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강 민 철**

The Effects of Cooperativeness and Information Redundancy on Team Performance : A Simulation Study

Mincheol Kang

Cooperativeness within an organization can be conceptualized as the degree of members' willingness to work with others. The simulation study investigates the relationships of cooperativeness with team performance at different levels of information redundancy by using a multi-agents model called Team-Soar. The model consists of a group of four individual AI agents situated in a network, which models a naval command and control team consisting of four members. The study used a 9 X 3 design in which agent cooperativeness was manipulated at nine levels by gradually replacing selfish team members with increasing numbers of neutral and cooperative members, while information redundancy was controlled at three different levels (i.e., low, medium, and high). Results of the Team-Soar simulation show that cooperation has positive impacts on team performance. Further, the results reveal that the impact of agent cooperativeness on team performance depends on the amount of information needed to be processed during the decision making process.

* 이 논문은 2001년도 두뇌한국 21사업에 의하여 지원되었음
** 아주대학교 경영대학 e-비즈니스학부

Ⅰ. Introduction

Cooperation within an organization can be conceptualized as the willful contribution of member effort to the successful completion of interdependent organizational tasks. Cooperation is necessary because no individual member has sufficient knowledge, information, or resources to solve all organizational problems. Cooperation among members of an organization is believed to affect the performance of the organization (e.g., Glance & Huberman, 1994; Carley, Park, & Prietula, 1993). In particular, the role of cooperation is more evident for small organizations like groups or teams, where the outcomes two or more people obtain are determined by both their behaviors. Group researchers suggest that cooperative members achieve higher team performance, especially on tasks that benefit from the sharing of information and ideas because they take one another's perspectives, communicate effectively, exchange resources, and assist one another (Johnson & Johnson, 1989).

Teams that make decisions must process information in such a manner that information that might be relevant to the goal is collected and analyzed. Members of teams tend to seek new and additional information in order to assist their efforts in performing decision-making tasks (Grunig, 1969). In short, decision-making teams cannot achieve their goal without handling information. Recognizing the importance of information, researchers in group studies have tried to find the relationships between information and team/group performance. From these efforts, they recognized that the way in which information is distributed within groups can affect their problem-solving performance (Larson & Christensen, 1993). For example, Kang (2000) found that the degree of information redundancy, that is, the degree of information overlapping among members, could affect team efficiency by constraining the number of possible responders.

More interestingly, researchers have also found relationships between information and other variables. For example, the effects of certain variables, such as agent activeness and team decision schemes, affect team performance differently at different degrees of information redundancy (i.e., at different degree of information overlapping among members) due to the interaction of the variables with information redundancy (Kang, 2000; Kang, Waisel, & Wallace, 1998). In particular, earlier studies have identified relationships between information and cooperation. Studies show that people in cooperative situations share information, whereas people in competitive situations restrict information exchange (Alper, Tjosvold, & Law, 1998; Johnson & Johnson, 1989; Deutsch, 1973). However, studies have focused only on how cooperation affects information processing. Little research, if any, has focused on how information affects cooperation. Recognizing the limitations of past studies, this study explores the effects of cooperation on team performance under different information conditions, especially, different degrees of information redundancy.

Ⅱ. Theoretical Background

2.1 Simulation Studies Using Multi-Agents Techniques

2.1.1 Computer Simulation Studies

The computer simulation method has

several advantages for studying organizational behaviors such as team performance. Simulated organizations have been shown to resemble real-world organizations in an ideal way (Lin & Carley, 1993). Researchers using a computer simulation can perform balanced experiments by controlling certain factors to examine the effect of other relevant factors, with lower costs in money and time than human experiments or field studies would incur. Although the computer simulation method has several advantages over traditional methods, few studies have been conducted this way mainly due to the difficulty in building computer simulation models. For this reason, there are only a few exiting studies which have investigated cooperation by using a computer simulation. Two of these studies are briefly described here.

Carley, Park, and Prietula (1993) examined the relationships between social characteristics of agents and their performance by using a simulation model called Plural-Soar that models a warehouse in which multiple workers fill orders by retrieving items stored in stacks located in different places. The researchers considered three social characteristics of the agent : honesty, cooperativeness, and benevolence. Each characteristic had opposing values. An honest agent always answers to the best of its knowledge, whereas a lying agent always gives a false answer to a query about the location of an item. A cooperative agent would choose to help others by answering other agents' questions before it helps itself, while selfish agents would help themselves (e.g., filling orders they picked up) before helping anyone else by answering a question. A benevolent agent forgives an agent that provides wrong information, while a non-benevolent agent is unforgiving in the sense that once it identifies another agent as unreliable, it never again changes that rating. In this simulation model, performance was measured by the number of decision cycles (cognitive effort), the number of agent movements (physical effort), the amount of cognitive effort done for communications (communication effort), and the amount of agent idle time (wait time). The results of the simulation demonstrated the orthogonality of social effort and physical effort. In addition, the construct of total cognitive effort, representing the combination of physical effort, communication effort, and wait time was mapped as a U-shaped curve. The U-shape occurred due to that as the number of agents increased, physical effort decreased whereas social overhead comprising communication effort and wait time increased.

Glance and Huberman (1994) studied the dynamic characteristics of cooperation by developing a computer simulation model. Individuals in social dilemmas must choose between acting selfishly or cooperatively for the common good in the absence of a central authority. In this simulation model, a social dilemma was presented to a society of computational agents who intermittently and asynchronously reevaluated their opinions and decided whether to cooperate or to defect based on information about how many of the others are cooperating. From this computer simulation, the researchers confirmed that cooperative behavior can indeed arise spontaneously in social settings, provided that the groups are small and diverse in composition and that the relationships among constituents are likely to continue for a long time. They also found that when cooperation does appear, it does so suddenly and unpredictably after a long period of stasis.

In concert with studies that have used computer simulation models for studying cooperation, the present study uses a simulation model for examining the relationships of cooperation with team performance.

2.1.2 Using Multi-Agents Models

One discipline that has actively studied the role of cooperation on group performance is distributed artificial intelligence (DAI) (Chaib-Draa, Moulin, Mandiau, & Millot, 1992; Decker, 1987; Genesereth, Ginsberg, & Rosenschein, 1986). DAI is a subfield of AI that has focused on how a collection of artificially intelligent agents in a problem solving situation can interact to achieve a common set of global goals (Chaib-Draa, Moulin, Mandiau, & Millot, 1992). In a DAI environment, the problems of different agents may be interdependent; hence, agents must interact cooperatively to solve them. Through cooperative interaction, several intelligent agents can combine their efforts. Researchers in DAI are especially interested in how multi-agents develop the willingness to cooperate. They have developed theoretical frameworks to describe the cooperation of intelligent agents (Werner, 1990). One example of cooperation in DAI is the development of multi-agents that interact cooperatively to interpret three dimensional scientific data (Gallimore, Jennings, Lamba, Mason, & Orenstein, 1999).

Most multi-agents systems have worked under the benevolent agent assumption, that is, the situation of complete cooperation (Genesereth, Ginsberg, & Rosenschein, 1986). However, the traditional way of viewing multi-agent systems (i.e., viewing agents as the ones acting based on the benevolence assumption) is gradually disappearing these days, particularly due to the fact that the software world is becoming extremely dynamic and diverse (Cunha & Neves, 1998). On account of that, it is necessary to study what cooperative attitude multi-agents should take in what situations.

Studies of social attitudes have important implications on improving cyber space where using internet agents (which are also called web agents, webots, softbots, software agents, mobile agents, etc.) has become enormously popular due to information overload. Some of the many agents interacting and roaming about the Web are benevolent (Huhns & Mohamed, 1999). For example, one of the most common internet agents is a query agent that would freely share their query results with other agents on the net (Huhns & Mohamed, 1999). By supplanting other agents' efforts in exploring sites for the same queries, the benevolent agents can help reduce internet traffic (Huhns & Mohamed, 1999). However, the benevolent attitude of query agents is not always beneficial for users who own the query agents owing to that the query agents may have to consume substantial resources to get and share the information. Thus, it is necessary to identify the appropriate cooperative attitude of query agents in different situations. The present study examines what cooperative attitude multi-agents should have in a given informational situation in order to enhance team performance.

2.2 Agent Cooperativeness

2.2.1 Levels of Cooperativeness

Cooperativeness within an organization is often manifested in the degree of members' willingness to work with others. Chatman and Barsade (1995) define cooperativeness as a single-dimension personality characteristic varying from high personal cooperativeness, at one extreme, to low personal cooperativeness, or individualism, at the other extreme. Decker (1987) indicates that the degree of cooperativeness displayed by agents ranges from benevolent to antagonistic. Cunha and Neves (1998) divide agent cooperativeness into categories : cooperative, hostile or competitive, and self-interested.

Although different researchers have classified cooperativeness slightly differently, broadly speaking there are five different levels of cooperativeness : altruism (or benevolence), aggression (or antagonism), cooperation, competition, and selfishness (or individualism) (Beggan and Allison, 1994). Altruistic (or benevolent) agents prefer maximizing the outcomes of others, regardless of their own outcomes, whereas aggressive (or antagonistic) agents prefer minimizing the outcomes of others, regardless of their own outcomes. Cooperative agents seek to maximize joint gain, which is measured as the sum of individual gains. Competitive agents try to maximize their own relative gains in comparison to the gains of others. Finally, selfish (or individualistic) agents try to maximize their own gains, regardless of the gains of others.

The degree of cooperativeness an agent displays is a function of the situation the agent is under as well as the personal characteristics of the agent (Glance & Huberman, 1994). For example, cooperation generally exists when the task success of one member enhances the probability of success of other members of the group (i.e., they share a common fate). An example of cooperativeness would be the case of a sports team. Competition, however, is likely to exist when the success of one group member comes at the expense of other group members, as in the case of grading on a curve. Cooperative behavior can be influenced both by personality and by formal and informal control systems that reward individual achievement or cooperative effort (Chatman & Barsade, 1995).

2.2.2 Cooperation as a Goal-Directed Behavior

Cooperation as a goal-directed behavior is a special form of interaction. Thus, interactions among members are deeply influenced by the nature of their goals as well as the individual member's tendency to pursue individualistic or collective goals (Chatman & Barsade, 1995). The way in which members believe their goals are related is an important variable affecting the dynamics and outcomes of their interaction (Deutsch, 1990). For example, goal interdependence motivates individuals to help each other in the interest of group productivity, because they, as individuals, will benefit (Ortiz, Johnson, & Johnson, 1996).

Deutsch (1990) identified three alternatives for people's interpretation of their goal interdependence : cooperation, competition, and independence. In a situation where goals are perceived as cooperative, one's goal attainment helps others reach their goals because all goals are positively related. On the contrary, in a situation where goals are competitive goals, one's goal attainment precludes, or at least makes less likely, the goal attainment of others because individual goals are negatively related to others' efforts and goal attainments (Johnson & Johnson, 1994). In a situation of goal independence, the goal attainment of one neither helps nor hinders the goal attainment of others because the goals are unrelated.

Whether people recognize their goals as primarily cooperative or competitive profoundly affects their orientation and intentions toward each other (Deutsch, 1973). For example, teams with highly cooperative goals tend to discuss their opposing views open-mindedly and constructively which in turn develops confidence in team dynamics, contributing to effective team performance. Competitive goals appear to interfere with constructive controversy, confidence, and effectiveness (Alper, Tjosvold, & Law, 1998).

In a team situation, the five levels of agent cooperativeness can be described with respect to individual and team (i.e., shared) goals. Selfish agents only pursue their individual goals regardless of team goals. Therefore, selfish agents give higher priority to activities promoting their individual goals than to other activities. On the other hand, cooperative agents are willing to sacrifice current activities being performed to reach their own goals in order to help other members for the sake of the team goal. Competition is most likely to occur when the individual goals of the members involved are incompatible. Competitive agents try to maximize their own relative gains in comparison to the gains of others while pursuing team goals. Altruistic agents help others voluntarily and may change their goals to suit the needs of other members without expecting an immediate reward or benefit for doing so (Huhns & Mohamed, 1999). On the other hand, aggressive agents may not cooperate at all and may even block others from attaining their goals (Chaib-Draa, Moulin, Mandiau, & Millot, 1992; Decker, 1987).

In this section, we have reviewed theoretical background for the present study, which examines the relationships between agent cooperation and team performance at different levels of information redundancy by using a multi-agent model.

Ⅲ. Team-Soar Modeling

3.1 Team-Soar

"Team-Soar" is a multi-agent system, which runs on a SUN machine. Team-Soar consists of a group of four individual AI agents situated in a network in which they communicate with each other by passing messages. The multi-agent system models a naval command and control team consisting of four members: the CARRIER (the leader), the CAD, the AWAC, and the CRUISER. The mission of the team is to identify aircraft that approach the airspace surrounding the carrier and to make decisions based on that identification.

The team tracks aircraft by radar and evaluates them in terms of nine attributes : angle, direction, speed, altitude, corridor status, IFF, range, and radar type. When an unidentified object comes into the team's airspace, each member must decide among seven possible courses of action by using the information available to it, then recommends this judgment to the leader. The seven possible courses of action vary in degree of aggressiveness from Ignore to Defend (Hollenbeck, Ilgen, Sego, Hedlund, Major, & Phillips, 1995). Upon receiving all other members' judgments, the leader makes a team decision based on all members' judgments, including its own.

To make a judgment, a member reads and evaluates the raw data for the attributes he can access. The member also may ask other members for evaluations of certain attributes that they can evaluate. The decision whether to evaluate attributes alone or to ask for the evaluations of other members is made randomly by the team member.

In the Team-Soar system, individual team members are modeled by the "Soar" agent, which is a theory-based cognitive model of a human being (Newell, 1990). Soar has a sufficiently detailed cognitive architecture and is believed to closely resemble that of a human's (Laird, Congdon, Altmann, & Doorenbos, 1993). Employing a single set of mechanisms that covers all cognition, Soar is capable of goal-oriented problem-solving, learning, and interacting with external environments (Laird, Congdon, Altmann, & Doorenbos, 1993). Since Soar is especially good for simulating goal-oriented problem-solving human behavior, it is an excellent tool for modeling individual humans who engage in decision-making tasks.

When engaging in a task, humans as problem solvers formulate the task as a problem to be solved and conceive the task and their potential behavior in terms of a problem space (Newell & Simon, 1972). Then they solve the problem by finding a sequence of actions, that is, by finding a set of operators, within the problem space, that transform the initial problem state into the desired goal state through one or more intermediate states (Newell & Simon, 1972). The problem space changes continually from the results of applying action (i.e., operators) to the current state during the problem-solving activity (Newell, 1990).

Human problem solving can be modeled as a series of decision cycles (Laird, Congdon, Altmann, & Doorenbos, 1993). In each decision cycle, humans first evaluate the possible alternatives of actions (i.e., operators) based on the information and knowledge available to them. Then they select an action among the alternatives, which is believed to best achieve their goals, and apply the action, which transforms the current state toward the goal state. As humans go through a number of decision cycles, the gap between the current state and the goal state is gradually reduced.

Like humans, Soar acts as a goal-oriented problem solver that casts all tasks as a collection of interacting problem spaces with associated goals, states and operators (Prietula & Carley, 1994). Soar achieves its task by selecting and applying a number of operators (i.e., a sequence of actions) that transform the current state into the goal state through intermediate states (Laird, Congdon, Altmann, & Doorenbos, 1993). Soar, as a symbol system, has explicit symbolic representations of the problem spaces and manipulates these representations by symbolic processes (Newell, 1990).

3.2 Modeling Agent Cooperativeness Using Team-Soar

The present version of Team-Soar considers three different degrees of agent cooperativeness : selfishness, cooperation, and neutrality. In Team-Soar, agent cooperativeness comes into play as agents make judgments and provide information to other member agents. Selfish agents tend to give higher priority to making their own judgments than to providing information to other members, whereas cooperative agents are willing to sacrifice their own judgment-making activities in order to help other members for the sake of team performance (cf. Carley, Park, & Prietula, 1993). For example, when receiving a request from other member, selfish agents disregard the request until they have nothing to do but the answer the request. On the other hand, cooperative agents suspend their current activities and help the requesting member, then resume the suspended activities. Neutral agents assign equal priorities to making their own judgments and providing information to others and indifferently (randomly) choose their next activity from between the two categories.

Among the five different levels of cooperativeness described in section 2.2, not all of the levels are considered in Team-Soar due to the characteristics of team that Team-Soar models after. Team-Soar models a naval command and control team whose members share a team goal, which is to identify aircraft correctly and efficiently. Therefore, team members need to cooperate by providing information to other members, in order to achieve the team goal. In such situation, it is unlikely for team members to display competitive or aggressive behaviors. Therefore, the two levels, competition and aggression, are not considered in this study. Remember that the degree of cooperativeness an agent displays is a function of the situation (Glance & Huberman, 1994). Further, in addition to the shared team goal, team members have individual goals to fulfill their own responsibilities. Thus, they may behave differently according to their personal characteristics when they seek for their own individual goals under the cooperative team context. Recall that the degree of cooperativeness an agent displays is also a function of the personal characteristics of the agent (Glance & Huberman, 1994). Selfish members may pursuit their own individual fulfillments first, whereas cooperative or altruistic members may take care of other members' requests first. Note that in the context of decision making team in which cooperation is achieved only through providing information upon requests, the distinction between altruistic and cooperative behaviors is meaningless. Due to the aforementioned reasons, Team-Soar considers three levels of agent cooperativeness, which are selfishness, cooperation, and neutrality.

Studies suggest that cooperative people have the strongest preferences for evaluating work performance on the basis of contributions to teams rather than on individual achievement (Chatman & Barsade, 1995). Accordingly, in Team-Soar, agent cooperativeness is modeled by the handling preferences of operators. The preference mechanism, which determines the contents of the problem spaces used by Soar agents, is part of the Soar architecture (Laird, Congdon, Altmann, & Doorenbos, 1993). Setting preferences is a way of characterizing the personality types of the agents, and also a way of imposing social, cultural, and group norms on the agents (Prietula & Carley, 1994). For example, cooperative agents in Team-Soar have a higher preference for reporting evaluations over reading attributes, evaluating attributes, asking for an evaluation, and so on. Therefore, whenever operators compete with each other to be applied next, the report operator will always be selected over the others. Conversely, selfish agents in Team-Soar have a lower preference for reporting evaluations compared to the other operators. Hence, reporting evaluations will always lose when it competes with the other operators.

3.3 Modeling Information Redundancy in Team-Soar

For decision-making teams, information is considered a crucial resource. In Team-Soar, resources (i.e., information about attributes) are divided so that each member has only a portion of the resources needed to complete the task. Information redundancy indicates the degree of data intersection among members. That is, information about an attribute is considered redundant if the attribute can be accessed by at least two team members (Hollenbeck, Ilgen, Sego, Hedlund, Major, & Phillips, 1995).

In Team-Soar, information redundancy is controlled by varying the number of target attributes that each member can access directly from the control panel. Team-Soar manipulates information redundancy at three different levels : low, medium, and high. At the level of low information redundancy, the leader, CARRIER-Soar, can access only two among a total of nine attributes, while other members can access three attributes each. In this level of redundancy, two out of nine attributes are accessed by at least two members (22.2% redundancy). At the level of medium information redundancy, the leader has access to three attributes, while each of the other members has access to five. Hence, six out of nine attributes are accessed by at least two members (66.6% redundancy). Finally, at the level of high information redundancy, the leader has access to four attributes, while the other members have access to seven. In this last case, all nine attributes are accessed by at least two members (100% redundancy).

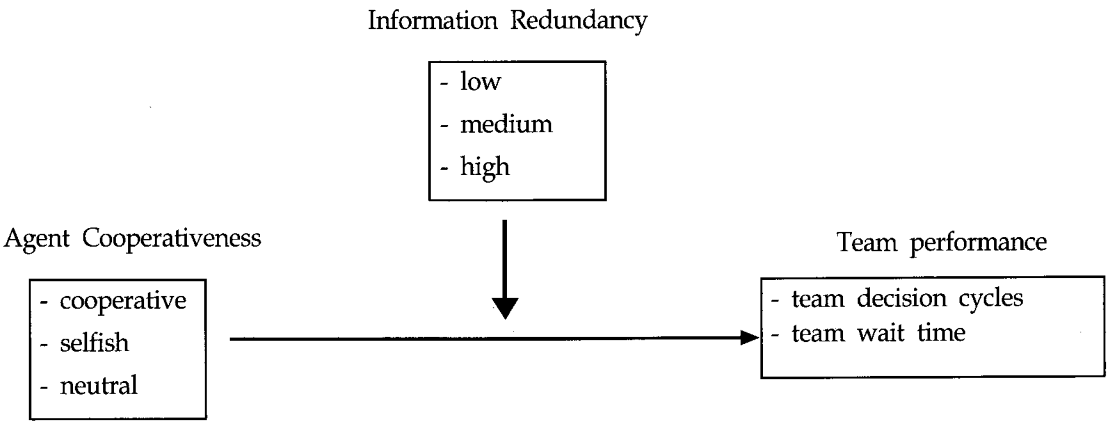
In Team-Soar, information redundancy has a strong relationship with the amount of information to be processed (i.e., read, evaluate) and communicated during the decision-making process. Members can either evaluate attributes they themselves can access or ask others to let them know the results of evaluations of the attributes. Therefore, team members with higher levels of information redundancy tend to process more information than ones with lower levels of information redundancy.

Ⅳ. Simulation Experiment

The experiment conducted using Team-Soar will be described from now on. The simulation study was designed to explore the effects of agent cooperativeness on team performance. In this experiment, the effects of agent types on team performances were measured as team efficiency, that is, the amount of time and effort it takes a team to reach a decision (Kang, 2000).

There are two reasons that the current version of Team-Soar is designed for studying team efficiency. Firstly, team efficiency itself is worth of being studied alone. For decision-making teams, performance can be evaluated in terms of the effectiveness of the decision they make (i.e., decision quality), and the efficiency in achieving that decision. It cannot too much to emphasize the importance of decision effectiveness. However, the importance of decision efficiency is not less than that of decision effectiveness, especially in the Age of Information. Speed becomes a critical success factor that provides competitive advantages. Timely decision making is crucial for modern organizations. All of them support the importance of efficiency. Secondly, the benefit of using the computer simulation model is materialized apparently when team efficiency is considered. In the Team-Soar, individual team members are modeled by "Soar" agents. As a cognitive model of humans, Soar mimics the human deliberation process by acting through a series of decision cycles. The theory-based mechanism of Soar enables researchers to measure team efficiency from the new internal criteria using decision cycles.

Two standards of team efficiency were used to evaluate the effects of agent types : team decision cycles and team wait time. In the Soar model (from which Team-Soar was derived) a decision cycle is a cognitive measure, an elementary deliberation unit that consists of an information processing step and a decision step. In Team- Soar, the variable "team decision cycles" is the sum of the number of decision cycles that each member goes through to complete a task. The other variable, team wait time, is simply the sum of the units of idle



<Figure 1> Research Model

time for all members; idle time is counted in terms of decision cycles. An example of idle time is the time a member spends doing nothing while waiting to receive a reply to a request.

Team decision cycles and team wait time that count the sum of individual members' decision cycles and wait time are functions of team decision making process. Team decision making is a multi-level phenomenon that must consider the individual-level and team-level processes. In order to capture the characteristic, Team-Soar models individual team members as well as the team structure. Simulating the multi-level process, Team-Soar agents work in parallel and interact with one another according to the predefined team structure. The multi-level process affects the values of the two variables.

4.1 Experimental Design and Hypotheses

As mentioned, the level of cooperativeness in Team-Soar can be described as either cooperative, selfish, or neutral. The study used a 9 X 3 design to examine the effects of nine combinations of agent cooperativeness on team efficiency at three different levels of information redundancy (See <Figure 1>). Based on this 9 X 3 matrix, a total of 27 team models performed 10,000 decision tasks each.

The study manipulated agent cooperativeness at nine levels by gradually replacing selfish team members with an increasing numbers of neutral and cooperative members. Each of the four selfish members in the four-member teams were replaced one by one by neutral members until the teams consisted of all neutral members. These neutral members were then replaced one by one by cooperative members until the teams consisted of all cooperative members. The order of positions to be replaced was predetermined : the AWAC position was switched first, then the CRUISER, CAD, and CARRIER positions were replaced in turn. This gradual change in the agent cooperativeness combination made it possible to examine the threshold of team performance.

Information redundancy was manipulated at three different levels : low, medium, and high. As described before, information redundancy controls the amount of information to be processed to reach a team decision by changing which agent can access how many and which attributes of the aircraft. At a low level of information redundancy, the leader agent can access only two, whereas other agents can access three attributes each. At the medium level, the leader and each of the other agents have access to three and five attributes, respectively. At the high level, the leader has access four attributes, while the other agents have access to seven.

The following null hypotheses were tested in order to study the effects of agent cooperativeness and information redundancy on team decision cycles:

(1) the nine different combinations of agent cooperativeness have equal effects on team decision cycles;

(2) the three levels of information redundancy have equal effects on team decision cycles; and

(3) there are no interaction effects for agent cooperativeness and information redun-

dancy on team decision cycles.

In addition, the following null hypotheses were tested to examine the effects of agent cooperativeness and information redundancy on team wait time:

(4) the nine different agent combinations of cooperativeness have equal effects on team wait time;

(5) the three levels of information redundancy have equal effects on team wait

<Table 1> Results of the Simulation Experiment

Team Configuration (Information level and member cooperativeness)	Mean of Team Decision Cycles (Tukey Grouping at (= 0.05)	Mean of Team Wait Time (Tukey Grouping at (= 0.05)
High & 4s0n0c	259.6 (A)	44.8 (A)
High & 3s1n0c	259.4 (A)	44.7 (A)
High & 2s2n0c	258.0 (B)	43.9 (B)
High & 1s3n0c	256.2 (C)	42.5 (C)
High & 0s4n0c	254.6 (D)	41.3 (E)
High & 0s3n1c	253.5 (E)	41.8 (D, E)
High & 0s2n2c	252.6 (F)	41.8 (D, E)
High & 0s1n3c	252.3 (F, G)	41.8 (D)
High & 0s0n4c	251.9 (G)	41.5 (D, E)
Medium & 4s0n0c	215.0 (H)	35.7 (F, G)
Medium & 3s1n0c	215.0 (H)	35.7 (F)
Medium & 2s2n0c	214.4 (I)	35.2 (G)
Medium & 1s3n0c	213.5 (J)	34.5 (H)
Medium & 0s4n0c	212.7 (K)	33.8 (I)
Medium & 0s3n1c	212.4 (K, L)	33.9 (I)
Medium & 0s2n2c	212.1 (L, M)	33.8 (I)
Medium & 0s1n3c	211.8 (M)	33.7 (I)
Medium & 0s0n4c	211.6 (M)	33.6 (I)
Low & 4s0n0c	168.0 (N)	22.9 (J)
Low & 3s1n0c	167.8 (N)	22.6 (J)
Low & 2s2n0c	167.6 (N)	22.5 (J)
Low & 1s3n0c	166.6 (O)	21.5 (K)
Low & 0s4n0c	166.2 (O, P)	21.1 (K, L)
Low & 0s3n1c	166.1 (P)	21.0 (L)
Low & 0s2n2c	165.3 (Q)	20.3 (M)
Low & 0s1n3c	164.5 (R)	19.4 (N)
Low & 0s0n4c	164.5 (R)	19.3 (N)

Note : N = 270 (team decision cycles), N = 270,000 (team wait time). low, medium, and high = levels of team information. 4s0n0c = team consisting of four selfish members, 3s1n0c = team consisting of three selfish members, one neutral member, and zero cooperative members, etc. In Tukey grouping, teams with the same letter are not significantly different.

time; and

(6) there are no interaction effects for agent cooperativeness and information redundancy on team wait time.

4.2 Results

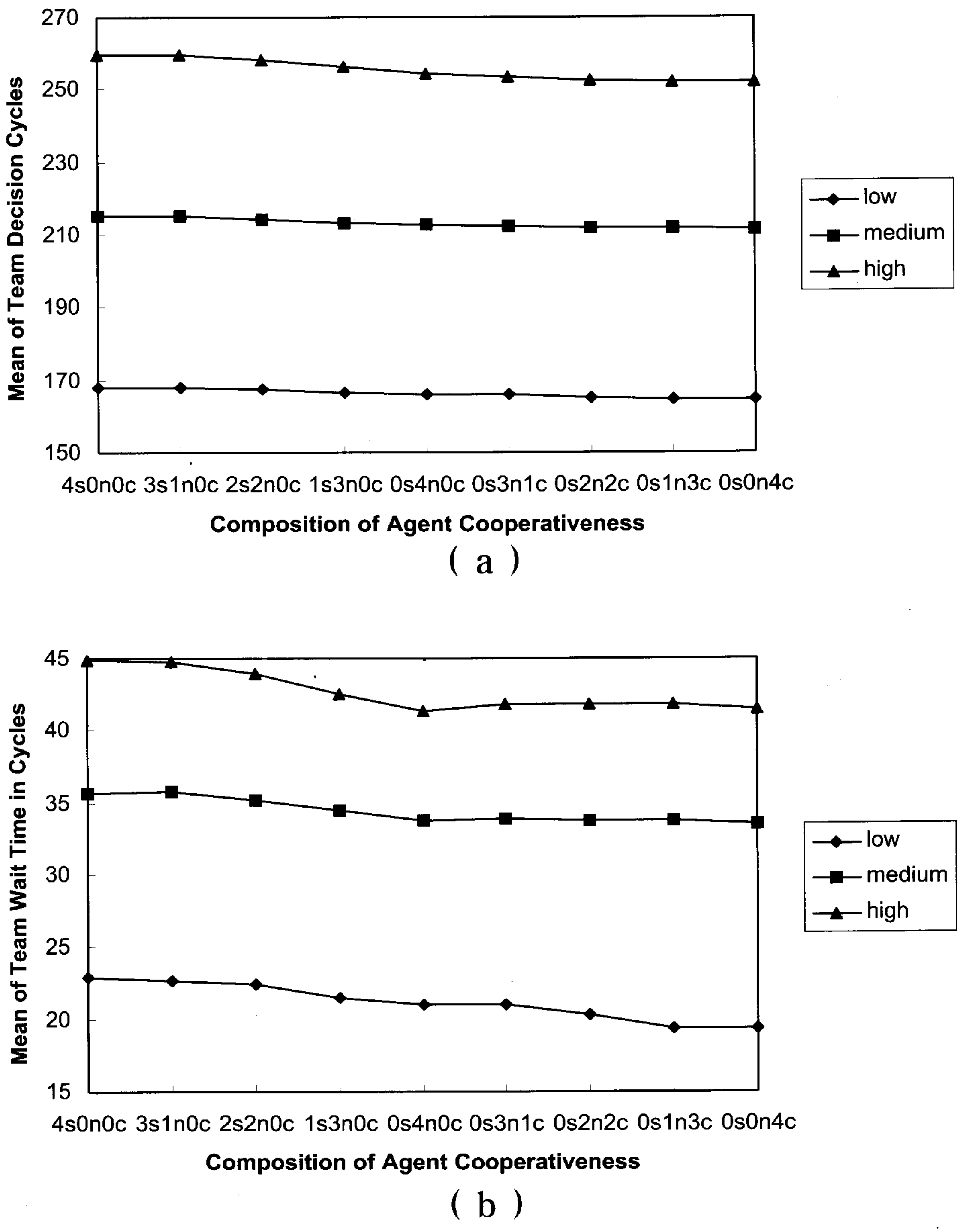
A two-way ANOVA performed to test the first three hypotheses showed that all of the three null hypotheses were rejected at the 0.0001 level of significance. The results strongly support the existence of main and interaction effects of agent cooperativeness and information redundancy on team decision cycles. Further, Tukey's studentized range test was performed at the 0.05 level of significance to find which combinations of decision variables (agent cooperativeness and information redundancy) differ significantly in their effects (see the second column of <Table 1>). From the Tukey test, the researcher found a tendency for the length of team decision cycles to decrease as the level of information redundancy decreased and as members changed from selfish to cooperative. A total of 270 observations was used for the above two statistical tests (9 X 3 X 10) because there were 10 observations of average team decision cycle length per team. Each average team decision cycle was calculated based on completion of 1,000 decision tasks.

The two-way ANOVA procedure performed to test the last three hypotheses revealed that all three null hypotheses were rejected at the 0.0001 level of significance. The results of this ANOVA strongly support the existence of main and interaction effects for agent cooperativeness and information redundancy on team wait time. Tukey's test performed at the 0.05 level of significance (see the last column of <Table 1>) showed a tendency similar to the results for team decision cycles: team wait time generally decreased as the level of information redundancy decreased and as members changed from selfish to cooperative. Note that unlike the number of observations used for the statistical tests performed with respect to team decision cycles, the number of observations used for the statistical tests done with respect to team wait time was 270,000 (9 X 3 X 10,000).

4.3 Discussion

Figure 2 shows the results of this study. The figure shows that teams at higher levels of information redundancy produced more mean decision cycles and a higher mean wait time than teams at lower levels of information redundancy, regardless of the combination of agent cooperativeness. This fact may reflect that the impact of the amount of information to be processed on team efficiency surpasses the impact of agent cooperativeness. However, it is danger to generalize the result owing to that this result might be tied to the design of Team-Soar.

In this study, the difference in mean decision cycles between the team that gave the best results and the team that gave the worst results did not always increase as the level of information redundancy increased (see <Table 1>). The same is true for team wait time. The results imply that the impact of agent cooperativeness on team efficiency is not always proportional to the amount of information to



<Figure 2> The Impact of Agent Cooperativeness on (a) Team Decision Cycles and (b) Team Wait Time at Different Team Information Levels

be processed by the team.

Teams having more selfish members are expected to produce longer team decision cycles and more team wait time than teams having fewer selfish members, whereas teams having more cooperative members are expected to produce shorter team decision cycles and less team wait time than teams having fewer cooperative members. That is, cooperation is expected to have a positive impact on team efficiency, while selfishness is expected to have a negative impact. These expectations were generally met at all levels of information redundancy.

The difference between the effects of cooperation and selfishness on team efficiency become more evident if the magnitudes of the impact of selfishness and the impact of cooperation are compared.

To this end, the magnitudes were calculated for each level of information redundancy (see <Table 2>). Here, the magnitude of the impact of selfishness on team decision cycles is defined as the difference in mean decision cycles between the team that gave the worst result among the teams which contained at least one selfish member and the team that consisted of all neutral members. Likewise, the magnitude of the impact of cooperation on team decision cycles is defined as the difference in mean decision cycles between the team that consisted of all neutral members and the team that gave the best result among the teams which contained at least one cooperative member. For example, the impact of selfishness on team decision cycles at the level of low information redundancy (1.8) is the difference between the mean decision cycles of the team at the level of low information redundancy consisting of all selfish members (168) and that consisting of all neutral members (166.2). The impact of cooperation on team decision cycles at the low level of information redundancy (1.7) is the difference between the mean decision cycles of the team at the level of low information redundancy consisting of all neutral members (166.2) that consisting of all cooperative members (164.5). (See <Table 1> and <Table 2>). The impacts of selfishness and cooperation on team wait time are similarly defined.

<Table 2> Magnitudes of the Impact of Selfishness and Cooperation on Team Decision Cycles and Team Wait Time at Different Team Information Levels

Cooperativeness at Team Information Level	Impact on Team Decision Cycles	Impact on Team Wait Time
Selfishness at low	1.8	1.8
Cooperation at low	1.7	1.8
Selfishness at medium	2.3	1.9
Cooperation at medium	1.1	0.2
Selfishness at high	5	3.5
Cooperation at high	2.7	-0.2

Note : low, medium, and high = levels of team information.

<Table 2> shows that the impact of cooperation on team wait time at the medium and high levels of information redundancy is quite small compared to that at the low level of information redundancy. Moreover, the impact of selfishness on team wait time increases as the level of information redundancy increases. This may indicate that as the amount of information to process increases, the effect of cooperation on team wait time becomes weaker

while the effect of selfishness becomes stronger. <Table 2> also shows that the impact of selfishness on team decision cycles increases as the level of information redundancy increases. This fact may indicate that the negative impact of selfishness on team decision cycles becomes stronger as the amount of information to be processed by the team increases. The relationship of cooperation and information redundancy with team decision cycles, however, was not apparent.

V. Conclusion

We have examined the effects of agent cooperativeness on team performance by performing a simulation study. Results of the study support the arguments that agent cooperativeness is an important contributor to of team efficiency. First of all, the results confirm existing research results. According to past research, for example, cooperation as a determinant of group performance yields higher performance (Johnson & Johnson, 1989; Dailey, 1977; Vroom, Grant, & Cotton, 1969). Specifically, the Team-Soar simulation shows that:

(1) Increased cooperation decreases team decision cycles and team wait time in general.

(2) Decreased redundancy decreases team decision cycles and team wait time.

(3) Increased redundancy slows the team efficiency regardless of the level of cooperativeness.

(4) The impact of agent cooperativeness on team performance is not always proportional to the amount of information to be processed.

Generally speaking, results of the study show that cooperation has a positive impact on team efficiency, therefore, cooperative teams exhibit better team efficiency than selfish or neutral teams. However, the effect of agent cooperativeness is strongly influenced by the level of information redundancy, which in this study has a stronger overall effect on performance than cooperativeness.

The present study has several limitations. First, the study examined the effects of agent cooperativeness only from the perspective of team efficiency (i.e., the amount of time and effort it takes a team to reach a decision). The study needs to be extended to inspect the roles of agent cooperativeness on team effectiveness that can be measured the accuracy of team decision-making. Further, the relationship between team efficiency and team effectiveness needs to be examined. Whereas a reduction in information redundancy in the Team-Soar simulation resulted in greater efficiency, it may be the case that a decrease in redundancy also may result in a loss of accuracy, as many real-life examples attest.

Team-Soar as a computer simulation model has some limitations in representing human team subjects because Team-Soar was built based on simplified assumptions due to lack of computer technology or to the need to simplify for modeling. Therefore, readers need to understand that Team-Soar agents cannot simulate every aspect of human beings. Further, readers are required to consider the level of abstraction that the model has when interpreting the results. However, comparing to the experiments using human subjects, these limitations are not unacceptable. Generally, human experiments are performed under the simplified settings, and therefore, results of the experiments are interpreted by considering the abstraction. The major differences between the simulation experiment and a human experiment are the levels of assumption and abstraction involved in these experiments. Nevertheless, results from the artificial model can provide valuable insights about team phenomena due to that the computer model enables researchers to perform balanced simulation experiment by controlling certain factors to examine the effect of other factors and to analyze their relationships systematically. If the findings from the simulation are worth of studying further, the findings can be tested as research hypotheses with human experiments.

The size of the team studied in Team-Soar also may be a limitation. Since the team size was held consistent four members, generalizations cannot be drawn to teams that are significantly larger in size or teams that change in size as other variables (cooperativeness, redundancy) are changed. Testing the six hypotheses using various team sizes is required in order to generalize the findings from this study.

As prescribed in section 3.2, the team that Team-Soar models after is a cooperative team in which team members pursuit their individual goals while sharing a team goal. It is necessary to be aware of the context when interpreting or applying the results of the Team-Soar simulation.

Finally, throughout the study, all other social attitudes of agents are assumed to be constant. However, interactions may exist between agent cooperativeness and other social characteristics. Therefore, examining the interactions of agent cooperativeness with other social attitudes may provide different results. For example, in this study, the activeness of members, which represents the degree to which agents participate in the team task, was assumed to be passive. Passive agents participate in team activities passively, that is, only upon request, whereas active agents involve themselves voluntarily (Kang, 2000). Examining the interactions between agent cooperativeness and activeness will be an interesting research topic.

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◆ 저자소개 ◆

강민철 (Min Cheol Kang)
현재 아주대학교 경영대학 e-비즈니스학부에 조교수로 재직 중이다. 한국항공대학교 항공전자공학과에서 학사(1984), 미국 뉴욕주립대 (SUNY at Albany)에서 전산학 석사(1989), 미국 렌슬리어 공과대학 (Rensselaer Polytechnic Institute)에서 공학박사(1996) 학위를 취득하였다.
삼보컴퓨터에서 연구원, 삼성SDS에서 경영컨설턴트, 그리고 계명대학교 경영학부 경영정보학 전공의 조교수로 근무한바 있으며, 주요 연구분야는 e-Business, Multi-Agents, Computational Organization Theory 등 이다.

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