	**Failed to reject H_0**
H5	Free info	Non-free info	Manager's profit	8	14	Small	47	26	**Failed to reject H_0**
H6.1	Six-sub groups	Four-sub groups	Sub's profit	9	13	Small	29	28	**Failed to reject H_0**
H6.2	Five-sub groups	Four-sub groups	Sub's profit	25	13	Large	4.385	1.96	**reject H_0**
H7.1	Six-sub groups	Four-sub groups	Manager's profit	9	17	Large	1.913	1.96	**Failed to reject H_0**
H7.2	Five-sub groups	Four-sub groups	Manager's profit	25	17	Large	2.524	1.96	**reject H_0**

Chapter 6

PERFORMANCE OF AN AUTOMATED MANAGER UNDER DIFFERENT DECISION RULES

6.1 Introduction

While employing subjects in lab experiments to collect decision makers' responses in every setting of interest may be the most desired approach in experimental economics, it is also quite costly. In the complex tuple of variables in our study, we thought it helpful to analyze our actual laboratory data under a variety of different decision mechanisms. One key purpose of this exercise is to identify the "best" rule, at least "best" relating to the data in these experiments and determine whether the "best" rule is consistent across these sets, i.e., is the same rule best for each of the experiments?

We implemented the majority vote as an aggregation method in our set of experiments using an automated machine manager. This straightforward rule gave us initial results and insight on the performance of the automated manager as detailed in Chapters 4 and 5. In this chapter, we apply a set of differing aggregation methods on the experimental data we collected from the experiments. These "simulations" of experimental data are used to compare the performance if different decision rules had been implemented for the automated manager.

We argue that this transformation and subsequent interpretation of the experimental data provide useful information since:

(1) The subjects acting as subordinates are not aware of the decision rule implemented for the automated machine manager. The only feedbacks they receive from the automated manager are the decision made by the automated manager and the actual demand.

(2) Each decision period is independent. The decision in one period does not affect the outcome of previous periods or subsequent periods as far as decision making itself is concerned. The only accrued result affecting the subordinates is their carry-forward cash balance.

(3) Decision rule employed by individual subordinate is not a variable in this simulation of the automated manager's performance.

In the set of experiments, the aggregation method employed was risk-averse most identical (not necessarily majority) votes. The following set of rules was implemented:

(1) If the number of subordinates choosing low production is more than or equal to that choosing medium and high production, then the automated manager chooses low production.

(2) If the number of subordinates choosing low production is less than that choosing medium production and the number of subordinates choosing medium production is equal to or more than that choosing high production, then the automated manager chooses medium production.

(3) If the number of subordinates choosing high production is more than that choosing medium and low production, then the automated manager chooses high production.

In the above rule set, the tie-breaker is a risk-averse choice. For example, in a four-subordinate group, if two subordinates recommend low level of production and the other two subordinates recommend medium level, then the automated manager chooses low production. In the following sections we use experiments of six-subordinate and four-subordinate groups as examples to apply the decision rules and discuss the results of simulation.

6.2 Application of Different Decision Rules to Six-Subordinate Groups

In this section we apply different decision rules to our experimental data. First we look at two sets of experimental data from two six-subordinate groups.

6.2.1 Decision Rules for the Automated Manager in A Six-Subordinate Group:

We devised a set of alternative decision rules to aggregate the subordinates' recommendation for the automated manager. They are listed here:

Rule 1:

Most identical inputs (not necessarily half majority) from non-bankrupt subordinates. The manager is risk averse. The manager always makes a production decision. (This rule was implemented in the experiment with automated manager.)

Rule 2:

Most identical inputs (not necessarily half majority) from non-bankrupt subordinates. The manager is a risk lover. The manager always makes a decision.

Rule 3:

At least three identical inputs among the non-bankrupt subordinates, otherwise the manager makes no decision. The manager is risk averse.

Rule 4:

At least three identical inputs among the non-bankrupt subordinates, otherwise the manager makes no decision. The manager is a risk lover.

Rule 5:

Half majority of all six inputs from the subordinates. The manager is risk averse. The manager makes no decision whenever there is a bankrupt subordinate.

Rule 6:

Half majority of all six inputs from the subordinates. The manager is a risk lover.

The manager makes no decision whenever there is a bankrupt subordinate.

Rule 7:

4/6 majority of all six inputs from the subordinates. The manager makes no decision whenever there is a bankrupt subordinate or if 4/6 majority is not reached.

Rule 8:

At least four identical inputs among the non-bankrupt subordinates, otherwise the manager makes no decision.

Rule 9:

5/6 majority of all six inputs from the subordinates. The manager makes no decision whenever there is a bankrupt subordinate or if 5/6 majority is not reached.

Rule 10:

5/6 majority of all six inputs from the subordinates. Five identical inputs are needed if there is one bankrupt subordinate, otherwise the manager makes no decision.

Rule 11:

A unanimity of all six inputs from the subordinates. The manager makes no decision whenever there is a bankrupt subordinate or whenever unanimity is not reached among the subordinates.

Rule 12:

A unanimity of all inputs from the non-bankrupt subordinates, regardless of the number of bankrupt subordinates.

In the application of decision rules for the automated manager to the experimental data in a six-subordinate group when bankrupt periods are not included, the rule set is revised and include only seven rules as follows: (In order to compare to the rule set with the 12 rules above, the rule number is not changed.)

Rule 4

At least three identical inputs among the subordinates, otherwise the automated manager makes no decision. The manager is a risk lover.

Rule 8

At least four identical inputs among the subordinates, otherwise the automated manager makes no decision.

Rule 10

At least five identical inputs among the subordinates. Otherwise, the automated manager makes no decision.

Rule 11

A unanimity of all six inputs from the subordinates. Otherwise, the automated manager makes no decision.

6.2.2 Application of the Set of Decision Rules to Experiment 10A: Periods with Bankrupt Subordinate Are Included

We applied the different aggregation rules to the data from Experiment 10A. This session has four cycles. Each cycle has 50 periods. First we simulated the case in which periods with bankrupt subordinate are included. The hypothetical profits for the automated manager are tabulated in Table 6.2.1. The number of periods in which the automated manager would make a production decision is also shown in the table. Periods where no decision is made occur for two reasons: (1) whenever a consensus cannot be reached to apply the decision rule. (2) whenever the number of non-bankrupt subordinates falls below the number necessary to apply the decision rule.

Overall, the automated manager makes the highest profit using Rule 1, where the manager makes a production decision based on most identical inputs (not necessarily half majority) from non-bankrupt subordinates and the automated manager is risk averse. Consequently, the automated manager always makes a decision when using this rule. The lowest profit the automated manager would make is by applying Rule 11. Rule 11 has the automated manager making a production decision only when there is unanimity of all six inputs from the subordinates. The automated manager makes no decision whenever there is a bankrupt subordinate or when not all subordinates concur. This rule is the strictest among all the rules we employed.

In the periods where the automated manager cannot make a production decision because of the restrictions of the decision rule, the automated manager loses the opportunity to make a profit.

Both Rules 3 and 4 instruct the automated manager to follow the recommendation if at least three identical inputs are provided among the non-bankrupt subordinates. Otherwise, the manager makes no production decision. The difference between these rules is that Rule 3 allows the manager to be risk averse, while Rule 4 makes the manager a risk lover. The profit resulting from Rule 3 ($2,623.00) is 1.10% better than that from Rule 4 ($2,594.50.)

This comparison of the performance of decision rules includes differing numbers of observations for each rule. As noted earlier, this occurs because of two conditions that result in the number of active subjects falling below the number needed to apply specific decision rules. We might also compare the rule performance by restricting the comparisons to experimental periods for which all decision rules could be applied. For example, if a subject bankruptcy first occurs in period 10 of Cycle 3, that triggers the first occurrence of a rule becoming non-applicable in period 11 since unanimity cannot be applied. Thus, our comparisons will be over only the first ten periods of that experiment.

In such a modified comparison the number of experiments is the same for all rules but data on an experiment only refers to the number of periods in an experiment prior to the first bankruptcy. These modified comparisons include periods of lost opportunity for some decision rules. For example, Rule 11 requires that unanimity be reached among the subordinates for the automated manager to make a production decision. If unanimity is not reached, the automated manager loses the opportunity to make a profit.

6.2.3 Application of the Set of Decision Rules to Experiment 10A: Periods with Bankrupt Subordinate Are Not Included

Now we simulate the experiment in which periods with bankrupt subordinate are not included. Table 6.2.2 displays the result of this revised comparison. Cycle 3 has only 10 valid periods because a bankruptcy occurs in that period. Using Rule 1 and 2, the automated manager always makes a decision. Thus there is no lost opportunity, no non-decision period, for the manager in this case. Rules 3 and 4 require that there are at least three identical inputs among the subordinates for the automated manager to make a decision. The automated manager was able to make a decision in all the periods in this same cycle when using Rules 3 and 4. The restriction of Rule 8 prevents the automated manager from making a decision in 2 periods. Similarly, the application of Rules 10 and 11 prevents the automated manager from making a decision in 3 and 4 periods respectively.

The profits of $2,156.5 using Rule 1 and 3 are the highest overall. The profits from Rule 2 and 4, $2,128, are tied as the second highest. The automated manager was able to obtain a half-majority consensus from this group of subordinates in all the 160 periods. It happened that in this case a risk-averse automated manager was slightly better off than the risk lover. Profit slips to $2,104.5 for the 2/3 majority rule (Rule 8), and to $2,095 for the 5/6 majority rule (Rule 10). The unanimity rule (Rule 11) results in the lowest profit, $1,843, for the automated manager.

We also tabulated two profit averages. They are the total profit from all four cycles divided by the number of periods. The first one is the average of the periods in which the automated manager makes a decision. The second average is that of all no-bankruptcy periods in the experimental data. This second average includes those periods of lost opportunity where the constraints of a rule prevent the automated manager from making a decision.

The average profit of Rule 11 from the periods in which the automated manager makes a decision is the highest. This might be expected since the Rule mandates that the automated manager follow six-subordinate unanimity to make a decision. Otherwise, the manager makes no decision.

We take into account the periods of lost opportunity and compute the second average. Rule 11 produced the lowest number in this computation. Rule 11 had 55 periods of lost opportunity out of the total of 160 no-bankruptcy periods while Rules 1, 2, 3, and 4 had no lost opportunity.

Will the subordinates benefit from a certain rule? It depends on whether the subordinate's profit is tied to the performance of the automated manager. If the subordinate's profit is a function of only the actual sales (the actual market demand) and is independent of the automated manager's decision, then the subordinate's profit is not affected by the application of different rules.

6.2.4 Application of the Set of Decision Rules to Experiment 9A

The next set of experimental data we examined is from Experiment 9A. This session has six subordinates and five cycles. Cycles 1, 2, and 3 each have 50 periods. Cycle 4 has 30 periods. Cycle 5 has 20 periods. In Experiment 10A the subordinates had to wait for 5 seconds before they were able to consult the next free forecast information in cycle 3. In Experiment 9A the subordinates had to wait for 5 and 4 seconds before they were able to consult the next free forecast information in cycles 4 and 5 separately. The waiting time carries a cost.

The experimental parameters used in this set of experiments made the forecast information less reliable than that for Experiment 10A, resulting in more bankruptcies. Table 6.2.3 lists the automated manager's profit and number of periods in which the actual manager would make a decision. This table takes into account all the experimental periods, even those bankrupt periods in which certain decision rules yield "no decision." The profits range from $2705 for Rule 2 to $530.50 for Rule 11.

As in the analysis of Experiment 10A we compared a restricted data set in which no-decision periods were deleted. In Table 6.2.4 the number of experiments is the same for all rules but data on an experiment only refers to the number of periods in an experiment prior to the first bankruptcy. These modified comparisons include periods of lost opportunity for some decision rules in which the rule prevents the automated manager from making a decision.

The profits resulted from various rules range between $999 for Rule 4 and $530.5 for Rule 11. The per-period earnings presented in the last two columns drop drastically as compared to those in Table 6.2.2 for Experiment 10A. The lesser profit accurately reflects the lesser reliability of the forecast information discussed earlier in this Section. When taking into account all the no-bankruptcy periods from the experiment, Rule 4 yields the best per-period profit of $10.98 followed by Rule 2 with $10.63 while Rule 11 results in the least at $5.83 per period. We note that the risk-lover automated managers in Rule 2 (with total profit of $967) and Rule 4 (with total profit of $999) fair better than the risk-averse managers in Rule 1 (with total profit of $854.5) and Rule 3 (with total profit of $847.5).

Table 6.2.1. Experiment 10A: Automated manager's profit and number of decisions made by applying different decision rules in a six-subordinate group -- all experimental periods included.

Rule #		Cycle 1 50 periods	Cycle 2 50 periods	Cycle 3 50 periods	Cycle 4 50 periods	All cycles 200 periods
Rule 1	Profit	$566.0	$681.5	$597.5	$806.0	$2,651.0
	# of periods manager makes decision	50	50	50	50	200
Rule 2	Profit	$546.5	$662.0	$597.5	$816.5	$2,622.5
	# of periods manager makes decision	50	50	50	50	200
Rule 3	Profit	$566.00	$681.50	$569.50	$806.00	$2,623.00
	# of periods manager makes decision	50	50	49	50	199
Rule 4	Profit	$546.5	$662.0	$569.5	$816.5	$2,594.5
	# of periods manager makes decision	50	50	49	50	199
Rule 5	Profit	$566.0	$681.5	$103.0	$806.0	$2,156.5
	# of periods manager makes decision	50	50	10	50	160
Rule 6	Profit	$546.50	$662.00	$103.00	$816.50	$2,128.00
	# of periods manager makes decision	50	50	10	50	160
Rule 7	Profit	$571.5	$664.0	$68.0	$801.0	$2,104.5
	# of periods manager makes decision	48	49	8	48	153
Rule 8	Profit	$571.5	$664.0	$416.5	$801.0	$2,453.0
	# of periods manager makes decision	48	49	34	48	179
Rule 9	Profit	$588.5	$688.0	$188.0	$768.0	$2,232.5
	# of periods manager makes decision	41	43	20	45	149
Rule 10	Profit	$588.5	$688.0	$50.5	$768.0	$2,095.0
	# of periods manager makes decision	41	43	7	45	136
Rule 11	Profit	$452.5	$714.0	$43.5	$633.5	$1,843.5
	# of periods manager makes decision	28	36	6	35	105
Rule 12	Profit	$452.5	$714.0	$389.0	$633.5	$2,189.0
	# of periods manager makes decision	28	36	29	35	128

Table 6.2.2. Experiment 10A: Automated manager's profit and number of decisions made by applying different decision rules in a six-subordinate group -- only experimental periods with no-bankruptcy included.

Rule #		Cycle 1 50 periods	Cycle 2 50 periods	Cycle 3 10 periods	Cycle 4 50 periods	All Cycles 160 periods	Profit per period in which manager makes decision	Avg. profit (Total profit from all cycles / 160 periods)
Rule 1	Profit	$566.0	$681.5	$103.0	$806.0	$2,156.5	$13.48	$13.48
	# of periods manager makes decision	50	50	10	50	160		
Rule 2	Profit	$546.5	$662.0	$103.0	$816.5	$2,128.0	$13.30	$13.30
	# of periods manager makes decision	50	50	10	50	160		
Rule 3	Profit	$566.0	$681.5	$103.0	$806.0	$2,156.5	$13.48	$13.48
	# of periods manager makes decision	50	50	10	50	160		
Rule 4	Profit	$546.5	$662.0	$103.0	$816.5	$2,128.0	$13.30	$13.30
	# of periods manager makes decision	50	50	10	50	160		
Rule 8	Profit	$571.5	$664.0	$68.0	$801.0	$2,104.5	$13.75	$13.15
	# of periods manager makes decision	48	49	8	48	153		
Rule 10	Profit	$588.5	$688.0	$50.5	$768.0	$2,095.0	$15.40	$13.09
	# of periods manager makes decision	41	43	7	45	136		
Rule 11	Profit	$452.5	$714.0	$43.5	$633.5	$1,843.5	$17.56	$11.52
	# of periods manager makes decision	28	36	6	35	105		
Avg. of profit (per rule)		$548.2	$679.0	$82.0	$778.2	$2,087.4	$14.32	$13.05

Table 6.2.3. Experiment 9A: Automated manager's profit and number of decisions made by applying different decision rules in a six-subordinate group -- all experimental periods included.

Rule #		Cycle 1 50 periods	Cycle 2 50 periods	Cycle 3 50 periods	Cycle 4 30 periods	Cycle 5 20 periods	All cycles 200 periods
Rule 1	Profit	$563.0	$605.0	$732.5	$339.0	$252.5	$2,492.0
	# of periods manager makes decision	50	50	50	30	20	200
Rule 2	Profit	$593.0	$666.5	$764.0	$399.0	$282.5	$2,705.0
	# of periods manager makes decision	50	50	50	30	20	200
Rule 3	Profit	$521.5	$605.0	$724.5	$339.0	$252.5	$2,442.5
	# of periods manager makes decision	46	50	45	30	20	191
Rule 4	Profit	$521.5	$666.5	$724.5	$399.0	$282.5	$2,594.0
	# of periods manager makes decision	46	50	45	30	20	191
Rule 5	Profit	$-0.5	$605.0	$-30.5	$110.0	$163.5	$847.5
	# of periods manager makes decision	4	50	4	17	15	90
Rule 6	Profit	$-0.5	$668.5	$-30.5	$170.0	$193.5	$1,001.0
	# of periods manager makes decision	4	49	4	17	15	89
Rule 7	Profit	$14.0	$613.0	$-30.5	$139.0	$165.5	$901.0
	# of periods manager makes decision	2	43	4	13	14	76
Rule 8	Profit	$191.0	$613.0	$643.0	$361.0	$226.5	$2,034.5
	# of periods manager makes decision	20	43	37	25	18	143
Rule 9	Profit	$7.0	$576.5	$7.0	$136.0	$67.5	$794.0
	# of periods manager makes decision	1	38	1	10	9	59
Rule 10	Profit	$-5.5	$576.5	$7.0	$290.0	$111.0	$979.0
	# of periods manager makes decision	2	38	1	17	12	70
Rule 11	Profit	$0.0	$470.5	$7.0	$34.5	$18.5	$530.5
	# of periods manager makes decision	0	28	1	6	5	40
Rule 12	Profit	$333.0	$470.5	$680.5	$188.5	$62.0	$1,734.5
	# of periods manager makes decision	24	28	34	13	8	107

Table 6.2.4. Experiment 9A: Automated manager's profit and number of decisions made by applying different decision rules in a six-subordinate group -- only experimental periods with no-bankruptcy included.

Rule #		Cycle 1 4 periods	Cycle 2 50 periods	Cycle 3 5 periods	Cycle 4 17 periods	Cycle 5 15 periods	All Cycles 91 periods	Profit per period in which manager makes decision	Avg. profit (Total profit from all cycles / 91 periods)
Rule 1	Profit	$-0.5	$605.0	$-23.5	$110.0	$163.5	$854.5	$9.39	$9.39
	# of periods manager makes decision	4	50	5	17	15	91		
Rule 2	Profit	$-0.5	$666.5	$-62.5	$170.0	$193.5	$967.0	$10.63	$10.63
	# of periods manager makes decision	4	50	5	17	15	91		
Rule 3	Profit	$-0.5	$605.0	$-30.5	$110.0	$163.5	$847.5	$9.42	$9.31
	# of periods manager makes decision	4	50	4	17	15	90		
Rule 4	Profit	$-0.5	$666.5	$-30.5	$170.0	$193.5	$999.0	$11.10	$10.98
	# of periods manager makes decision	4	50	4	17	15	90		
Rule 8	Profit	$14.0	$613.0	$-30.5	$139.0	$165.5	$901.0	$11.86	$9.90
	# of periods manager makes decision	2	43	4	13	14	76		
Rule 10	Profit	$7.0	$576.5	$7.0	$136.0	$67.5	$794.0	$13.46	$8.73
	# of periods manager makes decision	1	38	1	10	9	59		
Rule 11	Profit	$0.0	$470.5	$7.0	$34.5	$18.5	$530.5	$13.26	$5.83
	# of periods manager makes decision	0	28	1	6	5	40		
Avg. of profit (per rule)		$2.7	$600.4	$-23.4	$124.2	$137.9	$841.9	$11.30	$9.25

6.3 Application of Different Decision Rules to Four-Subordinate Groups

In this section we apply different decision rules to the experimental results collected from four-subordinate experiment sessions. The parameter values used in these experiments are listed in Table 4.2.1 in Chapter 4. The experiments analyzed here are 11A, 11H, 12A, and 12H. Experiments 11A, 12A used an automated machine manager in the actual experiments. Experiments 11H and 12H used a human manager in the actual experiments.

6.3.1 Decision Rules for the Automated Manager in A Four-Subordinate Group:

For a four-subordinate group with possible subordinate bankruptcy, the following rule set is implemented for simulation:

Rule 1

Most identical inputs (not necessarily half majority) from non-bankrupt subordinates. The manager is risk averse. The manager always makes a production decision. (This rule was implemented in the experiment with an automated manager.)

Rule 2

Most identical inputs (not necessarily half majority) from non-bankrupt subordinates. The automated manager is a risk lover. The automated manager always makes a production decision.

Rule 3

At least two identical inputs among the non-bankrupt subordinates, otherwise the automated manager makes no production decision. The automated manager is risk averse.

Rule 4

At least two identical inputs among the non-bankrupt subordinates, otherwise the automated manager makes no production decision. The automated manager is a *risk lover*.

Rule 5

Half majority of all four inputs from the subordinates. The automated manager is *risk averse*. The automated manager makes no production decision whenever there is a bankrupt subordinate.

Rule 6

Half majority of all four inputs from the subordinates. The automated manager is a *risk lover*. The automated manager makes no production decision whenever there is a bankrupt subordinate.

Rule 7

3/4 majority of all four inputs from the subordinates. The automated manager makes no production decision whenever there is a bankrupt subordinate or if 3/4 majority is not reached.

Rule 8

At least three identical inputs among the non-bankrupt subordinates, otherwise the automated manager makes no production decision.

Rule 9

A unanimity of all four inputs from the subordinates. The automated manager makes no production decision whenever there is a bankrupt subordinate or whenever unanimity is not reached among the subordinates.

Rule 10

Unanimity of all inputs from the non-bankrupt subordinates, regardless of the number of bankrupt subordinates.

For the simulation of a four-subordinate group with only periods in which there is no bankrupt subordinate, the following rule set is implemented (the rule number is kept the same as that in the simulation with bankrupt periods):

Rule 5

Half majority (2/4) of all four inputs from the subordinates. The automated manager is *risk averse*. The automated manager makes no production decision if 2/4 majority is not reached.

Rule 6

Half majority (2/4) of all four inputs from the subordinates. The automated manager is a *risk lover*. The automated manager makes no production decision if 2/4 majority is not reached.

Rule 7

3/4 majority of all four inputs from the subordinates. The automated manager if 3/4 majority is not reached.

Rule 9

Unanimity of all four inputs from the subordinates. The automated manager makes no production decision if unanimity is not reached among the subordinates.

6.3.2 Simulation Results of Experiments 11A, 11H, 12A, 12H

In this section we apply the rule set to four-subordinate groups. Tables 6.3.1 to 6.3.8 display the simulation results of the experiments. As indicated in Section 6.2.2, periods where no decision is made occur for two reasons: (1) whenever consensus cannot be reached to apply the decision rule; (2) whenever the number of non-bankrupt subordinates falls below the number necessary to apply the decision rule.

Tables 6.3.1, 6.3.3, 6.3.5, and 6.3.7 show the simulation results of all experiment periods, including the periods with bankrupt subordinate. The number of "decisions made" shown in the tables is the number of periods in which the simulated machine manager made decision. The "profit per decision period" is the per-period profit of the simulated manager in the periods where the manager made decision. The "profit per exp't period" is the per-period profit of the simulated manager averaged over all actual experiment periods. Since the number of decision periods is always less than or equal to the number of experiment periods, the "profit per decision period" is always greater than or equal to the "profit per exp't period". For example, in Table 6.3.1, the "profit per decision period" by applying Rule 10 is $15.81 ($2040.00/129) while the "profit per exp't period" is $10.20 ($2040.00/200).

Tables 6.3.2, 6.3.4, 6.3.6, and 6.3.8 show the simulation results excluding the periods with any bankrupt subordinate. The "profit per valid period" is the per-period profit of the simulated manager of all the periods with no bankrupt subordinate. For example, The number of valid periods is 167 is Experiment 11A (see Table 6.6.2). In applying Rule 9, the number of decision periods is 108 for the four cycles and the "profit per decision period" is $17.93 ($1936.50/108) while the "profit per valid period" is $11.60 ($1936.50/167).

The simulation results of Experiment 11H are shown in Table 6.3.3. In this case, the human manager in the actual experiment had the best total profit in every cycle. In Experiment 12H, however, the human manager did not have the best total profit in every cycle, as shown in Table 6.3.7.

Table 6.3.1. Experiment 11A: Simulation results of all experiment periods.

Rule #		Cycle 1 50 periods	Cycle 2 50 periods	Cycle 3 50 periods	Cycle 4 50 periods	All cycles 200 periods	Profit per decision period	Profit per exp't period
Rule 1	Decisions made	50	50	50	50	200		
	Profit	$879.50	$885.50	$626.00	$305.00	$2,696.00	$13.48	$13.48
Rule 2	Decisions made	50	50	50	50	200		
	Profit	$939.50	$827.00	$608.00	$417.50	$2,792.00	$13.96	$13.96
Rule 3	Decisions made	50	50	49	27	176		
	Profit	$879.50	$885.50	$619.00	$286.50	$2,670.50	$15.17	$13.35
Rule 4	Decisions made	50	50	49	27	176		
	Profit	$939.50	$827.00	$620.50	$307.50	$2,694.50	$15.31	$13.47
Rule 5	Decisions made	50	50	49	27	176		
	Profit	$879.50	$885.50	$619.00	$286.50	$2,670.50	$15.17	$13.35
Rule 6	Decisions made	50	50	49	27	176		
	Profit	$939.50	$827.00	$620.50	$307.50	$2,694.50	$15.31	$13.47
Rule 7	Decisions made	47	47	40	19	153		
	Profit	$887.00	$843.50	$511.00	$275.50	$2,517.00	$16.45	$12.59
Rule 8	Decisions made	47	47	40	19	153		
	Profit	$887.00	$843.50	$511.00	$275.50	$2,517.00	$16.45	$12.59
Rule 9	Decisions made	33	35	28	12	108		
	Profit	$600.00	$644.00	$451.00	$241.50	$1,936.50	$17.93	$9.68
Rule 10	Decisions made	33	35	30	31	129		
	Profit	$600.00	$644.00	$496.50	$299.50	$2,040.00	$15.81	$10.20

Legends:
1. Decisions made: number of periods in which the simulated machine manager made decision.
2. Profit per decision period: the per-period profit of the simulated manager in which the simulated manager made decision.
3. Profit per exp't period: the per-period profit of the simulated manager of all actual experiment periods.

Table 6.3.2. Experiment 11A: Simulation results of the experiment excluding the periods with any bankrupt subordinate.

Rule #		Cycle 1 50 periods	Cycle 2 50 periods	Cycle 3 45 periods	Cycle 4 22 periods	All cycles 167 periods	Profit per decision period	Profit per valid period
Rule 5	Decisions made	50	50	45	22	167		
	Profit	$879.50	$885.50	$538.50	$238.00	$2,541.50	$15.22	$15.22
Rule 6	Decisions made	50	50	45	22	167		
	Profit	$939.50	$827.00	$540.00	$259.00	$2,565.50	$15.36	$15.36
Rule 7	Decisions made	47	47	40	18	152		
	Profit	$887.00	$843.50	$511.00	$277.50	$2,519.00	$16.57	$15.08
Rule 9	Decisions made	33	35	28	12	108		
	Profit	$600.00	$644.00	$451.00	$241.50	$1,936.50	$17.93	$11.60

Legends:
1. Decisions made: number of periods in which the simulated machine manager made decision.
2. Profit per decision period: the per-period profit of the simulated manager in which the simulated manager made decision.
3. Profit per valid period: the per-period profit of the simulated manager of all the periods with no bankrupt subordinate.

Table 6.3.3. Experiment 11H: Simulation results of all experiment periods.

Rule #		Cycle 1 50 periods	Cycle 2 50 periods	Cycle 3 50 periods	Cycle 4 50 periods	All cycles 200 periods	Profit per decision period	Profit per exp't period
Human	Decisions made	50	50	50	50	200		
	Profit	$643.09	$845.67	$417.72	$680.49	$2,586.97	$12.93	$12.93
Rule 1	Decisions made	50	50	50	50	200		
	Profit	$414.50	$726.50	$297.50	$309.50	$1,748.00	$8.74	$8.74
Rule 2	Decisions made	50	50	50	50	200		
	Profit	$348.50	$708.50	$390.50	$641.00	$2,088.50	$10.44	$10.44
Rule 3	Decisions made	49	50	44	42	185		
	Profit	$397.00	$726.50	$401.00	$429.00	$1,953.50	$10.56	$9.77
Rule 4	Decisions made	49	50	44	42	185		
	Profit	$350.50	$708.50	$413.00	$619.50	$2,091.50	$11.31	$10.46
Rule 5	Decisions made	49	50	44	42	185		
	Profit	$397.00	$726.50	$401.00	$429.00	$1,953.50	$10.56	$9.77
Rule 6	Decisions made	49	50	44	42	185		
	Profit	$350.50	$708.50	$413.00	$619.50	$2,091.50	$11.31	$10.46
Rule 7	Decisions made	22	44	31	16	113		
	Profit	$277.00	$702.50	$385.00	$272.50	$1,637.00	$14.49	$8.19
Rule 8	Decisions made	22	44	31	16	113		
	Profit	$277.00	$702.50	$385.00	$272.50	$1,637.00	$14.49	$8.19
Rule 9	Decisions made	7	29	22	5	63		
	Profit	$103.00	$509.00	$326.50	$87.50	$1,026.00	$16.29	$5.13
Rule 10	Decisions made	18	29	28	10	85		
	Profit	$196.50	$509.00	$311.50	$187.00	$1,204.00	$14.16	$6.02

Legends:
1. Decisions made: number of periods in which the simulated machine manager made decision.
2. Profit per decision period: the per-period profit of the simulated manager in which the simulated manager made decision.
3. Profit per exp't period: the per-period profit of the simulated manager of all actual experiment periods.

Table 6.3.4. Experiment 11H: Simulation results of the experiment excluding the periods with any bankrupt subordinate.

Rule #		Cycle 1 35 periods	Cycle 2 50 periods	Cycle 3 38 periods	Cycle 4 21 periods	All cycles 144 periods	Profit per decision period	Profit per valid period
Rule 5	Decisions made	35	50	38	21	144		
	Profit	$321.50	$726.50	$347.00	$130.50	$1,525.50	$10.59	$10.59
Rule 6	Decisions made	35	50	38	21	144		
	Profit	$275.00	$708.50	$359.00	$321.00	$1,663.50	$11.55	$11.55
Rule 7	Decisions made	20	44	30	12	106		
	Profit	$261.50	$702.50	$357.00	$160.50	$1,481.50	$13.98	$10.29
Rule 9	Decisions made	7	29	22	5	63		
	Profit	$103.00	$509.00	$326.50	$87.50	$1,026.00	$16.29	$7.13

Legends:
1. Decisions made: number of periods in which the simulated machine manager made decision.
2. Profit per decision period: the per-period profit of the simulated manager in which the simulated manager made decision.
3. Profit per valid period: the per-period profit of the simulated manager of all the periods with no bankrupt subordinate.

Table 6.3.5. Experiment 12A: Simulation results of all experiment periods.

Rule #		Cycle 1 50 periods	Cycle 2 50 periods	Cycle 3 50 periods	Cycle 4 50 periods	All cycles 200 periods	Profit per decision period	Profit per exp't period
Rule 1	Decisions made	50	50	50	50	200	$6.78	$6.78
	Profit	$413.00	$360.50	$260.00	$321.50	$1,355.00		
Rule 2	Decisions made	50	50	50	50	200	$7.62	$7.62
	Profit	$354.50	$411.50	$263.00	$494.00	$1,523.00		
Rule 3	Decisions made	11	49	45	37	142	$6.06	$4.30
	Profit	-$37.00	$392.50	$192.00	$313.00	$860.50		
Rule 4	Decisions made	11	49	45	37	142	$6.31	$4.48
	Profit	-$95.50	$383.50	$214.50	$394.00	$896.50		
Rule 5	Decisions made	11	49	45	37	142	$6.06	$4.30
	Profit	-$37.00	$392.50	$192.00	$313.00	$860.50		
Rule 6	Decisions made	11	49	45	37	142	$6.31	$4.48
	Profit	-$95.50	$383.50	$214.50	$394.00	$896.50		
Rule 7	Decisions made	4	26	25	19	74	$11.97	$4.43
	Profit	$20.50	$308.00	$212.50	$344.50	$885.50		
Rule 8	Decisions made	4	26	25	19	74	$11.97	$4.43
	Profit	$20.50	$308.00	$212.50	$344.50	$885.50		
Rule 9	Decisions made	1	2	7	6	16	$12.53	$1.00
	Profit	$7.00	$15.50	$73.00	$105.00	$200.50		
Rule 10	Decisions made	42	21	20	19	102	$11.47	$5.85
	Profit	$423.00	$280.50	$231.50	$235.00	$1,170.00		

Legends:

1. Decisions made: number of periods in which the simulated machine manager made decision.
2. Profit per decision period: the per-period profit of the simulated manager in which the simulated manager made decision.
3. Profit per exp't period: the per-period profit of the simulated manager of all actual experiment periods.

Table 6.3.6. Experiment 12A: Simulation results of the experiment excluding the periods with any bankrupt subordinate.

Rule #		Cycle 1 8 periods	Cycle 2 12 periods	Cycle 3 24 periods	Cycle 4 20 periods	All cycles 64 periods	Profit per decision period	Profit per valid period
Rule 5	Decisions made	8	12	24	20	64		
	Profit	-$10.00	$60.00	$124.50	$192.50	$367.00	$5.73	$5.73
Rule 6	Decisions made	8	12	24	20	64		
	Profit	-$68.50	$51.00	$147.00	$273.50	$403.00	$6.30	$6.30
Rule 7	Decisions made	3	7	16	15	41		
	Profit	$22.50	$43.00	$134.50	$283.50	$483.50	$11.79	$7.55
Rule 9	Decisions made	1	2	7	6	16		
	Profit	$7.00	$15.50	$73.00	$105.00	$200.50	$12.53	$3.13

Legends:
1. Decisions made: number of periods in which the simulated machine manager made decisio
2. Profit per decision period: the per-period profit of the simulated manager in which the simulated manager made decision.
3. Profit per valid period: the per-period profit of the simulated manager of all the periods wit no bankrupt subordinate.

Table 6.3.7. Experiment 12H: Simulation results of all experiment periods.

Rule #		Cycle 1 50 periods	Cycle 2 50 periods	Cycle 3 50 periods	Cycle 4 50 periods	All cycles 200 periods	Profit per decision period	Profit per exp't period
Human	Decisions made	50	50	50	50	200		
	Profit	$328.15	$429.98	$518.64	$600.70	$1,877.47	$9.39	$9.39
Rule 1	Decisions made	50	50	50	50	200		
	Profit	$359.00	$422.00	$350.00	$362.00	$1,493.00	$7.47	$7.47
Rule 2	Decisions made	50	50	50	50	200		
	Profit	$330.50	$393.50	$333.50	$573.50	$1,631.00	$8.16	$8.16
Rule 3	Decisions made	50	50	50	45	195		
	Profit	$359.00	$422.00	$350.00	$414.00	$1,545.00	$7.92	$7.73
Rule 4	Decisions made	50	50	50	45	195		
	Profit	$330.50	$393.50	$333.50	$514.50	$1,572.00	$8.06	$7.86
Rule 5	Decisions made	50	50	50	45	195		
	Profit	$359.00	$422.00	$350.00	$414.00	$1,545.00	$7.92	$7.73
Rule 6	Decisions made	50	50	50	45	195		
	Profit	$330.50	$393.50	$333.50	$514.50	$1,572.00	$8.06	$7.86
Rule 7	Decisions made	43	43	37	29	152		
	Profit	$346.00	$439.00	$362.50	$362.00	$1,509.50	$9.93	$7.55
Rule 8	Decisions made	43	43	37	29	152		
	Profit	$346.00	$439.00	$362.50	$362.00	$1,509.50	$9.93	$7.55
Rule 9	Decisions made	28	28	25	11	92		
	Profit	$301.00	$304.00	$230.50	$132.50	$968.00	$10.52	$4.84
Rule 10	Decisions made	28	28	25	18	99		
	Profit	$301.00	$304.00	$230.50	$226.50	$1,062.00	$10.73	$5.31

Legends:
1. Decisions made: number of periods in which the simulated machine manager made decision.
2. Profit per decision period: the per-period profit of the simulated manager in which the simulated manager made decision.
3. Profit per exp't period: the per-period profit of the simulated manager of all actual experiment periods.

Table 6.3.8. Experiment 12H: Simulation results of the experiment excluding the periods with any bankrupt subordinate.

Rule #		Cycle 1 50 periods	Cycle 2 50 periods	Cycle 3 50 periods	Cycle 4 28 periods	All cycles 178 periods	Profit per decision period	Profit per valid period
Rule 5	Decisions made	50	50	50	28	178		
	Profit	$359.00	$422.00	$350.00	$254.50	$1,385.50	$7.78	$7.78
Rule 6	Decisions made	50	50	50	28	178		
	Profit	$330.50	$393.50	$333.50	$355.00	$1,412.50	$7.94	$7.94
Rule 7	Decisions made	43	43	37	22	145		
	Profit	$346.00	$439.00	$362.50	$268.00	$1,415.50	$9.76	$7.95
Rule 9	Decisions made	28	28	25	11	92		
	Profit	$301.00	$304.00	$230.50	$132.50	$968.00	$10.52	$5.44

Legends:
1. Decisions made: number of periods in which the simulated machine manager made decision.
2. Profit per decision period: the per-period profit of the simulated manager in which the simulated manager made decision.
3. Profit per valid period: the per-period profit of the simulated manager of all the periods with no bankrupt subordinate.

6.4 Simulation of An Experiment with No Occurrence of Bankrupt Subordinate: 13H

This experiment is designed to have no bankrupt subordinate. Five subjects are used in this experiment, a human manager and four subordinates. The experimental data from this session is used in the comparison of performance of automated and human manager. Unlike the previous experiments where the subordinate's starting balance was set at $100 experimental dollars, the starting balance for the subordinates in this set of experiments is set at $900 experimental dollars to prevent them from bankruptcy, thus allowing for application of decision rules for the automated machine manager to all experimental periods.

The payoff scheme for the subordinates is independent of the manager's performance. This allows for application of different payoff schemes in the aggregation analyses.

6.4.1 Decision Rules for An Automated Manager in A Four-Subordinate, No-bankruptcy Experiment

The following decision rules are applied in the simulation analysis:

Rule 1

Most identical inputs (not necessarily half majority) from all subordinates. The automated manager is risk averse, i.e., if there are identical number of subordinate inputs for different levels of production, the automated manager would choose a *lower* level of production. The automated manager always makes decision.

Rule 2

Most identical inputs (not necessarily half majority) from all subordinates. The automated manager is a risk lover, i.e., if there are identical number of subordinate inputs for different levels of production, the automated manager would choose a *higher* level of production. The automated manager always makes decision.

Rule 3

At least two identical inputs among the subordinates, otherwise the automated manager makes no decision. The automated manager is risk averse.

Rule 4

At least two identical inputs among the subordinates, otherwise the automated manager makes no decision. The automated manager is a risk lover.

Rule 5

3/4 majority of all four inputs from the subordinates. The automated manager makes no decision if 3/4 majority is not reached.

Rule 6

Unanimity of all inputs from the subordinates. The automated manager makes no decision if unanimity is not reached.

6.4.2 Application of the Set of Decision Rules to Experiment 13H:

This experiment was discussed in Section 4.15. The subjects used in this session were doctoral students in the DSIS department. They were all experienced participants. The subject acting as the human manager was randomly drawn among the five participants and acted as the human manager throughout the whole session.

The profits of the human manager in the experiment session and the automated manager by applying decision rules are tabulated in Table 6.4.1. The human manager had the highest profits in each cycle and consequently had the highest profits for all cycles combined, $4,051. Cycle 5 was a repetition of Cycle 2, but the profit in Cycle 5, $696.50, is less than that in Cycle 2, $776.

It turned out that applications of Rule 1 and 3 produced the same outcomes.

Applications of Rule 2 and 4 also yielded the same results. In applications of Rule 1, 2, 3, and 4, the automated manager made a decision in all periods. Application of Rule 5 prevented the automated manager from making a decision in 11 out of a total of 250 periods. Likewise, application of Rule 6 prevented the automated manager from making a decision in 58 out of 250 total periods. Of the six decision rules, Rule 2 (as well as Rule 4) had the highest profit, followed closely by Rule 1 (as well as Rule 3).

We calculated the standard deviation of the manager's profit in each cycle. The standard deviation was calculated among the different rules of each cycle. For example, the standard deviation for Cycle 1 was \$61.76 when the human manager's profit as well as those of the six rules were used in the calculation. It was \$56.66 for Cycle 2, \$56.54 for Cycle 3, \$47.98 for Cycle 4, and \$41.74 for Cycle 5. The standard deviation was also calculated using only data from the six rules. It was \$28.31 for Cycle 1, \$41.76 for Cycle 2, \$50.43 for Cycle 3, \$51.37 for Cycle 4, and \$41.98 for Cycle 5. As noted earlier, The experiment parameters in Cycles 2 and 5 were the same for the subordinates. The standard deviations, of the profit of the simulated automated manager applying rules 1 to 6, were \$41.76 for Cycle 2 and \$41.98 for Cycle 3. Using \$41.76 of Cycle 2 as the base, the difference of standard deviation between these two cycles was only .53%.

Table 6.4.1. Experiment 13H: The profits of the human manager from the experiment session and the profits of the automated manager by applying decision rules.

Rule #		Cycle 1 50 periods	Cycle 2 50 periods	Cycle 3 50 periods	Cycle 4 50 periods	Cycle 5 50 periods	All cycles 250 periods	Profit per decision period	Profit per exp't period
Human	Decisions made	50	50	50	50	50	250		
	Profit	$795.50	$776.00	$938.00	$845.00	$696.50	$4,051.00	$16.20	$16.20
Rule 1	Decisions made	50	50	50	50	50	250		
	Profit	$617.00	$696.50	$858.50	$864.50	$666.50	$3,703.00	$14.81	$14.81
Rule 2	Decisions made	50	50	50	50	50	250		
	Profit	$677.00	$668.00	$888.50	$806.00	$677.00	$3,716.50	$14.87	$14.87
Rule 3	Decisions made	50	50	50	50	50	250		
	Profit	$617.00	$696.50	$858.50	$864.50	$666.50	$3,703.00	$14.81	$14.81
Rule 4	Decisions made	50	50	50	50	50	250		
	Profit	$677.00	$668.00	$888.50	$806.00	$677.00	$3,716.50	$14.87	$14.87
Rule 5	Decisions made	48	46	49	48	48	239		
	Profit	$661.50	$677.50	$860.50	$840.00	$661.50	$3,701.00	$15.49	$14.80
Rule 6	Decisions made	39	35	40	41	37	192		
	Profit	$633.00	$584.00	$752.50	$728.00	$568.00	$3,265.50	$17.01	$13.06
Mean - 6 rules		$647.08	$665.08	$851.17	$818.17	$652.75	$3,634.25	$15.31	$14.54
Standard deviation (include human)		$61.76	$56.66	$56.54	$47.98	$41.74	$228.14	$0.86	$0.91
Standard deviation (6 rules)		$28.31	$41.76	$50.43	$51.37	$41.98	$180.78	$0.87	$0.72

Legends:

1. Decisions made: number of periods in which the simulated machine manager made decision.
2. Profit per decision period: the per-period profit of the simulated manager in which the simulated manager made decision.
3. Profit per exp't period: the per-period profit of the simulated manager of all actual experiment periods.

6.5 Conclusion

In our simulation exercises in this chapter we set out to find whether simple decision rules implemented for an automated manager resulted in profit earning compatible to a human manager. Although the data sets were not large enough for complete statistical analyses and we were unable to draw a comprehensive conclusion from the mixed results, we note, however, that the simplistic decision rules employed in the simulation produce compatible profit as compared to a human manager. We will continue the research in this aspect in the future. The simulation exercises here do provide us with the directions to pursue, namely, to find rule sets for a decision aggregation expert system.

Chapter 7

CONTRIBUTIONS AND DIRECTIONS FOR FUTURE RESEARCH

7.1 The Significance of Our Experimental Shell Development

One of the contributions we made in this dissertation is the development of an experimental shell and the underlying decision aggregation framework. The procedures we implemented enabled us to conduct a series of computerized laboratory experiments.

We structured a mechanism to formally investigate specific decision processes in specific decision problem settings, namely, settings where we are faced with choosing one level of production (low, medium, or high) but are uncertain as to the level of demand (low, medium, or high) for that production. A decision-making manager might attempt to analyze all information himself, making an individual decision based on this analysis. Alternatively, the manager may look to subordinates for various inputs, then make the decision individually. A third option might involve the manager relying upon inputs or recommendations from subordinates and then utilizing a predetermined aggregation mechanism for mapping these inputs into a decision choice.

We first developed a prototype implementing group decision making processes, noted above as the third option. The setup has an automatic manager relying upon inputs from subordinates. The manager then utilizes a predetermined aggregation mechanism to make a final production decision. After several sets of experiments utilizing an automated manager were completed, then the human-manager procedures were incorporated. Different payoff schemes were implemented as needed. I wrote all the programs in C language.

To study the managerial decision behaviors, we put sufficient controls into place to insure that what we measured relates to what was under study. We relied heavily on experimental economics in the design and conducting of the human subject incentive-driven computerized laboratory experiment. Further, to shed light on the usefulness of our framework, we consider it in the organizational context.

As pointed out in Marsden, Pingry, and Wang (1992), an intelligent firm in competitive markets is the firm that can adapt its structure, the one that has the knowledge necessary to change when change is optimal and to make enough profit to survive. In constructing a framework for an intelligent firm, we must take into account the tradeoffs among interacting variables.

7.2 Key Findings of the Research

In addition to the development of an experimental shell summarized in the previous section, we made distinct contributions in several areas. This section discusses the major findings in this dissertation. Contributions are reviewed in the next section.

As illustrated in Chapters 5 and 6, an automatic manager utilizing simplistic decision rules can perform as well as a human manager. When we first set up the experiments comparing the performance between an automated machine manager and a human manager, we might have expected that a human manager would fair better than an automated machine manager implemented with a simple set of rules to rely upon in making the decisions. It turned out that both types of manager perform at similar levels.

We noted that, in the decision rule simulation, in the periods where an automated manager cannot make a production decision because of the restrictions of the decision rule, the automated manager loses the opportunity to make a profit. An organization may need to eliminate or reduce the no-decision situation so that fewer lost opportunities arise.

One of our hypothesis tests compared the performance of subordinates and managers in the decision making situation where the subordinates pay for the forecast information without waiting for it to the situation where they have to wait and are charged with time cost before free forecast information becomes available. There is no statistical evidence that a manager with inputs from subordinates who had access to free information (but who had to wait for the free information) performed better than a manager with inputs from subordinates who had to purchase the information.

We argue that appropriate purchase of timely information may offset the cost. We illustrated this in the hypothesis test of experiments with free information against experiments with with-cost information. In the design of a framework for an intelligent firm, we would consider tradeoffs between the timeliness of a decision and associated information cost.

7.3 Major Contributions

This study drew from the methodology in experimental microeconomics research using real, live economic systems where behavior is motivated through a significant reward structure. Control is the essence of experimental methodology. We achieve significant environment control through the use of the computer network, uniform video introduction presentation, on-line tutorial, and real-time practice. Using monetary rewards tied to subject performance, we observed the behavior of subjects under various combinations of aggregation processes and incentive mechanisms.

As experimental economics has begun to take advantage of advancing computer and communication technology, the methodological approach used in this area has become more easily adaptable for studying the impact of technological advances on issues involving optimal organizational as well as intelligent information system design. This research serves as an illustration of the use of experimentation methodology for determining important human-computer-organization relationship under the controlled laboratory environment. This is an example of how laboratory experiments can be utilized where testing and validating is impossible or impractical using historical or field trial data.

We operationalized our decision aggregation framework by introducing a tuple of platform variables and designed a platform which is flexible enough to incorporate a variety of combinations of decision problems, decision making process, and incentive mechanism alternatives. It may be used in different disciplines to conduct distinctive research.

We view the conducting of human subject incentive-driven computerized experiments itself as a contribution. We submitted necessary application to get an approval in utilizing human subjects and worked to ensure that we followed the guidelines, such as anonymity in analyzing the results. We recruited subjects from different backgrounds. The control of the experiment flow also required delicate managerial skills in the part of the researcher.

In line with the interdisciplinary nature of the MIS field, we draw from various disciplines in this study: decision science, computer science, organizational theory, and microeconomics. This research gains a useful perspective on how people evaluate decision alternatives, especially in parallel decision making, timing of on-line parallel decision making, and decision aggregation. They are vital because distributed decisions are common in the context of organization. Different organization structures utilize different decision hierarchies. The quality of decisions depends upon not only the ability of the decision makers but also the structure of the decision aggregation process. Our study investigated both generic decision aggregation rules and the impact of organizational structure on the performance of such rules.

7.4 Directions for Future Research

This research points to many directions that we can pursue in continuous research. some suggestions and plans for future study are discussed here.

As we indicated in Chapter 5, issues relating to group size and performance are important and we suggest this area as one for future study. Issue of optimal group size is important for organizations. We have provided means for conducting the necessary analyses and we intend to pursue this research area.

Utilizing other voting mechanisms and subordinate payment structures in the decision aggregation implemented for the automatic manager are other issues that deserve further investigation.

In addition to the setting used in our experiments, conducting experiments in other environments (e.g., in other campuses or organizations) can widen the scope of this research and enable more comparative studies. The hypothesis tests that we performed were by no means exhaustive. We will continue to develop different data sets for comparisons.

Moving toward the realm of artificial intelligence, future research can be directed toward designing a framework for an intelligent firm incorporating our findings. Devising an expert system to automate the aggregation of group decision making in our decision setting also poses great opportunity. The simulation exercises provided us with directions to pursue.

With the advancement of technology, computers play an increasingly integral part in the operations of organizations. Utilizing the computer and information technology is essential and integral in the world of business. We believe that the research conducted in this dissertation is an initial step toward designing intelligent firms for the future. This study helps in pushing the frontier in the research of organizational science and business computing.

Appendix A:

Approval Sheet of Exemption Certification for Human Subject Experiments

UNIVERSITY OF KENTUCKY

Research and Graduate Studies

Research Subjects Office
301 Kinkead Hall
Lexington, Kentucky 40506-0057
Medical IRB 606-257-8295
Non-Medical IRB 606-257-3138
IACUC 606-257-2934

EXEMPTION CERTIFICATE SIGNATURE PAGE

IRB # 91-11015 P.I.'s Last Name: Wang

Institutional Review Board: ( ) Medical (X) Non-Medical

Title of Protocol: Testing the Hypotheses in Multiple Criteria Distributed Decision Making Through the Integration of Decision Support Systems Theory and Computerized Lab Experiments

IRB Reviewer's Comments:

Exemption Status:

(✓) Approved ( ) Additional Information Required

( ) Disapproved*

*The P.I. has the option of re-submitting the protocol for full review

Dr. Chung-In Moon /br — IRB Representative

2/20/91 — Date

0387T-(11/90)

Appendix B: Handout for Recruiting

Play Computerized Group Decision Game for CASH!

Please sign up for a computerized collaborative experiment in the MIS Research Lab, DSIS Department (Room BE435).

Cash payment: $5.00 flat cash reward for participating. **Additional money up to $15.00 can be earned depending upon your performance in the experiment.**

Time required: One hour.

The game: You play the role of assistant to the production manager in helping decide the production level for many future periods. You maximize your profit (and your **cash** reward) by making the correct forecast based on the information available to you in the game. Complete orientation and practice before the game.

You can participate in only **one** of the sessions listed below. Please indicate your preference of time slot below:

July 14 (Tue.) 1:00pm ____________________
July 15 (Wed.) 1:00pm ____________________
July 15 (Wed.) 11:30am ____________________
Time slots you may be available other than the above ______________

Every effort will be made to place you in your first choice time slot if possible. Your session will be confirmed as soon as possible.

Please contact Ken Wang at 257-3063 or in Room BE435 for any question.

Name: ________________________________

Telephone: ________________________________

Class: ________________________________

When: July ____ (_______) 1:00-2:00pm

Appendix C: Information Sheet for Experiment Subjects

Collaborative Decision Making Experiment

Information Sheet

--- This experiment is conducted by Ming-Chian Ken Wang, a Ph.D. candidate in the Department of Decision Science and Information Systems, College of Business & Economics of the University of Kentucky.

--- Participation in this experiment is voluntary and anonymous. The identity of the participant will not and can not be related to the experiment results.

--- The personal information obtained from the participant is only for the purpose of completing the experiment expense report to the University.

--- This experiment is approved by and on file with Research Subjects Office of Research and Graduate Studies, University of Kentucky.

--- The participation payment and performance bonus, if any, were established by the conductor of this experiment and will be paid after a participant has completed the experiment.

Appendix D: 1099 Information Sheet

UNIVERSITY OF KENTUCKY
1099 Information Sheet

Please Type or Print

1. NAME: ____
(First) (Middle In.) (Last)

2. Address: ____
____
______________________________ Zip Code: ______________

3. Voucher Number: ____________________

4. Account Number: *5-35409* Object Number: *3615* User Code: ________

5. Document Number:
DAV., P.O., etc. *D* Social Security No.: ____________________

6. Reason for Payment: *Laboratory Research Participation*

7. Amount: $________ Date: ______________

8. 1099 Code: ________________

9. Originating Department: *Decision Science & Information Systems, Col. B&E*

Instructions:

1. The University Department requesting payment must complete all items above except item No. 3 and item No. 8.

2. Items No. 3 and No. 8 will be completed by the Accounts Payable Department.

3. Attach the completed form to the paying document. (DAV or P.O.)

Signature ______________________________ Check # ____________________

Appendix E: Post-Experiment Survey

Collaborative Decision Making Experiment

Post-Experiment Survey

Date:___________

So that the experiment itself as well as the conducting of it can be improved, please feel free to comment or make suggestion on any aspect of the experiment.

The experiment:

- In general:
- Layout of the screen:
- Flow of the process:

Video presentation:

Tutorial & practice:

Others:

Your participation in this experiment is greatly appreciated.

Appendix F:

**Information Structure Matrices Groups
Used in the Experiments**

Information structure matrices group #1:

$$IS_1^1 = \begin{bmatrix} 0.700 & 0.150 & 0.150 \\ 0.150 & 0.700 & 0.150 \\ 0.150 & 0.150 & 0.700 \end{bmatrix} \quad IS_2^1 = \begin{bmatrix} 0.800 & 0.100 & 0.100 \\ 0.100 & 0.800 & 0.100 \\ 0.100 & 0.100 & 0.800 \end{bmatrix}$$

$$IS_3^1 = \begin{bmatrix} 0.820 & 0.130 & 0.050 \\ 0.090 & 0.820 & 0.090 \\ 0.050 & 0.130 & 0.820 \end{bmatrix} \quad IS_4^1 = \begin{bmatrix} 0.860 & 0.090 & 0.050 \\ 0.070 & 0.860 & 0.070 \\ 0.050 & 0.090 & 0.860 \end{bmatrix}$$

$$IS_5^1 = \begin{bmatrix} 1.000 & 0.000 & 0.000 \\ 0.000 & 1.000 & 0.000 \\ 0.000 & 0.000 & 1.000 \end{bmatrix}$$

Information structure matrices group #2:

$$IS_1^2 = \begin{bmatrix} 0.400 & 0.330 & 0.270 \\ 0.300 & 0.400 & 0.300 \\ 0.270 & 0.330 & 0.400 \end{bmatrix} \quad IS_2^2 = \begin{bmatrix} 0.500 & 0.300 & 0.200 \\ 0.250 & 0.500 & 0.250 \\ 0.200 & 0.300 & 0.500 \end{bmatrix}$$

$$IS_3^2 = \begin{bmatrix} 0.600 & 0.250 & 0.150 \\ 0.200 & 0.600 & 0.200 \\ 0.150 & 0.250 & 0.600 \end{bmatrix} \quad IS_4^2 = \begin{bmatrix} 0.800 & 0.100 & 0.100 \\ 0.100 & 0.800 & 0.100 \\ 0.100 & 0.100 & 0.800 \end{bmatrix}$$

$$IS_5^2 = \begin{bmatrix} 0.900 & 0.095 & 0.005 \\ 0.050 & 0.900 & 0.050 \\ 0.005 & 0.095 & 0.900 \end{bmatrix}$$

Information structure matrices group #3:

$$IS_1^3 = \begin{bmatrix} 0.480 & 0.330 & 0.190 \\ 0.260 & 0.480 & 0.260 \\ 0.190 & 0.330 & 0.480 \end{bmatrix} \quad IS_2^3 = \begin{bmatrix} 0.600 & 0.200 & 0.200 \\ 0.200 & 0.600 & 0.200 \\ 0.200 & 0.200 & 0.600 \end{bmatrix}$$

$$IS_3^3 = \begin{bmatrix} 0.650 & 0.175 & 0.175 \\ 0.175 & 0.650 & 0.175 \\ 0.175 & 0.175 & 0.650 \end{bmatrix} \quad IS_4^3 = \begin{bmatrix} 0.700 & 0.150 & 0.150 \\ 0.150 & 0.700 & 0.150 \\ 0.150 & 0.150 & 0.700 \end{bmatrix}$$

$$IS_5^3 = \begin{bmatrix} 0.750 & 0.125 & 0.125 \\ 0.125 & 0.750 & 0.125 \\ 0.125 & 0.125 & 0.750 \end{bmatrix} \quad IS_6^3 = \begin{bmatrix} 0.850 & 0.075 & 0.075 \\ 0.075 & 0.850 & 0.075 \\ 0.075 & 0.075 & 0.850 \end{bmatrix}$$

$$IS_7^3 = \begin{bmatrix} 0.850 & 0.145 & 0.005 \\ 0.075 & 0.850 & 0.075 \\ 0.005 & 0.145 & 0.850 \end{bmatrix} \quad IS_8^3 = \begin{bmatrix} 0.870 & 0.080 & 0.050 \\ 0.065 & 0.870 & 0.065 \\ 0.050 & 0.080 & 0.870 \end{bmatrix}$$

$$IS_9^3 = \begin{bmatrix} 0.950 & 0.045 & 0.005 \\ 0.025 & 0.950 & 0.025 \\ 0.005 & 0.045 & 0.950 \end{bmatrix} \quad IS_{10}^3 = \begin{bmatrix} 1.000 & 0.000 & 0.000 \\ 0.000 & 1.000 & 0.000 \\ 0.000 & 0.000 & 1.000 \end{bmatrix}$$

Information structure matrices group #4:

$$IS_1^4 = \begin{bmatrix} 0.600 & 0.200 & 0.200 \\ 0.200 & 0.600 & 0.200 \\ 0.200 & 0.200 & 0.600 \end{bmatrix} \quad IS_2^4 = \begin{bmatrix} 0.650 & 0.175 & 0.175 \\ 0.175 & 0.650 & 0.175 \\ 0.175 & 0.175 & 0.650 \end{bmatrix}$$

$$IS_3^4 = \begin{bmatrix} 0.650 & 0.250 & 0.100 \\ 0.175 & 0.650 & 0.175 \\ 0.100 & 0.250 & 0.650 \end{bmatrix} \quad IS_4^4 = \begin{bmatrix} 0.800 & 0.100 & 0.100 \\ 0.100 & 0.800 & 0.100 \\ 0.100 & 0.100 & 0.800 \end{bmatrix}$$

$$IS_5^4 = \begin{bmatrix} 0.850 & 0.075 & 0.075 \\ 0.075 & 0.850 & 0.075 \\ 0.075 & 0.075 & 0.850 \end{bmatrix} \quad IS_6^4 = \begin{bmatrix} 0.850 & 0.125 & 0.025 \\ 0.075 & 0.850 & 0.075 \\ 0.025 & 0.125 & 0.850 \end{bmatrix}$$

$$IS_7^4 = \begin{bmatrix} 0.860 & 0.090 & 0.050 \\ 0.070 & 0.860 & 0.070 \\ 0.050 & 0.090 & 0.860 \end{bmatrix} \quad IS_8^4 = \begin{bmatrix} 0.900 & 0.095 & 0.005 \\ 0.050 & 0.900 & 0.050 \\ 0.005 & 0.095 & 0.900 \end{bmatrix}$$

$$IS_9^4 = \begin{bmatrix} 0.970 & 0.025 & 0.005 \\ 0.015 & 0.970 & 0.015 \\ 0.005 & 0.025 & 0.970 \end{bmatrix} \quad IS_{10}^4 = \begin{bmatrix} 1.000 & 0.000 & 0.000 \\ 0.000 & 1.000 & 0.000 \\ 0.000 & 0.000 & 1.000 \end{bmatrix}$$

Information structure matrices group #5:

$$IS_1^5 = \begin{bmatrix} 0.600 & 0.200 & 0.200 \\ 0.200 & 0.600 & 0.200 \\ 0.200 & 0.200 & 0.600 \end{bmatrix} \quad IS_2^5 = \begin{bmatrix} 0.650 & 0.175 & 0.175 \\ 0.175 & 0.650 & 0.175 \\ 0.175 & 0.175 & 0.650 \end{bmatrix}$$

$$IS_3^5 = \begin{bmatrix} 0.650 & 0.250 & 0.100 \\ 0.175 & 0.650 & 0.175 \\ 0.100 & 0.250 & 0.650 \end{bmatrix} \quad IS_4^5 = \begin{bmatrix} 0.800 & 0.100 & 0.100 \\ 0.100 & 0.800 & 0.100 \\ 0.100 & 0.100 & 0.800 \end{bmatrix}$$

$$IS_5^5 = \begin{bmatrix} 0.850 & 0.075 & 0.075 \\ 0.075 & 0.850 & 0.075 \\ 0.075 & 0.075 & 0.850 \end{bmatrix} \quad IS_6^5 = \begin{bmatrix} 0.850 & 0.125 & 0.025 \\ 0.075 & 0.850 & 0.075 \\ 0.025 & 0.125 & 0.850 \end{bmatrix}$$

Information structure matrices group #6:

$$IS_1^6 = \begin{bmatrix} 0.450 & 0.330 & 0.220 \\ 0.275 & 0.450 & 0.275 \\ 0.220 & 0.330 & 0.450 \end{bmatrix} \quad IS_2^6 = \begin{bmatrix} 0.550 & 0.300 & 0.150 \\ 0.225 & 0.550 & 0.225 \\ 0.150 & 0.300 & 0.550 \end{bmatrix}$$

$$IS_3^6 = \begin{bmatrix} 0.670 & 0.280 & 0.050 \\ 0.165 & 0.670 & 0.165 \\ 0.050 & 0.280 & 0.670 \end{bmatrix} \quad IS_4^6 = \begin{bmatrix} 0.700 & 0.150 & 0.150 \\ 0.150 & 0.700 & 0.150 \\ 0.150 & 0.150 & 0.700 \end{bmatrix}$$

$$IS_5^6 = \begin{bmatrix} 0.800 & 0.100 & 0.100 \\ 0.100 & 0.800 & 0.100 \\ 0.100 & 0.100 & 0.800 \end{bmatrix} \quad IS_6^6 = \begin{bmatrix} 0.850 & 0.125 & 0.025 \\ 0.075 & 0.850 & 0.075 \\ 0.025 & 0.125 & 0.850 \end{bmatrix}$$

$$IS_7^6 = \begin{bmatrix} 0.870 & 0.080 & 0.050 \\ 0.065 & 0.870 & 0.065 \\ 0.050 & 0.080 & 0.870 \end{bmatrix} \quad IS_8^6 = \begin{bmatrix} 0.900 & 0.095 & 0.005 \\ 0.050 & 0.900 & 0.050 \\ 0.005 & 0.095 & 0.900 \end{bmatrix}$$

$$IS_9^6 = \begin{bmatrix} 0.970 & 0.025 & 0.005 \\ 0.015 & 0.970 & 0.015 \\ 0.005 & 0.025 & 0.970 \end{bmatrix} \quad IS_{10}^6 = \begin{bmatrix} 1.000 & 0.000 & 0.000 \\ 0.000 & 1.000 & 0.000 \\ 0.000 & 0.000 & 1.000 \end{bmatrix}$$

Information structure matrices group #7:

$$IS_1^7 = \begin{bmatrix} 0.500 & 0.300 & 0.200 \\ 0.250 & 0.500 & 0.250 \\ 0.200 & 0.300 & 0.500 \end{bmatrix} \quad IS_2^7 = \begin{bmatrix} 0.510 & 0.300 & 0.190 \\ 0.245 & 0.510 & 0.245 \\ 0.190 & 0.300 & 0.510 \end{bmatrix}$$

$$IS_3^7 = \begin{bmatrix} 0.600 & 0.200 & 0.200 \\ 0.200 & 0.600 & 0.200 \\ 0.200 & 0.200 & 0.600 \end{bmatrix} \quad IS_4^7 = \begin{bmatrix} 0.650 & 0.200 & 0.150 \\ 0.175 & 0.650 & 0.175 \\ 0.150 & 0.200 & 0.650 \end{bmatrix}$$

$$IS_5^7 = \begin{bmatrix} 0.800 & 0.100 & 0.100 \\ 0.100 & 0.800 & 0.100 \\ 0.100 & 0.100 & 0.800 \end{bmatrix} \quad IS_6^7 = \begin{bmatrix} 0.820 & 0.130 & 0.050 \\ 0.090 & 0.820 & 0.090 \\ 0.050 & 0.130 & 0.820 \end{bmatrix}$$

$$IS_7^7 = \begin{bmatrix} 0.870 & 0.080 & 0.050 \\ 0.065 & 0.870 & 0.065 \\ 0.050 & 0.080 & 0.870 \end{bmatrix} \quad IS_8^7 = \begin{bmatrix} 0.900 & 0.095 & 0.005 \\ 0.050 & 0.900 & 0.050 \\ 0.005 & 0.095 & 0.900 \end{bmatrix}$$

$$IS_9^7 = \begin{bmatrix} 0.990 & 0.005 & 0.005 \\ 0.005 & 0.990 & 0.005 \\ 0.005 & 0.005 & 0.990 \end{bmatrix} \quad IS_{10}^7 = \begin{bmatrix} 1.000 & 0.000 & 0.000 \\ 0.000 & 1.000 & 0.000 \\ 0.000 & 0.000 & 1.000 \end{bmatrix}$$

Information structure matrices group #8:

$$IS_1^8 = \begin{bmatrix} 0.650 & 0.175 & 0.175 \\ 0.175 & 0.650 & 0.175 \\ 0.175 & 0.175 & 0.650 \end{bmatrix} \quad IS_2^8 = \begin{bmatrix} 0.750 & 0.125 & 0.125 \\ 0.125 & 0.750 & 0.125 \\ 0.125 & 0.125 & 0.750 \end{bmatrix}$$

$$IS_3^8 = \begin{bmatrix} 0.820 & 0.130 & 0.050 \\ 0.090 & 0.820 & 0.090 \\ 0.050 & 0.130 & 0.820 \end{bmatrix} \quad IS_4^8 = \begin{bmatrix} 0.870 & 0.080 & 0.050 \\ 0.065 & 0.870 & 0.065 \\ 0.050 & 0.080 & 0.870 \end{bmatrix}$$

$$IS_5^8 = \begin{bmatrix} 0.900 & 0.050 & 0.050 \\ 0.050 & 0.900 & 0.050 \\ 0.050 & 0.050 & 0.900 \end{bmatrix} \quad IS_6^8 = \begin{bmatrix} 0.970 & 0.025 & 0.005 \\ 0.015 & 0.970 & 0.015 \\ 0.005 & 0.025 & 0.970 \end{bmatrix}$$

Information structure matrices group #9:

$$IS_1^9 = \begin{bmatrix} 0.500 & 0.300 & 0.200 \\ 0.250 & 0.500 & 0.250 \\ 0.200 & 0.300 & 0.500 \end{bmatrix} \quad IS_2^9 = \begin{bmatrix} 0.650 & 0.250 & 0.100 \\ 0.175 & 0.650 & 0.175 \\ 0.100 & 0.250 & 0.650 \end{bmatrix}$$

$$IS_3^9 = \begin{bmatrix} 0.700 & 0.150 & 0.150 \\ 0.150 & 0.700 & 0.150 \\ 0.150 & 0.150 & 0.700 \end{bmatrix} \quad IS_4^9 = \begin{bmatrix} 0.750 & 0.200 & 0.050 \\ 0.125 & 0.750 & 0.125 \\ 0.050 & 0.200 & 0.750 \end{bmatrix}$$

$$IS_5^9 = \begin{bmatrix} 0.820 & 0.130 & 0.050 \\ 0.090 & 0.820 & 0.090 \\ 0.050 & 0.130 & 0.820 \end{bmatrix} \quad IS_6^9 = \begin{bmatrix} 0.850 & 0.075 & 0.075 \\ 0.075 & 0.850 & 0.075 \\ 0.075 & 0.075 & 0.850 \end{bmatrix}$$

$$IS_7^9 = \begin{bmatrix} 0.870 & 0.080 & 0.050 \\ 0.065 & 0.870 & 0.065 \\ 0.050 & 0.080 & 0.870 \end{bmatrix} \quad IS_8^9 = \begin{bmatrix} 1.000 & 0.000 & 0.000 \\ 0.000 & 1.000 & 0.000 \\ 0.000 & 0.000 & 1.000 \end{bmatrix}$$

Information structure matrices group #10:

$$IS_1^{10} = \begin{bmatrix} 0.600 & 0.200 & 0.200 \\ 0.200 & 0.600 & 0.200 \\ 0.200 & 0.200 & 0.600 \end{bmatrix} \quad IS_2^{10} = \begin{bmatrix} 0.650 & 0.175 & 0.175 \\ 0.175 & 0.650 & 0.175 \\ 0.175 & 0.175 & 0.650 \end{bmatrix}$$

$$IS_3^{10} = \begin{bmatrix} 0.650 & 0.250 & 0.100 \\ 0.175 & 0.650 & 0.175 \\ 0.100 & 0.250 & 0.650 \end{bmatrix} \quad IS_4^{10} = \begin{bmatrix} 0.850 & 0.125 & 0.025 \\ 0.075 & 0.850 & 0.075 \\ 0.025 & 0.125 & 0.850 \end{bmatrix}$$

$$IS_5^{10} = \begin{bmatrix} 0.860 & 0.090 & 0.050 \\ 0.070 & 0.860 & 0.070 \\ 0.050 & 0.090 & 0.860 \end{bmatrix} \quad IS_6^{10} = \begin{bmatrix} 0.900 & 0.095 & 0.005 \\ 0.050 & 0.900 & 0.050 \\ 0.005 & 0.095 & 0.900 \end{bmatrix}$$

$$IS_7^{10} = \begin{bmatrix} 0.970 & 0.025 & 0.005 \\ 0.015 & 0.970 & 0.015 \\ 0.005 & 0.025 & 0.970 \end{bmatrix} \quad IS_8^{10} = \begin{bmatrix} 1.000 & 0.000 & 0.000 \\ 0.000 & 1.000 & 0.000 \\ 0.000 & 0.000 & 1.000 \end{bmatrix}$$

Information structure matrices group #11:

$$IS_1^{11} = \begin{bmatrix} 0.400 & 0.330 & 0.270 \\ 0.300 & 0.400 & 0.300 \\ 0.270 & 0.330 & 0.400 \end{bmatrix} \quad IS_2^{11} = \begin{bmatrix} 0.500 & 0.300 & 0.200 \\ 0.250 & 0.500 & 0.250 \\ 0.200 & 0.300 & 0.500 \end{bmatrix}$$

$$IS_3^{11} = \begin{bmatrix} 0.600 & 0.250 & 0.150 \\ 0.200 & 0.600 & 0.200 \\ 0.150 & 0.250 & 0.600 \end{bmatrix} \quad IS_4^{11} = \begin{bmatrix} 0.800 & 0.100 & 0.100 \\ 0.100 & 0.800 & 0.100 \\ 0.100 & 0.100 & 0.800 \end{bmatrix}$$

$$IS_5^{11} = \begin{bmatrix} 0.900 & 0.095 & 0.005 \\ 0.050 & 0.900 & 0.050 \\ 0.005 & 0.095 & 0.900 \end{bmatrix} \quad IS_6^{11} = \begin{bmatrix} 0.100 & 0.000 & 0.000 \\ 0.000 & 1.000 & 0.000 \\ 0.000 & 0.000 & 1.000 \end{bmatrix}$$

Information structure matrices group #12:

$$IS_1^{12} = \begin{bmatrix} 0.400 & 0.330 & 0.270 \\ 0.300 & 0.400 & 0.300 \\ 0.270 & 0.330 & 0.400 \end{bmatrix} \quad IS_2^{12} = \begin{bmatrix} 0.450 & 0.330 & 0.220 \\ 0.275 & 0.450 & 0.275 \\ 0.220 & 0.330 & 0.450 \end{bmatrix}$$

$$IS_3^{12} = \begin{bmatrix} 0.510 & 0.300 & 0.190 \\ 0.245 & 0.510 & 0.245 \\ 0.190 & 0.300 & 0.510 \end{bmatrix} \quad IS_4^{12} = \begin{bmatrix} 0.550 & 0.300 & 0.150 \\ 0.225 & 0.550 & 0.225 \\ 0.150 & 0.300 & 0.550 \end{bmatrix}$$

$$IS_5^{12} = \begin{bmatrix} 0.600 & 0.300 & 0.100 \\ 0.200 & 0.600 & 0.200 \\ 0.100 & 0.300 & 0.600 \end{bmatrix} \quad IS_6^{12} = \begin{bmatrix} 0.650 & 0.300 & 0.050 \\ 0.175 & 0.650 & 0.175 \\ 0.050 & 0.300 & 0.650 \end{bmatrix}$$

$$IS_7^{12} = \begin{bmatrix} 0.700 & 0.250 & 0.050 \\ 0.150 & 0.700 & 0.150 \\ 0.050 & 0.250 & 0.700 \end{bmatrix} \quad IS_8^{12} = \begin{bmatrix} 0.850 & 0.125 & 0.025 \\ 0.075 & 0.850 & 0.075 \\ 0.025 & 0.125 & 0.850 \end{bmatrix}$$

$$IS_9^{12} = \begin{bmatrix} 0.950 & 0.045 & 0.005 \\ 0.025 & 0.950 & 0.025 \\ 0.005 & 0.045 & 0.950 \end{bmatrix} \quad IS_{10}^{12} = \begin{bmatrix} 1.000 & 0.000 & 0.000 \\ 0.000 & 1.000 & 0.000 \\ 0.000 & 0.000 & 1.000 \end{bmatrix}$$

Information structure matrices group #13:

$$IS_1^{13} = \begin{bmatrix} 0.400 & 0.330 & 0.270 \\ 0.300 & 0.400 & 0.300 \\ 0.270 & 0.330 & 0.400 \end{bmatrix} \quad IS_2^{13} = \begin{bmatrix} 0.450 & 0.330 & 0.220 \\ 0.275 & 0.450 & 0.275 \\ 0.220 & 0.330 & 0.450 \end{bmatrix}$$

$$IS_3^{13} = \begin{bmatrix} 0.510 & 0.300 & 0.190 \\ 0.245 & 0.510 & 0.245 \\ 0.190 & 0.300 & 0.510 \end{bmatrix} \quad IS_4^{13} = \begin{bmatrix} 0.600 & 0.250 & 0.150 \\ 0.200 & 0.600 & 0.200 \\ 0.150 & 0.250 & 0.600 \end{bmatrix}$$

$$IS_5^{13} = \begin{bmatrix} 0.650 & 0.300 & 0.050 \\ 0.175 & 0.650 & 0.175 \\ 0.050 & 0.300 & 0.650 \end{bmatrix} \quad IS_6^{13} = \begin{bmatrix} 0.820 & 0.130 & 0.050 \\ 0.090 & 0.820 & 0.090 \\ 0.050 & 0.130 & 0.820 \end{bmatrix}$$

$$IS_7^{13} = \begin{bmatrix} 0.970 & 0.025 & 0.005 \\ 0.015 & 0.970 & 0.015 \\ 0.005 & 0.025 & 0.970 \end{bmatrix} \quad IS_8^{13} = \begin{bmatrix} 1.000 & 0.000 & 0.000 \\ 0.000 & 1.000 & 0.000 \\ 0.000 & 0.000 & 1.000 \end{bmatrix}$$

Information structure matrices group #14:

$$IS_1^{14} = \begin{bmatrix} 0.400 & 0.330 & 0.270 \\ 0.300 & 0.400 & 0.300 \\ 0.270 & 0.330 & 0.400 \end{bmatrix} \quad IS_2^{14} = \begin{bmatrix} 0.480 & 0.330 & 0.190 \\ 0.260 & 0.480 & 0.260 \\ 0.190 & 0.330 & 0.480 \end{bmatrix}$$

$$IS_3^{14} = \begin{bmatrix} 0.550 & 0.300 & 0.150 \\ 0.225 & 0.550 & 0.225 \\ 0.150 & 0.300 & 0.550 \end{bmatrix} \quad IS_4^{14} = \begin{bmatrix} 0.650 & 0.250 & 0.100 \\ 0.175 & 0.650 & 0.175 \\ 0.100 & 0.250 & 0.650 \end{bmatrix}$$

$$IS_5^{14} = \begin{bmatrix} 0.730 & 0.220 & 0.050 \\ 0.135 & 0.730 & 0.135 \\ 0.050 & 0.220 & 0.730 \end{bmatrix} \quad IS_6^{14} = \begin{bmatrix} 0.820 & 0.130 & 0.050 \\ 0.090 & 0.820 & 0.090 \\ 0.050 & 0.130 & 0.820 \end{bmatrix}$$

$$IS_7^{14} = \begin{bmatrix} 0.950 & 0.045 & 0.005 \\ 0.025 & 0.950 & 0.025 \\ 0.005 & 0.045 & 0.950 \end{bmatrix} \quad IS_8^{14} = \begin{bmatrix} 0.970 & 0.025 & 0.005 \\ 0.015 & 0.970 & 0.015 \\ 0.005 & 0.025 & 0.970 \end{bmatrix}$$

$$IS_9^{14} = \begin{bmatrix} 0.990 & 0.005 & 0.005 \\ 0.005 & 0.990 & 0.005 \\ 0.005 & 0.005 & 0.990 \end{bmatrix} \quad IS_{10}^{14} = \begin{bmatrix} 1.000 & 0.000 & 0.000 \\ 0.000 & 1.000 & 0.000 \\ 0.000 & 0.000 & 1.000 \end{bmatrix}$$

Information structure matrices group #15:

$$IS_1^{15} = \begin{bmatrix} 0.400 & 0.330 & 0.270 \\ 0.300 & 0.400 & 0.300 \\ 0.270 & 0.330 & 0.400 \end{bmatrix} \quad IS_2^{15} = \begin{bmatrix} 0.450 & 0.330 & 0.220 \\ 0.275 & 0.450 & 0.275 \\ 0.220 & 0.330 & 0.450 \end{bmatrix}$$

$$IS_3^{15} = \begin{bmatrix} 0.550 & 0.300 & 0.150 \\ 0.225 & 0.550 & 0.225 \\ 0.150 & 0.300 & 0.550 \end{bmatrix} \quad IS_4^{15} = \begin{bmatrix} 0.600 & 0.300 & 0.100 \\ 0.200 & 0.600 & 0.200 \\ 0.100 & 0.300 & 0.600 \end{bmatrix}$$

$$IS_5^{15} = \begin{bmatrix} 0.650 & 0.300 & 0.050 \\ 0.175 & 0.650 & 0.175 \\ 0.050 & 0.300 & 0.650 \end{bmatrix} \quad IS_6^{15} = \begin{bmatrix} 0.730 & 0.220 & 0.050 \\ 0.135 & 0.730 & 0.135 \\ 0.050 & 0.220 & 0.730 \end{bmatrix}$$

$$IS_7^{15} = \begin{bmatrix} 0.850 & 0.075 & 0.075 \\ 0.075 & 0.850 & 0.075 \\ 0.075 & 0.075 & 0.850 \end{bmatrix} \quad IS_8^{15} = \begin{bmatrix} 0.900 & 0.050 & 0.050 \\ 0.050 & 0.900 & 0.050 \\ 0.050 & 0.050 & 0.900 \end{bmatrix}$$

$$IS_9^{15} = \begin{bmatrix} 0.950 & 0.045 & 0.005 \\ 0.025 & 0.950 & 0.025 \\ 0.005 & 0.045 & 0.950 \end{bmatrix} \quad IS_{10}^{15} = \begin{bmatrix} 1.000 & 0.000 & 0.000 \\ 0.000 & 1.000 & 0.000 \\ 0.000 & 0.000 & 1.000 \end{bmatrix}$$

Information structure matrices group #16:

$$IS_1^5 = \begin{bmatrix} 0.450 & 0.330 & 0.220 \\ 0.275 & 0.450 & 0.275 \\ 0.220 & 0.330 & 0.450 \end{bmatrix} \quad IS_2^5 = \begin{bmatrix} 0.550 & 0.300 & 0.150 \\ 0.225 & 0.550 & 0.225 \\ 0.150 & 0.300 & 0.550 \end{bmatrix}$$

$$IS_3^5 = \begin{bmatrix} 0.650 & 0.200 & 0.150 \\ 0.175 & 0.650 & 0.175 \\ 0.150 & 0.200 & 0.650 \end{bmatrix} \quad IS_4^5 = \begin{bmatrix} 0.700 & 0.250 & 0.050 \\ 0.150 & 0.700 & 0.150 \\ 0.050 & 0.250 & 0.700 \end{bmatrix}$$

$$IS_5^5 = \begin{bmatrix} 0.800 & 0.150 & 0.050 \\ 0.100 & 0.800 & 0.100 \\ 0.050 & 0.150 & 0.800 \end{bmatrix} \quad IS_6^5 = \begin{bmatrix} 0.900 & 0.055 & 0.050 \\ 0.050 & 0.900 & 0.050 \\ 0.050 & 0.050 & 0.900 \end{bmatrix}$$

$$IS_7^5 = \begin{bmatrix} 0.970 & 0.025 & 0.005 \\ 0.015 & 0.970 & 0.015 \\ 0.005 & 0.025 & 0.970 \end{bmatrix} \quad IS_8^5 = \begin{bmatrix} 1.000 & 0.000 & 0.000 \\ 0.000 & 1.000 & 0.000 \\ 0.000 & 0.000 & 1.000 \end{bmatrix}$$

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Dr. Wang was a finalist in Chancellor's Awards for Outstanding Teaching Assistants at the University of Kentucky in 1991. Currently, he is a visiting professor in the Department of Computer and Information Science at Cleveland State University. Dr. Wang's research areas are Group Decision Support Systems, networking, and their implementations in an organization. He has extensive hands-on experiences in various computer platforms and knows the PC environment very well.

Ming-Chian Ken Wang

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