韓國經營科學會誌
第25卷 第1號
2000年 3月

행위자의 능동성이 팀 성과에 미치는 영향에 관한 연구

강 민 철*

A Study of the Effects of Agent Activeness on Team Performance

Mincheol Kang*

■ Abstract ■

Passive agents participate in team activities passively, that is, only upon request, whereas active agents involve themselves voluntarily. Teams composed of active agents are generally believed to perform better than those with passive agents. In this paper, by using a computational simulation model we examine the effect of agent activeness on the efficiency of decision-making teams that access different amount of information. "Team-Soar" is a computational framework that consists of a group of interconnected individual AI agents (i.e., Soar). A simulation experiment using Team-Soar was performed. Results of the simulation provide valuable insights on the roles of agent activeness. For example, the impact of having more active agents becomes more significant as the amount of information to process increases and when the team decision efficiency is important. Some of the results are counter-intuitive and therefore provides an opportunity to understand the roles of the agent activeness more deeply. For instance, the simulation results reveal that having more active agents did not always enhance team efficiency. Conclusively, the simulation experiment demonstrates how computational models contribute to the research of agents social characteristics.

---

* 계명대학교 경영학부 경영정보학과

1. Introduction

Assuming that the way agents approach problem affects organization's performance, organizational researchers have examined the relationship between organizational performance and the social nature of agent for a long time. Social characteristics of agent are especially examined since they characterize individual behaviors that are observable within a team by other agents and that are likely to affect team performance [5]. Among the social characteristics, agent activeness is of interest in this research.

Agent activeness has been believed to be related to team performance because it represents personal behaviors that are important elements for accomplishing team tasks. The social characteristic of agent, which can be observable from the agent's participation to the team task, decides the agent's attitude toward team task and other team agents. Accordingly, teaming (or team work) is strongly affected by agent activeness. Working as a team, agents are needed to communicate with each other in sharing information. In fact, a team is a small organization, where communication is a beneficial component of a task [5]. Here, active agents provide information voluntarily, while passive agents share information only when required by other agents. Therefore, passive or active information sharing is likely to affect team performance.

The evidence that different agents activeness occur with different individuals and team performances have been acquired from micro-level studies of organizational behavior and case studies of organizations facing crises. Lin and Carley [18] found the impacts of agent activeness on correctness of team decisions. Other researchers have uncovered the relationships of agent activeness with efficiency of response (i.e., response rate). They found that organizations filled with proactive agents generally outperform those with reactive agents, especially in the efficiency of response to a problem [10, 16, 29]. Crant [7] found the effects of proactive personality constructs on job performance of individual agents. From a case study of the Vincennes accident [27], Lin [17] has identified that those involved in the accident were passive and acted when ordered.

While teams composed of active agents are generally believed to perform better than those with passive agents, the relative benefit to the team of having active versus passive agents has not been systematically studied. In this paper, we will examine whether and how the activeness of a team's agents affects team performance.

The present research particularly uses a computational model to study the roles of agent activeness. Computational models are formal model instantiated on computers. They have been widely used for studying social natures of agent. For examples, by building a computational model of organization, Lin and Carley [18] studied the effects of different agent proactiveness (proactive and reactive) on organizational decision making performance (i.e., correctness of decisions). With a computational model, called Plural-Soar, Carley and her colleagues [5] examined the effects of agent honesty, cooperation and benevolence on different team efficiency (e.g., total time and wait time) when the number of agent in a team varied. Using a computational model, Macy and Skvoretz [20] showed how trust and cooperation between strangers can evolve without formal or informal social controls.

Using computational models has several advantages for studying organizational behaviors such as team performance. First of all, computational modeling can be valuable for the study of organizations as collection of intelligent agents [25]. As pointed by Lin and Carley [18], simulated organizations have been shown to resemble the real-world organizations in an ideal way. Under certain conditions, the performance characteristics of simulated organizations are comparable to the performance characteristics observed in the real world. Hence, by performing simulation experiment using computational models, researchers can get an insight into these important factors with less cost than conducting human experiments or field studies. Particularly, computational analysis can assist researchers in understanding some fundamentals of human information processing behavior such as decision making [28]. Further, computational models enable researchers to perform balanced simulation experiment by controlling certain factors to examine the effect of other factors. Actually, along with theoretical process and empirical process, computational process is considered as one of the three processes that are necessary to the development of any discipline [8]. See the following references for more information about computational models: [3, 4, 24, 25].

In this paper we look into the effect of agent activeness on the performance of teams accessing different amount of information by using a computational simulation model called "Team-Soar". The later parts of this paper are organized as follows: The next section explains agent activeness. In the third and fourth sections, computational models of individual agent and team are briefly described. The fifth section introduces a simulation experiment and its results with discussions. The last section presents the conclusions.

2. Agent Activeness

This research considers two different levels of agent activeness: passive and active. Passive agents participate in team activities passively, that is, only upon request, whereas active agents involve themselves voluntarily. For instance, a passive agent transfers information only when someone requests it. On the other hand, an active agent voluntarily passes information to other agents whenever new information is available. The concept of active-passive types are similar to the concept of proactive-reactive styles. According to Lin's [17] classification, a proactive agent tends to engage in organizational decision making whenever possible, while a reactive agent tends not to engage in the decision-making process until being asked or until absolutely necessary.

Actually, the classification of the agent type came from Carl Jung's [11] personality dimension of extraversion-introversion, which is the most basic dimension that formulates a description of human behavior with concerning of individual differences. Extraversion is defined as being sociable, talkative, assertive, active, carefree, energetic, and sensation-seeking. On the other hand, introversion is defined as being quiet, reserved, passive, controlled, and less sociable and outgoing [1]. In short, extraversion can be understood in terms of sociability, while introversion can be considered as a tendency to withdraw from social contact.

3. Soar

In this study, a computational model called Soar, is used to model individual team members [14]. The main reason for using Soar is that it reflects a comparatively complete general architecture for reasoning and problem solving [5]. Soar, an exemplar of Newell's "Unified Theories of Cognition", is a candidate of the computational model of humans which has sufficiently detailed cognitive architecture [14, 15, 21]. Employing single set of mechanisms as the cognitive architecture, Soar processes information, represents tasks, and controls its behavior. Soar is capable of knowledge- based problem solving, learning, and interacting with external environments [14].

As a computational model of general problem solver [23], Soar casts all its behavior as a search through problem spaces in service of satisfying goals. A problem space is the domain of operators that represents the set of possible actions. Within a problem space, the current state is changed continually from the result of applying operators to it during the problem-solving activity [21]. When engaging in a task, humans are believed to formulate the task as a problem to be solved and conceive the task and their potential behavior in terms of a problem space [19]. Then they solve the problem by finding a sequence of actions within the problem space by transforming the initial problem state into the desired goal state through one or more intermediate states [6, 22]. 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 [15, 24].

Soar continuously makes decisions while solving problems. In other words, Soar acts through a series of decision cycles. Decision cycles in Soar reflect attempts to find operators within a problem space that may be applied to achieve a particular goal. A decision cycle consists of two parts, the elaboration phase and the decision phase, which are comparable to the information processing phase and the decision phase in the elementary deliberation level of humans. During an elaboration phase, the content of the working memory is elaborated with all directly available information that is relevant to the current situation. During a decision phase, an appropriate problem space, state, or operator is selected.

4. Team-Soar

4.1 Team-Soar Modeling

"Team-Soar" is a computational framework that consists of a group of interconnected individual agents (i.e, Soar). It models a naval command and control team consisting of four agents (i.e., CARRIER, CAD, AWAC, and CRUISER) who have different areas of expertise and are located apart from one another. The goal of the team is to identify aircraft and make decisions based on the identification. Agents of the team cooperate interactively to make decisions. In Team-Soar, which is realized on a SUN machine, all agents were programmed in the C language-based Soar 6 environment and the multi-agent Soar technique [14] was used to model the team collectively.

In the Team-Soar framework, the team's task is to monitor the airspace surrounding the carrier. Aircrafts are tracked by radar and evaluated in terms of nine attributes (i.e., angle, direction, speed, altitude, corridor status, IFF, range, and radar type). When an unidentified object comes into this space, whoever first spotted the target announces the appearance of it to the other agents (announce- target operator). To participate in a team decision, each agent first makes its own judgment about the best course of action by using the information available to it (make-member-judgement operator), then recommends this judgment to the leader agent (report-member-judgment operator). To make a judgment, an agent first reads the values of attribute data (read-attribute operator) and evaluates each attribute on a scale of one to three (evaluate- attribute operator). The agent also may ask other agents for their evaluations of certain attributes that can be evaluated by other agents as well as itself (ask-evaluation operator and report-evaluation operator). The decision whether to evaluate the attributes by itself or to ask for the evaluations of other agents is made randomly (read-or-ask operator). When an agent has made the required evaluations, it then makes a judgment about which of seven possible courses of action to recommend to the leader agent. The seven possible courses of action varied in degree of aggressiveness from Ignore, which has a value of zero, to Defend, which has a value of six [9]. Intermediate actions on this scale are Review (1), Monitor (2), Warn (3), Ready (4), and Lock-on (6). Upon receiving all other agents' judgments, the leader agent makes a team decision based on all agents' judgments, including its own (make-team-decision operator). Once made, the leader agent's response is announced to all other agents (announce-team-decision operator) and compared with the correct decision that is predetermined by the Team-Soar mechanism. Then all agents wait for a new task. Refer to "Team-Soar: A Model for Team Decision Making" [12] for more description of Team-Soar model.

4.2 Modeling Agent Activeness in Team-Soar

Generally speaking, an agent's activeness is generic attribute that comes from the personal characteristic of the agent. For this reason, in Team-Soar, agent activeness is embedded into the operators. For example, whenever new information is available, an operator of reporting the information to other agents (i.e., report-evaluation operator) is proposed for the case of active agents. On the other hand, for the case of passive agents, the report-evaluation operator is proposed only if someone has requested the information. Remind that like humans, Soar achieves its task by applying a number of operators (i.e., a sequence of actions) that transform the current state into the goal state through intermediate states [14].

5. Simulation Experiment

An experimental study done with Team-Soar is introduced in this section. The simulation study was designed to examine the effects of agent activeness on team efficiency when different amounts of information need to be processed during the decision making process.

5.1 Measures of Team Efficiency in Team-Soar

In the simulation experiment, the effects of agent activeness on team performances were measured as team efficiency, that is, the amount of time it takes a team to reach a decision. For decision-making teams, their performance can be evaluated in terms of the efficiency to achieve that decision. Particularly, two measures of team efficiency were used to evaluate the effects of the agents social characteristic: team decision cycles and team wait time. The variable "team decision cycles" is the sum of the number of decision cycles that each agent goes through to complete a task. The number of decision cycles was used here for the reason that it can serve as nominally calibrated metrics for comparison [5]. Remind that a decision cycle is an elementary deliberation unit that consists of an information processing step and a decision step [2]. Further, note that like other studies using Soar models (e.g., [5]), it is assumed that one decision cycle was sufficient to complete a fundamental deliberative act. The act can be asking an information, providing an information, reading an attribute, evaluating an attribute, making an agent judgment, reporting an agent judgment, making a team decision, or any other acts available to the agent.

The other variable "team wait time" is simply the sum of the idle time for all the agents; idle time is counted in terms of decision cycles. An example of idle time is the time an agent spends doing nothing while waiting to receive a reply to a request.

As pointed out by [5], some agent capabilities are endogenous to the agents (e.g., deliberation time) and less visible, though perhaps no less important, in terms of their effect on organizational events. The present research particularly uses the internal measures-team wait time and the number of team decision cycles-to capture such agent capabilities. These internal measures shed light on what normally are hidden in cognitive processes. These internal measures are possible since Team-Soar was built from individual cognitive models (i.e., Soar).

5.2 Experimental Design and Hypotheses

This simulation study used a 5 X 3 design to examine the effect of agent activeness on team efficiency at different levels of team information (i.e., when different amounts of information need to be processed during the decision making process). For this study, fifteen team models performed 10,000 decision tasks each. We manipulated the combination of agent activeness in teams at five levels by increasing the number of active agents from zero to four for teams that originally consisted of all passive agents. The gradual change in the number of active agents in the teams enabled researchers to examine the threshold of team performance at the addition of active agents.

Team information level represents the amount of information to be processed to reach a team decision. It can be manipulated by changing which agent can access how many and which attributes of the aircraft. In the simulation study, three different team information levels were used to control the amount of information. At the low information level, the leader agent can access only two among nine attributes, while other agents can access three attributes each. At the medium information level, the leader has access three attributes, while each of the other agents has access to five. Finally, at the high information 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 activeness and team information level on team decision cycles:

(1) the five different combinations of agent activeness have equal effect on team decision cycles;
(2) the three team information levels, that is, the

three levels of information to be processed, have equal effect on team decision cycles; and

(3) there are no interaction effects for agent activeness and level of team information on team decision cycles.

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

(4) the five different combinations of agent activeness have equal effect on team wait time;

(5) the three team information levels have equal effect on team wait time; and

(6) there are no interaction effects for agent activeness and the level of team information on team wait time.

5.3 Results

The two-way ANOVA performed to test the first three hypotheses showed that all 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 activeness and team information level on team decision cycles. Tukey's studentized range test was performed at the 0.05 level of significance to find which combinations of varying levels of the decision variables (agent activeness and team information level) differ significantly in their effects (see the second column of Table 1). From the Tukey test, we found that at the medium and high team information levels, generally the inclusion of more active agents resulted in fewer mean team decision cycles; however, it was not the case at the low team information level. The Tukey test results also indicated that team's mean decision cycles decreased as team information level went down. When teams were sorted according to their mean decision cycles, they were grouped first by the team information level; except that the teams of "High & 0p4a," which had less than or no significantly different mean of team decision cycles with the teams of "Medium & 4p0a" and "Medium & 3p1a." We should not interpret this result as that the impact of team information level on team decision cycles is greater than the one of agent activeness because the result might be different when the three levels of team information were designed differently other than the ones described in Section 5.2. Instead, the results can be interpreted as that teams processing more information require more team decision cycles than teams processing less information; and agent activeness can affect the relationship.

〈Table 1〉 Results of the Simulation Experiment

Team Configuration (Information level and member activeness)	Mean of Team Decision Cycles (Tukey Grouping α 0.05)	Mean of Team Wait Time (Tukey Grouping α 0.05)
High & 4p0a	254.6 (A)	41.3 (A)
High & 3p1a	251.7 (B)	41.2 (A)
High & 2p2a	240.5 (C)	35.3 (B)
High & 1p3a	226.0 (D)	27.5 (F)
High & 0p4a	212.2 (F)	22.0 (I)
Medium & 4p0a	212.7 (E, F)	33.8 (D)
Medium & 3p1a	213.1 (E)	34.4 (C)
Medium & 2p2a	211.4 (G)	33.4 (D)
Medium & 1p3a	205.9 (H)	30.5 (E)
Medium & 0p4a	196.9 (I)	26.4 (G)
Low & 4p0a	166.2 (M)	21.1 (J)
Low & 3p1a	170.2 (L)	23.0 (H)
Low & 2p2a	172.6 (J)	23.2 (H)
Low & 1p3a	172.9 (J)	22.0 (I)
Low & 0p4a	171.9 (K)	22.0 (I)

Note: low, medium, and high: levels of team information.
4p0a : team consisting of four passive members,
3p1a : team consisting of three passive members and one active member, and so on.
In Tukey grouping, teams with the same letter are not significantly different.

The total number of observations used for the above two statistical tests was 150 (5 X 3 X 10) since there were 10 observations of average team decision cycles per team, while each number of average team decision cycles was acquired from every 1,000 decision tasks.

The two-way ANOVA procedure performed to test the last three hypotheses showed that all three null hypotheses were rejected at the 0.0001 level of significance. The ANOVA test results strongly support that there are main and interaction effects of agent activeness and team information level on team wait time. Tukey's test performed at the 0.05 level of significance (see the last column of Table 1) showed that team wait time was not always proportional to the team information level. 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 150,000 (= 5 X 3 X 10,000).

5.4 Discussion

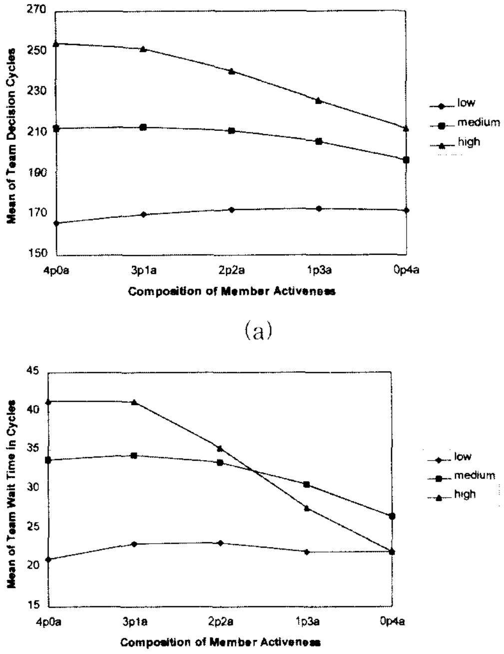
[Figure 1] shows the results of the simulation experiment done with respect to both measures of team efficiency (team decision cycles and team wait time). The results of the simulation experiment show that the role of agent activeness at the low team information level was inconsistent with the role of agent activeness at the other team information levels (see Figure 1). In general, having more active agents was beneficial to teams at the medium and high team information levels. However, at the low team information level, having more active agents did not enhance either team decision cycles or team wait time. Instead, it seemed detrimental to team efficiency. At the low information level, the team consisting of all active agents was less efficient than the team consisting of all passive agents. The results indicate that active agents do not always contribute to team performance more than passive agents, and that the size and direction of the impact (i.e., positive impact or negative impact) depend on the amount of information to be processed (i.e., evaluated and communicated). The benefit of active agents becomes stronger and more evident as team information level increases.

The differences in both mean decision cycles and mean wait time between the team that gave the best results and the team that gave the worst results became larger as team information level increased (see Figure 1). Furthermore, among all results measured with respect to team wait time, both the best result (from the team consisting of all passive agents) and the worst result (from the team consisting of all active agents) occurred at the high team information level (see part (b) of Figure 1). From the results, we may conclude that having more active agents or training agents become more significant as the amount of information to process increases and when the team decision efficiency is important.

As pointed out earlier, having more active agents did not always enhance team efficiency. Sometimes, it even made team efficiency worse (see Figure 1). For example, at the low information level, the team consisting of three passive and one active agents used fewer mean decision cycles and produced less mean wait time than the team consisting of four passive agents without an active agent. This phenomenon can occur if active agents waste extra time or resources due to their activeness. In Team-Soar, active agents spend one decision cycle to report to the other agents each with new piece of information they acquire (i.e., each evaluation of attributes they make). Moreover, communication lines need to be used for this activity. Therefore, in order to get an advantage from having an active agent, the extra cost of time or resource spent by active agents due to their activeness should be surpassed by the benefit of other agents receiving the information. Note that in Team-Soar, when an active agent reports new information to all the other agents, the active agent uses the broadcasting communication method to report the information; as a result, it takes only one decision cycle. Team-Soar was designed in this way in order to examine the effect of active agents on team efficiency while maintaining the communication cost for agent activeness at a minimum.

One example of having an active agent resulting in a negative impact on team efficiency is as follows: An active agent devotes its time and communication line to report new information (i.e., an evaluation of attribute A), while other agents, who asked the active agent for an evaluation of attribute B, is waiting for the reply. As another example, several active agents could develop and report the same information at the same time redundantly. This case is more likely to happen at the low team information level in which each agent has small number of attributes to evaluate. This may be the reason why the teams having more active agents resulted in lower team efficiency than the teams having fewer or no active agents.

When gradually changing the level of a team's agent activeness, that is, when switching passive agents with active agents one by one, the magnitude of impact for each addition of an active agent increased unequally (see Figure 1). But there seemed to be no critical point or marginal point



(a)

(b)

[Figure 1] The Impact of Agent Activeness on (a) Team Decision Cycles and (b) Team Wait Time at Different Team Information Levels

which was common to all team information levels. Here, a critical point refers to the point where the impact's magnitude changes radically once beyond it, and a marginal point refers to the point where the impact no longer changes significantly after the point where the level of the agent type combination (i.e., number of active agents in teams in this experimental case) changes gradually.

6. Conclusion

In this paper, we have examined the effects of agent activeness on team performance by performing a simulation experiment. Results of the simulation provide a valuable insight about the roles of agent activeness. First of all, the results support the arguments that agent activeness is important decision factor of team efficiency. Researchers have found that social characteristics of agents affect the response rate, that is, efficiency of response [13, 16, 26]. The simulation results coincide with the existing research results.

Some results of the simulation study supplement the findings from previous researches that overgeneralize the role of the agent activeness. For instance, one of the simulation results is more specific than the findings of previous researches which simply suggest that organizations of proactive agents generally outperform organizations of reactive agents, especially in response to problems [10, 16, 17, 29]. Results of the simulation study discovered that though teams of active agents generally produce higher decision efficiency than teams of passive agents, gradual replacement of passive agents with active agents do not always guarantee the enhancement of the team's decision efficiency. Having more active agents enhances team efficiency provided that the extra cost incurred by the activeness is surpasses by the benefit of other agents who receive favors of the activeness. Such results do not meet our general expectation and therefore provide an opportunity for the researchers to understand the roles of the agent activeness more deeply.

The simulation results also show that the impact of agent activeness depends on the amount of information need to be processed during the decision making process. For example, the impact of having more active agents becomes more significant as the amount of information to process increases and when the team decision efficiency is important.

The simulation experiment introduced in this paper demonstrates how computational models contribute the research of agents social characteristics, which is the area that often prevents researchers from using human subjects directly. Conclusively speaking, the simulation study is an instance of incorporating simulation for theory development [25].

REFERENCES

[1] Brody, N., "Traits", In Ramachandran, V.S. (Ed.), *Encyclopedia of Human Behavior*, Vol.4, Academic Press, New York, NY, 1994, pp.419-425.

[2] Carley, K.M., "The Value of Cognitive Foundations for Dynamic Social Theory", *Journal of Mathematical Sociology*, Vol.14(2-3) (1989), pp.171-208.

[3] Carley, K.M., "Sociology: Computational Organization Theory", *Social Science Computer Review*, Vol.12, No.4 (1994), pp.611-621.

[4] Carley, K.M. and M.J. Prietula, "Computational Organization Theory - An Introduction", In Carley, K.M. and M.J. Prietula (Eds.), *Computational Organization Theory*, Lawrence Erlbaum Associates, Hillsdale, NJ, 1994, pp.xi-xvii.

[5] Carley, K.M., D. Park, and M. Prietula, "Agent Honesty, Cooperation and Benevolence in an Artificial Organization", *AAAI Proceeedings 1993 Workshop* (1993), Washington, DC.

[6] Cohen, P.R. and E.A. Feigenbaum, *The Handbook of Artificial Intelligence*, HeurisTech Press, Stanford, CA, Vol.3, (1981), pp.3-21.

[7] Crant, J.M., "The Proactive Personality Scale And Objective Job Performance Among Real Estate Agents", *Journal of Applied Psychology*, Vol.80, No.4 (1995),

pp.532-537.

[8] Fararo, T., *The Meaning of General Theoretical Sociology*, Cambridge University Press, New York, 1989.

[9] Hollenbeck, J.R., D.R. Ilgen, D.J. Sego, J. Hedlund, D.A. Major, and J. Phillips, "Multilevel Theory of Team Decision Making: Decision Performance in Teams Incorporating Distributed Expertise", *Journal of Applied Psychology*, Vol.80, No.2 (1995), pp.292-316.

[10] Jauch, L.R. and K.L. Kraft, "Strategic Management of Uncertainty", *Academy of Management Review*, Vol.11, No.4 (1986), pp.777-790.

[11] Jung, C., *Psychological Types*, Princeton University Press, Princeton, NJ, 1921.

[12] Kang, M., L. B. Waisel, and W. A. Wallace, "Team-Soar: A model for team decision making", In Prietula, M., Carley, K. and L. Gasser (Eds.), *Simulating Organizations: Computational Models of Institutions and Groups*, AAAI Press / MIT Press, Menlo Park, CA, 1998, pp.23-45.

[13] Kets de Vries, M.F. and D. Miller, "Personality, Culture, and Organization", *Academy of Management Review*, Vol.11, No.2 (1986), pp.266-279.

[14] Laird, J., C.B. Congdon, E. Altmann, and R. Doorenbos, *Soar User's Manual: Version 6*, Electrical Engineering and Computer Science Department, University of Michigan and School of Computer Science, Carnegie Mellon University, 1993.

[15] Laird, J., A. Newell, and P.S. Rosenbloom, "SOAR: An Architecture for General Intelligence", *Artificial Intelligence*, Vol.33 (1987), pp.1-64.

[16] LaPorte, T.R. and P.M. Consolini, "Working in Practice But Not in Theory: Theoretical Challengers of 'High-Reliability Organizations'", *Journal of Public Administrative Research and Theory*, Vol.1, No.1 (1991), pp.19-47.

[17] Lin, Z., *Organizational Performance - Theory and Reality*, Doctoral Dissertation, School of Public Policy and Management, Carnegie Mellon University, 1993.

[18] Lin, Z. and K.M. Carley, "Proactive or Reactive: An Analysis of the Effect of Agent Style on Organizational Decision-making Performance", *Intelligent Systems in Accounting, Finance and Management*, Vol.2 (1993), pp.271-289.

[19] Mackenzie, K.D., *Organizational Structures*, AHM Publishing Co., Arlington Heights, Illinois, 1978.

[20] Macy, M.W. and J. Skvoretz, "The evolution of trust and cooperation between strangers: a computational model", *American Sociological Review*, Vol.63, No.5 (Oct. 1998), pp.638.

[21] Newell, A., *Unified Theories of Cognition*, Harvard University Press, Cambridge, MA, 1990.

[22] Newell, A. and H.A. Simon, *Human Problem Solving*, Prentice-Hall, Englewood Cliffs, NJ, 1972.

[23] Newell, A. and H.A. Simon, "Computer Science as Empirical Inquiry: Symbols and Search", *Communications of the ACM*, Vol.19 (1976), pp.113-126.

[24] Prietula, M.J. and K.M. Carley, "Computational Organization Theory: Autonomous Agents and Emergent Behavior", *Journal of Organizational Computing*, Vol.4, No.1 (1994), pp.41-83.

[25] Prietula, M.J., K.M. Carley, and L. Gasser, "A Computational Approach to Organizations and Organizing", In Prietula, M.J., K.M. Carley, and L. Gasser (Eds.), *Simulating Organizations: Computational Models of Institutions and Groups*, AAAI Press / MIT Press, Menlo Park, CA, 1998, pp.xiii-xix.

[26] Roberts, K., "New Challenges to Organizational Research: High Reliability Organizations", *Industrial Crisis Quarterly*, Vol.3, No.3 (1989), pp.111-125.

[27] Rochlin, G.I., "Iran Air Flight 655 and the USS Vincennes: Complex, Large-scale Military Systems and the Failure of Control", In LaPorte, T.R. (Ed.), *Social Responses to Large Technical Systems: Control or Anticipation*, Kluwer Academic Publishers, Amsterdam, 1991.

[28] Simon, H.A., "Applying Information Technology to Organizational Design", *Public Administrative Review*, Vol.33 (1973), pp.268-278.

[29] Smiar, N.P., "Cool Heads: Crisis Management for Administrators", *Child Welfare*, Vol.71, No.2 (1992), pp.147-156.